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2D numerical model upon a water discharge from a mountain river

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Abstract: The paper presents a 2D numerical modeling of the flow on River "Alb", the village of Coroiești – Sălașul de Sus in Hunedoara County, aiming to establish the proper allowable water discharge towards a trout fish farm, with respect to the enforced specific national regulations. The numerical simulations are to support the study of water flows and levels on both the river main course and its left side branch, which is to be endowed with the specific hydraulic structure (overflow weir, side intake and apron). The modeled river section will have to allow the pass of the maximum design flow needed to be considered for the hydraulic structure, according to its importance class and given by a synthetic high waters curve.

Keywords: river engineering, water flow modeling, water catchment, 2D numerical model.

1. GENERAL DESCRIPTION, LOCATION AND HYDROLOGICAL DATA

In order to establish the „Fish farm and processing hall" investment planed by a local developer [4], comprising also the specific object of „Water catchment on Alb River", a hydraulic study which is to establish the allowed discharge in accordance with the enforced regulations concerning this specific water engagement had to be developed.

The structures needed by the mentioned investment (fig.1.1) are located about 500m upstream of the village of Coroieşti - Sălaşul de Sus in Hunedoara County, with its needed water catchment – overflow weir, side intake, apron [4] – placed on the newly developed branch of the River "Alb", a creek of continuous running flow. The hydraulic structure general geometry with its specific dimensions (mainly the proposed spillway and weir top levels – 641.55mSL and 643.50mSL, fig.1.2) as proposed by the developer are also to be verified and confirmed by the flow modeling under various conditions.

The specific data base, representing the site layout – topographic measurement by "Stereo 70" methodology – and a number of 33 cross view profiles spaced at about 5 meters from each other, was established in order to model in two dimensions the river course geometry. The modeled river layout was considered distinctively by four sections [5]: "*Alb River Upstream*", "*Alb River Central*", "*Alb River Branch*" and "*Alb River Downstream*" respectively (fig.1.3).

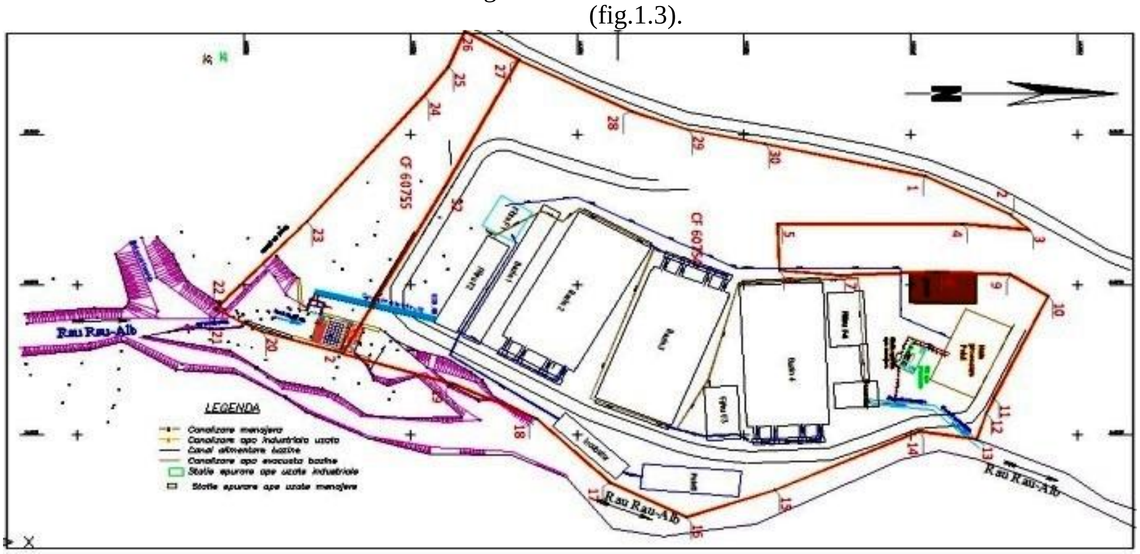

Figure 1.1 Location of comprising structures on the layout of „Alb" River sector [4]

The river course general configuration in the area of the planed structures, regarding also the left side branch, can be perceived from Photos 1.1.

The hydrological data needed in order to design the water catchment hydraulic structure was supplied as issued by the "Romanian Waters" National

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Administration based on a study according to National Institute of Hydrology and Water Management, corresponding to the site of Coroieşti on "Alb" River at the level of 642 mSL. Following flow values were provided: $Q_{av.yearly}$= 0.855 m^3/s; $Q_{sanitary}$= $Q_{95\%}$= 0.193 m^3/s; $Q_{2\%}$= 100 m^3/s; $Q_{5\%}$= 71 m^3/s; $Q_{10\%}$= 47m^3/s; $Q_{70\%}$= 0.238m^3/s and $Q_{80\%}$= 0.225m^3/s.

A high waters typical curve was than artificially developed by the help of HEC-RAS v5.03 dedicated software [3]. Probable curves were than scaled as reaching the mentioned maximum flow values of different overrunning probabilities.

The cross view profiles corresponding both to "*Alb River Central*" and "*Alb River Branch*" sections, as framed by the two fork joints, are divided in two by the dotted line (see in fig.1.3, as a water parting line linking the splitting and confluence ends). Consequently these cross views are numbered individually getting the corresponding "*-left*" or "*-right*" indication.

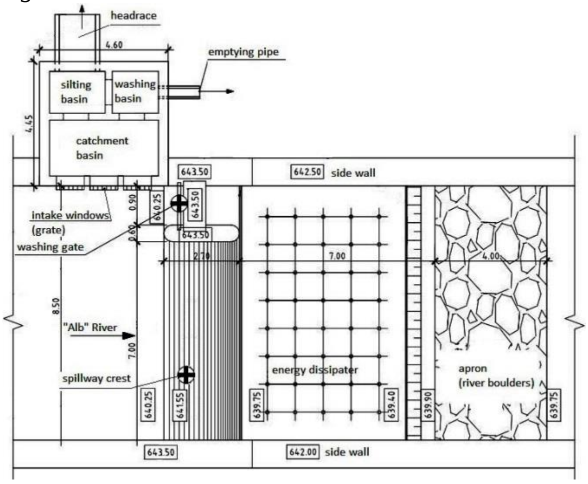


Figure 1.2 Catchment hydraulic structure proposed by developer [4]

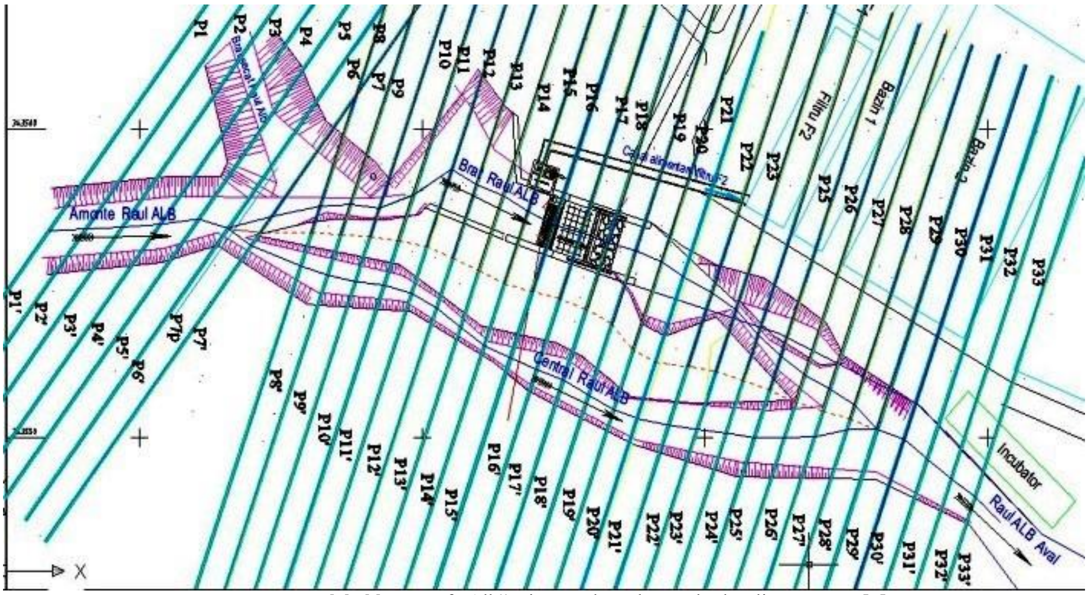


Figure 1.3 Modeled layout of „Alb" River and catchment hydraulic structure [5]

Photos 1.1 River course site configuration: upstream, left side branch and downstream sections

Under the natural configuration, the river runs on the considered section at a mean hydraulic grade of J=0.048, it shows a rapid state of motion and presents two falling steps.

2. RIVER COURSE NUMERICAL SIMULATION

The cross view profiles identification in the model [1, 3] employs a "milestone" kind of labeling (fig.2.1) which facilitates the generation of new interleaved cross-views by automatic interpolation, useful for calculations refinement.

The captured water surveying at the side intake [5] can be modeled by considering a lateral discharging structure on the left bank of the river branch. The assumed structure was designed as with three rectangular openings of b=0.90m x h=1.20m (fig.2.2) and characterized by a discharge ratio m_{sa} = 0.8 (submerged aperture). Depending on the flowing state determined by imposed condition of sanitary flow downstream the overflowed weir, the model was set to consider variable dimensions of these openings: b=0.05…0.156m and h=0.20…0.37m respectively.

Since the discharge monitoring along the headrace canal towards the fish farm constructions was not requested, the side structure at the downstream connection area was designated by the option "Out of the system".

The catchment overflow weir was modeled by a facing spillway structure of given dimensions, its profile geometry being pictured by figure 2.3. The central gap had to be considered as b=0.40m x h=0.20m in order to ensure the passing of the imposed sanitary flow, as the weir spilling crest is designed at the sanitary corresponding water level.

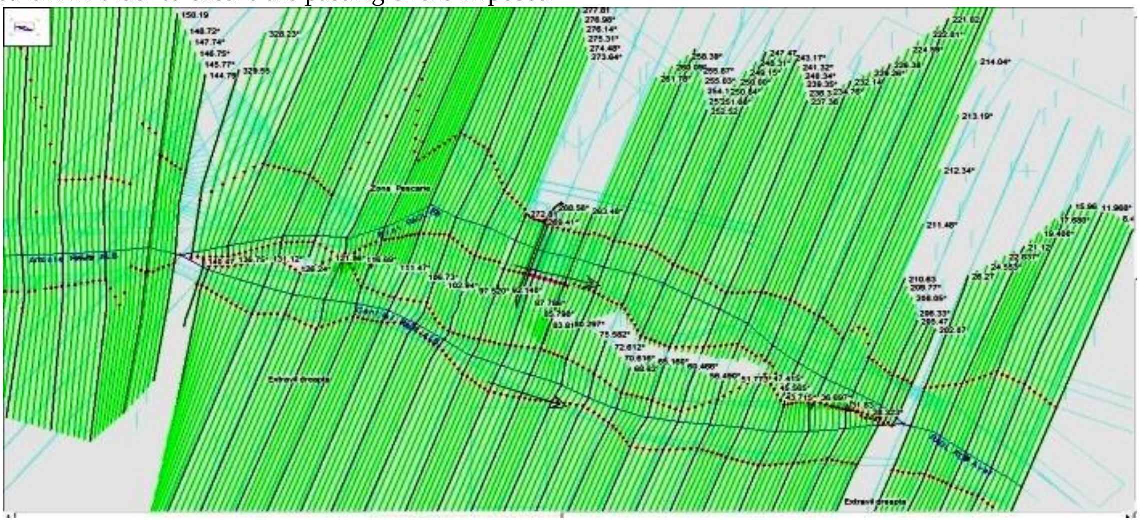


Figure 2.1 Layout of the numerical model with the overlaid catchment hydraulic structure [5]

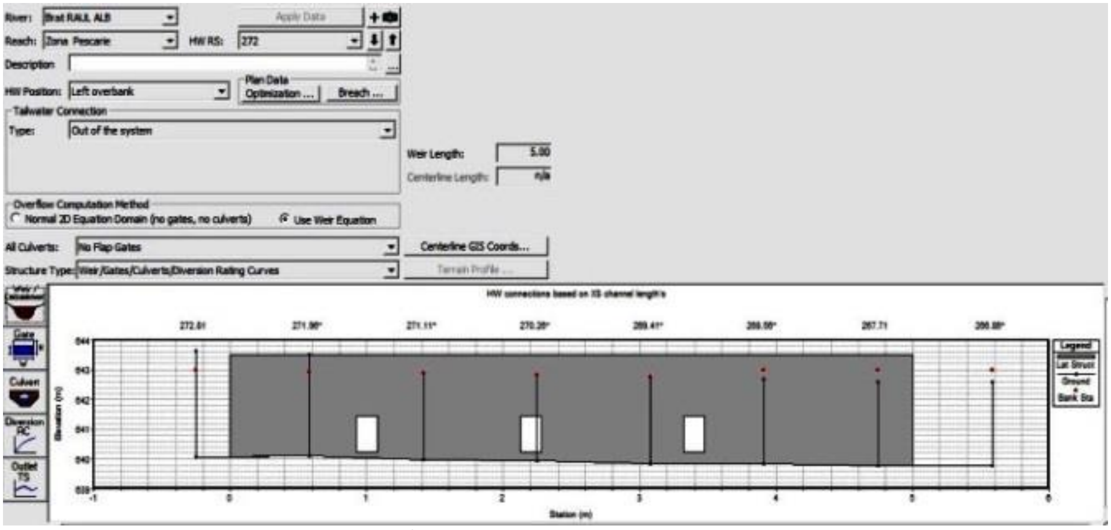


Figure 2.2 Model of side discharging structure with three intake openings

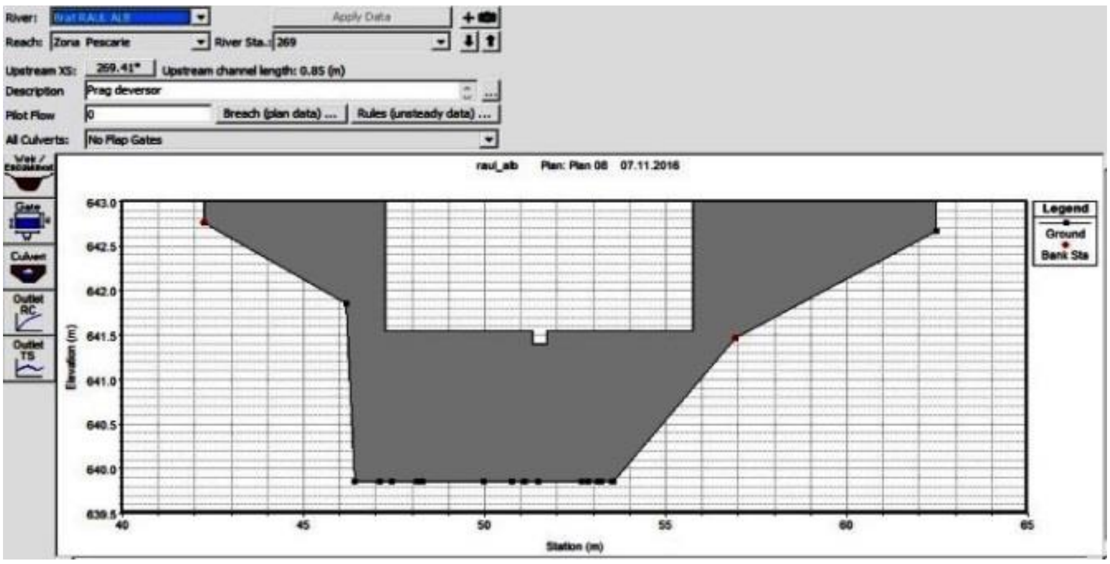


Figure 2.3 Model of facing spillway structure with sanitary central gap

The roughness ratios values distribution in the cross views were considered as follows: for the major watercourse n=0.045…0.065, for the riverbed n=0.040, while for the concrete part n=0.025 and the apron length (rear side including) n=0.104.

Based on the supplied water flow data (as measured at Coroiești Hydrometric Station) a specific sanitary ratio can be considered with respect to the average yearly flow value:

$k_{sanitary} = Q_{sanitary} / Q_{av.yearly} = 0.193/0.855 = 0.225$

by the help of which one can estimate the sanitary flow corresponding to the flow values of high overrun probabilities:

$Q_{sanitary\ 80\%}=k_{sanitary}xQ_{80\%}= 0.225x0.225 = 0.0506\ m^3/s$;

$Q_{sanitary\ 70\%}=k_{sanitary}xQ_{70\%}= 0.225x0.238 = 0.0536\ m^3/s$.

Farther on, following the model setting operations based on the watercourse geometry (both along the "*Alb River Central*" and "*Alb River Branch*" sections) and corresponding to the natural running situation, the water flows of different overrunning probabilities along the left side river branch were estimated:

$Q_{80\%}= 0.225\ m^3/s \rightarrow Q_{branch80\%}= 0.1086\ m^3/s$,

$Q_{70\%}= 0.238\ m^3/s \rightarrow Q_{branch70\%}= 0.1150\ m^3/s$ and

$Q_{av.yearly}= 0.855\ m^3/s \rightarrow Q_{branch\ av.yearly}= 0.3142\ m^3/s$.

Consequently, the sanitary flow values considered on the branch cross section of needed catchment hydraulic structure can be estimated by employing the same specific sanitary ratio:

$Q_{branch\ sanitary\ 80\%}= 0.0244\ m^3/s$,

$Q_{branch\ sanitary\ 70\%}= 0.0259\ m^3/s$ and

$Q_{branch\ sanitary\ av.yearly}= 0.0707\ m^3/s$.

Five high water curves were successively engaged for the river model [5] at the upstream entering and downstream leaving cross views, as for five running scenarios on "Alb" River when assuming the foreseen situation with catchment hydraulic structures: R1 – corresponding to the maximum flow of $Q_{80\%}$, R2 – for $Q_{70\%}$, R3 – for $Q_{av.yearly}$, R4 – for $Q_{5\%}$ and R5 – for $Q_{2\%}$. Out of these five simulated scenarios there are further on considered only two, meaning the R3 one, which would help to estimate the allowable discharge towards the fish farm, and the R4 one, which is to lead us to the significant high water level that has to be verified along the upstream sector.

3. RUNNING THE NUMERICAL MODEL AND RESULTS PRESENTATION

As a common approach, the actual running of the model goes for specific boundary conditions consisting from the following two hydraulic parameters: the passing flow of a given overrunning probability considered by the synthetic high waters curve attached to the most upstream cross section ("km 176.82"), and the watercourse hydrodynamic grade as given for the downstream cross section ("km 5.97") respectively.

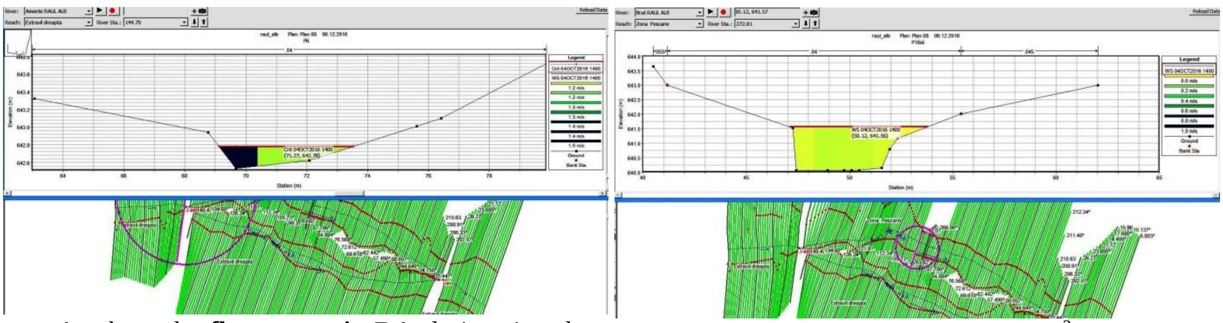
Regarding the **flow scenario R3**, designating the yearly average flow regime, the specific enforced boundary conditions are:

- the initial and the maximum water flows of the artificially developed high waters curve attached to "km 176.82" ingoing cross section are $Q = 0.20\ m^3/s$ and $Q_{max}= 0.85\ m^3/s$,
- the hydrodynamic grade of J=0.048176 attached to the "km 5.97" outgoing cross section.
- in the same time, as resulting from the model setting phase, the windows gap for the side discharging structure was adjusted at b=0.0925 m, while their height was fixed by considering the gates lifted at h=0.37 m.

All the fixed or time depending parameters regarding levels or water flow and velocity related to each cross section were obtained by running the model numerical simulation. Subsequent to the post processing graphic operation, the results were structured as follows:

- the piezometric line (the water level as mSL) and water velocity development (in m/s) characterizing several significant cross sections mainly on the left branch (fig.3.1 – the upstream splitting point and immediately upstream the overflow weir, and fig.3.2 – the facing overflow structure, the rear apron and the confluence point);
- the longitudinal view comprising the given geometry (thalweg, left/right banks, modeled structures) and presenting the piezometric line expansion (fig.3.3);
- water flow and piezometric line time development presented for several significant cross sections (fig.3.4a/b, from which one can notice the maximum inflow of 0.85 m^3/s produced on cross section "144.79" at the hour 10).

Figure 3.1 Flow scenario R3: water level and velocity in cross sections "144.79"-upstream of splitting point and "272.81"- upstream of overflow weir on the river left branch (at the hour 10)



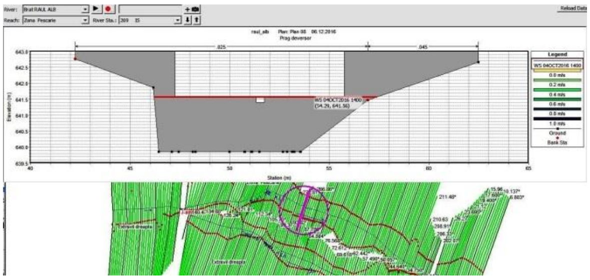
As about the **flow scenario R4**, designating the flow regime corresponding to the 5% overrunning probability on the modeled river sector, the specific enforced boundary conditions are:

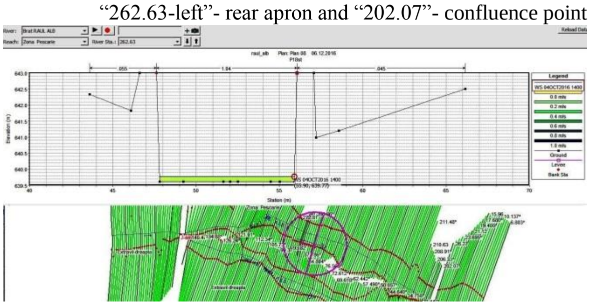
- the initial and the maximum water flows of the synthetic high waters curve attached to "km 176.82" ingoing cross section are $Q = 0.20\ m^3/s$ and $Q_{max}= Q_{5\%}= 70\ m^3/s$,
- the hydrodynamic grade of J=0.048176 attached to the "km 5.97" outgoing cross section.
- following the model setting operations, the windows gap for the side discharging structure was adjusted at

b=0.156 m, while the gates modeled to control their height were lifted at h=0.37 m.

The fixed and time depending river flowing parameters reached by running the numerical model were graphically organized following at large the same approach as for the previous scenario:

- the piezometric line (the water level as mSL) and water velocity development (in m/s) characterizing several cross sections (fig.3.5a/b – upstream and downstream of splitting point, immediately upstream the overflow weir, the facing overflow structure, the rear apron);
- the longitudinal view comprising the given geometry of the modeled river sector and presenting the piezometric line expansion (fig.3.6).





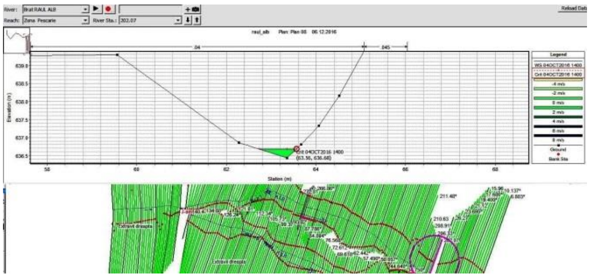


Figure 3.2 Flow scenario R3: water level and velocity in cross sections “269-left”-overflow structure, “262.63-left”- rear apron and “202.07”- confluence point

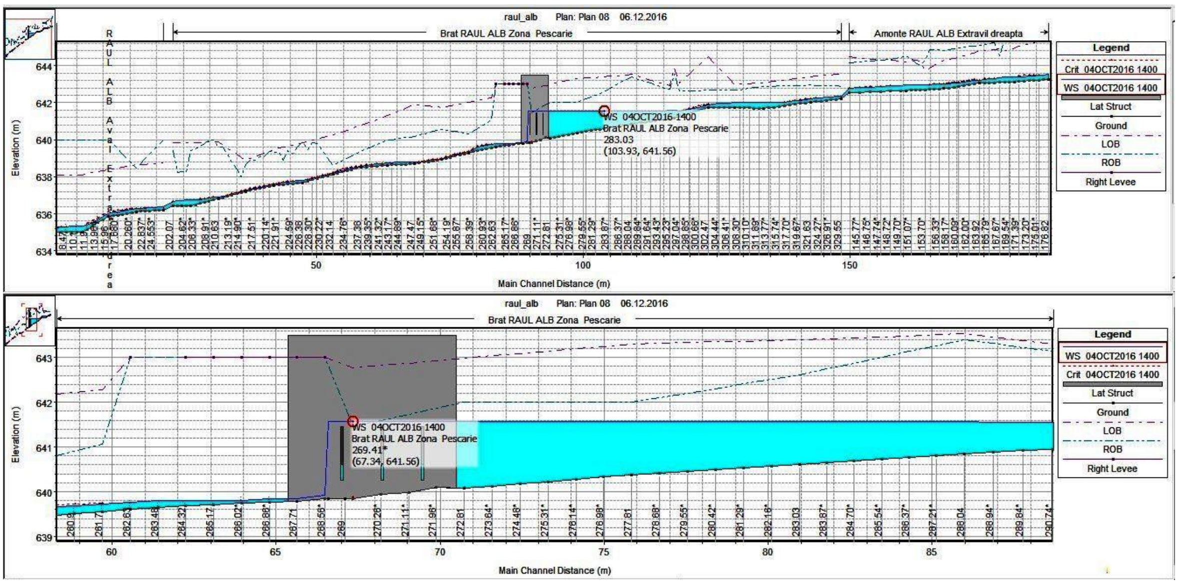
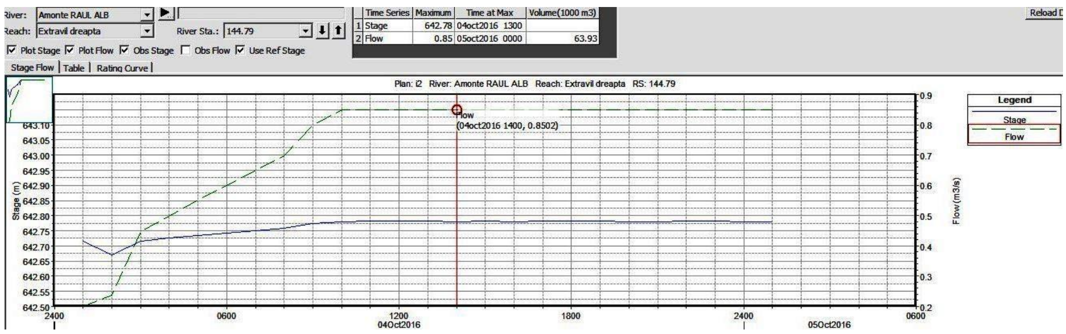


Figure 3.3 Flow scenario R3, longitudinal views (at the hour 13):
entire modeled river stretch (“*Alb River Upstream*” - “*Alb River Central*” / “*Alb River Branch*” - “*Alb River Downstream*”)
detailing of the overlaid middle sections (“*Alb River Central*” / “*Alb River Branch*”)



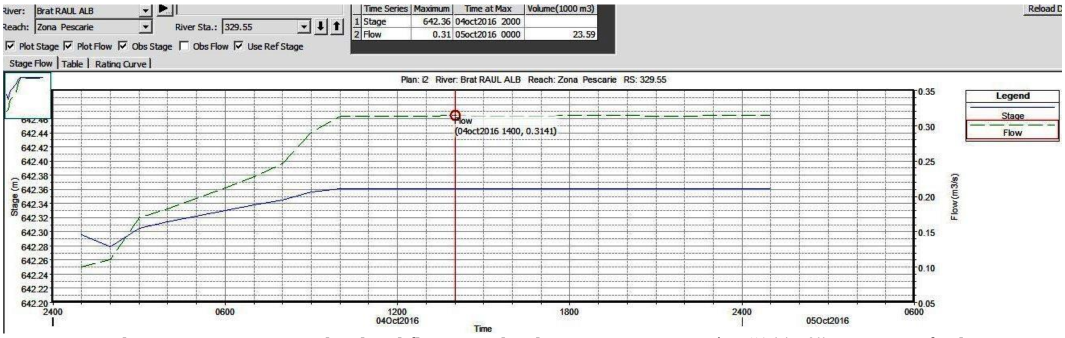
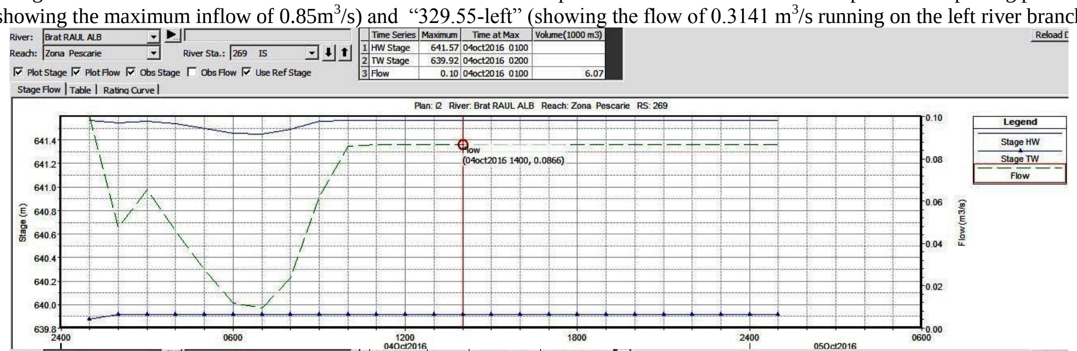


Figure 3.4a Flow scenario R3: water level and flow time development in cross section “144.79”-upstream of splitting point (showing the maximum inflow of 0.85m^3/s) and “329.55-left” (showing the flow of 0.3141 m^3/s running on the left river branch)



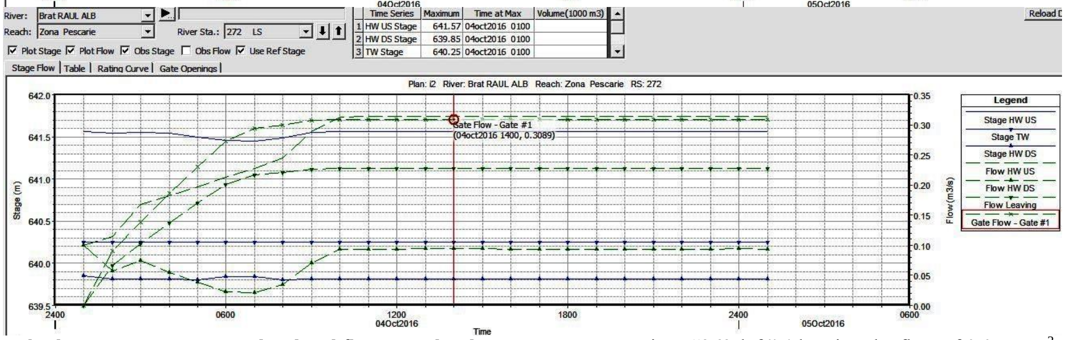
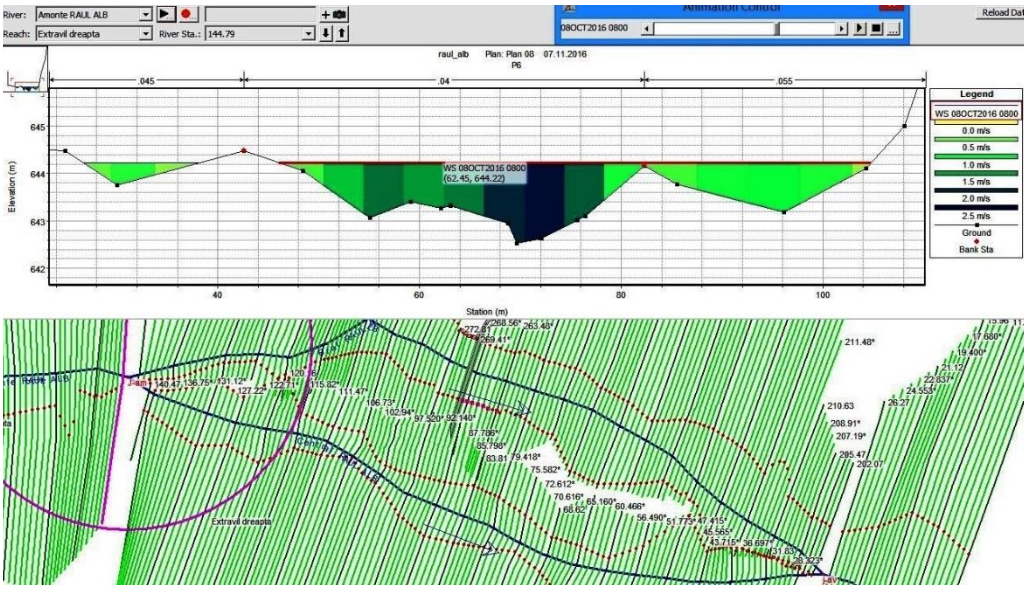


Figure 3.4b Flow scenario R3: water level and flow time development in cross sections “269-left” (showing the flow of 0.0866 m^3/s on the overflow weir) and “272-left” (showing the maximum discharge of 0.3089 m^3/s at the intake structure)



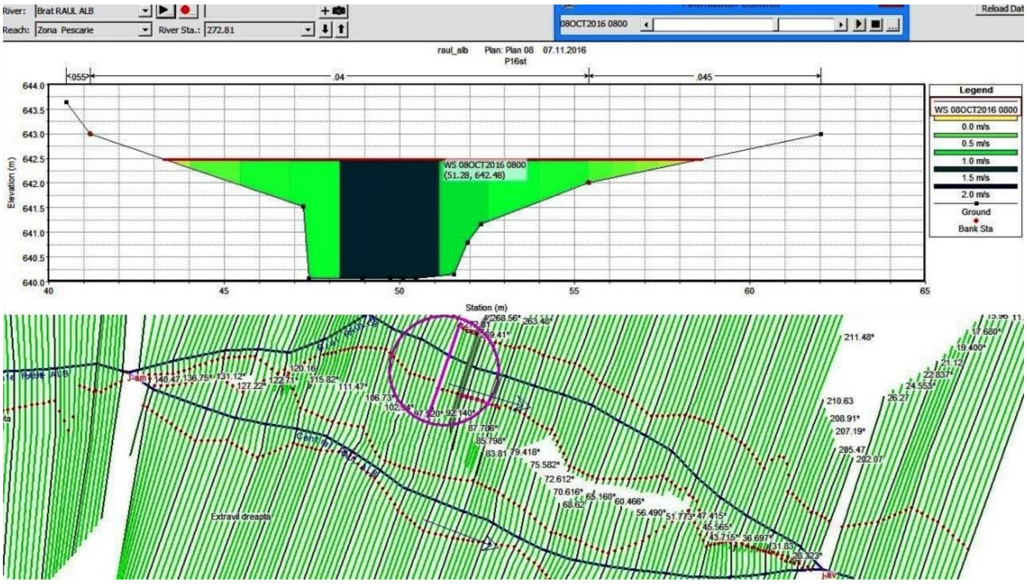


Figure 3.5a Flow scenario R4: water level and velocity in cross sections “144.79”- upstream of splitting point and “272.81-left”- upstream of overflow weir

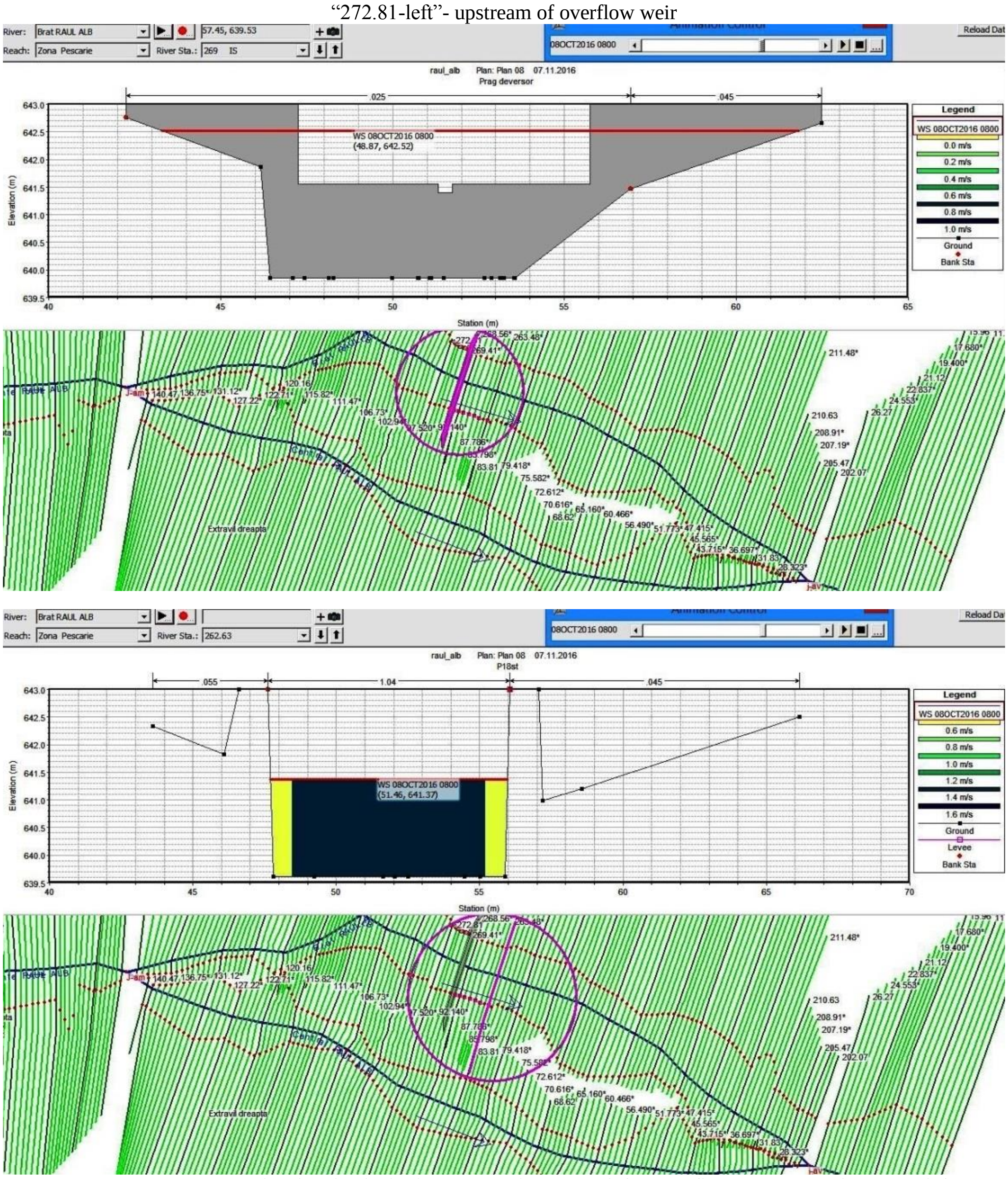


Figure 3.5b Flow scenario R4: water level and velocity in cross sections “269-left” -overflow structure and “262.63-left”- rear apron

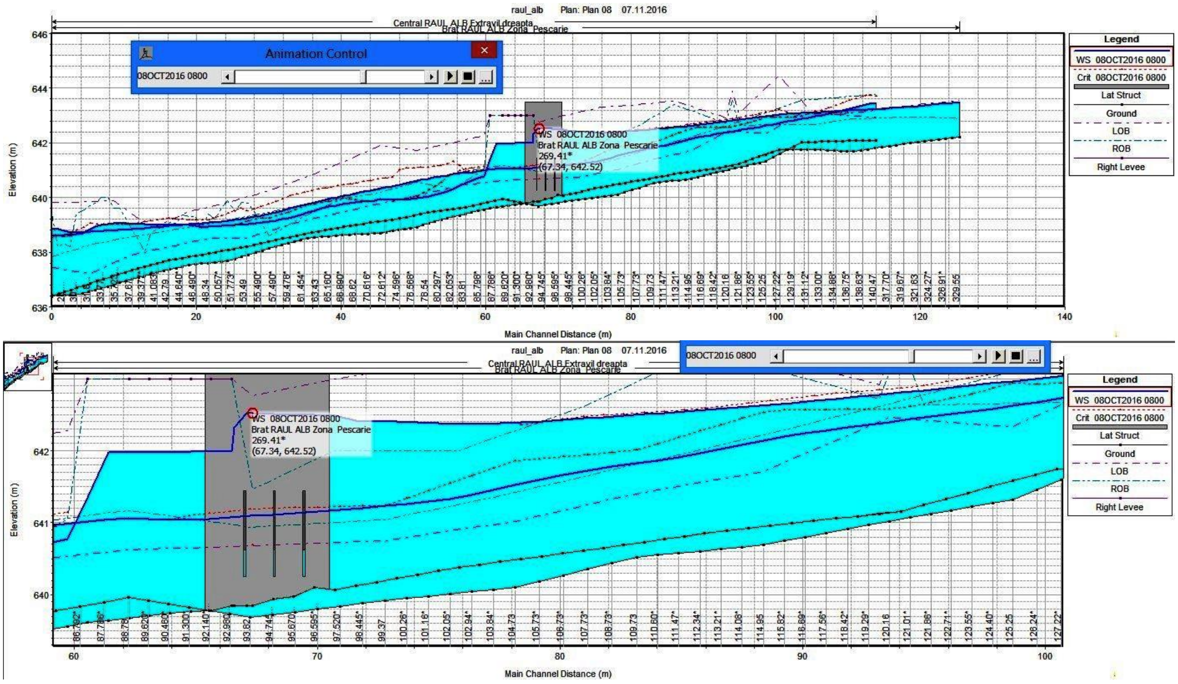


Figure 3.6 Flow scenario R4, longitudinal views (at the hour 08):
the overlaid sections of the modeled river stretch ("*Alb River Central*" / "*Alb River Branch*")
detailing of the overlaid middle sections ("*Alb River Central*" / "*Alb River Branch*")

4. CONCLUSIONS

By studying the simulations results [5] there can be concluded, as it was expected, that the flow transition is generally produced by the low streambed (as for the flow scenarios R1, R2 and R3, corresponding to the high overrunning probabilities – 80%, 70% or yearly average), but also partly by the river major valley (as proved by the R4 and R5 scenarios corresponding to the low overrunning probabilities of 5% and 1%) especially due to the planed hydraulic structure (overflow weir).

Since the low flow seasons are the challenging ones regarding the available discharge to be captured, the study can indicate the following situations corresponding to the first three flow scenarios:

R1, considering as the maximum river flow $Q_{80\%}= 0.225\ m^3/s$ to which corresponds the maximum flow on the river left branch $Q_{branch80\%}= 0.1086\ m^3/s$, leads to the weir overflow of $Q_{spill}= 0.032\ m^3/s$ and an available left intake discharge of $Q_{capt}= 0.106\ m^3/s$;

R2, considering $Q_{70\%}= 0.238\ m^3/s$ and $Q_{branch70\%}= 0.115\ m^3/s \rightarrow Q_{spill}= 0.032\ m^3/s$ and $Q_{capt}= 0.113\ m^3/s$;

R3, considering $Q_{av.yearly}= 0.850\ m^3/s$ and $Q_{branch\ av.yearly}= 0.3141\ m^3/s \rightarrow Q_{spill}= 0.0866\ m^3/s$ and $Q_{capt}= 0.3089\ m^3/s$.

Further on it is on the fish farm management to organize the running process based on this available fresh water supply.

As about the other two flow scenarios, R4 and R5, corresponding to the large water flows $Q_{5\%}= 71\ m^3/s$ and $Q_{2\%}= 100\ m^3/s$ and thus of low interest from the available discharge point of view, the modeling results show an overflow of $Q_{spill}= 18.41\ m^3/s$ or $25.06\ m^3/s$, versus a controlled discharge to be captured of $Q_{capt}= 0.47\ m^3/s$ or $0.1\ m^3/s$ (as one would maintain reduced intake opening in order to reach unfavorable upstream level conditions).

Regarding the water level upstream the catchment structure as an important result with respect to the spillway crest and weir top levels (641.55mSL, 643.50mSL), the first three flow scenarios show a value barely passing the crest with about a couple of centimeters and so allowing a sanitary flow on the last part of the river branch. More important from this point of view are the results obtained for the high waters flow scenarios R4 and R5. By considering in these cases a reduced intake capacity as a special running assumption, the numerical modeling leads to the maximum levels of about 642.52 mSL (R4) and 642.74 mSL (R5), well below the weir top, which proved to be properly designed with an appropriate safeguard height.

Besides the two aimed aspects of the 2D modeled phenomenon, one should be also concerned on the water spread beyond the low riverbed common limits in case of high waters. This can be obtained by overlaying the reached water levels with the supplied topographic layout or by performing a 3D modelling with another specialized software.

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*[4] ***** Documentație "Crescătorie intensivă de pește și hală de procesare a peștelui. Obiectiv: Captare secundară pe Râul Alb", S.C. HIDRO – A.C.S.R.L. Deva*

*[5] ***** Întocmire studiu privind scurgerea apelor de suprafață la diverse debite, pe cele două brațe din zona captării apelor, pentru păstrăvăria Coroiești, Beneficiar: ABI ECOACVA-CULTURA SRL, Deva, Contract nr.: BC 82/ 8.08.2016.*