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COMBINED 1D/2D NUMERICAL MODEL OF THE TRANSIT OF AN ACCIDENTAL FLOOD WAVE ON A WATER COURSE

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Abstract: The paper presents a discrete 1D/2D numerical model – Hec-RAS v.5.07 Program Package – of transiting the liquid flow on the Crasna River – Craidorolţ area, Satu Mare County, at the occurrence of a possible accidentally flood with known configuration as given by a registered hydrographer. The numerical simulation is intended to estimate the flood zone on the left bank of Crasna River, the area associated with the water course route, as well as the determination of transient hydraulic parameters (non-permanent). The study also seeks to specify constructive aspects of flood protection (defense embankment) for locations in the northern vicinity of the technology platform of a company property on the left bank of the river.

Keywords: river course hydraulics, high waters, flood protection, numerical model

1. GENERAL CONSIDERATIONS

The discrete numerical modeling for the considered location (photo 1) is the basis of a flood study on the Crasna River looking to establish some constructive aspects of flood protection for the technological platform on the near left bank, belonging to the agricultural company TOPAGRAR SRL [1].

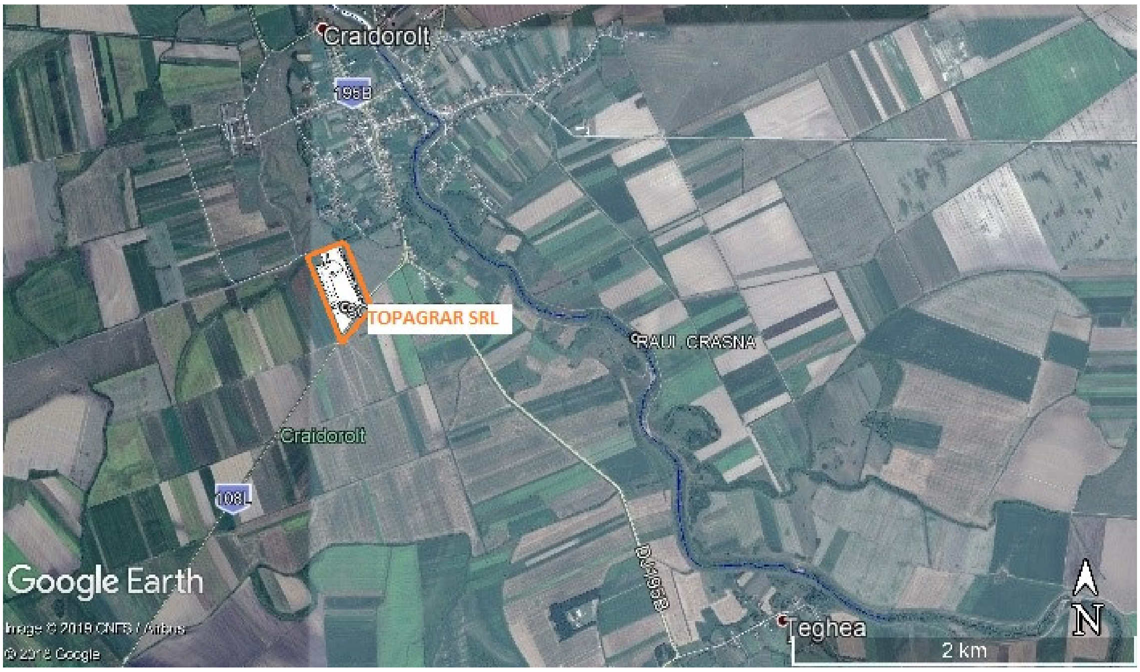

Photo 1. Aerial view of the study location and respectively the route of the Crasna River in the vicinity of the concerning farming company technology platform – Google Maps, 2018

The modeling was performed using the program package HEC-RAS vers. 4.1 [2] and 5.07 [3], and has as numerical layout two discrete systems: a discrete single-dimensional system (1D) and a discrete coupled system (1D/2D).

The concerning technological platform (Photo 2) is located at a distance of about 1 km from the Crasna river course (specifically with respect to the left side existing flood defense embankment). The ground employment in the platform area comes as farming land, it is situated at an average level of 125.50 mSL and stretches over a total area of 60,000 m^2 (Photo 1).

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Photo 2. View over the TOPAGRAR SRL agricultural company technological platform, the left side flood plain of Crasna River in the numerical model

As for 1D numerically shaping the Crasna River valley geometry, there was considered a section with a length of about 1872 m. A database has been created for this section, as modeling the given situation plan (Stereo 70 topographical measurements), the produced 49 cross profiles (37 of which being shorter profiles framed by the flood defense embankments, highlighting the riverbed and flood plains morphology, respectively, while the remaining 12 are longer profiles that cover also the agricultural company property), and respectively a spatial image in an "Oblique Stereographic" topographical system.

The spatial view was developed by the Atlas Mapping SRL specialized company based on drone imaging (see figure 1-upper) and stored in the file "topagrar.ecw". The ground representation was also given as obtained by a two-direction graphical interpolation (Figure 1–down).

The analysis section of the Crasna River was divided into straight segments (49 segments) limited to the ends by 50 cross-sections obtained according to the actual topographical measurements. One segment still had to be obtained by linear automatic interpolation as framed by the two cross-sections upstream / downstream at the motor bridge on 195B regional road, of known geometric characteristics. A bridge type structure was considered between the two cross-sections.

The topographic profiles locations are indicated (red color) in the spatial representation of figure 1 and also in the detailed image in Figure 2 covering the area of specific interest.

From the current configuration of the natural terrain, based on the spatial points (of coordinates x, y, ground level) as given by the standard Stereo 70 topographical measurements [1] and on the 3D graphical processing of the geometric surface (see various approaching procedures for the discrete numerical modeling employed for similar models [4…7]), the spatial configuration of the flow domain was reached as shown in Figure 3.

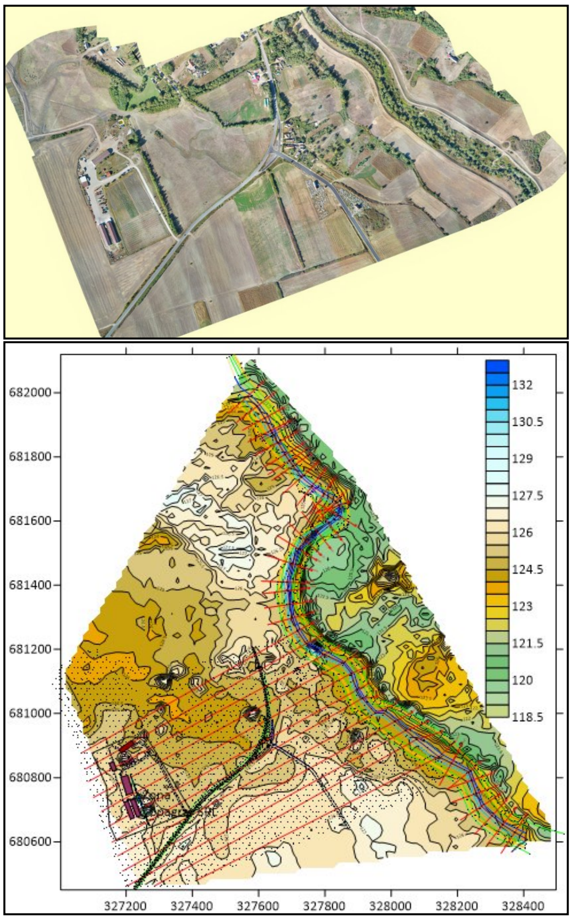

Figure 1. Detailed spatial view of the TOPAGRAR SRL property area (upper) and its topographical image obtained by spatial interpolation (down)

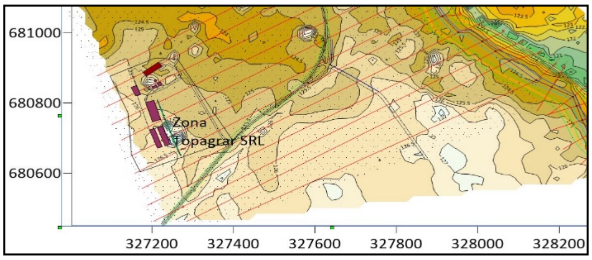

Figure 2. Additional detail of the spatial model of the TOPAGRAR SRL assets location with level lines

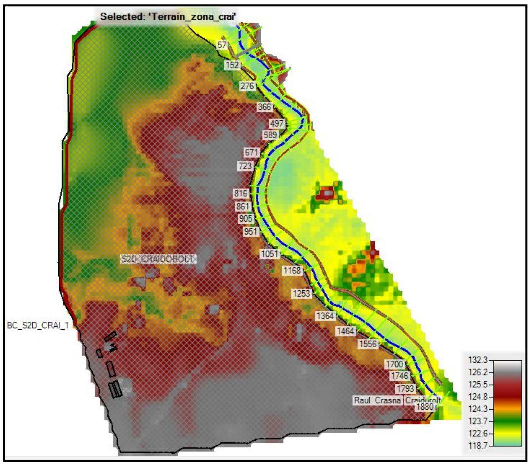

Figure 3. Combined discrete numerical model: 1D - Crasna River path and 2D - the side area attached to the fictitious river alongside structure "1836", as developed by HEC-RAS 5.07

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The maximum flow rates with different overrunning probabilities on Crasna River in the area of Craidorolţ village, specifically on the road bridge location – Craidorolţ Hydrometric Station, were given as: $Q_{5\%}=322m^3/s$ and $Q_{1\%}=570m^3/s$.

As for the graphical accomplishment of a ground 3D representation, the satellite graphics given by Earth Explorer are usually employed. Still, this available graphical presentation is coarse, being limited to a discrete network of points most often of 30m×30m and at the same time very difficult to access.

References [4…7] present a facile and useful method for the graphical processing of discrete topographical data as available from current measurements. The method uses a topographical 2D graphical interpolation program, from which a spatial surface can then be generated as shape type (.shx extension). This surface is then loaded into ArcMAP 9.3 [8] where is divided by discrete triangular elementary surfaces producing a final 3D shape of type TIN (Triangulated Irregular Network). In order for this spatial shape to be recognized by the RAS Mapper module (graphical processing or postprocessing module within HEC-RAS 5.07 program [9]), there is necessary to convert it to a file of an accessible loading form of DTM grid type (Digital Terrain Model).

A 3D graphic representation "satellite" model resulting by this method was also obtained for the present analysis (Figure 3). Although such spatial representations are usually based on a limited number of points supplied by topographical measurements, they yet reproduce quite well a real 3D surface. In the same time, this type of model would not generate with suitable fidelity the configuration of the flood defense embankments and of the river-bed underwater ground. In order to overcome this aspect, an existing facility in HEC-RAS program is to be addressed for adding a fictitious route by which different adjustments can be made to the 3D surface [10]. This route may follow a defense embankment or a water course thalweg, where one can perform successive alterations to the created model in order to update the cross sections below the water level too. By considering these options for this presented study, the finally obtained discrete surface of the 3D space resulted as presented by Figure 3.

2. ACHIEVING THE 1D/2D DISCRETE NUMERICAL MODEL

The flooding study [1] considers in a first phase a 1D discrete numerical model where the flooding area was meshed as a "polder " enclosed by the actual contour given by topographical map (1:25000) of Craidorolţ area, Satu Mare County. The polder water level and possible storing water volume correlation (Table no. 1) was determined by planimetry and level lines surfaces processing.

The water flow transition along the built 1D numerical model was developed by three stages as follows:

stage 1 – model calibration under a known hydrograph transition, specifically the one over May 26th to 30th, 2015, $Q_{max}=146m^3/s$;

stage 2 – transition of a synthetic highwaters hydrograph reaching the flow maximum value of $Q_{5\%}=322m^3/s$ (special loading situation);

stage 3 – transition of a synthetic highwaters hydrograph reaching the flow maximum value of $Q_{1\%}=570m^3/s$ (exceptional loading situation).

Table no.1

Crt. no.	Level [mSL]	Planimetry surface [m^2]	Area mean value [m^2]	Stored volume [$\times10^3$ m^3]
0	122.25	1075791.00	–	0.000
1	123.75	9202968.40	5139380.00	7,709,070
2	125.00	17639613.88	13421291.22	24,485,683
3	126.25	22759503.43	20199558.63	42,026,062
4	127.20	–	–	–

In order to perform a monitoring of the foreseen water spilling over the left or right banks flood protection embankments of Crasna River, two false side structures were considered of wide step spillway type for which a 0.248 flow ratio was specified. The crest path configuration of the two spilling structures resulted from the actual topographical measurements (longitudinal profiles). The most unfavorable situation of exceptional load under $Q_{1\%}$ was in the end followed in order to establish the water volume over-spilling the left side lateral structure towards the defined polder ("Polder la_ 125.00"). The minimum outline of real representation has been chosen to roughly visualize the inner contour determined by the polder accumulated water surface close to about 125mSL ground level.

As considering the results reached by the situation of stage 3, it was found that the polder water level goes to 124.50mSL. By studying the company's platform area, as concerning the actual ground configuration (northern side designated for three investment objects), the existence of a drainage/irrigation canal was revealed. The thalweg route of about 330m length in the vicinity of the technological platform is below the level of 124.50mSL (124.25...124.50mSL, Figure 4). Therefore, it was also required to achieve a coupled 1D/2D discrete numerical model which would replace the polder of previous configuration with a discrete spatial area (the actual flooding area corresponding to the fictitious side structure was replaced by a limited 2D meshed surface named "S2D CRAIDOROLT", Figure 3) [3].

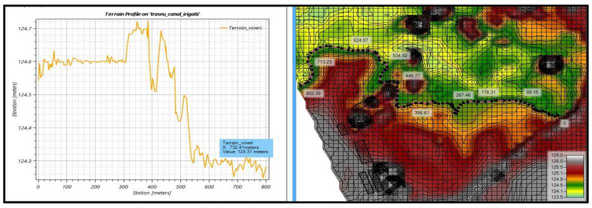

Figure 4. Clogged hydro-ameliorative canal thalweg path in the 2D graphical interpolated area

Following the actual computer simulation for this adjusted discrete model, the flood of the northern area platform was revealed as one can see by the graphical representations of Figure 5 and additionally detailed Figure 6. Additional improvement upon the described

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model was required to protect the investment objects on the north side of the agricultural company. Two connection structures were introduced within the discrete spatial area "S2D CRAIDOROLT", visible in the detailing Figure 7, modelling a couple of flood protection embankments. Their location intersects the existing drainage/irrigation clogged canal, as it's observable in the presented Figure 7.

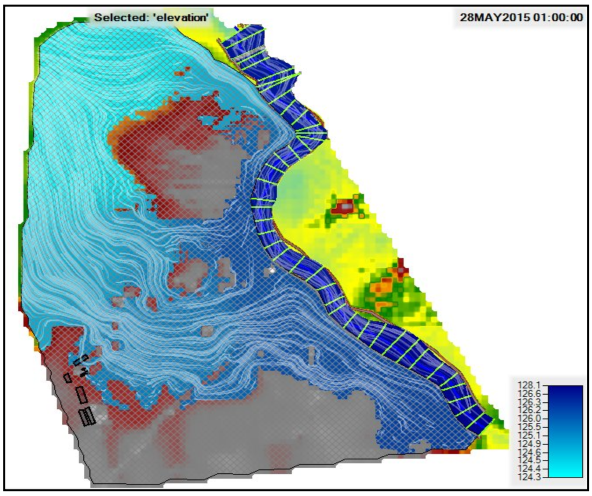

Figure 5. Water surface level development and particles trajectories in the coupled 1D/2D model at the specific moment of 01:00 on May 28th, 2015, for the exceptional river flow of 570 m^3/s

The roughness coefficient value considered in the improved model is variable for each cross-section and from one section to another, corresponding to the encountered vegetation of Crasna River: 0.053 to 0.055 for the flood plains, 0.083 to 0.085 within the embankments framing the river-course and respectively 0.042 for the actual river-bed. As for the left bank flooding area corresponding to the 2D space, the roughness coefficient was estimated as 0.055.

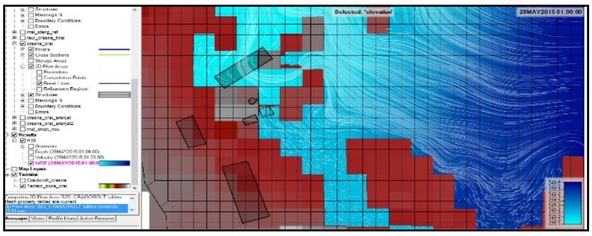

Figure 6. Particles trajectory detailed view in the technological platform area at 01:00 on May 28th, 2015, for the exceptional river flow of 570 m^3/s

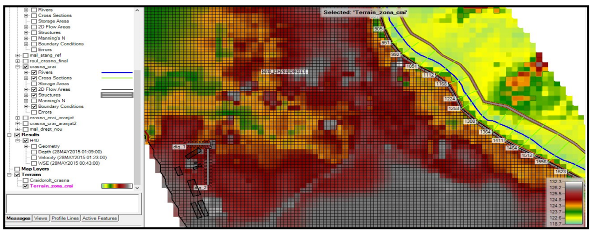

Figure 7. Additional meshing for the two connected flood defending embankment structures "dig_1" and "dig_2" towards the north-eastern side of the technological platform

3. BOUNDARY AND INITIAL CONDITIONS

As currently, the boundary conditions for the 1D route are represented by the transited flow of a named overrunning probability (known highwaters hydrograph) assigned to the upstream section – specifically the "1880" one in this model, and either the water course hydrodynamic gradient (0.0695‰) or the key curve (flow vs. level) assigned to the "21" downstream final section of the model. The initial conditions refer in this model to the known initial flow value, 65.98m^3/s, assigned to the model entering cross-section "1880". The analysis boundary conditions for the 2D space are enforced by attaching this additional "S2D_CRAIDOROLT" model to the false left bank side structure ("1836"), and respectively by assigning a hydrodynamic gradient (0.0695‰) to the defined "BC_S2D_CRAI_1" boundary line.

The highwaters hydrograph configuration was considered by scaling the known hydrograph that occurred along the special hydrologic phenomenon of May 26th to 30th, 2015, with a ratio of 3.9041 in order to show the required exceptional maximum flow value of 570m^3/s. So, the actual flow transition numerical simulation was carried out over a modeled known period starting at 06:00 on May 26th and ending at 18:00 on May 30th, 2015. The analysis was performed for a 10 seconds time step, while the output storage was set at each 10 minutes.

4. NUMERICAL SIMULATION AND SIGNIFICANT OUTPUT

Following the execution of the actual numerical simulations, the specific parameters (constant or time dependent) have been obtained – water level, flow and velocity – in all cross sections of the 1D numerical model and on the entire 2D domain as connected by the fictional left bank side structure to the studied Crasna River sector. The results revealed by the 1D/2D model analysis are further on graphically presented after performing the postprocessing operations in the RasMapper area.

As studying the graphical representation in figure 8, one can notice that the two flood defense embankments are saving the northern location of the developing company platform from the entire possible flooding area even in case of an exceptional hydrological event.

There can be also noticed from figure 9 that, as expected, the highest velocity values are produced on Crasna River path. The highest velocity under the specified circumstances goes to about 7.5m/s in the narrowed area of the road bridge. As about the technological platform flood defense embankments, the water velocity reaches maximum to about 0.21m/s at structure "dig_1" and 0.64m/s at "dig_2".

The graphical representations of Figure 11 look to indicate the water level time development in the 3 cross-sections carried out through the closing embankments and also intersecting the aside hydro-ameliorative canal. These maximum levels go to

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about 125.13mSL against structure "dig_1" and 125.31mSL against "dig_2".

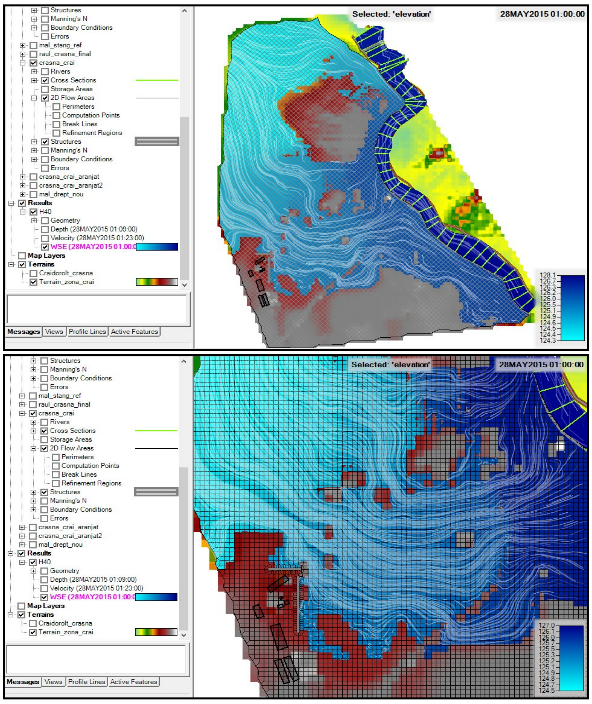

Figure 8. Water surface overlaid particles trajectories on the general 1D/2D model at the significant moment of 01:00 on May 28th, 2015, for the exceptional river flow of 570 m^3/s and a focus image upon the river left flood plain towards the area of specific interest

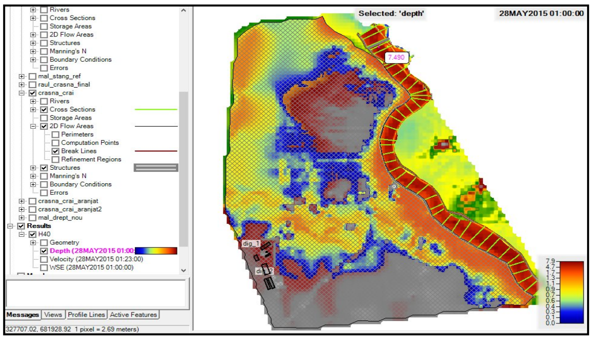

Figure 9. Water velocity development over the general 1D/2D model at 01:00 on May 28th, 2015, for the 570m^3/s river flow

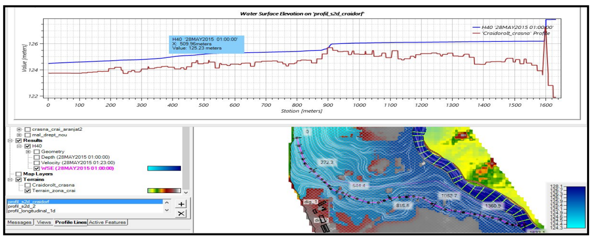

Figure 10. Left bank flood plain particles trajectories with the corresponding main stream longitudinal profile at 01:00 on May 28th, 2015, for the 570m^3/s river flow

5. CONCLUSIONS

The concluded specific geometrical features required for the closing embankments at the clogged hydro-ameliorative canal and the consequently maximum water level values as possible under the exceptional hydrological conditions (maximum river discharge of $Q_{1\%}$=570m^3/s) are offered in the following figure 12.

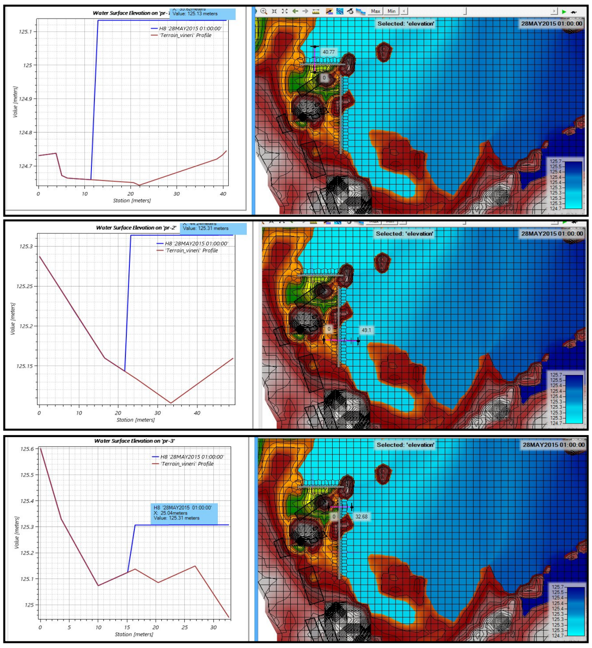

Figure 11. Water surface development with respect to actual ground configuration in three cross-section considered by the proposed embankments "dig_1" and "dig_2" shielding the concerning technological platform

The general transit of water is made mainly by the riverbed, but also, under special (i.e. the maximum flow value of 5% overrunning probability $Q_{5\%}$=322m^3/s) and exceptional (i.e. at 1% overrunning probability $Q_{1\%}$=570m^3/s) conditions, by the entire framed river valley and over a significant length of the embankments on the adjacent flood plains of Crasna River. Still, regardless of the hydrological conditions, the technological area under the property of TOPAGRAR SRL agricultural company would be unfloodable under the protection of two embankments (Figure 12).

In conclusion, in the case that the river longitudinal framing embankments remain at their existing configuration and an additional couple of specific defending embankments is carried out at the clogged hydro-ameliorative canal, the investment objective foreseen in the Crasna River left side flood plain remains safe even if the river flow goes up to an exceptional enforced value.

There has to be mentioned that the present study did not consider the likely possibility that the river framing embankments over-spilling can lead to time developing structures breaching. The described analysis didn't aim to determine some possible breaches that might develop at the two Crasna river banks.

Looking to such a further subject of study, there can be employed a specific facility in HEC-RAS v.4.1 to v.5.07, designed to allow a live monitoring of the breaching phenomenon by an intervention and repair modelling possibility for time developed over-spilling breaches. This remains an open subject regarding the safety in retaining earth-fill structures operation in the event of over spilling accidental highwaters.

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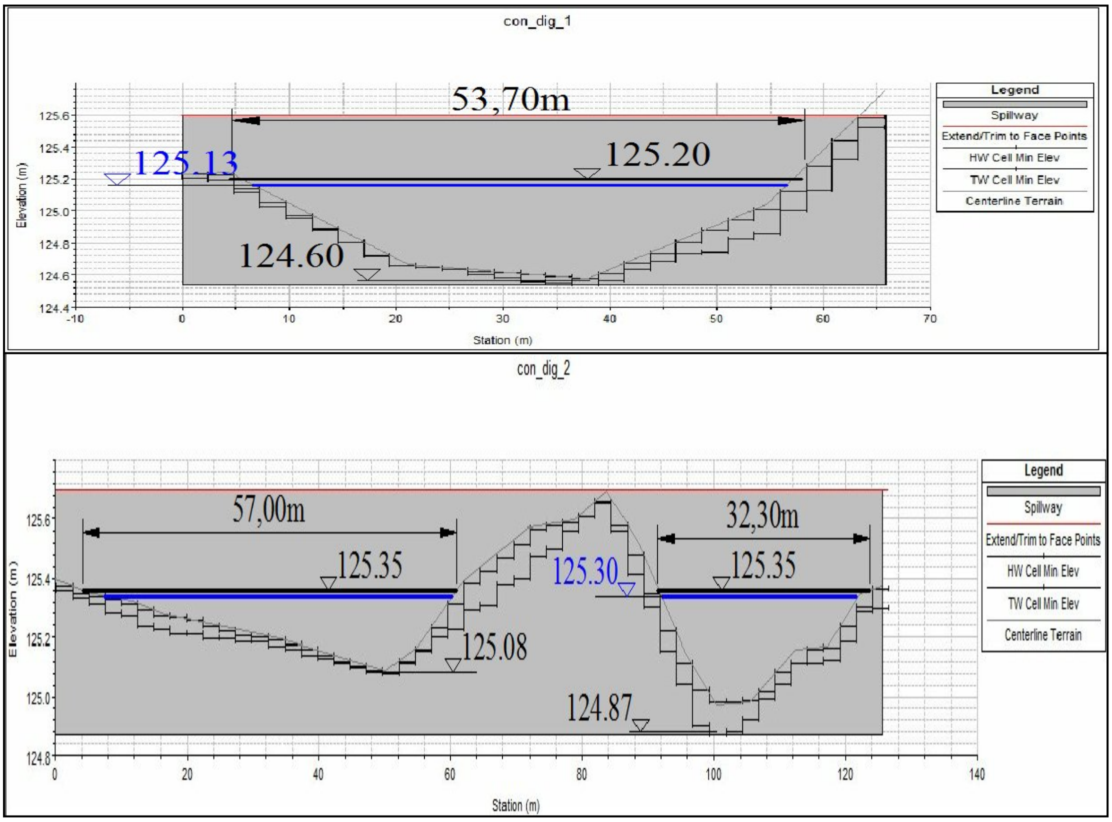

Figure 12**.** Geometrical and hydraulic characteristics as suggested for the accomplishment of two flood platform shielding embankments over the clogged hydro-ameliorative canal

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