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# Flood Wave Transit on Trotuș River, with the Left Bank Flood Defence Raised

PhD.Eng. **Marie-Alice GHIȚESCU[1,*]**, PhD.Eng. **Gheorghe I. LAZĂR[1]**,
PhD.Eng. **Albert Titus CONSTANTIN[1,*]**, PhD.Eng. **Şerban Vlad NICOARĂ[1]**

[1] Politehnica University Timisoara (UPT), Romania

* alice.ghitescu@upt.ro; albert.constantin@upt.ro

***Abstract:*** *The paper presents a discrete 2D numerical modelling on Trotuș River – in Tg-Ocna, at an accidental flood and known configuration, given by the hydrograph registered between 2–8 June 2016. The purpose of this modelling is to estimate the parameters of transient hydraulics (non-permanent), respectively, specifying some constructive aspects of flood protection by establishing the geometric and hydraulic parameters when raising the flood defence dam in the vicinity of the technological platform on the left bank of Trotuș River.*

***Keywords:*** *2D hydraulic modelling, flood wave transition, flood defence*

## 1. General Consideration

Discrete numerical modelling is based on the existence of a flood study on the Trotuș River to establish constructive aspects of non-flooding of the technological platform on the left bank, in the southern part of Târgu-Ocna, area with car access on the national road DN12A [1].
A new project will be carried out in the vicinity of the Trotuș riverbed (in the immediate vicinity of the flood defence). The construction site is located at an average elevation of approx. 254.50 maSL and covers a total area of 51.665 m$^2$ (Fig.1). For the modelling the geometry of Trotuș riverbed, a section with a length of approx. 1566 m; on this section a database was created concretized by a situation plan (topographic survey in Stereo 70), 35 transversal profiles (of which 3 transversal profiles on the Slănic brook - right tributary; 14 transversal profiles that intersect the flood defence dam on the left bank, near the technological platform, 1 longitudinal profile on the route of the existing defence dam, from the transversal profiles the morphology of the minor and major riverbeds is highlighted, respectively, the characteristics of the technological platform (Fig.2).


**Fig. 1.** Plan view of the area of interest on Trotuș River

In the study of the accidental flood hydrograph transit on the Trotuș River, two discrete numerical models were made.

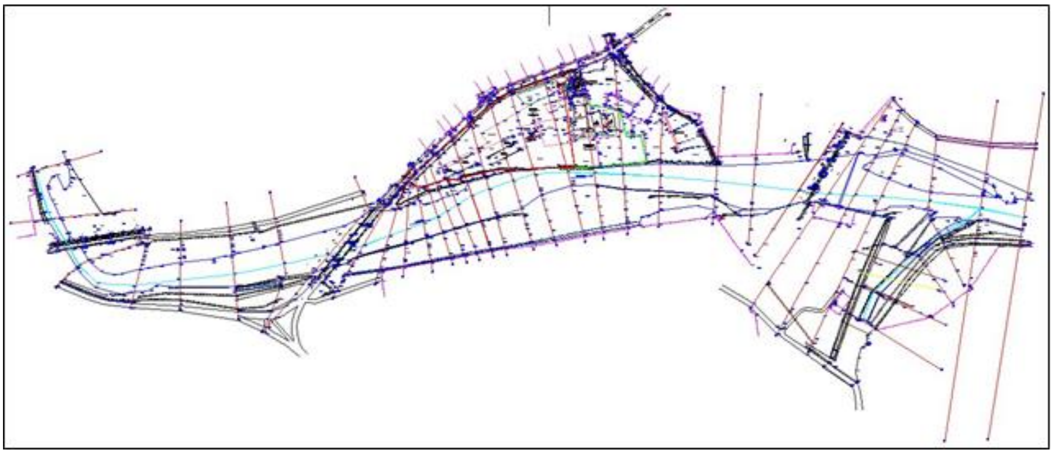

**Fig. 2.** Plan view with Stereo 70 Survey of cross sections location

**The first discrete numerical model** was made on a one-dimensional section (1D) and includes the 3 bridges crossing the Trotuș River. This section was divided into 3 sectors: *Raul_Trotuș_am* in length of 1494m; *Raul_Trotuș_av*, in length of 71.85m; and sector *Paraul_Slanic* in length of 220m. These three sectors are connected at the junction and labelled *Jonctiune 1*, (Fig.3).

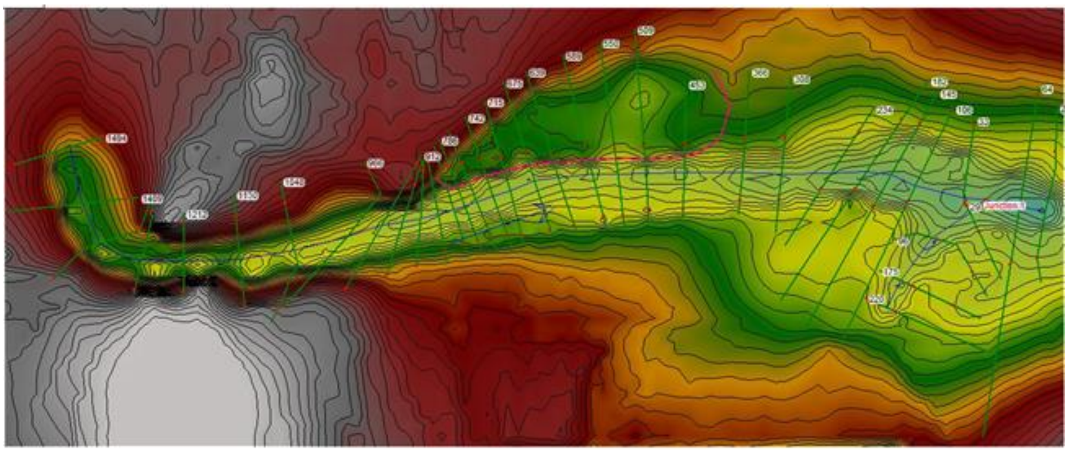

**Fig. 3.** Numerical model in 1D (HEC-RAS vers.4.1) applied with Ras Mapper cu HEC-RAS vers.6.0 Beta 3

**The second discrete numerical model** was made on a two-dimensional area (2D) - the graphical representation is presented in Chapter 3; the model contains the 3 bridges crossing the Trotuș River and the end zone of the numerical model (2D) stopping at the cross section S29 not including the confluence zone of the numerical model (1D). Because this area is being downstream of the studied area, respectively, of the confluence where it is made a catchment threshold for the Tg-Ocna Treatment Plant, and because Slănic brook cannot produce a significant turbulence which could have an impact on the analysed area, a fact found on the 1D numerical modelling.
The description flood study only includes the numerical model in (2D). However, geometric references developed in the (1D) model will be made only to describe the generation of the discrete model geometry in (2D). In this discrete numerical model (2D), it will be clearly observed the way of passing the accidental flood wave (the allure of the synthetic flood hydrograph is given by the allure of the flood of June 2-8, 2016). The topographic database (represents about 829 distinct points in geographical coordinates and land elevations) was made by the company SC.Geo Point Expert SRL from Bacău.
For the calculations and hydraulic verifications necessary to determine the variation of water level, the regime of run-off velocities and the transit mode of the flows on the Trotuș river, in the urban area of Târgu-Ocna, the following elements were necessary: maximum flows with different probabilities of exceeding; the appearance of the flood hydrograph; roughness coefficients in the minor and major riverbed; hydrodynamic drainage slope or key curve in the downstream section of

the analysed sector. The hydrological data are provided by the National Administration "Romanian Waters", the Siret Bacău Water Basin Administration, and the hydrograph is presented in (Fig.4). The flood level hydrograph for June 27, 2005, sent by the National Administration "Romanian Waters", Siret Bacău Water Basin Administration, was registered at the Târgu-Ocna Hydrometric Station and is an important database used to simulate the model numerically discrete.
The geometric shape of the synthetic flood hydrograph was assimilated in all the numerical simulations analysed in the present study, respectively, amplification coefficients (am.coef.) were used to reach the maximum return period flow values for: $Q_{1\%}$ = 1160 $m^3$ / s (am.coef = 1.6905) and $Q_{MAX}$ = 965$m^3$ / s (am.coef. = 1.405). When generating the synthetic flood hydrograph for the calibration flow, the June 2016 flood wave configuration was used, with an amplification coefficient of about = 1.405 corresponding to the maximum level $H_{max}$ = 252.996 maSL recorded at S.H. Targu Ocna.

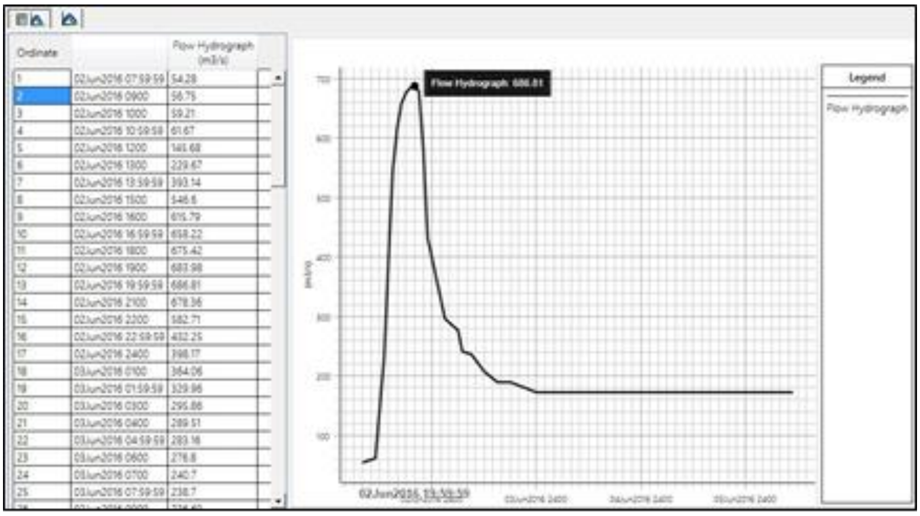


**Fig. 4.** Graphical representation of flood hydrograph at SH. Târgu-Ocna on 2-8 of June 2016

## 2. Maximum flows for different return periods

The main hydrotechnical works associated with the project site: "Flood study" were classified in importance class IV and consequently the sizing flow corresponds to the probability of exceeding 5%, respectively, the verification flow with the probability of exceeding 1%. Therefore, the corresponding exceeding probability of 5% is $Q_{5\%}$ = 770$m^3$ / s, respectively, the corresponding exceeding probability of 1% is $Q_{1\%}$ = 1160 $m^3$ / s. With the HEC-RAS program vers. 4.1 [2] modeled the transit of flows in transitional regime (flood wave), in modified regime. The use of numerical modeling in the current study aimed to establish cross sections on the Trotuș River and Slănic tributary with real-scale graphical representation (terrain representation in (1D) from survey).

## 3. Building the numerical model

For building the discrete numerical model, a section of the Trotuș River, Târgu-Ocna urban location, was considered; with a length of 1566m. The analysed sector of Trotuș River and of Slănic tributary was divided into sectors (34) limited by 35 cross-sections obtained in accordance with the actual topographic surveys. The topographic sections on the route are visible (red colour) in the linear interpolation representation of the terrain presented in (Fig.5). The natural terrain model in the representation (2D) with the afferent surface obtained from a two-dimensional interpolation is modified within the HEC-RAS vers program. 6.0 Beta 3 by using several facilities described in particular in the documentation [4] and which may be applied to a known watercourse (in this case the Trotuș River). Therefore, the adjustment operations were performed in two stages:

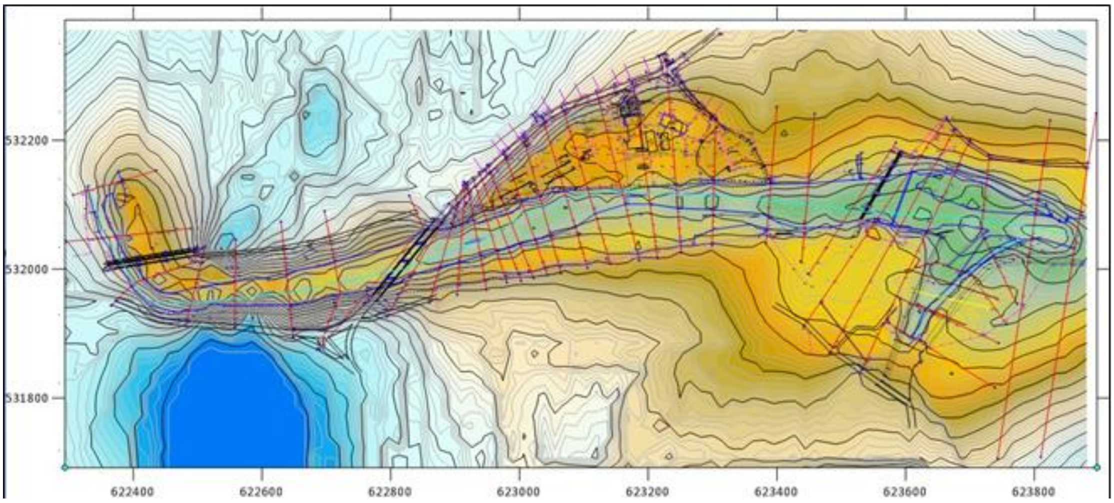


**Fig. 5.** Plan view of the terrain with level lines and interpolated cross sections

**In the first stage**, the natural terrain model resulting from the two-dimensional interpolation using the surface domain (2D) called Zona_2SD_Tg_Ocna is used. A perimeter area is defined that includes only the upstream sector of the Trotuș River (which was developed in the discrete 1D model). Select the grid spacing points in meters (Dx = 20, Dy = 20), generate the points associated with the facility (Generate Computations Ponts) as well as the corresponding property tables for points (Compute Property Points). The Refinement Regions facility is used, and an additional region is defined for the thickening of the grid in the area of the minor river bed of Trotuș River (from the beginning to the confluence area). This region is used to perform an additional network thickening operation (Dx = 10, Dy = 10).

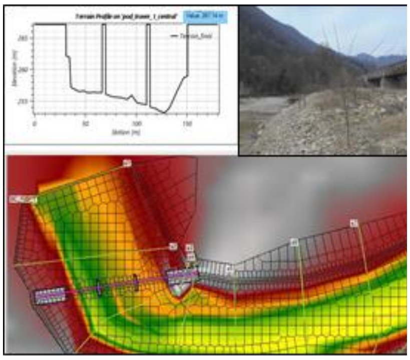

**Fig. 6.** Overpass structure – Railway bridge

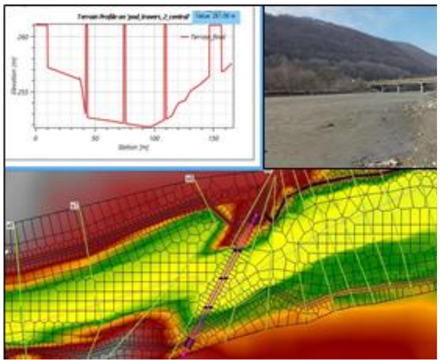

**Fig. 7.** Overpass structure - Road bridge

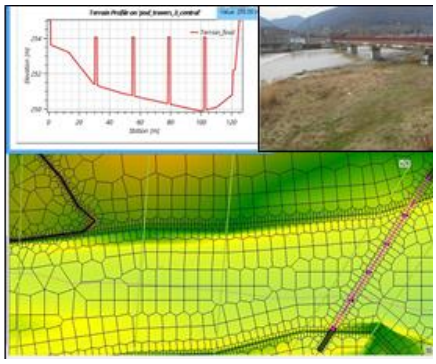

**Fig. 8.** Overpass structure - Pedestrian bridge

**In the second stage**, the new additional facilities of HEC-RAS ver. 6.0 Beta 3, adjust the banks of the watercourse in accordance with the known geometric data from the topographic survey, along the entire length of the banks; the three overpass structures are introduced in accordance with the topographic elevations as one can observe in the graphic presentation in (Fig.6). In the graphical representations (Fig.7 and Fig.8), are represented in detail the three areas related to the discrete numerical model that contain the crossing elements in (2D), both in plan view, and cross sections; the cross sections intersect the central area of the overpass structures.
The mode of flows transit on the numerical model (2D) was carried out in 3 stages, namely:
Stage 1 Model calibration to the transit of the historical hydrograph where the maximum level reaches the registered value $H_{max}$ = 252.966 maSL and corresponds to a maximum flow value of. Qmax = 965 $m^3$ /s.
Stage 2 Transit of the synthetic flood hydrograph and identification of floodable areas on the discrete numerical model and where the flow reaches the maximum value of $Q_{1\%}$ = 1160 $m^3$ /s.

Stage 3 Synthetic flood hydrograph transit the on the improved discrete numerical model, in which a lateral connection structure was introduced - simulates the elevation of existing defence dam to protect the technological enclosure from flooding when maximum flow reaches $Q_{1\%}$ = 1160 $m^3$ /s.

### 3.1. Initial and boundary conditions

Currently, the boundary conditions on the river path are given by: the transit flow with a certain probability of exceeding entered as a known flood hydrograph, values that are introduced in the upstream area of the numerical model; in the present case (2D) - the condition on line BC_S2D_1 which is also associated with the hydrodynamic slope necessary for the distribution of flows on the line; hydrodynamic slope in the downstream area of the numerical model in (2D) - condition on line BC_S2D_2 (see Fig.9); In this discrete numerical model in (2D), no initial conditions are required.

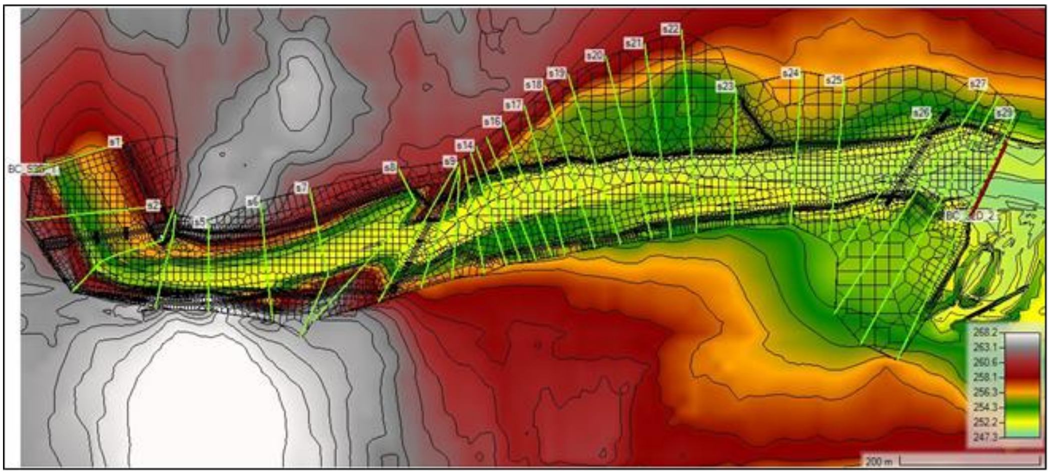

**Fig. 9.** Model discretization with the boundary location- upstream BC_S2D_1 and downstream BC_S2D_2

Stage 1 – Model calibration - Simulation of the runoff on the Trotuș River, in the situation of the existing flood defence system, in non-permanent regime, for the flow corresponding to the historical flood hydrograph from 2005, registered at SH. Târgu-Ocna where the maximum value of water level is reached → $H_{max}$ = 252.966 maSL and corresponds to a maximum flow of $Q_{max}$=965$m^3$/s - in the location marked with "pod_travers_central_3" (value of the historical level was received from the National Administration " Romanian Waters ", Siret Bacău Water Basin Administration) includes:

• a historical flood wave introduced in the upstream section, on line BC_S2D_1, where the maximum level reached was $H_{max}$ = 252.966 maSL, resulting in the associated flow Q=965$m^3$/s, and the hydrodynamic slope for the flow distribution on the boundary condition is: J = 0.0076;

Stage 2 - Transit of the synthetic flood hydrograph that corresponds as an allure to the hydrograph registered between 2-8 of June 2016 at SH. Târgu-Ocna (approx. 1.6905) and where the flow reaches the maximum verification value of $Q_{1\%}$ = 1160 $m^3$/s. Therefore, the simulation of the runoff on the Trotuș River in the situation of the existing dam system, non-permanent regime, for the maximum flow $Q_{1\%}$ = 1160 $m^3$/s includes:

• a wave of synthetic flood generated in the upstream section located on the line BC_S2D_1 with the maximum flow reached at the value of $Q_{1\%}$ =1160 $m^3$/s and the hydrodynamic slope for the distribution of the flow on boundary condition, located on line BC_S2D_at the value: J = 0.0076;

Stage 3 - Transit of the synthetic flood hydrograph on the discrete numerical model in which a lateral connection structure was introduced which simulates the elevation of the existing defence dam to protect the technological enclosure from flooding when the maximum flow reaches $Q_{1\%}$ = 1160 $m^3$/s. The simulation of the runoff on the Trotuș River in the situation of the existing dam system, non-permanent regime, with a lateral connection structure at the maximum flow $Q_{1\%}$ = 1160 $m^3$/s includes:

• a synthetic flood wave generated in the upstream section located on the line BC_S2D_1 with the maximum flow reached at the value of $Q_{1\%}$ =1160 m$^3$/s and the hydrodynamic slope for the distribution of the flow on boundary condition, located on line BC_S2D_at the value: J = 0.0076;

### 3.2. Numerical model simulation

The initial conditions and boundary conditions have been applied for all three stages. The numerical modeling for the situation of the flood waves (Stage: 1,2 and 3) takes place in time, for a known period starting from June 2, 2016 at 8.00 am until June 8, 2016 at 6.00 am. The actual (reduced) execution analysis was performed only between 8-21 o'clock, has a time step $\Delta t$ = 0.5 seconds, the internal mapping interval $\Delta t$ = 5 minutes, and the results are stored at a time interval of 10 minutes.

### 3. Results presentation

Following the execution of the numerical simulations, all the constant or time-varying parameters were obtained, referring to: levels, flows and speeds, on the whole discrete numerical model, for all the three stages of water transit along the Trotuș river in the area of Târgu- Ocna. The presentation of the results obtained after the post-processing in graphic form are presented for the 2 stages (Stage 2 and Stage 3) as follows:
Stage 2 - Transit of the synthetic flood hydrograph corresponding to the hydrograph registered between 2-8 of June 2016 at SH. Târgu-Ocna (approx. 1.6905) and where the flow reaches the maximum verification value $Q_{1\%}$ = 1160 m$^3$/s is included in this stage.

- Plan view with the visualization of the transit mode of the flood hydrograph; water depth distribution (in m); visualization of floodable areas - graphical representations at the current time: June 2, 2016, 20.00, Q = 1160m$^3$ / s – (Fig.10).

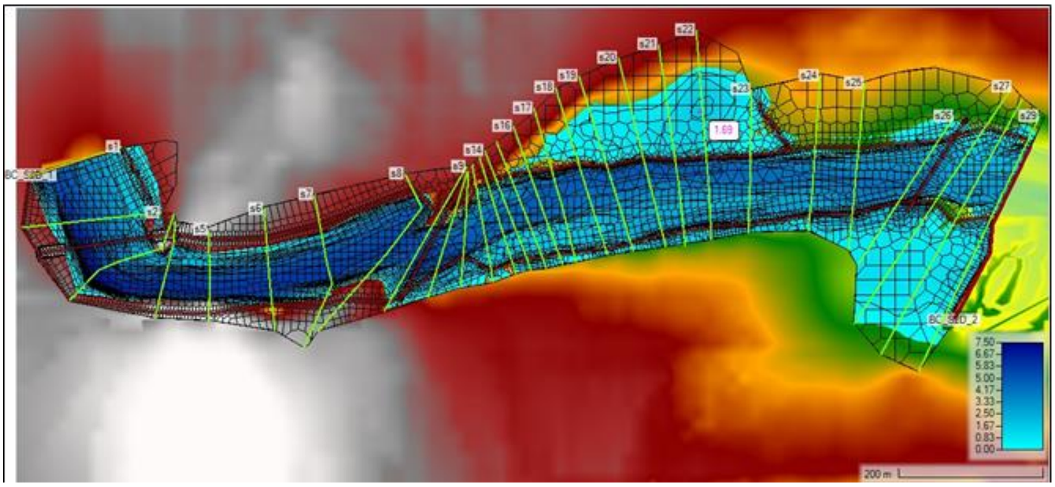


**Fig. 10.** Plan view with water depth distribution -Stage 2

It is observed on the model that the maximum depth in the area of the technological platform is 1.69 m when reaching the flow value $Q_{max}$ = 1160 m$^3$ / s at which the maximum level reached is $H_{max}$ = 253.37maSL in the location of S.H. Târgu-Ocna.

- Plotting the trajectories of overlapping particles over the velocities variation (in m/s) - graphical representations at the current time: June 2, 2016, 20.00, Q= 1160m$^3$/s – (Fig.11)

It is found that the water level at S.H. Târgu-Ocna (the 2005 flood reaches a maximum level of 252.966 maSL) increases to 253.37 maSL, so it is higher by $\Delta$ = 0.404m. Therefore, in Stage 2, the water discharges over a significant area of approx. 200 m, over the flood protection dams on the left bank of the river, to the technological area, as in accordance with the current topographic situation of the terrain elevation.

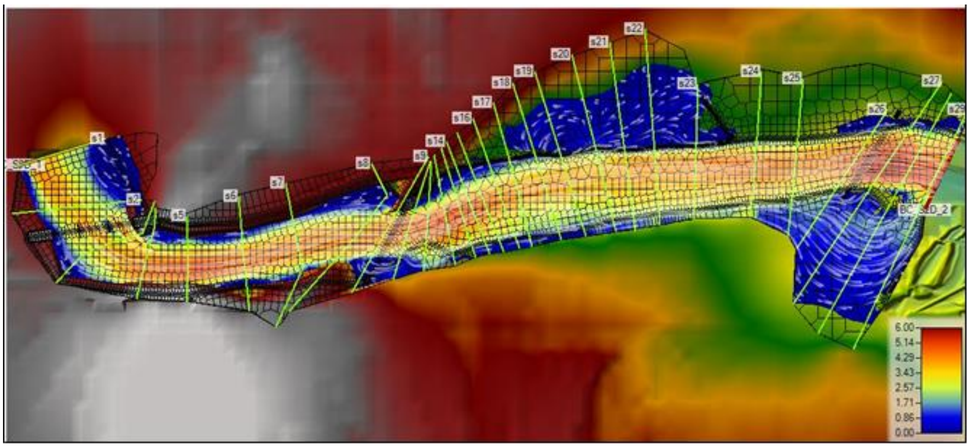


**Fig. 11.** Plan view of velocities distribution - Stage 2

Stage 3 - Transit the synthetic flood hydrograph on the discrete numerical model in which a lateral connection structure was introduced to simulate the elevation of the existing defense dam, to protect the technological enclosure from flooding when the maximum flow reaches the value of $Q_{1\%}$ = 1160 m$^3$ / s.

- Plan view with the visualization of the transit mode of the flood hydrograph; water depth distribution (in m); visualization of floodplains (Fig.12).

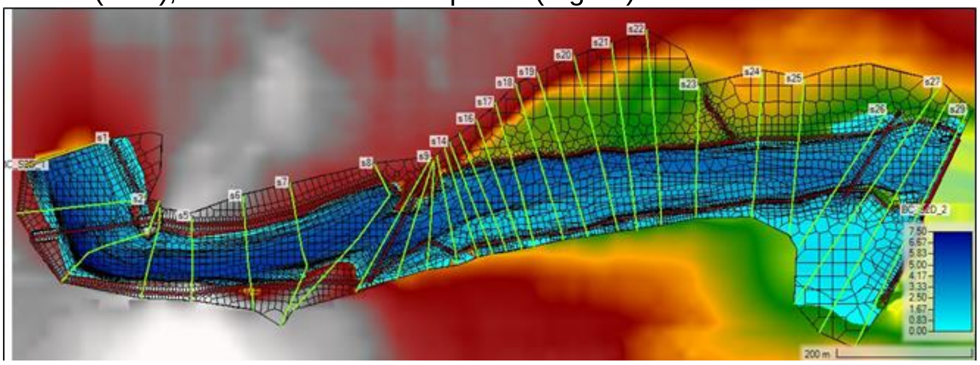


**Fig. 12.** Water depth distribution map -Stage 3

- Plotting the trajectories of overlapping particles over the velocity's variation (in m/s) - graphical representations at the current time: June 2, 2016, 20.00, Q= 1160m$^3$/s – (Fig.11)

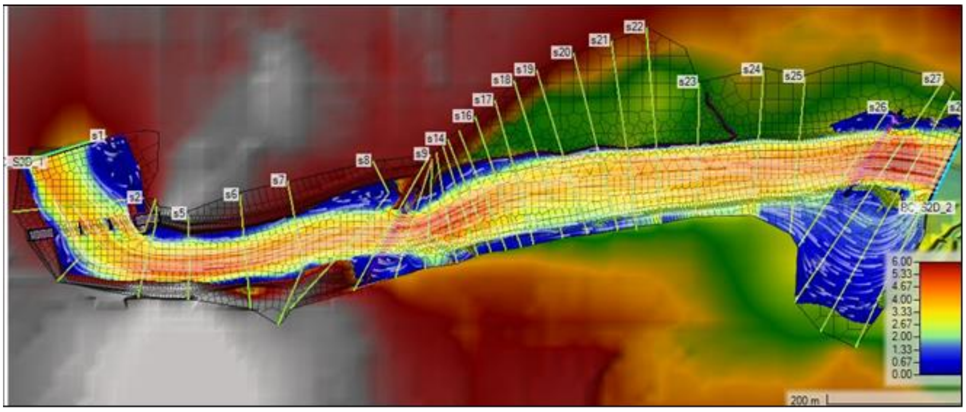


**Fig. 13.** Plan view of velocities distribution - Stage 3

At this stage it is found that the water transits through the minor riverbed, the major riverbed on the left bank, where the dam was raised ,and that the water no longer passes over the dam, and the area of the technological enclosure is no longer floodable and becomes a flood protected enclosure, corresponding to flow rate $Q_{1\%}$ = 1160 m$^3$ / s.

The graphical representation in (Fig.14) shows the configuration in plan as well as in cross section through the lateral connection structure that simulates the profile of the raised defence dam on the left bank of the river Trotuș.

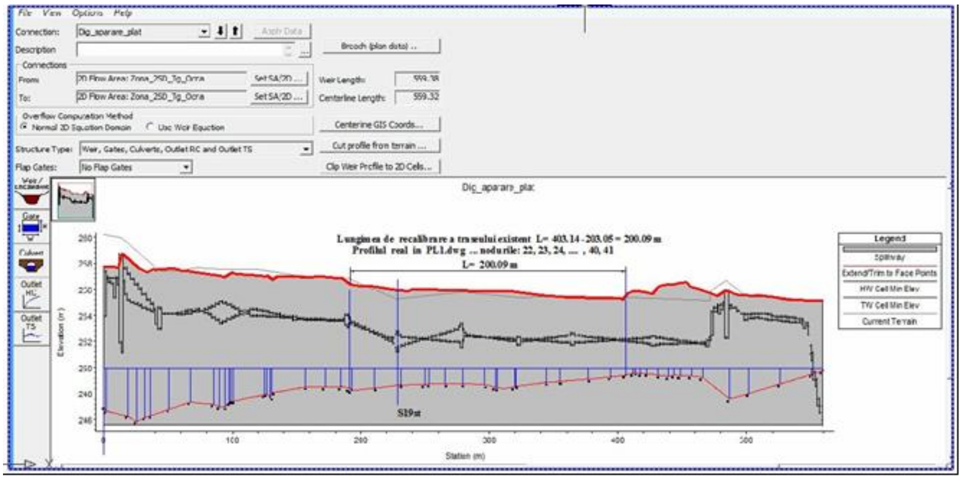

**Fig. 14.** Longitudinal profile through lateral structure along flood defence structure

It can be observed that the area which the flood defence should be raised extends over 200m (22-41 nodes).
A comparative graphical presentation of the results from Stage 2 and Stage 3, in several characteristic sections (notation: S21 and S22) with the variation of levels (in maSL) and velocities variation (in m/s) - at the current time: June 2, 2016, 20.00, when the maximum flow is Q = 1160m$^3$/s – (Fig.15).

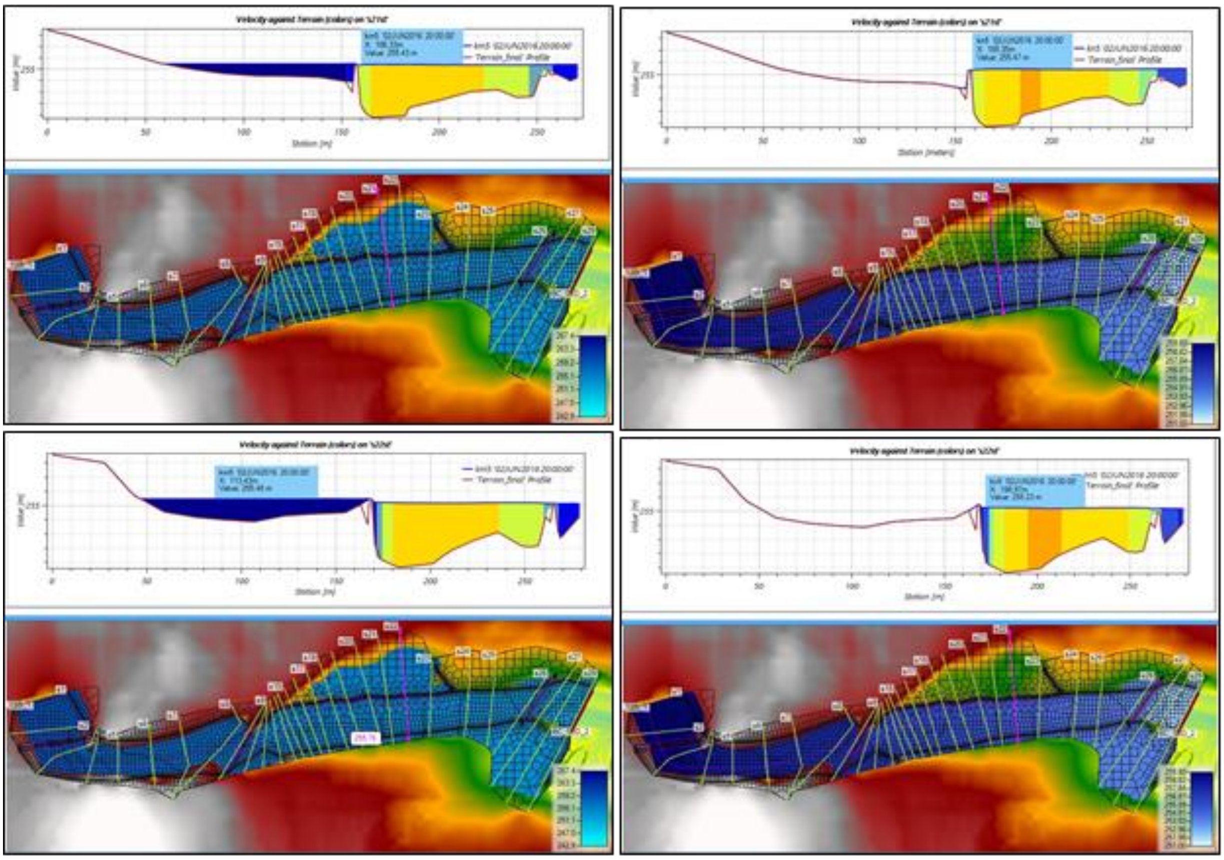

**Fig. 15.** Water level variation (in maSL) and velocities variation (in m/s) in cross sections S21 and S22-Stage 2 on left side and Stage 3 on right side

## 6. Conclusions

From the analysis of the comparative results associated with the technological enclosure, the length of the raised area of the flood defence dam was obtained. Fig. 16 also presents in tabular the geometric and hydraulic characteristics necessary to raise the dam in the vicinity of the technological enclosure which represent: topographic number; partial distances; topographic coordinates; the existing elevation of the dam on the left bank; the share of water in the transit regime with the dam raised; the elevation of the dam in the water discharge area; a safety guard of 0.20 m was pre-tapered and resulted in the current heights in the elevation sections. One can also observe that the elevation area of the dam has a length of approx. 200 m, and the maximum height elevation reaches a value of approx. 1.06 m.
Therefore, given the lateral connection structure in the area of the technological enclosure (with the topographic nodes: 22 - 41 resulting from the actual lifting) which simulates the necessary portion of the elevation of the floods defence structure, it is justified to raise the existing flood defence dam over a length of approx. 200 m.

| Nr.topo. | Distante cumulate (m) | Coord. X | Coord. Y | Cota existenta dig stanga (mdM) | Cota hidro. (mdM) | Cota dig final (mdM) | Δ (m) |
|---|---|---|---|---|---|---|---|
| | 203.05 | | | 256.290 | 255.95 | 256.29 | 0.00 |
| 23 | 211.29 | 623095.223 | 532117.798 | 255.860 | 255.90 | 256.21 | 0.35 |
| 24 | 230.46 | 623111.874 | 532119.455 | 255.260 | 255.86 | 256.06 | 0.80 |
| 25 | 248.16 | 623130.905 | 532121.793 | 255.620 | 255.84 | 256.04 | 0.42 |
| 26 | 251.49 | 623148.607 | 532121.880 | 254.960 | 255.82 | 256.02 | 1.06 |
| 27 | 255.12 | 623148.797 | 532125.205 | 255.320 | 255.80 | 256.00 | 0.68 |
| 28 | 263.26 | 623160.560 | 532125.091 | 255.755 | 255.78 | 255.98 | 0.22 |
| 29 | 275.81 | 623173.111 | 532125.152 | 256.220 | 255.75 | 256.22 | 0.00 |
| 30 | 291.87 | 623189.150 | 532124.272 | 255.660 | 255.70 | 255.90 | 0.24 |
| 31 | 301.43 | 623198.442 | 532122.032 | 255.460 | 255.64 | 255.84 | 0.38 |
| 32 | 306.45 | 623203.426 | 532121.451 | 255.367 | 255.58 | 255.83 | 0.46 |
| 33 | 314.56 | 623211.425 | 532122.788 | 255.520 | 255.45 | 255.83 | 0.38 |
| 34 | 315.18 | 623211.889 | 532123.209 | 255.700 | 255.45 | 255.83 | 0.46 |
| 35 | 337.38 | 623233.926 | 532125.837 | 255.570 | 255.42 | 255.62 | 0.05 |
| 36 | 347.46 | 623243.974 | 532126.671 | 255.458 | 255.35 | 255.55 | 0.09 |
| 37 | 368.41 | 623264.848 | 532128.402 | 255.300 | 255.26 | 255.46 | 0.16 |
| 38 | 384.88 | 623281.246 | 532129.947 | 255.280 | 255.21 | 255.41 | 0.13 |
| 39 | 395.63 | 623291.926 | 532131.242 | 255.190 | 255.15 | 255.35 | 0.16 |
| 40 | 401.26 | 623297.372 | 532132.651 | 255.100 | 255.13 | 255.33 | 0.23 |
| 41 | 403.14 | 623299.147 | 532133.269 | 255.351 | 255.12 | 255.35 | 0.00 |

**Fig. 16.** Geometric and hydraulic parameters of flood defence dam

In conclusion, the area of the technological enclosure bordered by the retaining wall to be raised (upper elevations that will respect the geometric and hydraulic characteristics in Fig.16) becomes not flooded when the accidental flood hydrograph passes with the maximum flow value exceeding capacity $Q_{1\%}$ = 1160m$^3$ / s.
Therefore, it is necessary to redesign a retaining wall whose upper dimensions comply with the indications of this study.

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