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Numerical modelling of high water flow transit for a specific river reach

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Abstract: The paper presents a numerical simulation of a special water flow on the lower course of Timiș River, in the Town of Caransebeş, which would happened during a possible exceptional high-water phenomenon. An accidental high-water development was engaged by configuring the noteworthy hydroflow registered on the beginning of April, 2000, on the mentioned river sector in the West plain of Romania. The simulation by a numerical model aimed to estimate the water surface elevation development in order to give an indication with respect to the possibility of locating a public building in the river right side major valley, nearby a crossing bridge. In the same time the study looked to establish the water velocity spectrum in order to further estimate if specific protection measures would be needed for the right river bank to avoid possible erosions in the planed building vicinity.

Keywords: river engineering, high-water flow, flooding, flow computer modelling.

1. GENERAL CONSIDERATIONS

Following a request from a public institution for new and proper local premises – Caransebeș Courthouse, the Town Municipality offered a relatively central and sizeable piece of land in the Timiș River major valley as a possible development location. Still, the place is situated in a high-water flooding area near a vehicle / pedestrian crossing bridge (photo 1.1), area which previously too demanded specific flood protection works.

Photo 1.1 View towards the proposed building construction site, right bank of Timiș River

Exceptional hydrological events that happened along time in Romania, leading to flooding of large land surfaces and significant damages upon buildings, farms, transport infrastructures and specific protection works, called for certain development regulations. There is thus stipulated that buildings accomplishment in the watercourses floodplain has to be avoided. The European policy regarding the affected watercourses consists basically in their renaturation, meaning even partly demolishing the accompanying embankments and meanders revitalization. There is also considered the accomplishment of "wet areas" by allowing temporary flooding of certain regions which may comprise relatively low importance arrangements, such as recreational, transportation or buildings, designed especially to minimize their deterioration along the few days or even weeks of washing. Once the high-water has naturally passed, the affected objects are supposed to be fit into use with low costs regarding mainly the alluvia evacuation.

In case the renaturation would not to be decided for due to the given density of urban structures aside the protecting embankments, a new building development in floodplain area could be technically possible by adopting a specific arrangement for sheltering its stability and functionality. For example, the building to be accomplished with its first floor (±0.00) at a level immediately above the highest water level occurring during high-water, this level value being estimated according to the enforced regulations. The under space can be set up either as a parking lot (floodable eventually) or a storage room, in which case the space would be sealed off by waterproof walls and windows. In order to fulfil the building operation also during a high-water event, the main public access is to be arranged by a footbridge linking its first floor to the embankment top. Another solution for building development would be by accomplishing a surrounding supporting wall with its top level immediately above the estimated highest water level. Certainly, a minimum affected area should be considered and so not significantly influencing the water flow on the river sector during a high-water event (not to shrink the water discharge capacity). The responsibility regarding the general safeguard

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sustainability falls on the shoulders of the developer & hydraulic engineer team, while the "Romanian Waters" National Administration (RoWNA, the water management authority) would be relieved of any responsibility in the area once the design is fulfilled and assumed.

Thus, under the presented circumstances, the developer by its general contractor asked us for a study seeking to estimate the water level regime accompanied by the velocity spectrum along the affected river stretch.

Specifically, the suggested construction site lies down on the area of Teiuşului and Dâlmei Streets crossroad, left side of the bridge ramp (photo 1.2). Since the spot is part of the flooding area, Dâlmei Street is guarded in case of a special high-water event by a concrete parapet of about 90 cm height.

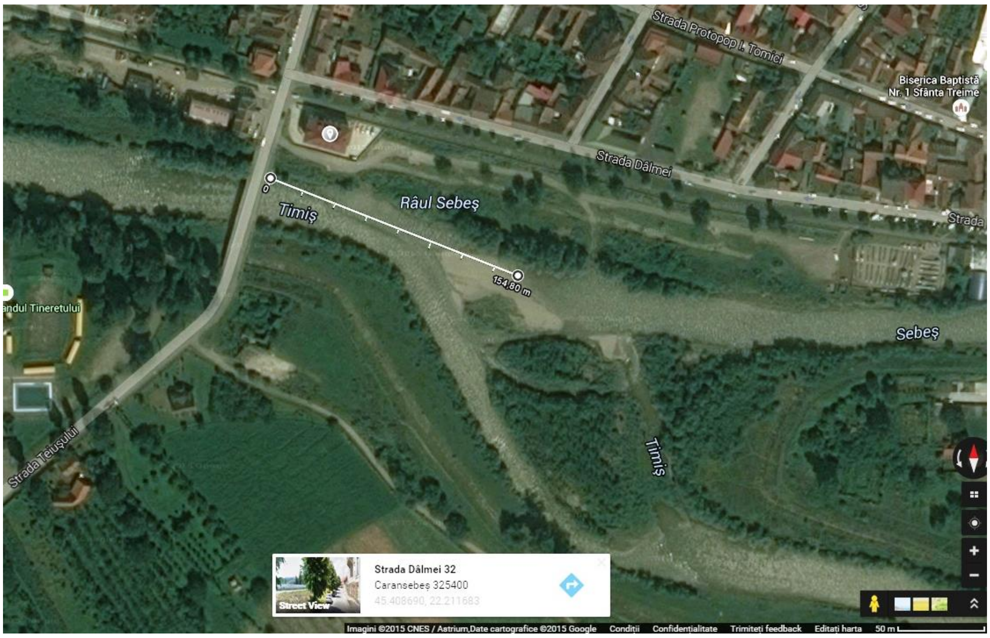


Photo 1.2 Aerial photo upon the study site: Timiș - Sebeș Rivers confluence in Caransebeș Town (Google Maps 2015, proposed building accomplished)

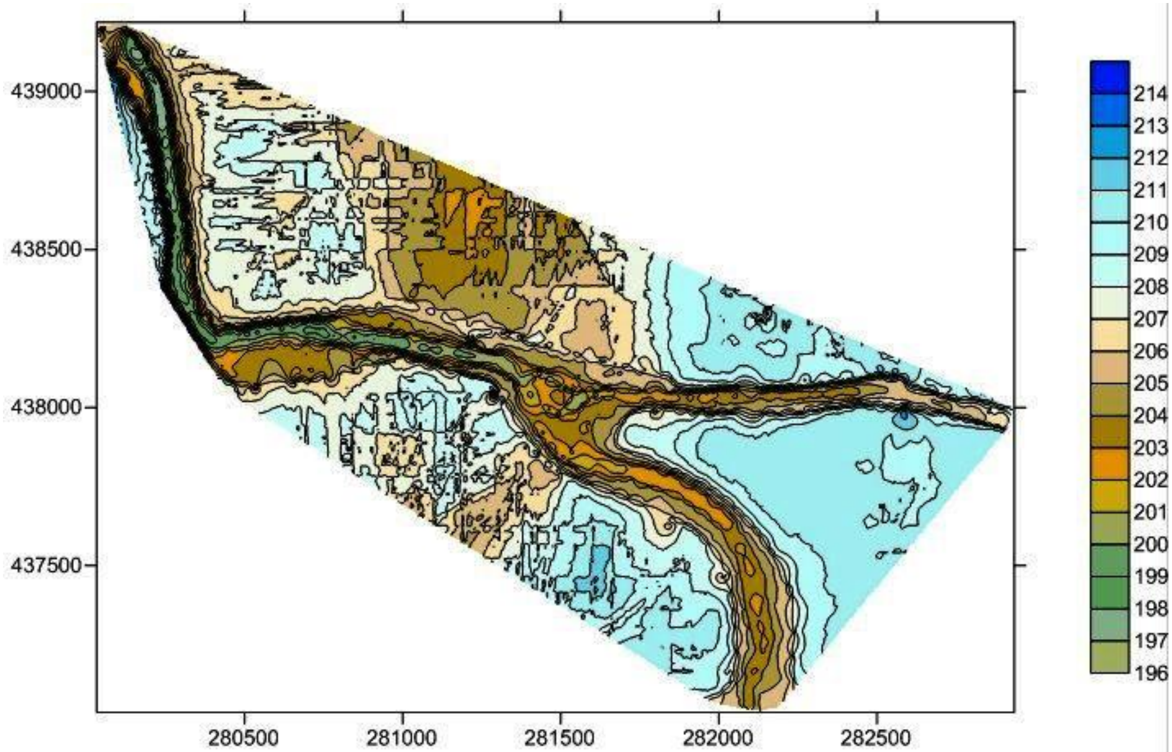


Figure 1.1 Plan view of the modeled sectors of Timiș and Sebeș Rivers, centering the confluence area

About 150m upstream of the bridge, the Timiș River gets the Sebeș River as a right tributary, which, besides its natural flow, also brings the water outflow of Ruieni Hydropower Station ($Q_{installed}$ = 2x27.25 m^3/s). This tributary flow, even regulated by Zervești Buffer Lake, varies between 3 and 54.5 m^3/s.

The plan course of Timiș River in the area is not a straight one but it convexly develops on the bridge upstream. Consequently, the flow direction at high waters points towards the right bank, specifically meaning against the given construction site.

The two river courses geometry, the confluence area including, was modeled by defining three sectors: the Caransebeş sector of Timiş River – about 2270m, the confluence upstream sector of Timiş River – about 1329m, and the confluence upstream sector of Sebeş River – about 1489m. A specific topographic database corresponding to these sectors, represented by a situation plan (Stereo 70) and 19 cross view profiles, was considered in order to numerically model the two river valleys morphology. The figure 1.1 presents the level lines obtained by bi-dimensional graphic interpolation modeling the natural land configuration, based on the spatial coordinates (x,y,z) given by the standard topographical measurements – Stereo 70.

The adopted 1D numerical model was developed by the help of HEC-RAS 5.0 Beta 2014 software, an up to date version which also allows the water flow modeling combining 1D/2D display systems [2,3]. As implemented by ArcGIS 9.3, the HEC-GeoRAS 4.3 module was engaged [6].

2. ORIGINAL STATE; SPECIFIC WATER FLOWS

The hydrological information required for developing a high-water study was supplied by the Banat branch of "Romanian Waters" National Administration. The maximum values of Timiş River water flows in the Town of Caransebeş, immediately downstream of the mentioned bridge, are presented as corresponding to several levels of the overrun probability: $Q_{5\%}$ = 477 m^3/s, $Q_{1\%}$ = 765 m^3/s, and $Q_{0.5\%}$ = 860 m^3/s. It was mentioned that these values are related to the specific high-water flow regime in the receiving basin of the modeled river and that they do not cover any safety marge.

Since the most significant hydro-technical works involved by the modeled sectors are considered as covered by the IVth importance class (constructions of low importance), the study has to employ the dimensioning water flow of a 5% overrunning probability and the confirmation water flow of a 1% overrunning probability, respectively.

The water flow under the bridge is split by the two abutments of 1 m thickness each. The central gap of 24m covers the main river bed, while the two side spans of about 23m each cover the framed floodplains.

Both from field visits and topographical interpretations, the developer alongside the municipality concluded that the river right bank immediately upstream of the bridge could be a proper site for the foreseen building. Still, as bearing in mind specific considerations regarding the high-water flow phenomenon [5], the space was estimated as limited at about 20m from the concrete parapet lining the Dâlmei Street. The minimum ground level was fixed at 205.24 mSL, while the corresponding thalweg level is about 200.35 mSL.

As long as the foreseen investment partially covers the original high-water flowing space in the bridge vicinity, a specific study by numerical modeling was suggested in order to illustrate the complex hydraulics process. Consequently, the final decision regarding the optimum structure position, showing the less disruption upon the flowing phenomenon, was to be made.

3. GENERAL CONSIDERATIONS REGARDING THE NUMERICAL MODELING OF THE RIVER FLOW

The given ground unfolding was based on updated topographic measurements performed by a specialized office and supplied as a situation plan accompanied by several cross view profiles covering the low riverbed and the side floodplains [4].

3.1 NUMERIC MODEL

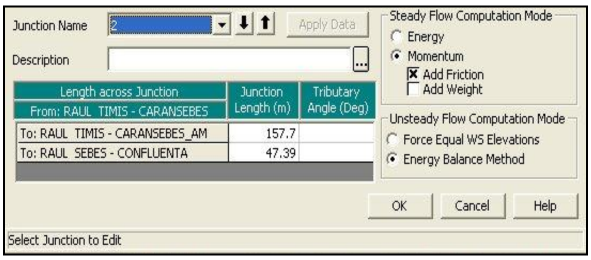
The shape of the given ground surface was uploaded as a base layer in ArcMap 9.3 (an ArcGIS product) by considering the North American Datum 1983 (NAD83) geographic coordinates system and the Universal Transverse Mercator (UTM) projection system. So, the ground surface was generated by discrete elementary surfaces as a Triangulated Irregular Network (TIN) spatial shape. In order to be assimilated by RasMapper (in the HEC-GeoRAS 4.3 graphic processing module of HEC-RAS 5.0) the ground spatial shape had to be converted into a file of Digital Terrain Model (DTM) grid type.

Specific in-depth information regarding the practical uploading procedure of the actual river course trail, of the riverbed banks, of the flow path, of the cross view profiles and of the crossing bridge structure, followed by the procedures regarding automatic data interpretation from the TIN spatial shape and their storage in the HEC-GeoRAS 4.3 database may be tracked down in the reference technical documentation [4].

The database embodying the modeled geometry is transferred from ArcMap toward HEC-RAS in a FLoaTing point raster type file created in two steps: the TIN ground shape is converted in a DTM grid type file which is further on saved as a .FLT file. Afterwards, this final file type can be opened by the RasMapper module in HEC-RAS 5.0. Figure 3.1 shows the graphical view of the numerical model as represented by HEC-RAS 5.0 Beta 2014 software after importing the data file created by ArcMap 9.3.

The variable roughness ratio value n in the river course cross section was considered as from 0.075 to 0.065 corresponding to the floodplain and 0.035 for the riverbed (the specifically assigned value being indicated above each cross section view).

As regarding the coverage of the two rivers confluence, the length of the two converging branches had to be defined with respect to the theoretical junction point (node no.2), while the approaching mode had to be selected as by the Energy Balance Method:



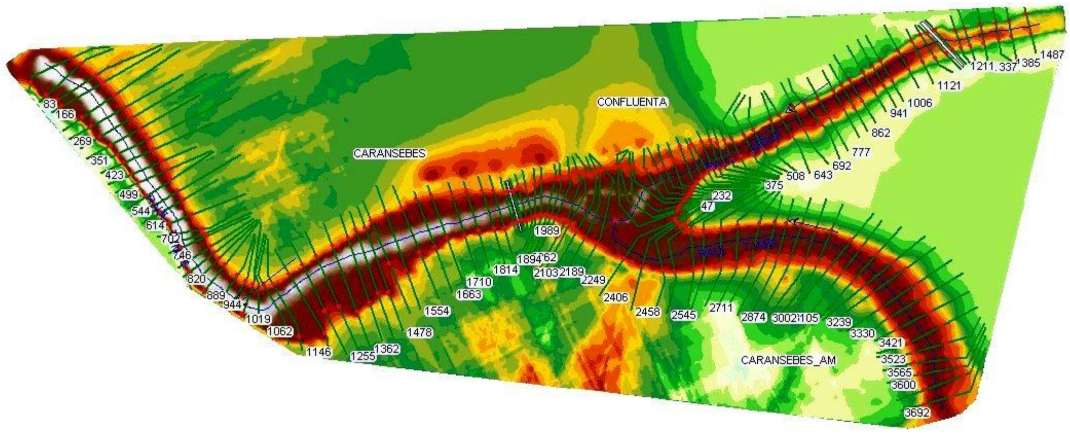


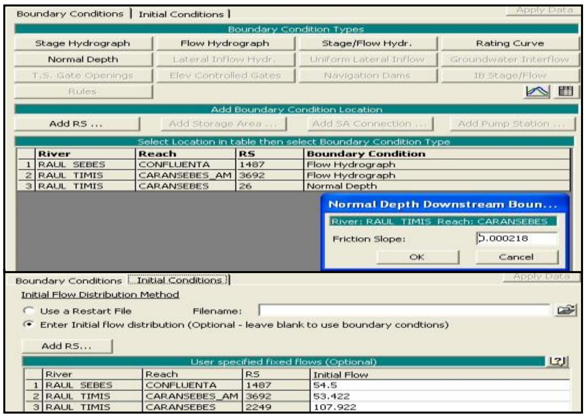
Figure 3.1 1D geometrical elements imported by HEC-RAS 5.0:
river trail, banks configuration, cross view profiles, crossing structures (1199 - bridge over Sebeş River, 1944 - bridge over Timiş River)

3.2 INITIAL AND BOUNDARY CONDITIONS

The boundary conditions for the 1D river model [1,4] are currently represented by the water flow of a specific overrunning probability assigned to the upstream cross sections as a synthetic high-water hydroflow - labeled with "1487" for the Sebeş River sector and with "3692" for the upstream Timiş River sector - and the watercourse hydrodynamic grade corresponding to the downstream cross section - labeled as "26".

The assumed shape of the synthetic high-water hydroflow was supplied based on the Timiş River flow measurements at Lugoj Hydrometric Station (about 55km downstream) registered along the significant hydrological phenomenon of April 2000. The measured hydroflow had to be scaled by a sub-unitary ratio in order to reach the given maximum water flow value of 1% overrunning probability for Caransebeş, meaning $Q_{1\%}$ = 765 m^3/s (see figure 4.2).

As about the initial conditions, the given flow values on the entering cross sections of 54.5 m^3/s at point "1487" and of 53.422 m^3/s at point "3692" were counted in; consequently, the flow value initially attached to the first cross section downstream of confluence, labeled as "2249", was 107.922 m^3/s:



Following the assumed hydroflow development, the actual numerical simulation of the water flow transit unfolds in time for a specific interval of 186 hours (starting at 10:00 on April 4th and ending at 04:00 on April 11th, 2000). The analysis was set to run with a time step of Δt = 5s, while the output was set to be registered at every 60s.

4. NUMERICAL SIMULATION AND OUTPUT DATA DISPLAY

The numerical model was considered for the distinctive situations: state I (initial) – without any structure developed in the framed floodplain, and state II – with the expected structure partly obstructing the high-water flow in the right floodplain closely upstream the bridge ramp, respectively [4]. The foreseen (required by developer) second model state differs with the reference first one by the specific flowing obstruction conditions geometrically imposed to the right bank of the cross views covering the structure site (see the output figures 4.7 and 4.8).

The specific steady or time depending parameters, such as water levels, flows and velocities for each defined cross section in the 1D model, were reached by running the numerical simulations of the two situations. Following the post processing operations, the results are stored in specific files that can be afterwards visualized, either as graphic representations or as data spreadsheets.

Specifically, the 1D model outputs come up as follows:

- as piezometric lines (the water level in mSL) and velocity spectrum (in m/s) depicting the cross sections - the figures 4.1 and 4.2 show the mentioned parameters in several designated successive cross sections on the significant moments of their maximum reached levels corresponding to the state II situation of the numerical model.
- as time depending piezometric lines (the water level in mSL) and water flows (in m3/s) attached to the cross sections - figures 4.3 show the mentioned parameters behavior in several designated successive cross sections corresponding to the state II situation of the numerical model.
- as a piezometric line (the water level in mSL) spreading along the modeled longitudinal profile - figures 4.4 present the total piezometric line corresponding to the synthetic high-water hydroflow of 1% overrunning probability, $Q_{1\%}$ = 765.68 m^3/s, considered as loading the state II situation of the numerical model.
- as graphic visualizations of flood development with time - the last figure 4.5 shows the phenomenon

development in terms of water surface stretching and water height spectrum at some consecutive moments along the high-water event of 1% overrunning probability applied to the state II situation of the numerical model: 10:00 on April 4th (initial moment), 22:30 on April 6th (61st hour), 05:00 on April 7th (end of the 67th hour), 22:00 on April 7th (end of the 84th hour), 19:00 on April 9th (end of the 129th hour), 17:00 on April 10th (end of the 151st hour, from the total 162 hours of the entire engaged high-water phenomenon).

• as output data spreadsheets presenting the values of specific hydraulic parameters characterizing the defined cross section on the river sector: total water flow (Q Total), thalweg level (Min Ch El), water surface (piezometric line) maximum level (W.S. Elev), critical surface level (Crit W.S.), maximum level of hydraulic energy line (E.G. Elev), maximum hydraulic grade (E.G. Slope), maximum water velocity (Vel. Chnl), maximum area of flow cross section (Flow Area) and maximum spread of cross section top (Top Width).

Tables 4.1 and 4.2 present a selection of the reached values covering the Timiș River sector downstream the confluence point, focusing thus on the cross section running through the foreseen construction site: “2012”, “1989”, “1971”, “1955”, “1949”. The same river sector is referred for both circumstances: the initial state of the water course and the expected state of the obstructed water flow.

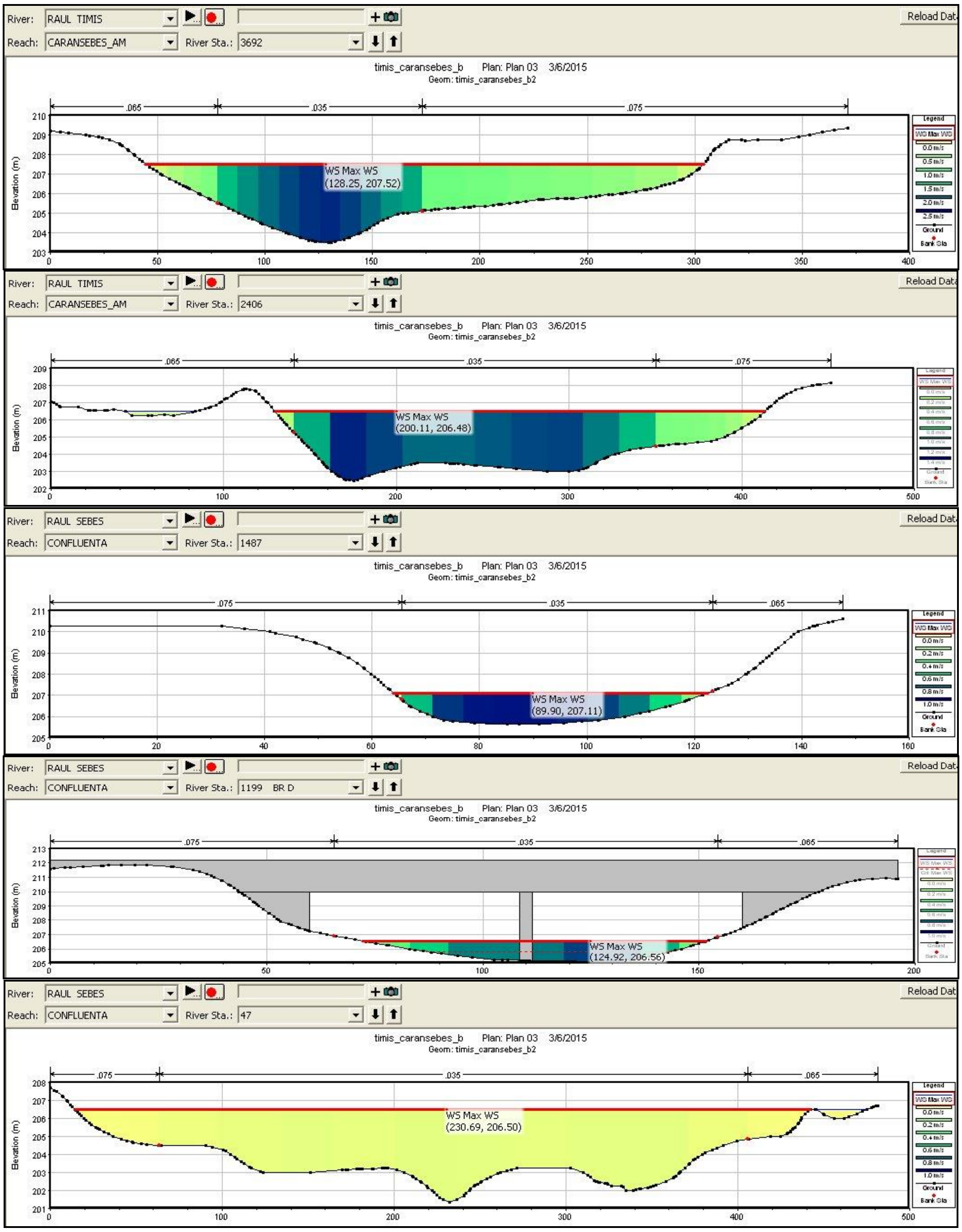


Figure 4.1 Piezometric lines and velocity spectrums for several significant sections on Timiș / Sebeș River sectors, upstream of the confluence point

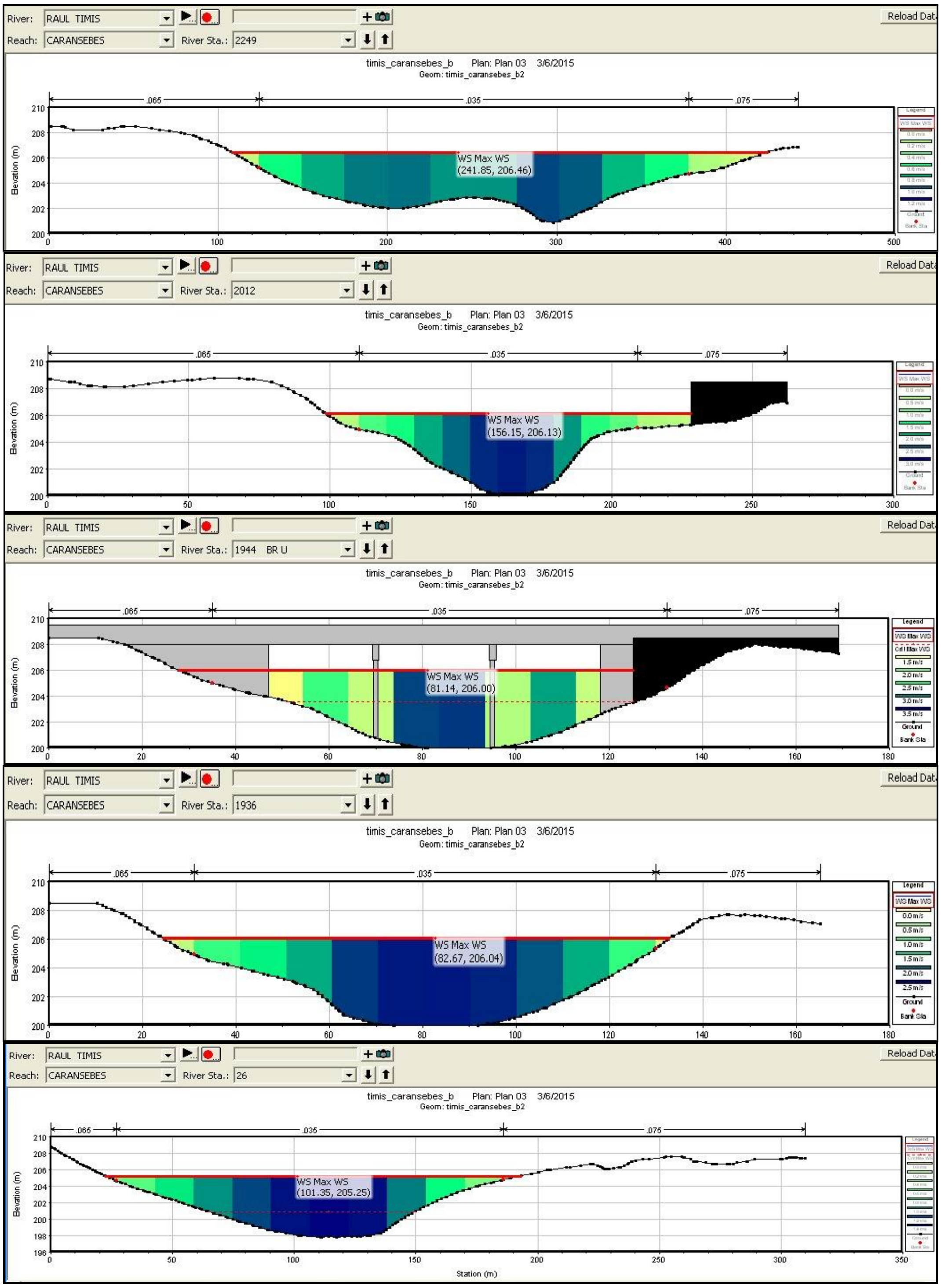


Figure 4.2 Piezometric lines and velocity spectrums for several significant sections on Timiș River sector, downstream of the confluence

5. OUTPUT EXAMINATION. CONCLUSION

As was expected due to location immediately upstream of the bridge and of relatively reduced expansion, the selected output values show that the required obstruction produces only a slight and local disorder upon the high-water flow conditions. With respect to the state I, the flow of state II indicates for the obstruction cross sections a small decrease of the water surface level (in the range of a few centimeters) and consequently an increase of the water velocity maximum value. Regarding the mean value of the maximum velocity along the obstructed sector, it came out an increase of about 4.4% with respect to the initial state.

In conclusion, there can be noticed that the building development closely to the bridge ramp would meet the benefit of a favorable construction site, even if this is still situated in the river flood plain (towards the right framing embankment).

In the same time, specific watercourse protection works are recommended in order to stabilize the riverbed processes and to protect the obtained shape of the right bank contour that might have to operate under significant water velocities (about 2.1 … 2.45m/s) in case of accidental high-water.

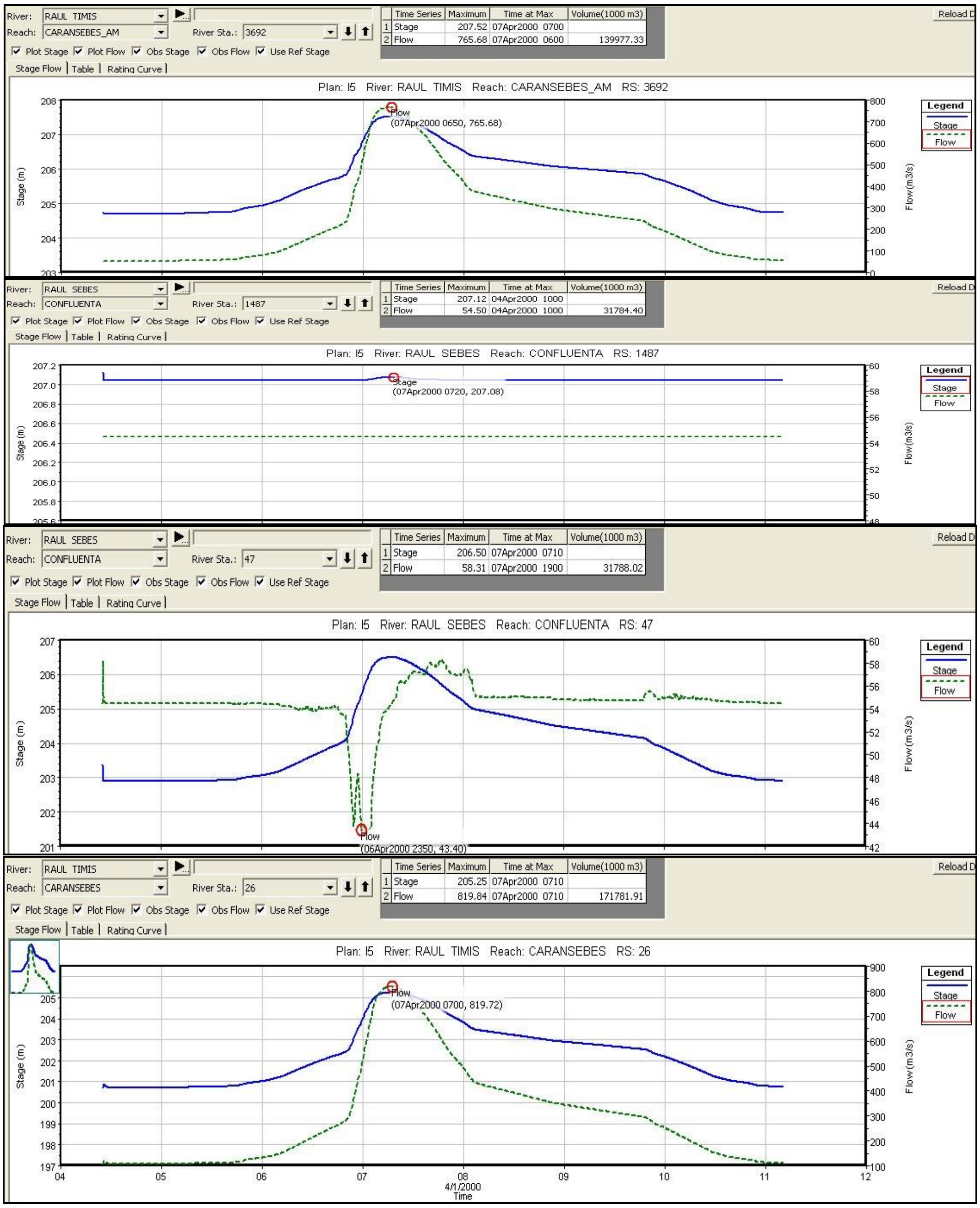


Figure 4.3 Time development of the piezometric lines (in mSL) and water flows for the entering sections, the section immediately upstream of the confluence and the outgoing section

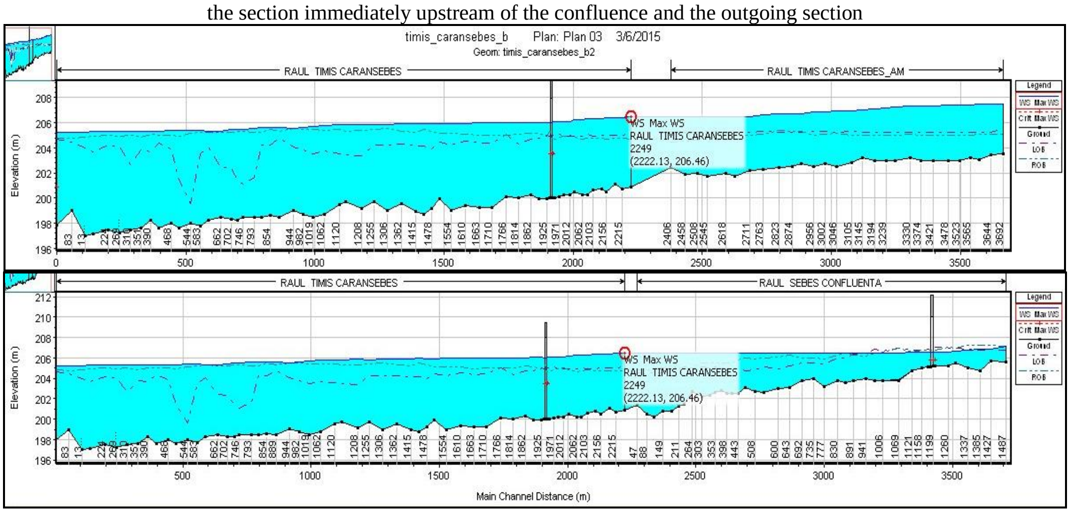


Figure 4.4 Longitudinal piezometric line (in mSL) spreading from the two entering sections "3692" and "1487" (Timiș / Sebeș Rivers) toward the outgoing section "26"

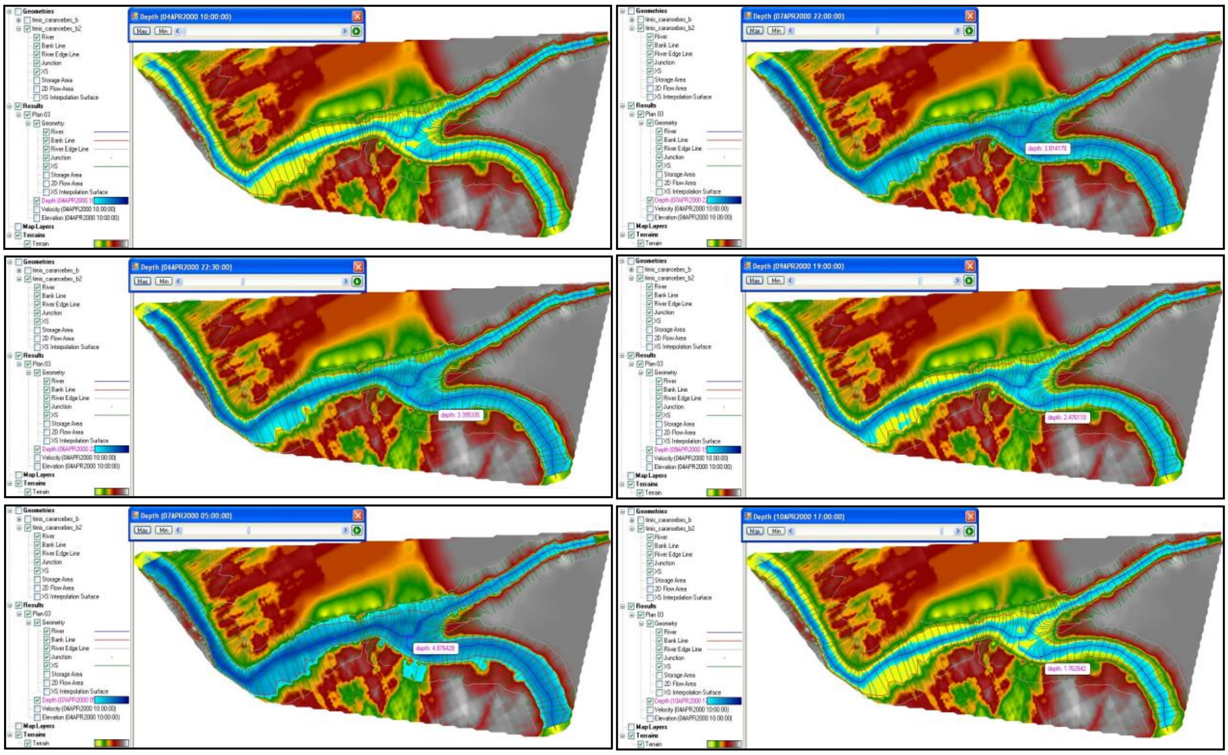


Figure 4.17 Water surface stretching and water height spectrum development along the considered high-water phenomenon

Table no.4.1 (State I, selection)

HEC-RAS Plan: I3 River: RAUL TIMIS Reach: CARANSEBES Profile: Max WS — Reload Data

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Fr
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
CARANSEBES	2249	Max WS	819.99	200.89	206.48		206.52	0.000158	0.86	999.73	317.37	
CARANSEBES	2215	Max WS	819.98	200.70	206.47		206.51	0.000168	0.92	928.75	273.33	
CARANSEBES	2189	Max WS	819.99	201.11	206.45		206.51	0.000250	1.10	798.23	251.17	
CARANSEBES	2156	Max WS	819.98	200.50	206.42		206.50	0.000296	1.22	729.01	234.09	
CARANSEBES	2136	Max WS	819.98	200.75	206.39		206.49	0.000572	1.49	629.83	257.47	
CARANSEBES	2103	Max WS	819.97	200.62	206.34		206.48	0.000618	1.64	533.32	181.85	
CARANSEBES	2081	Max WS	819.97	200.25	206.32		206.46	0.000611	1.71	515.97	169.19	
CARANSEBES	2062	Max WS	819.97	200.25	206.30		206.45	0.000592	1.73	508.99	164.55	
CARANSEBES	2032	Max WS	819.95	200.50	206.25		206.43	0.000775	1.92	451.53	150.94	
CARANSEBES	2012	Max WS	819.95	200.25	206.17		206.43	0.001152	2.26	395.99	151.92	
CARANSEBES	1989	Max WS	819.94	200.25	206.12		206.40	0.001184	2.39	371.15	133.51	
CARANSEBES	1971	Max WS	819.94	200.11	206.17		206.37	0.000865	2.02	421.95	132.93	
CARANSEBES	1955	Max WS	819.93	200.00	206.16		206.36	0.000700	1.96	429.46	116.88	
CARANSEBES	1949	Max WS	819.93	200.00	206.15	203.55	206.35	0.000720	1.99	420.16	111.74	
CARANSEBES	1944		Bridge									
CARANSEBES	1936	Max WS	819.94	200.00	206.04		206.25	0.000765	2.02	411.00	108.30	
CARANSEBES	1925	Max WS	819.93	199.94	206.05		206.24	0.000671	1.92	436.93	123.04	
CARANSEBES	1894	Max WS	819.94	199.94	206.05		206.22	0.000650	1.78	474.14	156.31	
CARANSEBES	1862	Max WS	819.88	200.29	206.04		206.19	0.000611	1.72	490.87	181.83	
CARANSEBES	1814	Max WS	819.92	200.00	206.02		206.16	0.000632	1.71	501.36	174.61	

Table no.4.2 (State II, selection)

HEC-RAS Plan: I5 River: RAUL TIMIS Reach: CARANSEBES Profile: Max WS — Reload Data

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)
CARANSEBES	2249	Max WS	819.98	200.89	206.46		206.49	0.000162	0.87	992.48	316.57
CARANSEBES	2215	Max WS	819.99	200.70	206.44		206.49	0.000172	0.93	922.42	272.83
CARANSEBES	2189	Max WS	819.99	201.11	206.42		206.48	0.000256	1.10	792.34	250.85
CARANSEBES	2156	Max WS	819.98	200.50	206.40		206.48	0.000302	1.23	723.46	233.42
CARANSEBES	2136	Max WS	819.98	200.75	206.36		206.47	0.000588	1.50	623.40	256.99
CARANSEBES	2103	Max WS	819.97	200.62	206.32		206.45	0.000634	1.65	528.67	181.49
CARANSEBES	2081	Max WS	819.97	200.25	206.29		206.44	0.000626	1.72	511.59	168.94
CARANSEBES	2062	Max WS	819.97	200.25	206.28		206.43	0.000606	1.75	504.68	164.18
CARANSEBES	2032	Max WS	819.96	200.50	206.22		206.41	0.000795	1.93	447.35	150.41
CARANSEBES	2012	Max WS	819.96	200.25	206.13		206.40	0.001204	2.30	378.24	129.56
CARANSEBES	1989	Max WS	819.93	200.25	206.07		206.37	0.001265	2.45	341.30	99.12
CARANSEBES	1971	Max WS	819.90	200.11	206.11		206.35	0.000942	2.16	381.69	101.75
CARANSEBES	1955	Max WS	819.93	200.00	206.11		206.33	0.000789	2.08	398.71	99.16
CARANSEBES	1949	Max WS	819.94	200.00	206.10	203.54	206.33	0.000798	2.10	394.98	97.89
CARANSEBES	1944		Bridge								
CARANSEBES	1936	Max WS	819.90	200.00	206.04		206.25	0.000765	2.02	411.00	108.30
CARANSEBES	1925	Max WS	819.90	199.94	206.05		206.24	0.000671	1.92	436.93	123.04
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