River-Bed Processes Numerical Analysis in the Influence Area of a Crossing Structure

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Abstract: *There is described a 1D numerical study of scouring and sedimentation processes on a specific altered river sector. The model developed and analysed by the help of HEC-RAS software package is concerned by the immediate upstream and downstream vicinity of an existing road bridge. The general quasi-unsteady (transitory) flowing regime assimilates a given hydrologic development unfolding over a generous time period, from August 1st, 1985 to July 31st, 1988.*
The present paper considers a casual approach by which the specific crossing structure is replaced by two characteristic cross-sections along the concrete bridge faces. The scourings expansion and depth or the silting spread and height can so be revealed especially along the bothering bridge span but also along the influenced river sector as modelled.

Keywords: *River flow, bridge hydraulics, highwaters flow, sediment transport, river-bed processes, numerical model.*

1. General site and model information

The 1D numerical model covers a sector of 352.20 m on Someș River, downstream of its confluence with Agrij tributary, as altered by a crossing driveway bridge right outside of Jibou Town building area, about 25 km from Zalău Municipality in the North-West of Romania. The Town of Jibou in Sălaj County, north-east of Romanian historical Province of Crișana, lays down on the left bank of Someș River, at about 25km north-east of the county administrative municipality, Zalău.

The Someș River crossing by the east side connecting roadway is arranged by a bridge of six gaps determined by concrete piers, the total span covering the streambed and the adjacent flood plains [1]. The bays have slightly variable gaps of about 33.40m, 25.40m, 26.30m, 24.90m, 25.80m and 23.80m, as going from left to right. The bridge stands on the two flanking abutments and the five piers (about 2.20m width, 5.20m length, 184.00mSL top level) founded by concrete blocks (top level at 175.05mSL).

The numerical analysis performed by the help of HEC-RAS 5.0.6 [2] considers the quasi-unsteady flow regime over the given time period spreading from August 1st, 1985 to July 31st, 1988.

A topographic database was created as given by a general situation plan (comprising 371 measured points) and five cross profiles. Covering the studied river path and its adjacent areas, this data reflects the geometrical configuration of the river sector cross-sections, offering also the proper image of the stream-bed and flood plains morphology.

As about the crossing structure presence in the performed model, it is going to be considered by its upstream and downstream faces river cross-sections initial geometry. Since there were no accessible measurements of the scouring/silting situation, it was first necessary to numerically estimate [3] a start configuration properly matching former visual observation on bridge site.

There was followed a facile approach with respect to graphical processing of the available measured topographical data under similar given circumstances with the studied river site [4,5]. The approach employs a specialised 2D graphical interpolation software extension (specified 0x and 0y directions) that can further on generate a 3D shape surface (.shx extension file). So, by considering the previously created topographic database, a 3D ground surface associated to the Someș River sector was shaped. Further on, this shape was meshed by the help of RAS Mapper module and the discrete river-path was endowed with a contained bridge type crossing structure [6].

The boundary conditions for a steady flow regime under existing conditions are represented by the maximum entering discharge of 226.53 m^3/s and the known hydro-dynamic gradient of 2.75‰ as corresponding to the outgoing section.

The piezometric line development along the river sector model resulted by running the numerical analysis. The option Type was then considered under Hydraulic Design Functions menu and, after checking the Bridge Scour box, the input values of corresponding parameters were specified.

As following considered by the present paper, the analysis regarding the movable river-bed local washing capacity under transited flow and the effect of local stream contractions at piers and abutments is revealed by running the Compute command. The total maximum scouring amount reached at the crossing bridge (river station 148), i.e. Pier scour + Contraction scour = 1.59 m, as a parameter defining the simulated reference cross-sections at the bridge faces that follows to be considered in the sediments transport analysis, is revealed by the graphical representation in figure 1.

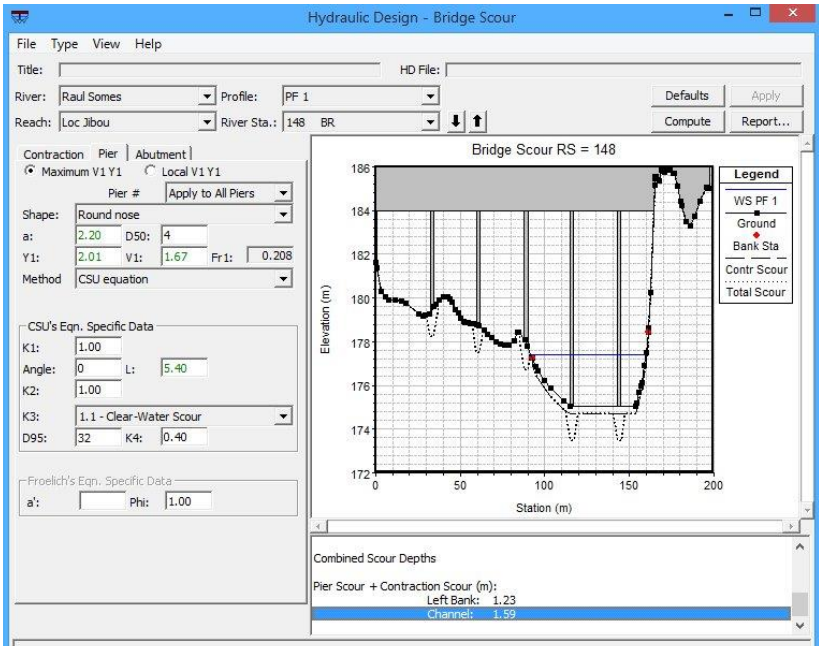


Fig. 1. Total scouring amount numerically revealed at the crossing road bridge, as to be considered for the sediments transport analysis

As about the sediment transport study, since available specific information is relatively uncertain and the driving theory is considerably empirical and parameters sensitive, it could be a difficult problem [3]. HEC-RAS 5.0.6 covers also sediments transport capacities related to the ground movable surface, successively adjusting the river cross-sections geometry as a response to solid material dynamics. The software combines the sediments transport computations with the unsteady or quasi-unsteady hydraulics.

By considering the quasi-unsteady flow regime, the hydrodynamics is simplified as the continuous hydrograph is modelled as a series of constant discrete flow values. So, for each registered constant flow the software makes the sediment transport calculations along the corresponding stated time interval. Specifically, each constant flow time interval is sub-divided by a user defined computational increment representing the sediment transport calculation time step. The system’s hydraulic and corresponding cross-section geometry is so successively updated for each computational increment. This time step covers several mixing stages at the level of the movable ground surface for the river-bed layers.

2. Accomplishment of the liquid and sediment transport 1D numerical model

Once the geographic coordinates established, the final ground surface shape (an ".FLT" extension file) is uploaded in the graphical window of HEC-RAS 5.0.6 by the help of RAS Mapper facility [1]. The 1D numerical model is generated by following the specific operations (river path drawing and cross-sections geometry, sequential generating procedure, conversion procedure, river banks or cross-sections alteration procedure etc.) given by HEC-RAS options [7,4]. The graphical visualization is achieved by the main menu, following the associated "Lid to XS" option (figures 2 and 3).

The two images in figure 3 show the significant river cross-sections – River Stations 151 and 146 – defined at the bridge faces to simulate the crossing structure. The specific area under the concrete bridge (of about 5.2m width) is covered by the geometric interval ΔL = 153.7 - 142.5 = 11.2m and its movable river-bed numerical characteristics are going to be updated only by extending the framing 153.7 and 142.5 cross-sections characteristics (and not by actual calculation). Thus, by establishing these simulated cross-sections, the river-bed levels on the particularly concerning bridge area are successively adjusted along the entire running period, allowing so the study of scouring as crossing structure effect.

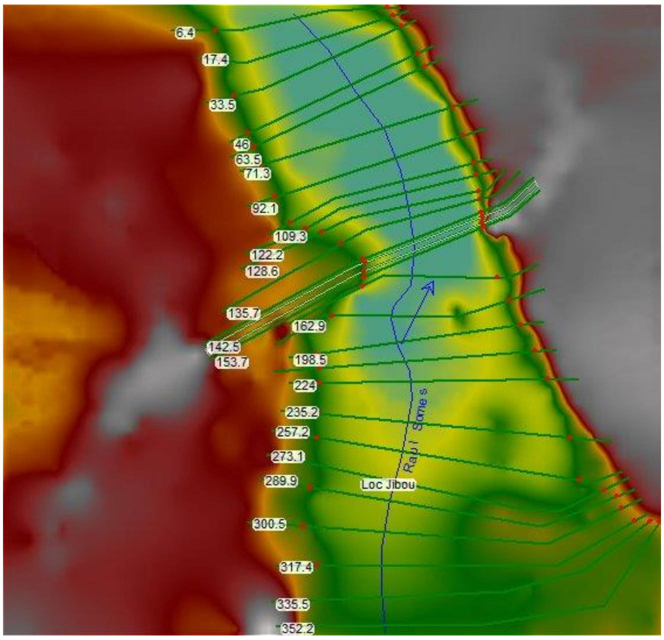


Fig. 2. Plan view of the 1D numerical model for the analysed Someș River sector indicating the cross-sections (river stations)

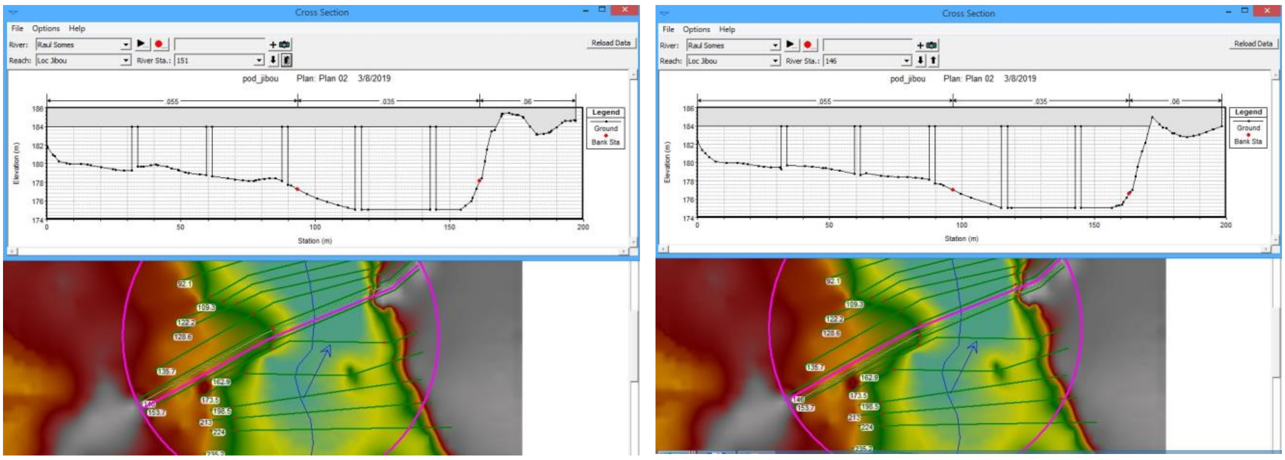


Fig. 3. Detail view of the Someș River sector numerical model indicating the two special river cross-sections defined at the upstream and downstream bridge faces (River Stations 151 and 146)

Figures 5 and 6 indicate the approaching ways for uploading the three years flowing hydrograph of the quasi-unsteady regime and the corresponding temperature series respectively. The hydrograph development on the studied site on Someș River reaches the maximum value of 226.53 m^3/s.

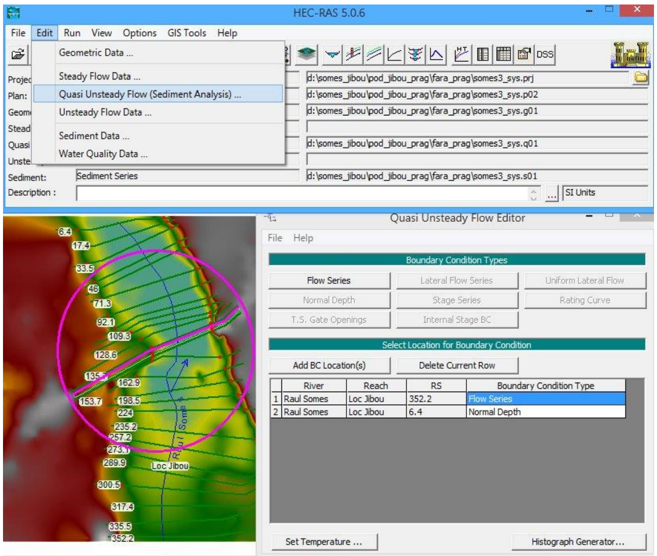


Fig. 4. Flowing hydrograph approaching way as considering a quasi-unsteady regime

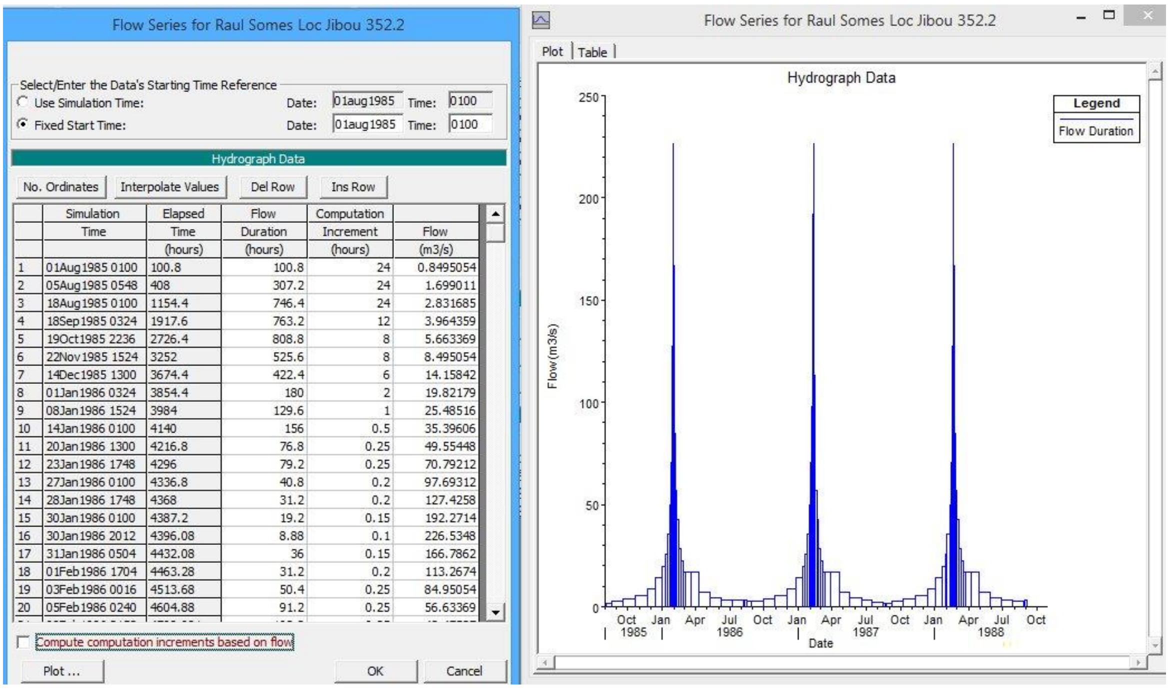


Fig. 5. Accustomed flow hydrograph over the total simulation period, August 1st, 1985 ÷ July 31st, 1988

Besides three regular files developed by a HEC-RAS 5.0.6 modelling – the flow one (constant or unsteady), the geometry one and the plan model one (as bonding the data files), the sediment transport analysis requires a fourth file covering the solid material data. Figure 7 illustrates the uploaded sediment data and the specific geometry elements. The sediment data editor shows three facilities: Initial Conditions and Transport Parameters, Boundary Conditions and USDA-ARS Bank Stability and Erosion Model (BSTEM), the first two needing to be always accessed in a sediment transport model, while the third one being required only for an analysis concerning river-banks failing processes.

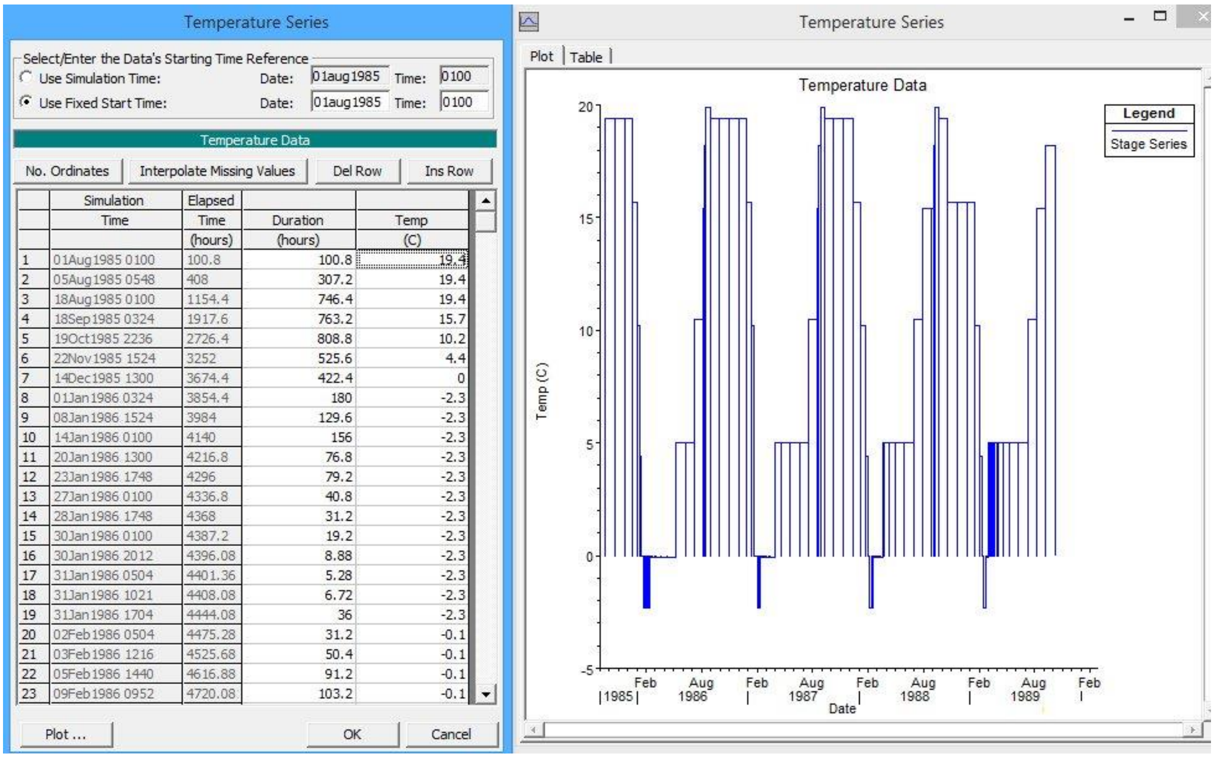


Fig. 6. Temperature series development covering the simulation period

Some sediment parameters need to be defined for each of the numerical model cross-section, the two simulated ones including. The following elements were adopted for the sediment transport analysis: the Yang transport function, the Thomas river-bed mixing method and the Rubey fall velocity computation method.

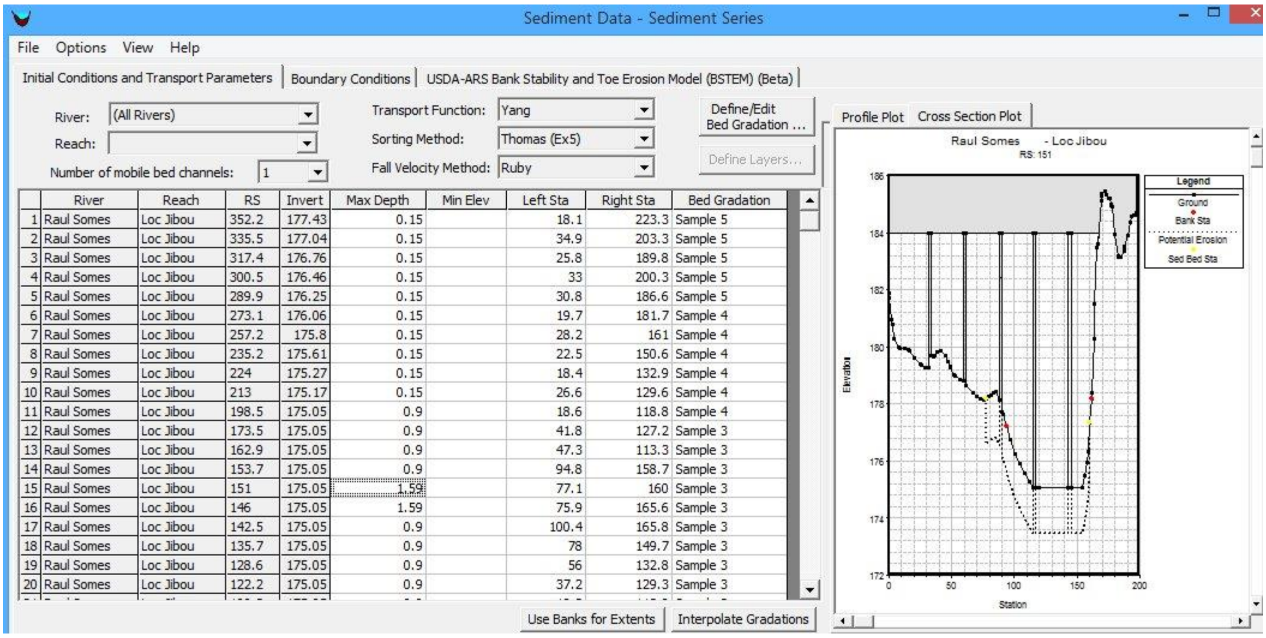


Fig. 7. Cross-sections sediment specific data

The movable river-bed surface was defined by six bed layers gradation templates, specifying the shallow ground granulometry. The graphical representation of figure 8 exemplifies the ground gradation curve in the crossing structure area (Sample 3) according to the associated granulometry.

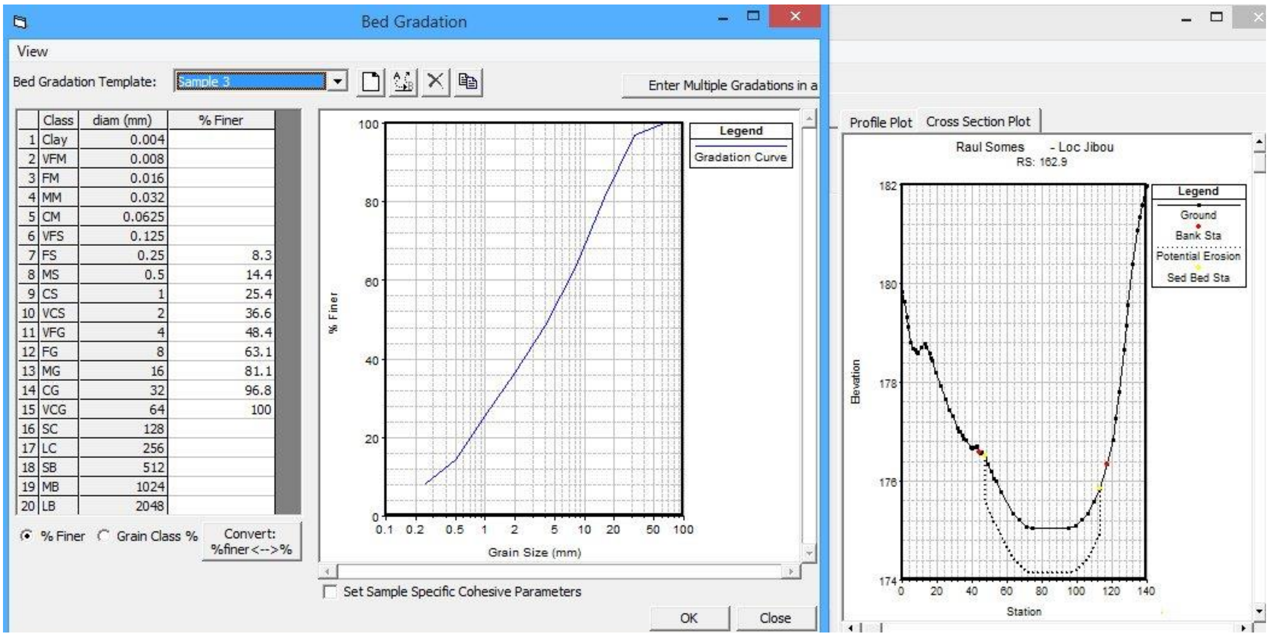


Fig. 8. Gradation curve of the movable river-bed shallow ground corresponding to the crossing bridge area on Someș River analysed sector, as attached to River Station 162.9

It must be mentioned that the employed data regarding the solid flow and the movable river-bed layers gradation was only adjusted from other similar river courses and sites, following recommendations and eloquent templates [2]. Even if the values modelling these parameters closely follow a possible natural case on the studied site, still they are not obtained by authorized monitoring and measurements. Similarly, the adopted temperature development generally complies with thermal monthly evolution in the specific geographical area of Jibou Town.

As about the model boundary initial conditions, they were edited in the Sediment Analysis sub-menu by employing the BC Line option with respect to the upstream entering river cross-section (River Station 352.2). The constant flow values and the flow steps duration, as modelling the natural hydrograph, together with the computation increment of each step were assigned there (figure 9).

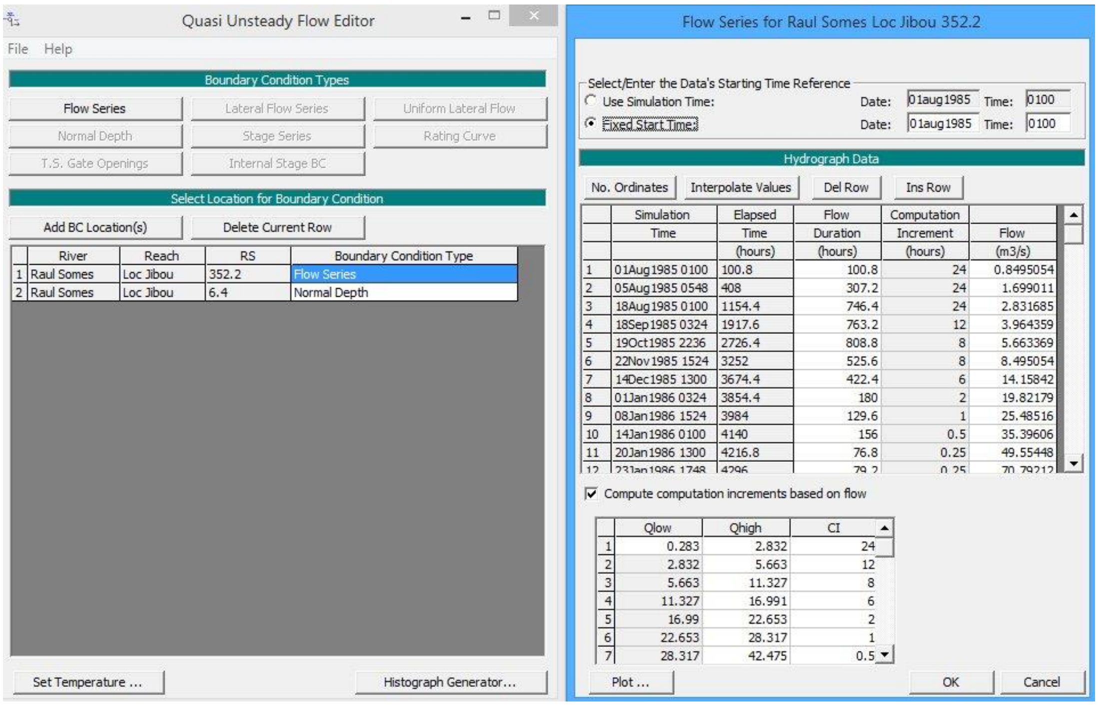
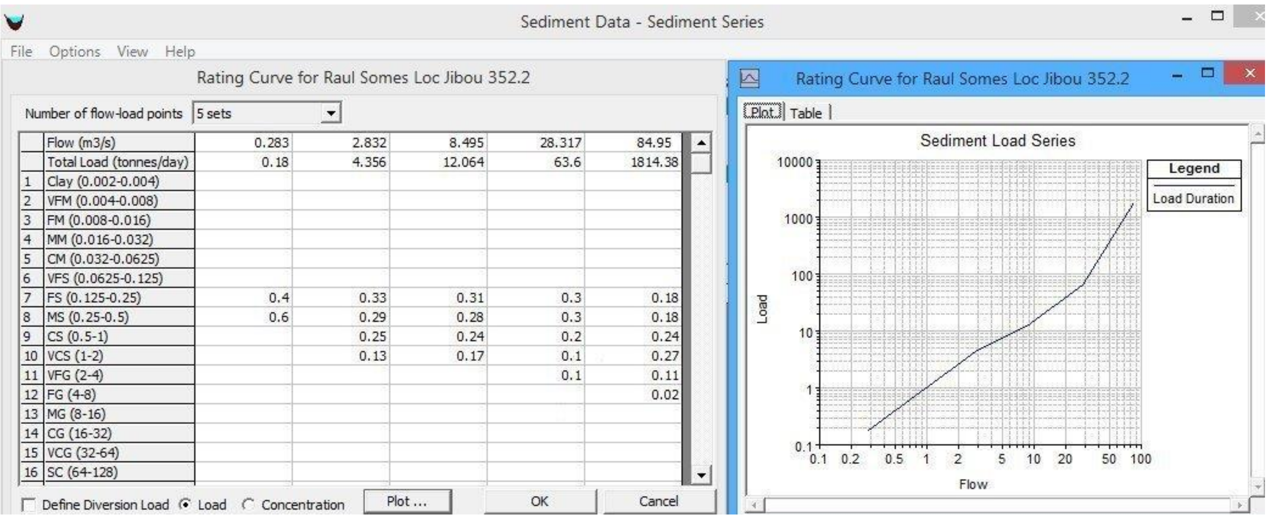


Fig. 9. Assignment of upstream entering river station boundary conditions – constant flow series

The computation increment value is estimated as related to the constant flow level, decreasing with the flow value increase (Compute computation increments based on flow facility). In the same time, a downstream boundary condition was edited by assigning the given 2.75‰ hydro-dynamic gradient to the model outgoing river cross-section (River Station 6.4).

The solid flow sets of values (tons/day), as estimated in relation to the liquid one (m^3/s), were uploaded as boundary conditions of the numerical model by following the given sequence of software menus: Sediment Data → Data sediment – Sediment Series → Boundary Conditions → Rating Curve. There were considered five sets, for each being specified the fractions contribution in the sediment load according to the material granulometry (figure 10), which were assigned as boundary condition to the river sector entering cross-section (River Station 352.2).



	Flow (m3/s)	0.283	2.832	8.495	28.317	84.95
	Total Load (tonnes/day)	0.18	4.356	12.064	63.6	1814.38
1	Clay (0.002-0.004)					
2	VFM (0.004-0.008)					
3	FM (0.008-0.016)					
4	MM (0.016-0.032)					
5	CM (0.032-0.0625)					
6	VFS (0.0625-0.125)					
7	FS (0.125-0.25)	0.4	0.33	0.31	0.3	0.18
8	MS (0.25-0.5)	0.6	0.29	0.28	0.3	0.18
9	CS (0.5-1)		0.25	0.24	0.2	0.24
10	VCS (1-2)		0.13	0.17	0.1	0.27
11	VFG (2-4)				0.1	0.11
12	FG (4-8)					0.02
13	MG (8-16)					
14	CG (16-32)					
15	VCG (32-64)					
16	SC (64-128)					

Fig. 10. Definition of the five sets of sediment load as corresponding to the liquid flow level, assigned to the upstream entering river station

3. Numerical simulation and results

The liquid and solid transport numerical simulation along the specific river sector was performed over a three years given period, from 01:00 of August 1st, 1985, to 23:00 of July 31st, 1988. The steady and time dependent representative flowing parameters – water level, velocity and discharge – along the entire modelled river sector were revealed by running the numerical simulation.

Particular files of numerical values were created by performing the output regular processing operations [1,5,6]. As specifically looking to study the effect of considering the two simulated bridge framing crossing-sections with respect to a reference situation when the model considers the actual crossing structure (analysed by Popescu-Buşan et.al., 2019, under the same flow and sediment loading conditions [1]), the numerically reached results are going to be fairly presented further on.

Since the analysed phenomenon runs over a relatively long period of time, for expressiveness reasons, there were considered six particular moments of given constant liquid flow (figure 11): August 18th, 1985, of 2.83m^3/s transported flow, January 8th, 1986, of 25.485m^3/s, January 30th, 1986, of 226.53m^3/s, August 5th, 1986, of 2.83m^3/s, February 20th, 1987, of 186.79m^3/s, and February 20th, 1988, of 226.53m^3/s.

As comparatively examining the numerical output regarding scouring depths (or silting heights, at some moment) in the immediate bridge area (geometric interval ΔL = 153.7 - 142.5 = 11.2m), one would notice that the values reached by the presently described model are slightly different from the values given by the reference model (table no.1).

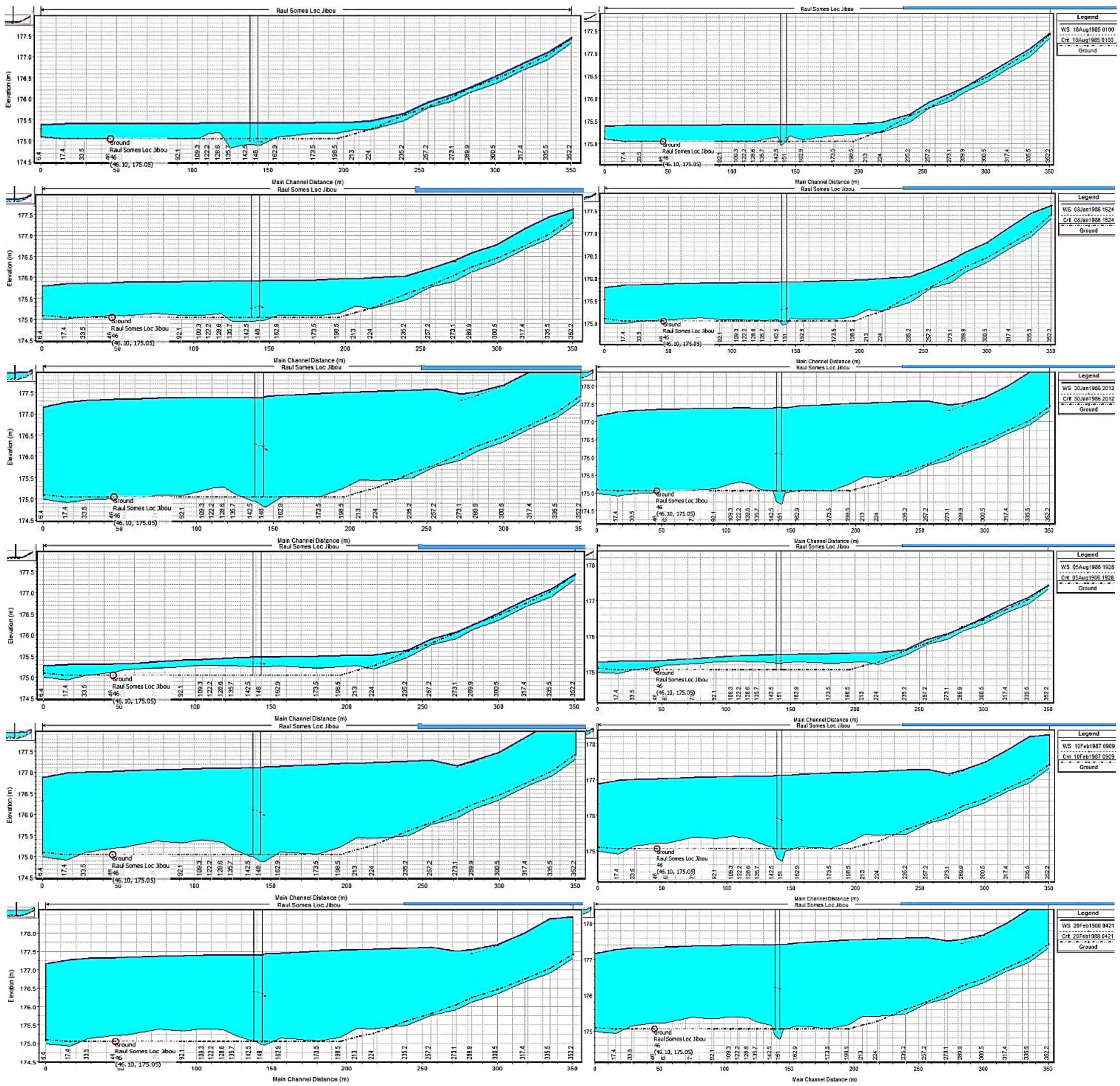


Fig. 11. Comparative water surface and river-bed longitudinal profiles (reference model on the left side) on the Someș River analysed sector at six particular moments along the liquid and solid transport simulation period: August 18th, 1985, January 8th, 1986, January 30th, 1986, August 5th, 1986, February 10th, 1987, and February 20th, 1988

Even if the values are in the expected range and so not outsize for the analysed phenomenon under the given judicious circumstances, there is still noticed that the major difference appear as larger scourings – January 30th, 1986 $\rightarrow \Delta$ = 9cm, February 10th, 1987 $\rightarrow \Delta$ = 19cm or February 20th, 1988 $\rightarrow \Delta$ = 18.6cm.

Regarding the concerning river cross-section right at the bridge upstream face, tagged as River Station 151, the correlated river-bed minimum level – water surface maximum level time development revealed by the presented model (figure 12) show a general tendency of scouring decreasing with respect to the foundation structure top level (175.05mSL) from about 38cm, in the first part of the considered three years simulation period, to about 22cm, as the maximum depth towards the ending part.

Table 1: Movable river-bed levels in the bridge area at several moments

	River Station	Movable river-bed level (mSL)					
		August 18th, 1985	January 8th, 1986	January 30th, 1986	August 25th, 1986	February 10th, 1987	February 20th, 1988
Reference model	153.70	174.9000	174.9700	174.8100	175.2400	174.8900	174.9700
	151	174.9000	174.9700	174.8100	175.2400	174.8900	174.9700
	146	174.9100	174.9100	174.9300	175.2600	175.0200	175.0900
	142.50	174.9100	174.9100	174.9300	175.2600	175.0200	175.0900
difference from the minimum bed level to foundation block top level (175.05mSL)		- 15.0cm scouring	- 14.0cm scouring	- 24.0cm scouring	+ 19.0cm silting	- 16.0cm scouring	- 9.8cm scouring
Present model	153.70	175.2010	175.0994	175.1198	175.2991	175.0052	175.0440
	151	174.9879	174.9705	174.7200	175.2353	174.7000	174.7664
	146	174.9378	174.9623	174.7900	175.2444	174.8195	174.8862
	142.50	175.1721	175.0986	175.0861	175.2476	175.1111	175.1564
difference from the minimum bed level to foundation block top level (175.05mSL)		- 11.2cm scouring	- 8.8cm scouring	- 33.0cm scouring	+ 18.5cm silting	- 35.0cm scouring	- 28.4cm scouring
deviation with respect to reference model		3.8cm	5.2cm	9.0cm	0.5cm	19.0cm	18.6cm

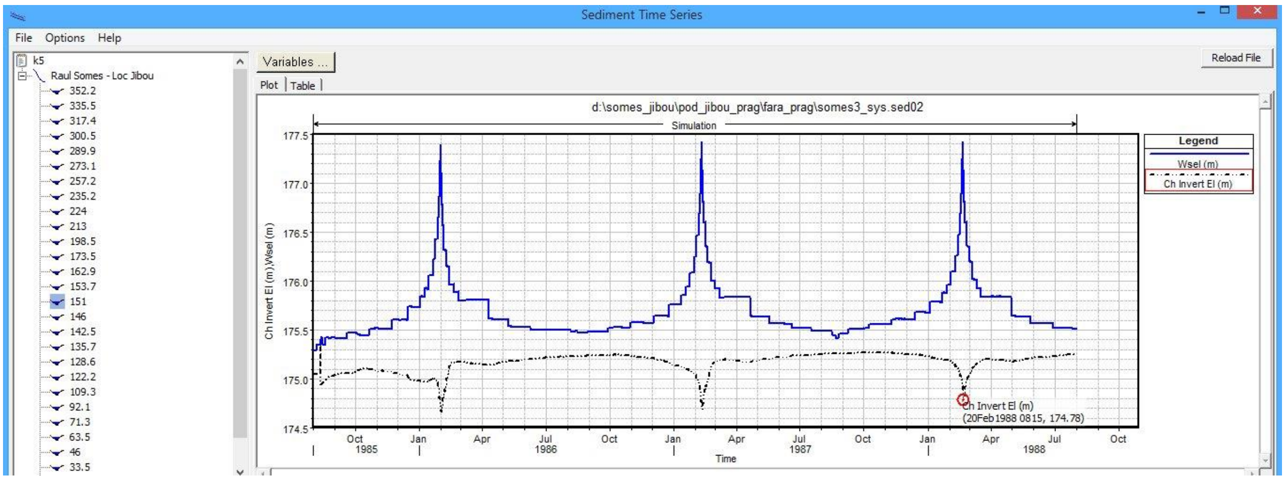


Fig. 12. Correlated river-bed minimum level – water surface maximum level time development on the bridge upstream face river station 151 along the three years simulation period

4. Conclusions

By performing the liquid and solid transport numerical study for the bridge influenced Someș River sector in order to analyse the river-bed dynamic processes, one can conclude that in case of lack of specific local geometry information (e.g. new river crossing structures on other sites) there is possible to engage a two steps modelling. In order to reach a potential local scouring estimation for the bridge area, the first model step considered the explicit bridge structure under transited by the steady maximum flow of 226.53m^3/s and led to the total maximum scour depth of 1.59m with respect to piers foundation top level. This under bridge river-bed geometry, obtainable only by involving the actual crossing structure model, is to be further on engaged to define the required parameters for the second model step. Thus, the actual crossing structure was than replaced by two simulated framing river cross-sections bearing also the bridge supporting piers structural shape. The altered numerical model of the second step is recommended for a liquid and sediment transport analysis.

The comparative study of the outcome revealed by the proposed two steps model and the results of a previously performed numerical simulation under similar flowing conditions, which however considered a given state of river-bed and bridge structure, shows a considerable reversion of the starting local scouring limits but also significant differences (maximum about 19cm) regarding the scouring depths, mainly larger for the present approach.

As it was already suggested by the former analysis results, looking at the presently reached outcome it may be once again concluded that the accomplishment of a bridge downstream bottom step would be required in order to improve the general river-bed processes development over time. Its location may be estimated by the help of the graphical longitudinal output, meaning on the inflection point parting the silting and scouring sections in the bridge downstream area (about River Station 46). The bottom step optimum height may be further on proposed by performing some successive additional analysis.

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