2D Numerical Model of a River Sector Flow in Case of Hypothetical Side Flooding Due to Embankment Failure

Lect.dr.eng. **Albert Titus CONSTANTIN**[1], Assoc.prof.dr.eng. **Gheorghe I. LAZĂR**[2], Lect.dr.eng. **Şerban-Vlad NICOARĂ**[3]

[1] POLITEHNICA University Timişoara, albert.constantin@upt.ro

[2,3] POLITEHNICA University Timişoara

Abstract: *The paper presents a 2D numerical modelling of water flow on a sector of about 7800m of Timiş River downstream of Lugoj Town, west of Romania, in case of accidental highwaters produceing side flooding due to a hypothetical embankement breach. The numerical simulation, assimilating the special high-flow values that occurred on site along the April 4th to 11th hydrological event of 2005, aims to estimate the possible water levels on the river sector and the flood development, meaning the flood area contour and its eventual threaten with respect to an economic objective (important logistic warehouse) existing on the right river plain.*

Keywords: *River flow, high water flow, embankment failure, side flooding, numerical model.*

1. General considerations

The numerical modelling of the analysed river site is based on a flooding study on Timiș River, covering a sector of about 7800m outside of Lugoj Town, west of Romania, downstream towards Coșteiu Water Arrangements, looking to estimate the eventual implications upon the accomplishment of a logistic warehouse in the immediate vicinity of the river right flooding plain [1]. In the same time, the present approach considers a 1D numerical modelling performed by HEC-RAS ver.4.1 [2,3] that looked to retrace the special high waters passing by the considered river sector during the exceptional hydrological event of the spring of 2005.

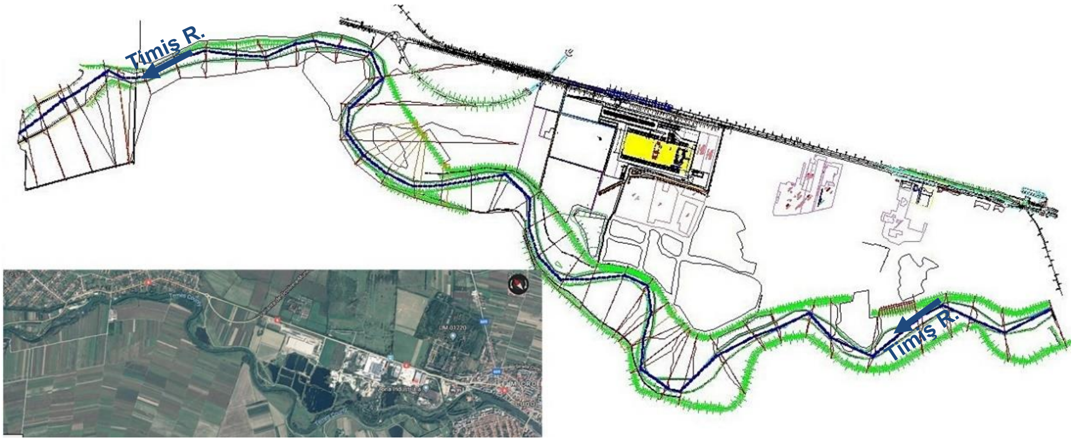

Fig. 1. General plan view of analysed Timiş River area (warehouse located) based on the topographical measurements downstream of Coșteiu Water Arrangements

As considering the mentioned river sector with its side areas, a data base objectified by a general site plan (Stereo70 standardized topographical measurement) comprising 49 short cross-view profiles (framed by flood protection embankments and pointing out the streambed morphology) and 49 long cross-view profiles (covering the possible affected floodplain between the left protection dike and the railway embankment, and respectively the right dike and the national road structure) was created. The specified economic objective, consisting from the actual warehouse, the administration / operation office building and the sanitary and traffic infrastructure, is placed at about 300m from the side embankment on the right flood plain of Timiș River. The specific developed area covering about 180 m^2 in total is situated at a mean level of about 115.30 meters with respect to the Sea Level.

The graphic accomplishment of a 3D terrain representation is usually performed by the help of the additional satellite application Earth Explorer. A useful and comfortable methode of topographical data graphical processing is presented by Nicoara & al., 2018 [4]. The methode employes a specialized topography application for 2D graphical interpolation on two directions – 0x and 0y – by which a 3D shape surface can be generated as a .shx extention file.

The created surface is then loaded with ArcMAP 9.3 [5] where is to be divided in discrete spatial areas of triangularly shapes leading to a digital final outline asa 3D real space of Triangulated Irregular Network (TIN) type (figure 2). In order to be acknowledged by the RAS Mapper module in HEC-RAS 5.0.6 the outline had to be converted as a grid loadable file of Digital Terrain Model type [4,6].One can accept that by the help of "satellite" model, terrain results quite accurate as a meshed domain even if it was based on a relatively reduced number of topographic measured points – 6045 points for the considered area – and so suitable fulfilling the usual requirements of a 3D graphic representation. Still the model can not truly generate nither the flood protection embankments configuration and nor the underwater streambed.

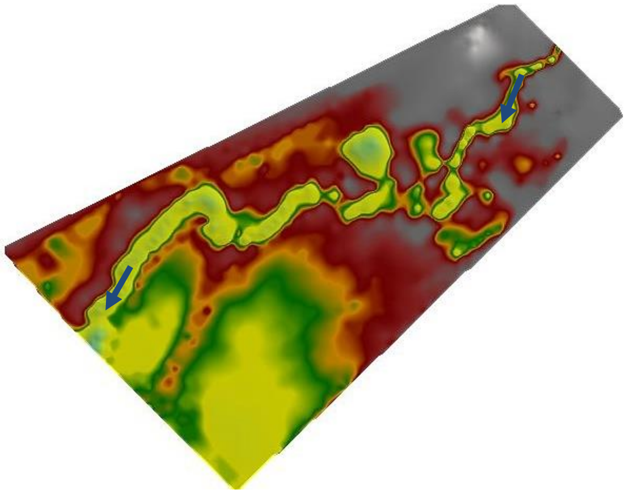

Fig. 2. 3D terrain representation of the studyed Timiş River sector with its adjoining flooding plains protected by embankments

As so, the 3D representation model reached by bidimensional interpolation was afterwards enhanced in HEC-RAS 5.0.6 [6] by upgrading the streambed ground geometry and the embankments top configuration according to the available topographic cross-sections. HEC-RAS 5.0.6 offers a usefull and casual facility that may be considered also for surface geometry updating operations [6,7]. A given water course can be overlaid as defined by a series of successive cross-sections specifying the side structures geometry. This known procedure is described by Kiers, 2015 [8], while a specific application was performed by Nicoara & al., 2018 [4].

2. Accomplishment of 2D numerical model

The 3D model reached by bi-dimensional interpolation and imported to HEC-RAS 5.0.6 was so geometricaly upgraded by adding the particular sector of Timiș River course defined by a double series of discrete points following the axes along the top of the two flood protection embankments.
First, the 2D surface domain – timis_lugoj_costei – was generated for the initial terrain model. The 2D Flow Areas facility is considered in the Explorer Window (figure 3) and the domain contour named S2D is established. There was adopted a grid defined by Dx = Dy = 25m, following to generate the associated points (Generate Computations Points) with their corresponding properties tables (Compute Property Points).
Similarly, the paths of the two embankments top were defined in River facility – right and left river banks as supplyed by topographical measurements – and distinctly saved as mal_drept_dig and mal_stâng_dig. Two perimeter fields covering the two paths are defined right away in the 2D Flow Areas facility in order to perform an automatic additional grid thickening to Dx = Dy = 3.5m. Further on the embankments cross sections types were successively inserted along the two paths. The actual procedure of accesing the Geometry Data facility in the main menu is presented by Kiers, 2015 [8], the cross-section types being attached one by one to the paths bending points.
Returning to RAS Mapper window, the Interpolation Surface option is to be considered in Cross Sections menu. The embankments geometry, both for the right and left banks, is considered in the Explorer Window and so is exported by the Export Layer facility as engaging the Create Terrain GeoTiff from XS' s (Overbanks and Channel) option.

A terrain image type file – maluri_dig – was so obtained and saved. Based on this "maluri_dig" image and the "Terrain_neact" image (supplied by the Terrain option in 2D Flow Areas facility), a new and final terrain image – Terrain_dum_final – was than defined [3] and selected by a check mark (figure 3). Once the geometry upgrading operations are fulfilled, the overlaid given river sector (meaning the embankment top paths with the associated cross-sections) can be eliminated. There results a clean but sharpened with respect to elevations 2D numerical model. Figure 3 aims to present the final 3D type terrain configuration bearing the river bed and side embankments enhancements.

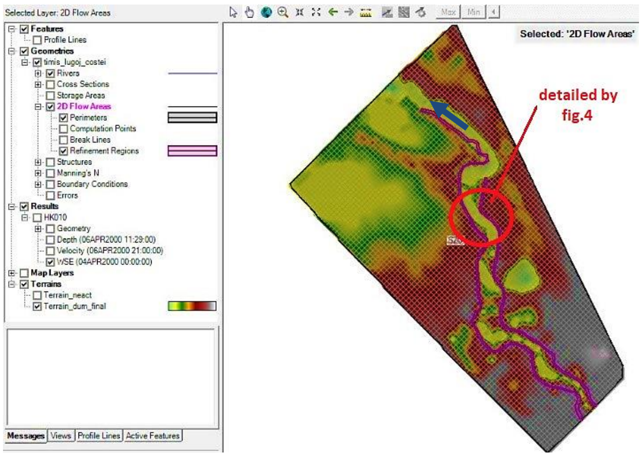

Fig. 3. 3D type view of the analysed site of Timiş River sector and side floodplains with upgraded geometry of riverbed and embankments

As about the river site hydrological conditions, the standard flow values of various overrunning probabilities that may occur on the analysed sector of Timiş River, downstream of Lugoj Town towards Coştei Water Arrangement, as provided by the Banat Regional Water Branch of Romanian Waters National Administration, are presented by the following table:

Table 1: Hydrological data

River	Station	F [km^2]	Qmax [m^3/s]					
			0.1%	0.5%	1%	2%	5%	10%
Timiş	logistic warehouse Lugoj	2827	2520	1540	1266	1100	860	695

As a result of two exceptional hydrological events that occurred on the highwaters seasons of April 2000 and April 2005, a long breach of about 154m in length and a minimum level of about 114.55mSL got developed on the left-side embankment of Timiş River (located on figure 3 and detailed by figure 4). At a highwater phenomenon defined by a water flow of already 5% overrunning probability, the river water level would overcome the left embankment lower crest level and volumes would start spill towards the adjoining floodplain.

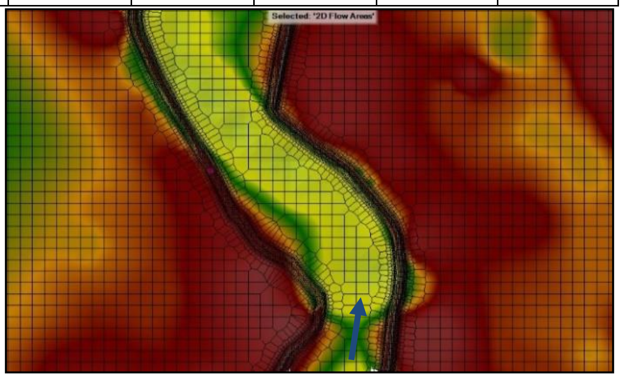

Fig. 4. Detailed terrain configuration in the area of the top breached left embankment

The final stage of the 2D numerical model development is the initial / boundary conditions definition. The SA/2D Area BC Lines option is to be considered by the boundary conditions (BC Line) facility in Geometric Data main menu (figure 5). Three zones were considered for the employed 2D domain, one on the upstream side (BC_S2D_11) upon which the highwaters hydrograph of a given water energy gradient was applied, and two on the downstream side (BC_S2D_22 and BC_S2D_33) upon which the corresponding water hydro-dynamic gradient was considered. As reported by the competent authority after the spring of 2000 and so attached to the upstream BC_S2D_11 boundary line, the highwaters hydrograph on the analyzed sector of Timiş River reached a maximum value of 1241.295 m3/s with an accompanying water energy gradient of 0.000475 (value for which the engaged HEC-RAS 5.0.6 software will settle the entering flow distribution). As for the downstream BC_S2D_22 and BC_S2D_33 boundary lines, the resembling value of 0.000375 was assigned as hydro-dynamic gradient.

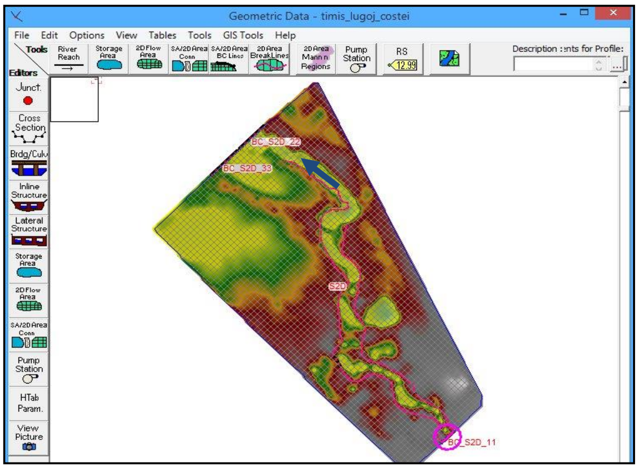

Fig. 5. Upstream and downstream zones assigned with boundary conditions of the analysed river sector

Looking to estimate the consequences of a hypothetical but still possible event, the actual numerical simulation of water flow transit was performed over a time period as corresponding to the special hydrologic phenomenon that actualy occurred on the spring of 2000, meaning from April 4th, 00:00 hours, to April 6th, 23:00 hours. There was set an analysis running step of Δt = 10 secunde, while the results recording moment was set to each 10 minutes.

3. Numerical simulation and output processing

Specific steady or time dependent parameters – water levels, velocity and flow – were reached for each grid cell of the 2D model by running the numerical simulation. Following the postprocessing operations, the numerical output is stored in designated files that can be further on visualized by employing the facilities of RAS Mapper [9], either regarding specific grid cells or defined paths.
Several significant options were considered, specifically levels, particles trajectories and velocity distributions along the flow or crossways. Figure 6 points out the eventual particles trajectories as overlaid to the corresponding water surface elevation (in mSL) by graphic representations at some considered noteworthy moments along the simulation period.

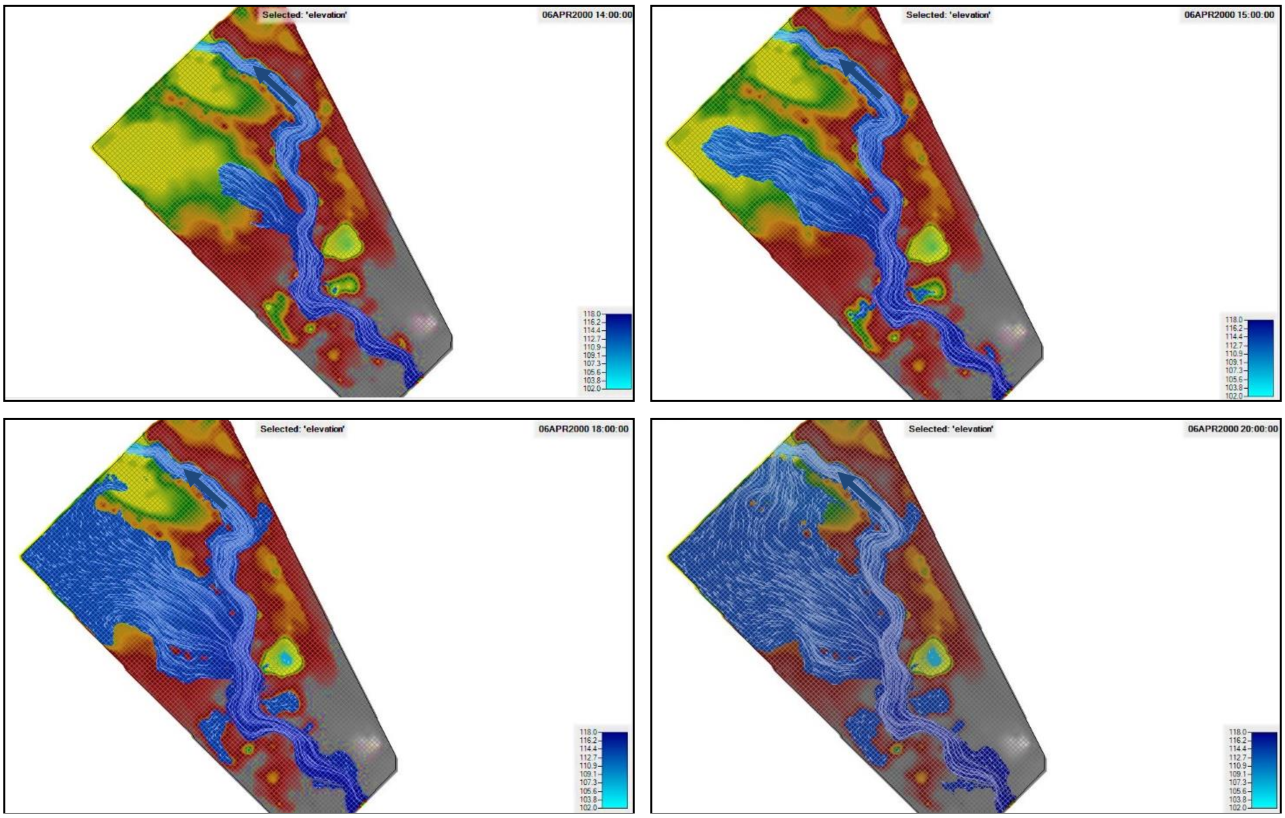

Fig. 6. Particles trajectories overlaid on surface elevation at 14:00 – 870.998 m^3/s corresponding flow, 15:00 – 1006.375 m^3/s, 18:00 – 1227.355 m^3/s and 20:00 – 1241.295 m^3/s, on April 6th, 2000

The following figures 7 and 8 show the water surface longitudinal eventual developments, the first one along the Timiș River sector thalweg and the second one through the adjoining left-side floodplain, both at the given moment of maximum flow 1241.295 m^3/s, i.e. 21:00 on April 6th, 2000.

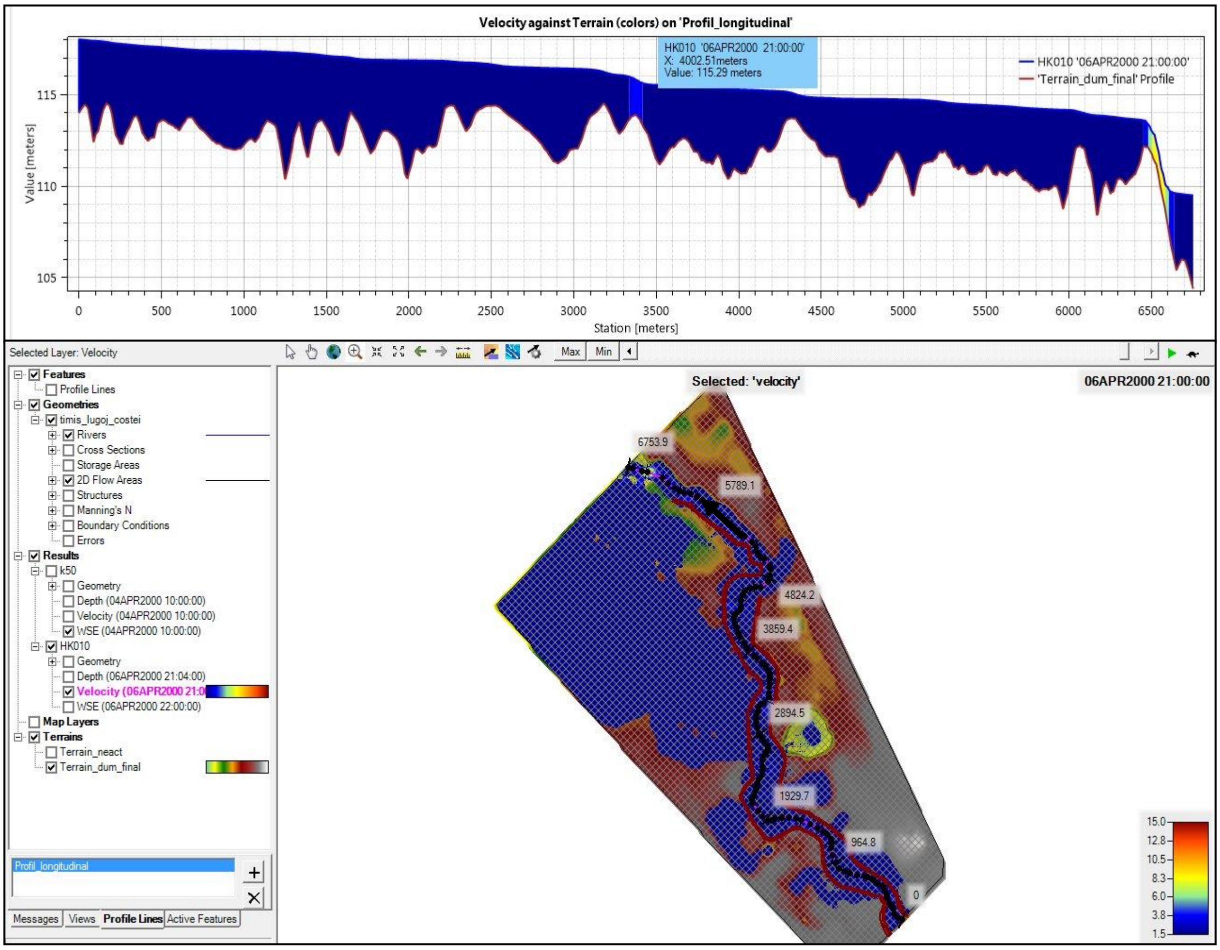

Fig. 7. Water surface elevation (mSL) longitudinal profile and spread along the river sector thalweg at 21:00 on April 6th, 2000, the corresponding moment of maximum flow of 1241.295 m^3/s

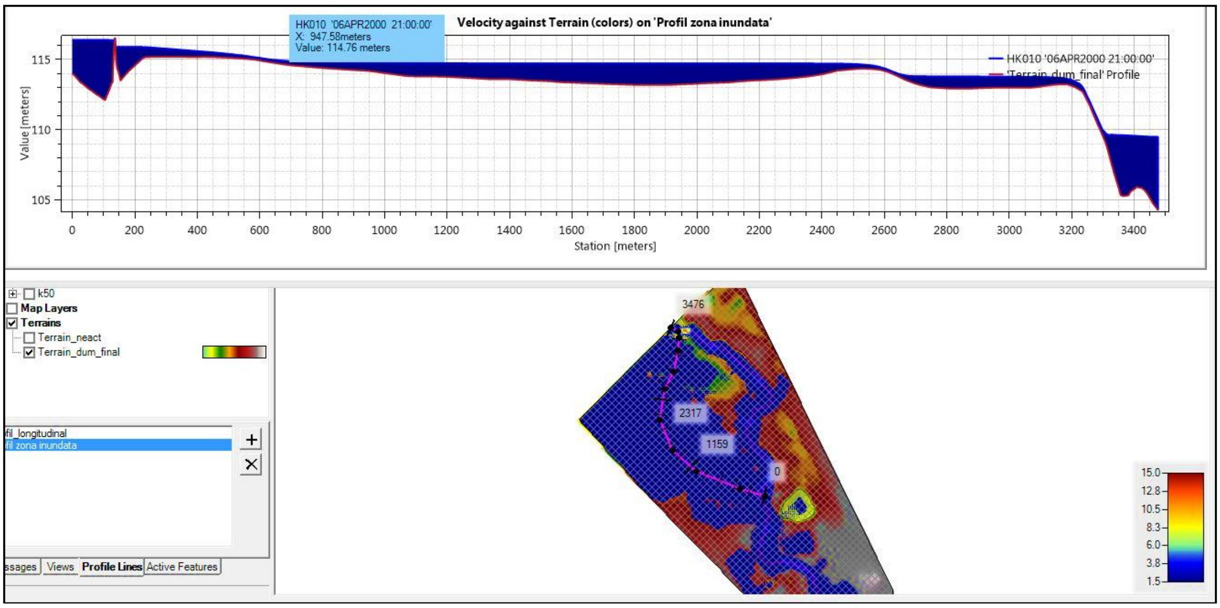

Fig. 8. Water surface elevation (mSL) longitudinal profile and spread along the river sector adjoining floodplain at 21:00 on April 6th, 2000

Figure 9 brings the piezometer line and water flow time developments on the upstream entering BC_S2D_11 and downstream outgoing BC_S2D_22 boundary lines as related to the river course.

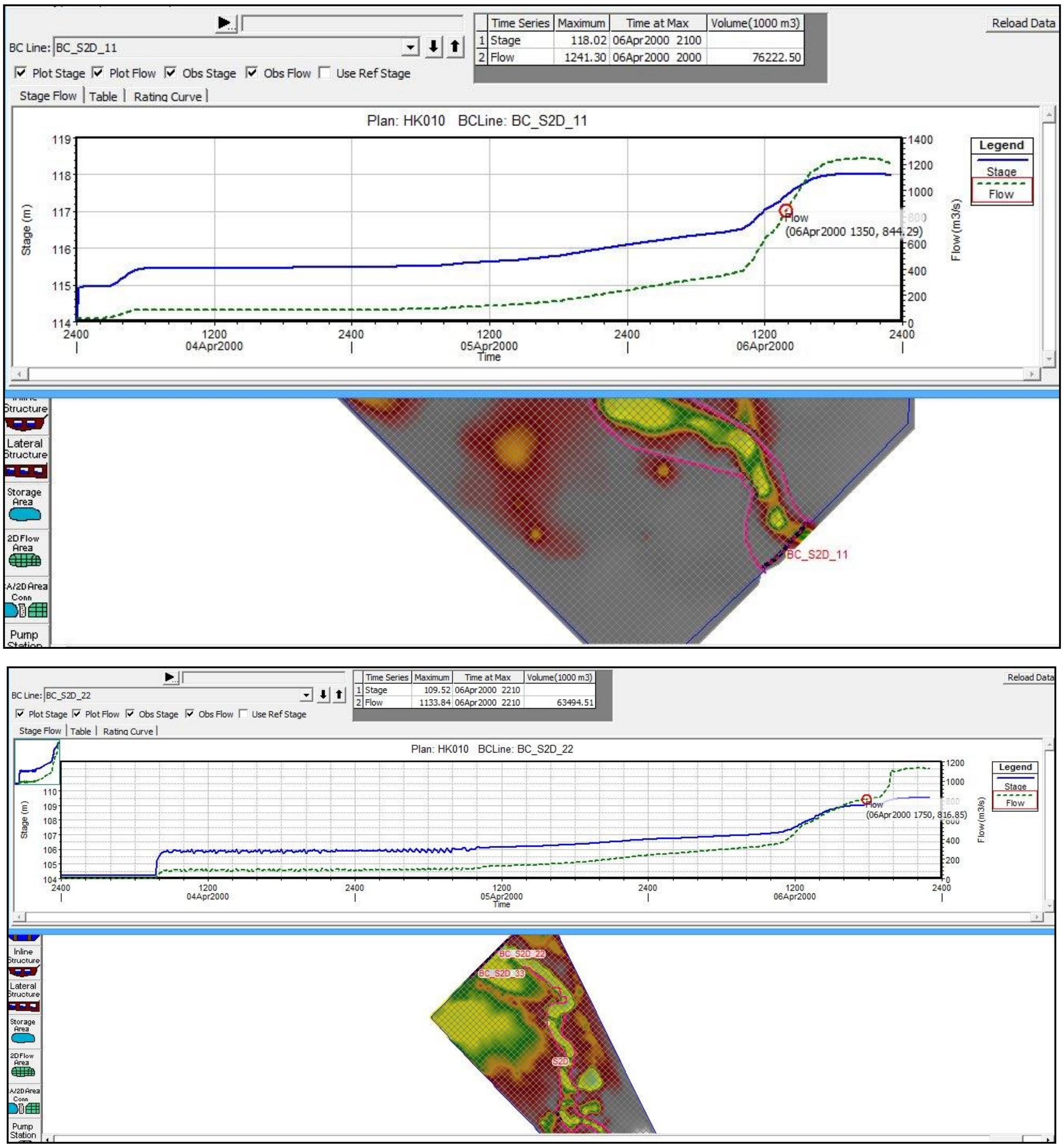

Fig. 9. Piezometric line and water flow time development on the river course sector upstream and downstream boundary lines

As considering an overall flow balance, it results that to an entering flow of the accidental highwaters at about its maximum value 1241.30 m^3/s corresponds a later on maximum outgoing flow of 1132.84 m^3/s. As about the velocity regime, the maximum value on the main path along the river sector goes up to about 10 m/s, towards Coșteiu overflowing structure, and to about 1.5 m/s in the flooded area on the left bank.
Consequently, one can also say that the flooding area over the left side protection embankment works as a given polder that determines an attenuation of the special highwater by cutting its flow maximum value with about 108.46 m^3/s.

4. Conclusions

The performed 2D numerical modeling of the concerning Timiş River sector show that under the given geometry circumstances and for a possible hydrological special event, the flow transit would

unfold both by the framed riverbed but also over the left-side embankment through a considerable gap (going from about 350m to 1493m) into the adjoining floodplain, either for the checking flow value of 1% overrunning probability ($Q_{1\%}$ = 1266m^3/s) and even for the dimensioning value of 5% overrunning probability ($Q_{5\%}$ = 860m^3/s).
There can be also confirmed that under foreseen and also regulations stipulated hydrological extreme conditions, the right-side embankment of the analysed Timiş River sector ensures the flood protection of the entire area covering correspondingly the site of the logistic warehouse investment.
In the same time, there can be concluded that the time developed gap – erosions under previous overspillings – along the top of the left-side framing embankment of the river sector might act favorable (on professional monitoring) at dimensioning and cheking values of transited water flow, since the idle (except for farming) adjacent floodplain can be employed as a highwaters atenuating polder.

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