

# **RESEARCH ON THE SIMULATION OF THE ALLUVIAL TRANSPORT ON THE NUMERICAL MODEL AND THE ESTIMATION OF THE MORPHOLOGICAL MODIFICATIONS, WITH APPLICATION ON THE DANUBE RIVERBED FOR A PROPOSED SECTOR, IN THE PERIOD OF 2005-2010**

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## **Abstract**

The elaborated researches regard the estimation of the Danube river bed morphological modifications, on an extended sector, situated upstream Bistreț (km730) gauging station and downstream Bechet (km675) gauging station, with detailed application on a small sector (km 686+300-km 684+300) and punctual in a study section with sufficient data (km685+300). The main objectives on the proposed researches achievement is constituted by the fields selection (hydrological, hydrometrical, geological, topometrical, software, etc) of the complex database necessary for the hydraulic type mathematical modelling and of simulation of the river bed specific phenomena simulation through aggradation or degradation. The modelling of the Danube river bed geometry on the liminary area (km 686+300 – km 686+300) through transverse profiles executed with small equidistance (around 100 m) for the flowing section between dams (Romanian bank) and slope (Bulgarian bank) and also on an extended upstream sector (km 730) and upstream (km 675) with bigger equidistance. The establishing of the granulometric composition of the sediment discharges (for each rate of water flow - 1000 m<sup>3</sup>/s) and river bed for the potential eroded horizons taken from the geotechnical studies for the studied sector. The analysis of the chemical composition of the sediments from the river bed and the water chemistry of the Danube river with application on aggressiveness at metal and concrete (as auxiliary data). Hydrological data (daily average discharges, probability curves of the average and maximum water discharges) and the recent hydrometric activity at the above mentioned gauging station. The effective simulations on the model and the results elaboration were constituted on stages.

**Keywords:** alluvial transport, morphological modifications, numerical modeling

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## **1. PURPOSE OF RESEARCH**

The Danube, an international and navigable river, is a waterway liable to some restrictions established by international agreements which, besides the water quality problems, concern the liquid storage distribution among the riparians, the flooding conditions and the maintenance of navigation conditions. The alluvial transport phenomena on a high water course is very complex, and its effects on the riverbed mobility can be appreciated through qualitative and quantitative estimations with the help of using simulation through numerical type modeling on a characteristic period of time, considering the experience of some similar papers, and also based on time measurements of different hydro – morphological parameters in characteristic sections for the calibration and verification of the specific coefficients applied by the used models. The elaborated research regard the estimation of the Danube riverbed morphological modifications on an extended sector (Fig.1), situated upstream of Bistreț (km730) gauging station and downstream of Bechet (km 675) gauging station, with detailed application on a small sector (km 686+300-km 684+300) and punctually in a study section with sufficient data (km 685+300). The main objectives on the proposed research achievement are represented by the selection of complex database fields (hydrological, hydrometrical, geological, topometric, software, etc) necessary for the mathematical modeling of hydraulic type and the simulation of specific phenomena of riverbed mobility through aggradation or degradation.

### **1.1 Main objects of the research**

In order to properly treat the implications and consequences of the alluvial transport and riverbed mobility phenomena, it is required to present the natural conditions of river on the stretch affected by these works. Thus, it is necessary to know the riverbed characteristics in respect of its form and structure, the size and time variation of liquid flows, the variation and statistical parameters of the levels, the slopes dependence on fluid velocity flows, the size and time variation of sediment flows, grain composition of the bed sediments and sediments carried by the water flow and the dynamic characteristics of the riverbed bottom. The following shows selectively the main objectives of the study on this approach:

- Modeling of the Danube's riverbed geometry on the analyzed sector (686 km 300 - km 684 300) by cross sections performed with small equidistance (about 100m) for the flow section between the dikes (Romanian bank.) and the slope (Bulgarian bank) and also on an extended section upstream and downstream with greater equidistance
- The creation of complex data bases necessary for the mathematical models of hydraulic type on the extended sector of the Danube and simulation of the aggradation (clogging) or degradation (erosion) phenomena specific to the morphological changes of the riverbed in the studied section, km 685 +300.
- The choice of the mathematical models of hydraulic and alluvial transport type according to the calculation modules available. The choice of the specific functions (reported to the hydro – morphological data of the river bed) regarding: the simulation of the alluvial transport, establishing the sedimentary critical average speeds of training, and also the sorting of the alluvial particles from the riverbed mobility gauge
- The hydraulic calculations prepared for the Danube's extended sector located between the upstream Bechet gauging station and the downstream Bistret gauging station for a diverse range of probabilities of maximum and medium flows; calibration of the hydraulic model in the area of hydrometric station. The analytical and graphic results of the hydraulic calculations applied in the crossing sector (km 686+ 300 – 684+ 300 km): medium velocities in the section, velocities in the design sectors of sections, level of free surface curve, wetted area, etc.
- The estimation of the morphological changes developed on the Danube riverbed for the analyzed section by simulating the daily flows recorded during 2006 - 2010. The analytical and graphic results applied to: general longitudinal section of the extended sector concerning the morphological evolution of the riverbed thalweg, cross section in the analyzed section area concerning the morphological changes for different significant periods of sediments transport simulation. The calibration of the sediments transport simulation model, the riverbed morphological evolution on cross sections measured and calculated over the period of 2005 - 2010 at Bechet Gauging Station
- The SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) of the present study on the alluvial transport and the estimation of changes in the riverbeds morphology, the limits of mathematical modeling and the implementing the researches performed

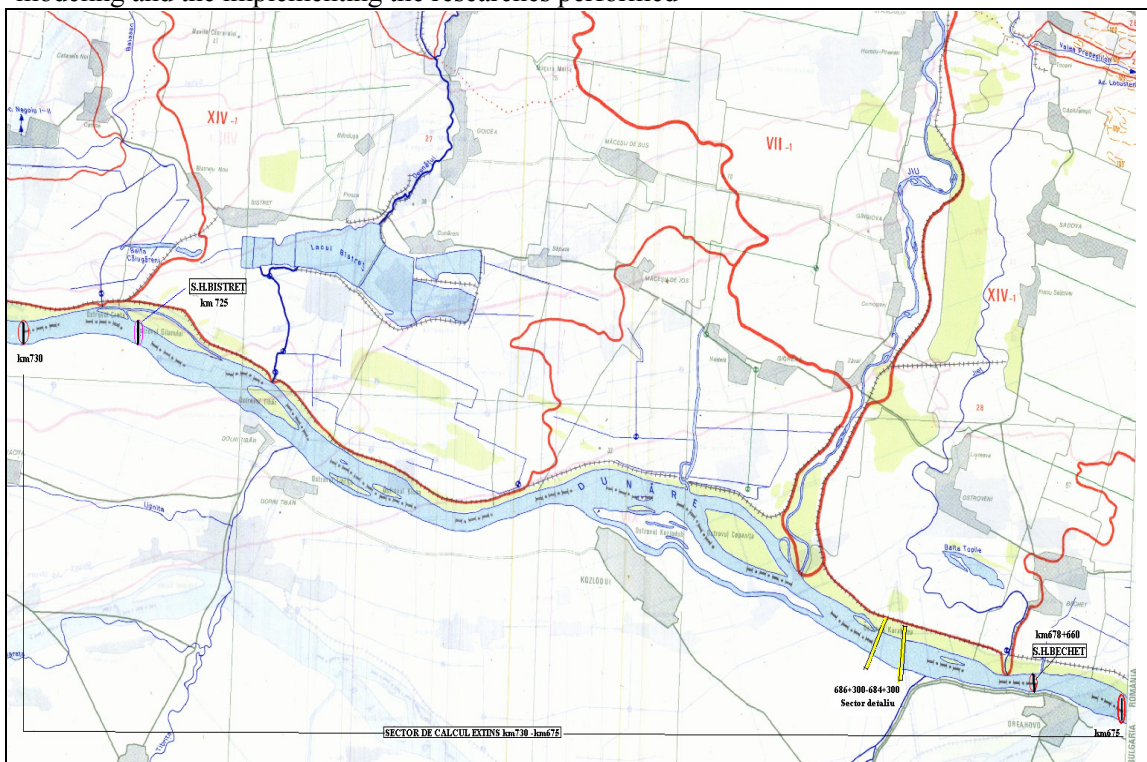


Fig. 1. The extended research sector of the Danube, with the indication of the main gauging stations

## 2. DATA BASES NECESSARY FOR THE NUMERICAL MODELS

In order to determine the morphological and dynamic mobility characteristics of the riverbed in the crossing section, it was necessary to develop the following related studies:

## 2.1. Hydrological study

The hydrological data on the determination of:

- The value of maximum and medium water flows associated to the occurrence probability; Pearson III,  $C_s=3C_v$

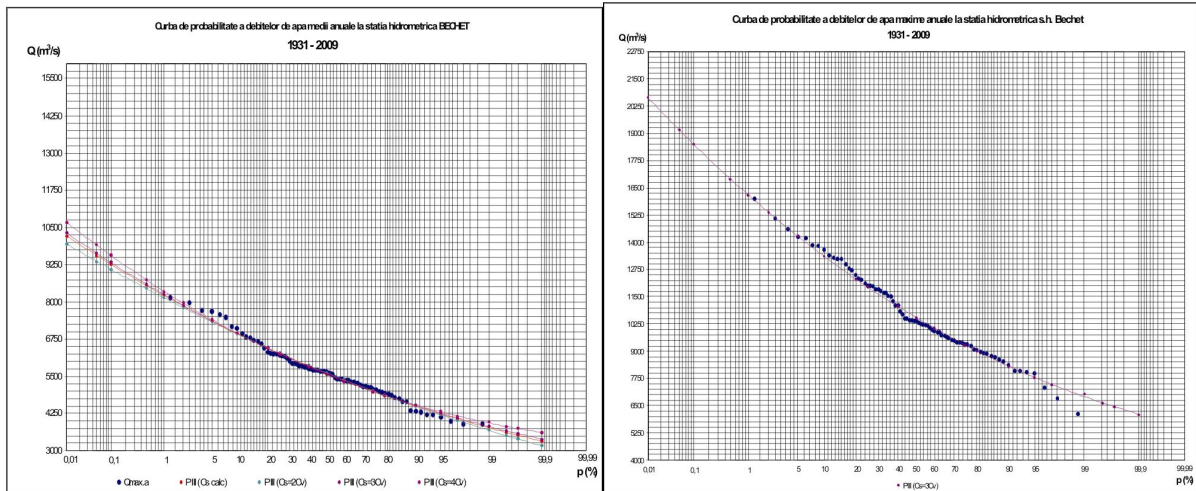


Fig. 2. Probability curve of maximum and medium annual water flows at Bechet St. during 1931 – 2010  
- Value of medium daily flows during 1931-2010 and the selected simulation period between 2005-2010

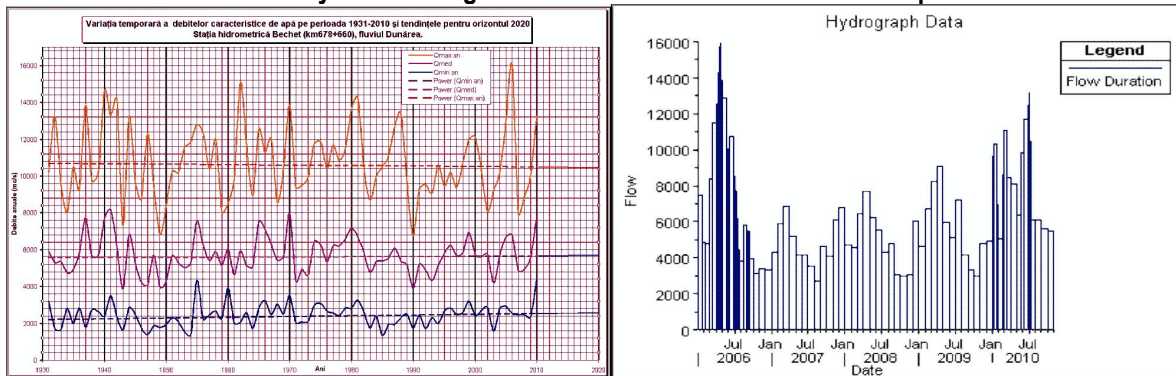


Fig.3. Hydrograph medium daily flows used, between 1931-2010 and selected period 2005 -2010, at Bechet St.  
- Value of total solid flows (suspended and bedload) depending on the respective water flows; and also their grain size distribution at Bechet St.

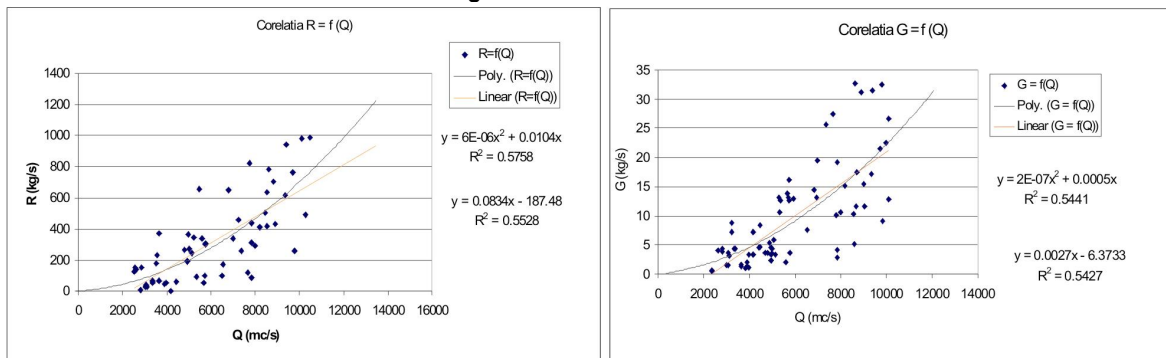


Fig.4. Correlation between the water flow values and the suspended sediment and bed load values

-The grain size composition of the total solid flow of suspended and bedload sediments used as input data in the mathematical model, was expressed for each size class compared to the whole). The solid flow rates are given in tons / day depending on the respective water flow (Table 1).

Table 1. Content (related to the whole) of grains depending on the diameters range (mm) and water flow.

Inclusion in grain	Range	Qwater (m3/s)	2674	3493	4718	6720	7649	11500	13000
size classes	size (mm)	Qsedim. (t/day)	9331	10315	19016	28261	32080	87177	100000
Clay	0.002-0.005	C	0.01	0.02	0.02	0.01	0.06	0.05	0.03

Very Fine Silt	0.005-0.008	VFM	0.1	0.17	0.22	0.11	0.19	0.26	0.25
Fine Silt	0.008-0.016	FM	0.1	0.17	0.19	0.11	0.14	0.18	0.18
Medium Silt	0.016-0.032	MM	0.26	0.24	0.32	0.35	0.31	0.32	0.34
Coarse Silt	0.032-0.0625	CM	0.3	0.2	0.19	0.3	0.2	0.12	0.13
Very Fine Sand	0.0625-0.125	VFS	0.21	0.17	0.04	0.1	0.08	0.05	0.05
Fine Sand	0.125-0.25	FS	0.01	0.015	0.01	0.01	0.01	0.01	0.01
Medium Sand	0.25-0.5	MS	0.006	0.01	0.006	0.006	0.006	0.006	0.006
Coarse Sand	0.5-1.00	CS	0.003	0.003	0.002	0.002	0.002	0.002	0.003
Very Coarse Sand	1.00 2.00	VCS	0.0005	0.001	0.001	0.001	0.001	0.001	0.001
Very Fine Gravel	2.00 5.00	VFG	0.0005	0.001	0.001	0.001	0.001	0.001	0.001

- Specific data recorded in the gauging stations located on the design sector. Gauging stations on the Danube in the studied area, Bechet St., km 678+660, Limnometrical graphic key  $Q=f(H_{staff})$ , 2006-2010 (Fig.5). The morphological evolution of the riverbed on transverse measured profiles on the interval 1980 – 2010 at Bechet gauging station (Fig.6).

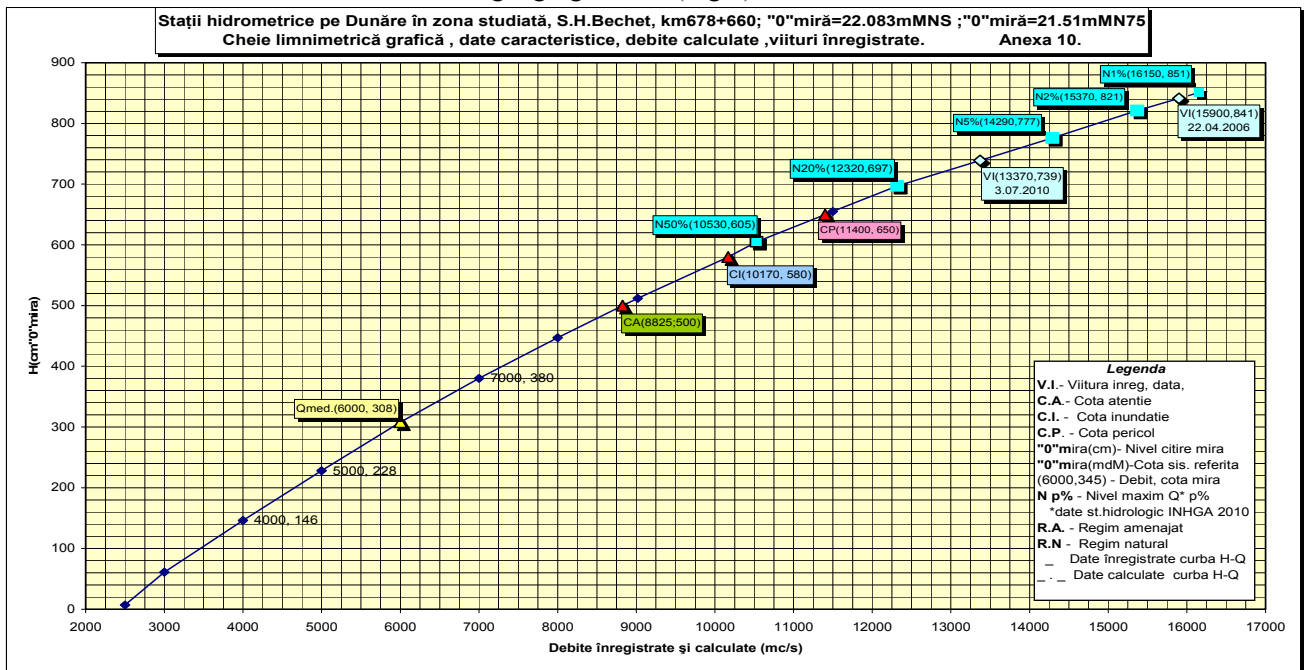


Fig.5. Gauging stations in the studied area: Bechet. Limnometric graphic key  $Q=f(H_{lev.gauge})$ ,

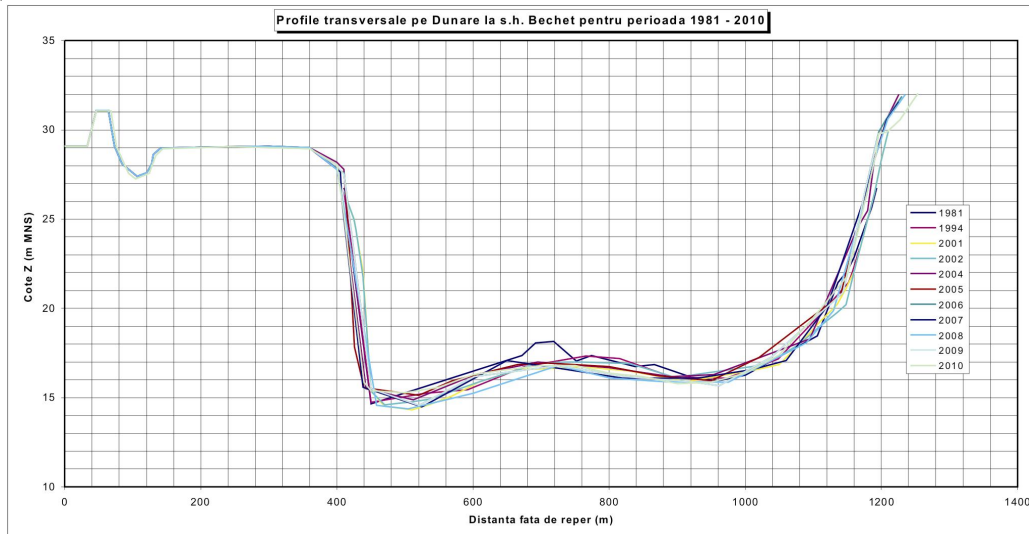


Fig.6. Cross-sections (graphic) on the Danube in the Bechet area performed during the period of 1980– 2010

## 2.2. Hydro-topometric survey

The hydro-topometric survey contains: The modeling of the Danube riverbed geometry on the liminary area (km 686+300 – km 686+300) through transverse profiles (Fig.7) executed with small equidistance (around 100 m) for the flowing section between the dams (Romanian bank) and slope (Bulgarian bank) and also on an extended upstream sector (km 730) and upstream (km 675) with bigger equidistance. The main characteristics and technical parameters of the cross sections include: the coordinate (x; y; z) in STEREO 70 system and the reference plan MN75 of the constitutive points; laying-out of dikes and corresponding elevations of the crest; setting-out of the banks, bathymetry works, measurement of depths and determination of the surveyed points, lay-outs and cross sections, checking and editing the original documents.

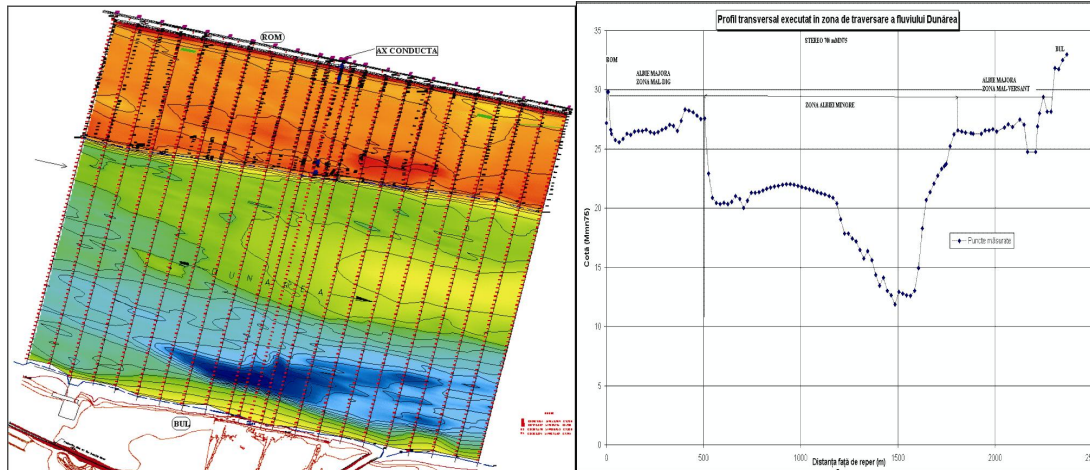


Fig.7. Site plan and bathymetry of the cross sections performed in 2010 in the Danube's study area

## 2.3. Geotechnical survey

The purpose of the study is to define the geotechnical conditions for the Danube sector under study between Bulgaria and Romania, in order to determine the soil stratification and geo-mechanical properties of the intercepted rocks. The geotechnical surveys along the route were based on the implementation of the following works: 2 on-shore drillings F1 and F2 and 5 off-shore drillings in the Danube riverbed: F3; F4; F5; F6; F7. The topographic location and listing of the geotechnical drillings are presented in the lay-out and also in the cross section. The main data needed as input data required by the mathematical model used for the alluvial transport simulation are the riverbed grains distribution on a cumulative grain size curve (Fig.8).

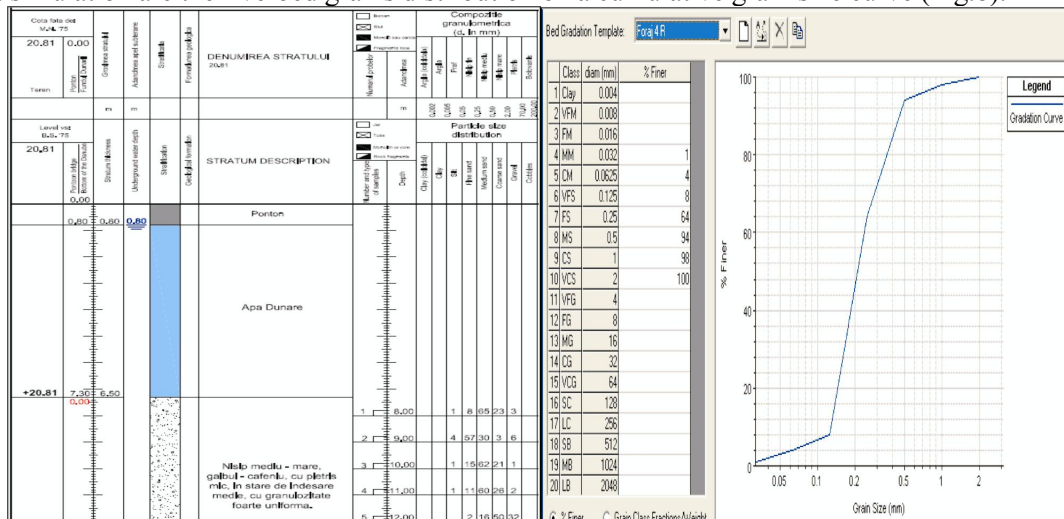
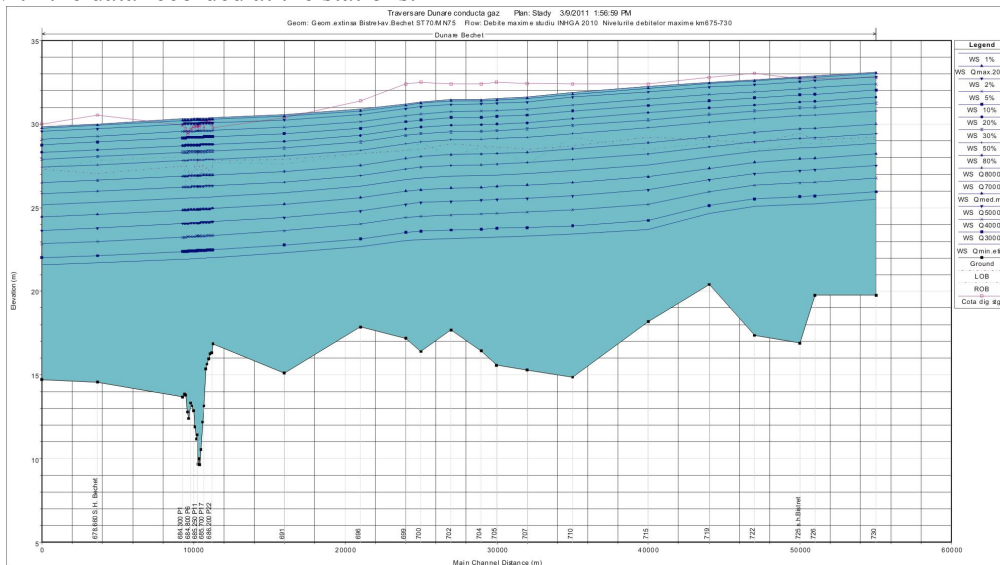


Fig.8. The soil stratification and the riverbed grains distribution on a cumulative grain size curve

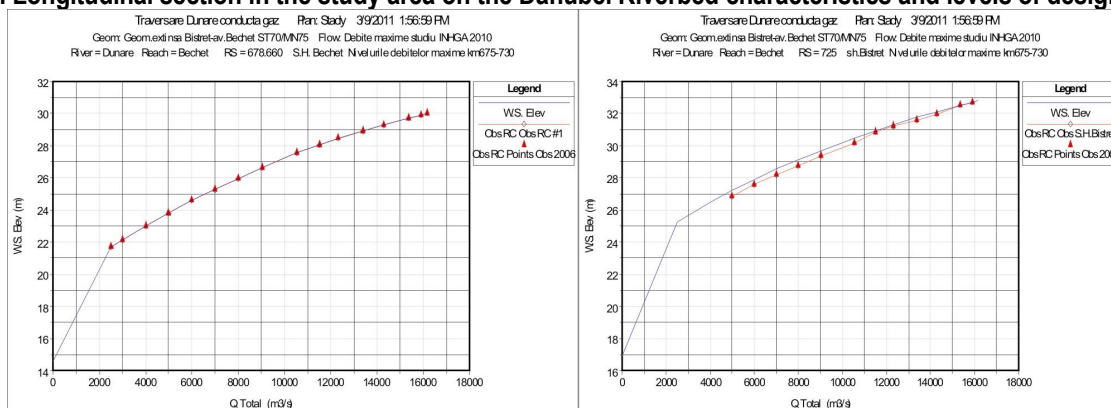
## 2.4. Hydraulic study.

An important chapter in this study is the development of hydraulic calculations under the conditions of the model calibration (Fig.10) and in order to obtain more precise results. The data matrices resulting from the hydraulic model for steady flow are used as input data of the alluvial transport simulation model and the estimation of the changes in the riverbed morphology for the Danube sector under consideration.

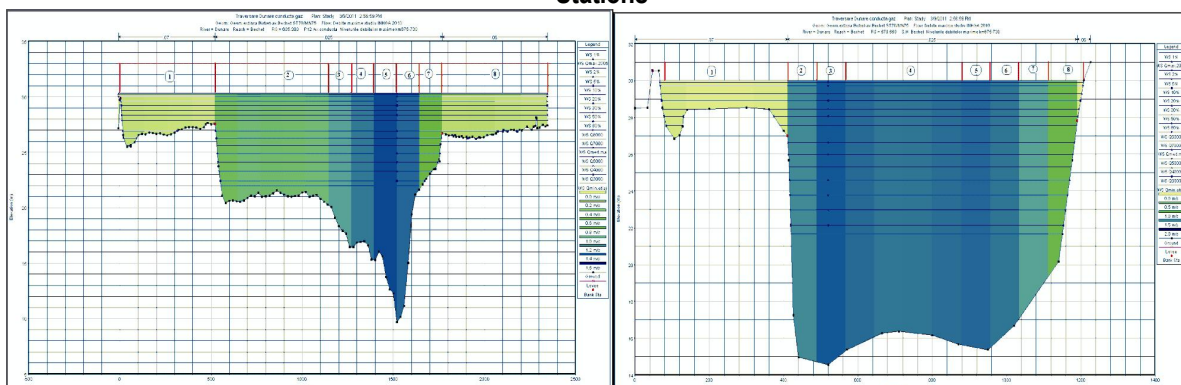
The hydraulic calculations were developed for a wide range of frequencies and annual exceeding probabilities of maximum and medium flow rates, which generally include all medium daily rates recorded during 2006 - 2010 and used for the alluvial transport simulation model and the estimation of changes in the riverbed morphology. For connecting the levels of free surface curve of the design flows on a general section that includes at least two hydrometric stations to measure the water flow rates and corresponding levels (Fig. 9;11), the hydraulic study has been extended on a Danube sector located between the upstream Bistret Station (km 730) and the downstream Bechet Station (km 675). The calibration operation of the mathematic model of hydraulic type consisted of the reconstruction of the flow levels recorded according to the data obtained to perform the hydraulic calculations. Generally, the operation is made based on the successive calculations for changing the Manning strength factors of minor and major riverbeds, and if the case, by changing the riverbeds geometry (where there are doubts in respect of performed topographic surveys). To calibrate the hydraulic model, the results of model calculations have shown the identity of discharge rating curves [type  $H=f(Q)$ ], calculated with the data recorded at the stations.



**Fig.9. Longitudinal section in the study area on the Danube. Riverbed characteristics and levels of design flows**



**Fig.10. Calibration of the hydraulic model. Flows and levels recorded and calculated at the Bechet and Bistret Stations**



**Fig.11. Cross sections in the Danube riverbed, levels of discharge flows, average velocity rates on sections**

### 3. NUMERICAL MODELS AND MAIN ALGORITHMS OF THE APPLIED FUNCTIONS

Determination of the analysis period to simulate the alluvial transport. In order to perform the time variation analysis of the changes in the Danube riverbed morphology on the analysed sector, it was necessary to choose the simulation period of 2005-2010 concerning the manifestation of these phenomena, and characterized by the medium daily flow (i.e. hourly medium flows during the detailing period of max. flows) including two floods in 2006 and 2010 with the exceeding probability of 2% and 10%

For the calculations carried out in respect of the alluvial transport analysis on a mobile riverbed bottom and the estimation of morphological changes of the Danube riverbed in the studied area, the numerical model was used for the movement in steady/unsteady flow regime "River Analysis System" and the use of the special module specifically annexed for these calculations "Sediment Transport Analysis".

#### 3.1. Numerical model for the hydraulic type, "River Analysis System".

##### 3.1.1. Steady flow regime

The steady flow one-dimensional movement with gradually varied free surface, is governed by Bernoulli's equation (used for the model calibration, 2.4)

$$dZ + d(\alpha * V^2 / 2 / g) + JE * dX = 0 \quad (1),$$

The free water surface level is calculated from one section to another to solve the energy equation 1 through an iterative routine called the standard step method. The energy equation is written as follows:

$$y_2 + z_2 + \frac{\alpha_2 v_2^2}{2g} = y_1 + z_1 + \frac{\alpha_1 v_1^2}{2g} + h_e \quad (2),$$

where:  $y_1, y_2$  – water depth in cross sections;  $z_1, z_2$  – apron level in the minor riverbed;  $h_e$  - energy loss  
 $v_1, v_2$  - medium velocities;  $\alpha_1, \alpha_2$  - Coriolis's coefficient;  $g$  - gravitational acceleration ;

##### 3.1.2. Unsteady flow regime

The model works on a given hydrotechnical scheme and can treat the one-way riverbeds and the riverbed in the dendritic or circular network. It is based on the digital integration of the system of equations with Saint Venant partial derivatives, after a rectangular grid in the X, T plane, in an implicit scheme with linearization of the equations. For a one-dimensional channel element  $dX$ , the movement and continuity equations are as follows:

$$\partial Z / \partial X + 1/g * \partial V / \partial T + \alpha/g * V * \partial V / \partial X + JE = 0 \quad (3),$$

$$\partial A / \partial T + \partial Q / \partial X = 0 \quad (4),$$

where:  $JE$  – energy slope, and  $\alpha_{us}, \alpha_{ds}$  - Coriolis' coefficients in the downstream and upstream section

The limit conditions of the first stage involve determining the hydraulic characteristics of the riverbeds for an initial flow in permanent regime according to the algorithm.

#### 3.2. Numerical model, "Sediment Transport Analysis"

The numerical model was used for the alluvial transport phenomena and the estimation of the morphological changes developed in the Danube riverbed. An important role in the correct simulation of phenomena is represented by the selection of available calculation functions offered by the model (Fig.12) on alluvial transport simulation; the determination of the medium critical erosion/sedimentation velocities as well as the sorting of alluvial particles in the riverbed mobility range.

##### 3.2.1. Calculation function offered by the model on alluvial transport simulation

The special module for these calculations "Sediment Transportation Analysis" attached to the "River Analysis System" model uses special functions related to the alluvial transport. Choosing the best function was performed according to the hydraulic characteristics, grain size composition of the riverbed bottom, water temperature etc. To simulate the alluvial transport, the applied function including the optimal characteristics on the Danube riverbed for the surveyed under crossing area is Laursen (Copeland). The Laursen Method is a total sediment load predictor derived from a combination of qualitative analysis, experiments on wide areas and supplementary data to define the phenomena. The transport of sediments is primarily defined based on the hydraulic characteristics of medium velocity, design flow rates, energy gradient and characteristics of sediment mobility depending on the velocity variation in unsteady flow regime conditions. The Copeland's contribution (1989) extended the range of applicability to gravel-sized sediments. The range of applicability is 0.011 mm - 29 mm for medium grain diameter. The general sediment transport equation for the Laursen (Copeland) function for a single grain size is:

$$C_m = 0.01 * \gamma * \left(\frac{d_s}{D}\right)^{7/6} * \left(\frac{\tau_0}{\tau_c}\right) * f\left(\frac{u_0}{\omega}\right) \quad (3)$$

where:  $C_m$  = sediment discharge concentration, (weight/volume);  $\gamma$  = unit weight of water  
 $d_s$  = medium grain diameter;  $D$  = effective flow depth ;  $\zeta_0$  = bed shear stress due to grain resistance  
 $\zeta_c$  = critical bed shear stress;  $f(u_0/\omega)$  = function of the ratio of shear velocity to fall velocity.

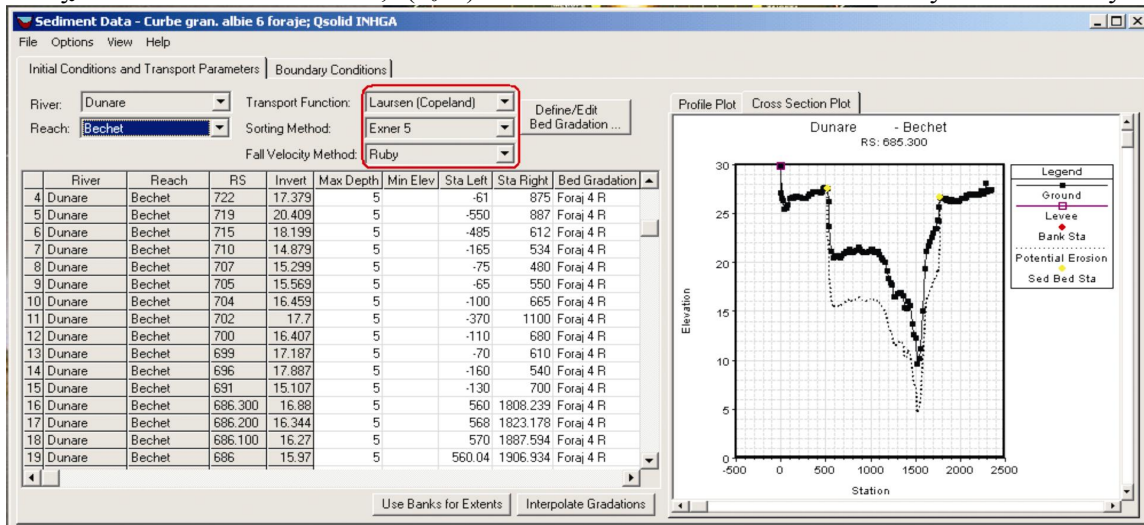


Fig.12. Selection of optimal available calculation functions offered by the model “Sediment Trans. Analysis”

### 3.2.2. Calculation function to determine the critical fall velocity of grains

A grain of the suspended sediment flow will remain in suspension as long as the vertical components of the bed bottom turbulence are greater than those of the sedimentation rate. As a consequence, the sediment transport is determined in accordance with the grain sedimentation rate. By applying the model of “Sediment Transport Analysis”, the user can select the design method for the mobility speed. There are available 3 design methods – Toffaleti (1968), Van Rijn (1993) and Rubey (1933). Specifically it was used the Rubey method of sedimentation rate depending on the specific character of the grain size curve and the hydraulic characteristics of the surveyed riverbed. The Rubey method: (Rubey 1993) developed an analytical relationship between the fluid, properties of the sediments and sedimentation rate, the relationship being based on the combination of Stoke's law (fine to viscous grains) and an impact formula (for large grains outside Stoke's area). This equation can be adapted to silt, sand and gravel. Rubey suggested that crushed quartz grains with specific gravity around 2.65 are the most applicable to this equation. The equation is provided in respect of the sedimentation rate.

$$\omega = F_1 \sqrt{(s-1)gd} \quad (6); \quad \text{where: } F_1 = \sqrt{\frac{2}{3} + \frac{36v^2}{gd^3(s-1)}} - \sqrt{\frac{36v^2}{gd^3(s-1)}} \quad (7)$$

and:  $v$  = kinematic viscosity;  $s$  = specific weight;  $d$  = size diameter;  $g$  = gravitation acceleration  
The sedimentation rates of grains, according to the grain class and water temperature, for  $s=2.65$ , calculated by these model.

### 3.2.3. Calculation function for sorting the alluvial particles within the riverbed mobility range

The erosion can also be limited. In the case of many rivers, the riverbed bottom is covered with a layer of coarse material called reinforcement layer. This layer can be formed of coarse static materials or material resulting from the transport of the finer sediments. In particular, downstream of the dams, most water leakages mobilize the fine particles, while the coarse material is static and collects the deep transport material from the protection surface. The reinforcement layer may also be formed by reinforcing the dynamics of coarse particles to achieve a transport balance of the material (Parker, 2008). In any case, the composition of a reinforcement layer tends to reduce the transport due to particles surface and the only particles available for transport have a tendency to be coarser and harder to move. This is also a physical limitation of the transport capacity. Regarding the model of this reinforcement layer, the model of “Sediment Transport Analysis” has introduced 2 simulation algorithms for sorting and reinforcement (Fig.13). Both ones are based on dividing the bed into one active layer and one inactive layer, the key difference between them being as follows: when the transport capacity is calculated by multiplying the potential transport with



the percentage of grain size, the latter is based only on the grain distribution in the active layer. The Exner5 model was adopted for the study.

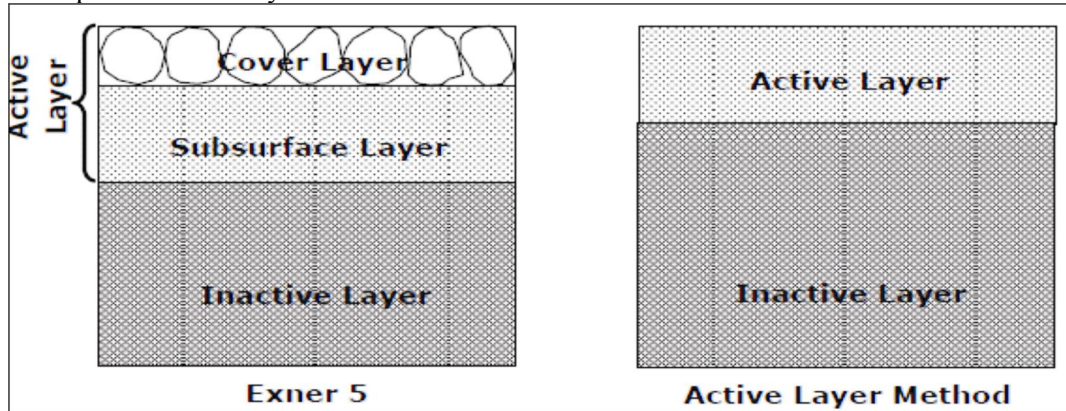


Fig. 13 Available sorting schemes: Exner 5 method and Active Layer Method

The *Exner 5 Model* is a bed model with 3 layers and designed to calculate the influence exerted by the reinforcement. This algorithm was developed by Tony Thomas (Thomas, 1982). This algorithm divides the active layer in two parts - one covering layer and one underground layer. The sedimentation and erosion occur in the covering layer. The sedimentation capacity calculation is based on combining the covering layer with the underground layer. The Exner5 concepts were formulated by Al Harrison's thesis at Berkeley, where he studied under Einstein's guidance.

#### 4. RESULTS OF CALCULATIONS

The main purpose of the calculation results concerning the alluvial transport on the mobile bed of the Danube riverbed was to estimate the morphological changes elaborated on the mathematical model within the extended sector, with detailed application on a small sector (686+300 km – 684+300 km) by simulating the transit of daily flows recorded in 2006 - 2010.

##### 4.1. The results on the extended sector

There can be noticed the alternation of aggradation (sedimentation) and degradation (erosion) phenomena along the sector depending on the specific velocities and the thalweg configuration (Fig.14). Such aggradation phenomena were formed in the thalweg depression areas located at km 684+500 – km 696 with medium aggradations of about 0.25m, and at km 702 – km 719 with medium aggradations of about 0.15 m. The degradation phenomena are presented mainly in the formation areas of sills or negative slopes of the thalweg, located at km 675 km-684+500 (reverse slope) with medium degradations of about 0.05 m at km 696 – km 702 (sill) with medium degradations of about 0.30 m and km 719 km 730 with medium degradations of about 0.20 m.

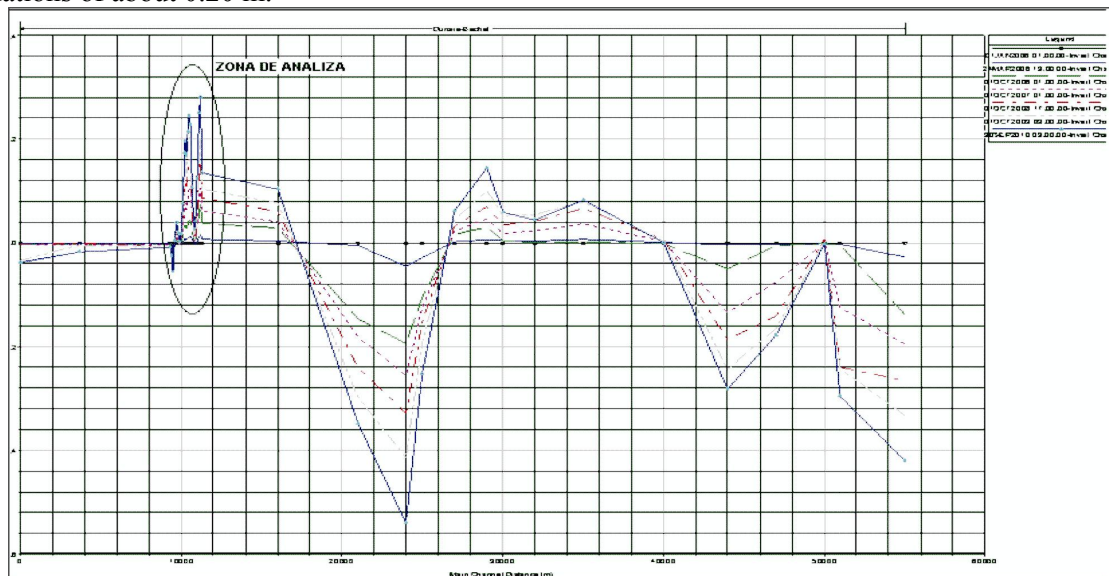


Fig.14. General longitudinal section with the morphologic evolution of the riverbed thalweg. Differences  $\Delta H$  as to the original state

#### 4.2. The results detailed application on a small sector

On a small sector (686+300 km – 684+300km) with detailed application, it has been noticed that the thalweg aggradation as well as the additional cumulative volume is constant during the simulation period except certain intervals of relative stability. The main stability intervals: 04.2006 ; 07.2010, correspond to several maximum flows and respectively to certain higher velocities. At the end of the simulation interval, there is noticed an aggradation of about 17 cm which corresponds to the rate of about 3-4 cm per year.

The analytical and graphical results: general longitudinal section in the undercrossing sector (km 686+300 – km 684+300) concerning the morphological evolution of the riverbed; cross section in the section area (km 685+300) with morphological changes for various significant periods of alluvial transport simulation (Fig15)

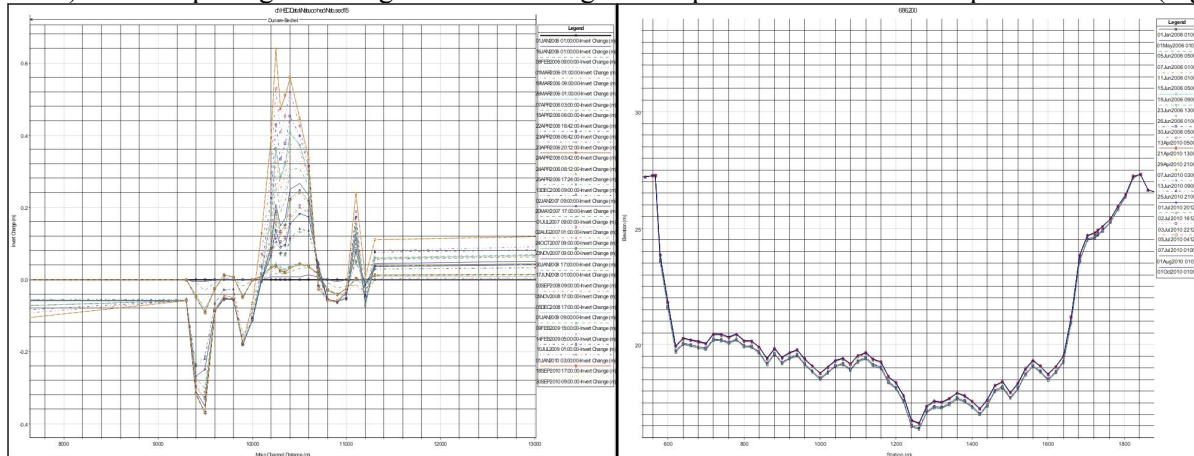


Fig.15. Detail in the general longitudinal and crossing area sector (km 686+300 – km 684+300) of the Danube riverbed. Differences  $\Delta H$  as to the original state

#### 4.3. The evolution of main model variables for the punctual section.

The evolution of main model variables for the punctual section (km 685+300) for the total simulation period (2005 – 2010), is constituted by: Hydrograph flows 01.01.06 – 1.10.10; Medium velocities section; Modifications  $\Delta H$  (m) thalweg; Cumulative sediment volumes for the surveyed period relating to the design section modification (Fig. 16.a;b;c;d.).

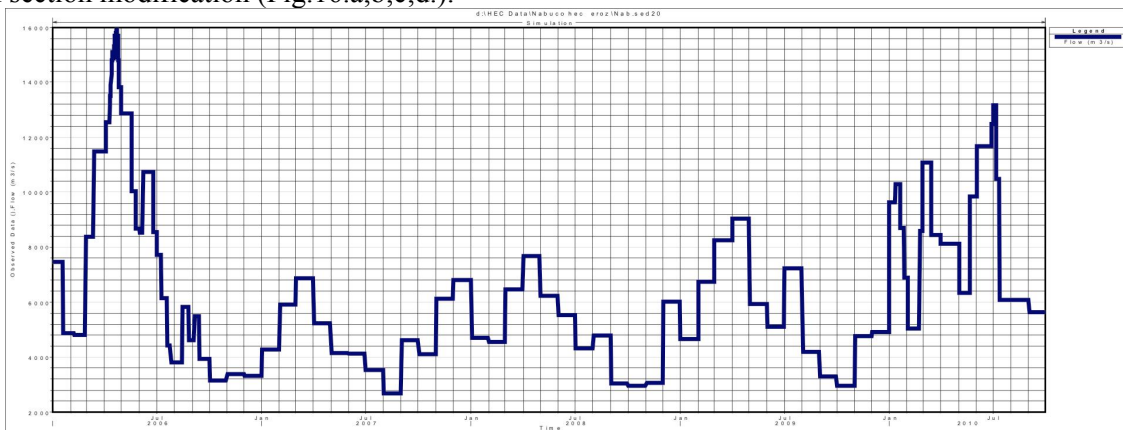


Fig.16.a. Hydrograph flows (m<sup>3</sup>/s) 01.01.06 – 1.10.10

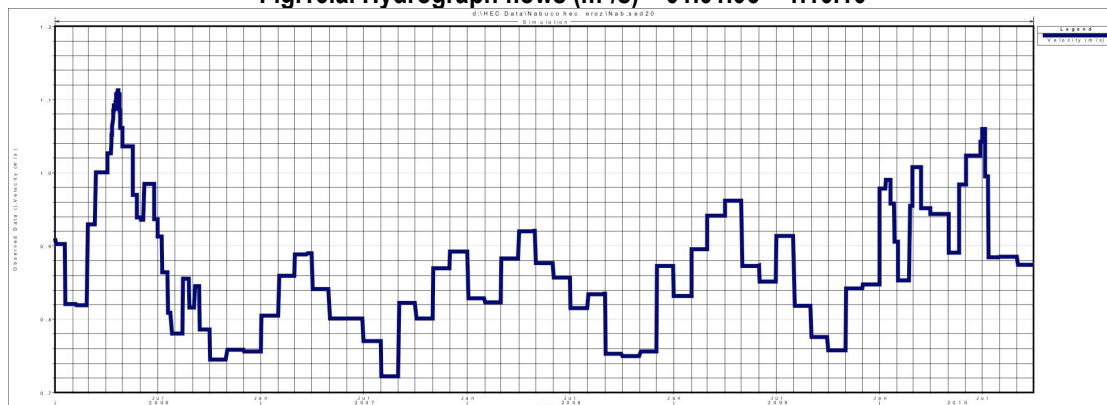


Fig.16.b. Medium velocities (m/s) section

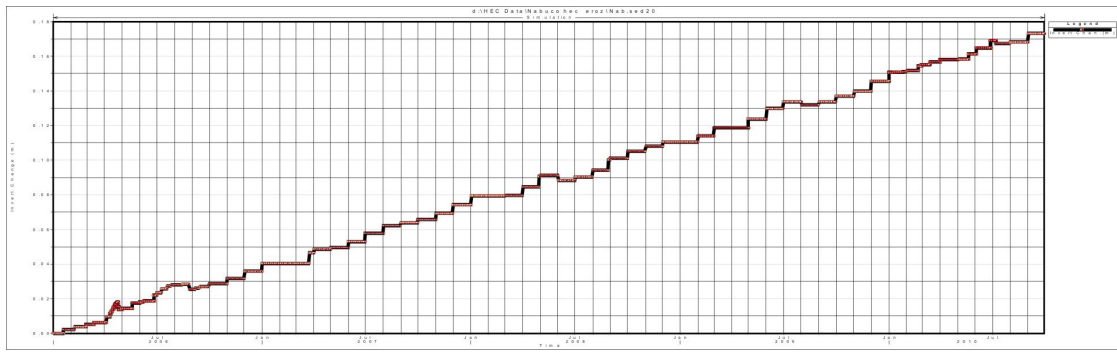


Fig.16.c. Modifications  $\Delta H(m)$  thalweg

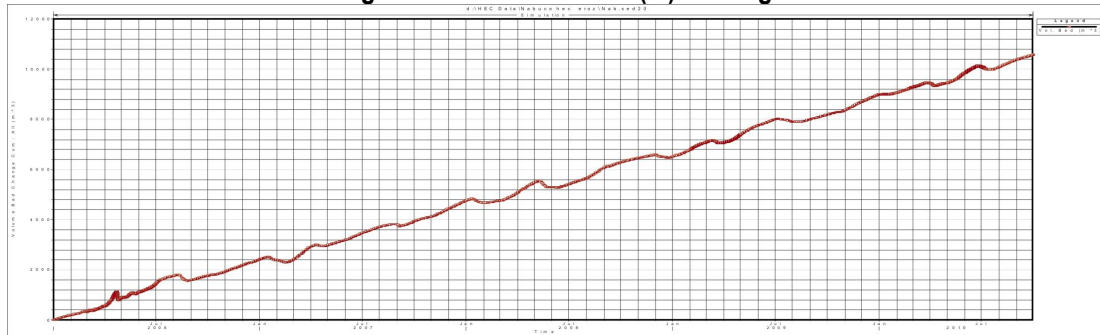


Fig.16.d. Cumulative sediment volumes ( $m^3$ ) for the surveyed period relating to the design section modification

#### 4.4. Calibration of the alluvial transport simulation model .Verification of the results

##### 4.4.1. Graphic method

In order to calibrate the used mathematical model and to determine the morphological evolution in the surveyed section (685+300 km), there were used the cross sections measured at Bechet Hydrometric Station during 2005-2010, which presents a highest degree of credibility (Fig.6). For this period, there is generally found an erosion of the riverbed bottom of about 0.20m. The calculation results superposed on the recorded data have largely confirmed the morphological changes reported in this period with minimum errors

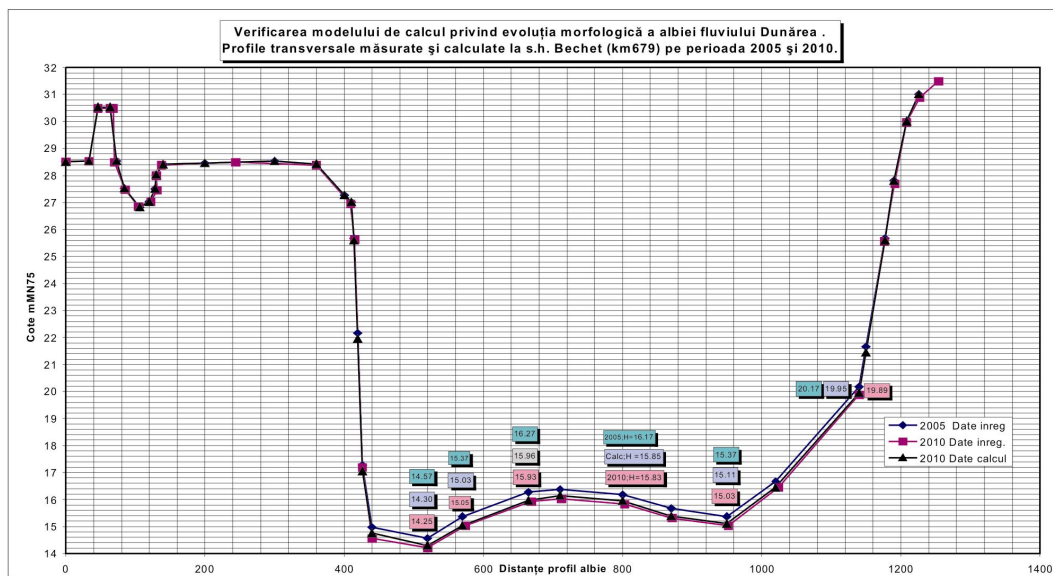


Fig.17. The measured and calculated morphologic evolution of the Danube riverbed in the area of Bechet hydrometric station (km678+660) in the years 2005 and 2010

##### 4.4.2. Analytic method

Checking the results of the model calculations relating to the occurrence possibilities of riverbed degradation and aggradation phenomena has mainly consisted of: the comparison of maximum rates for the design flows in 8 main sectors of the section (Fig. 11) with the medium critical entraining rates – water depth specific to the diameter of the grains  $d_{50}$  (Table 2).

**Table 2. Verification of the results of the calculations relating to the riverbed morphological stability**

Design	Probab.	Design	Design Sectors sector length from the marker (m)/ medium riverbed bottom level (mMN75)								Water level
flows	discharge	hydraulic	I (0 – 410)	II (410 – 500)	III (500 – 580)	IV (580 – 870)	V (870 – 950)	VI (950 – 1035)	VII(1035 – 1110)	VIII(1110 – 1200)	Med.water velocity
mc/s		data	28.50	17.20	15.00	16.10	15.50	16.20	18.00	24.10	Med.crt. velocity
INHGA data			Verification of the results of the calculations relating to the riverbed morphological stability								Obs. riverbed
1	2	3	4	5	6	7	8	9	10	11	12
15900	Qmax 2006 (Qmax 1%)	Hwater (m)	1.51	12.81	15.01	13.91	14.51	13.81	12.01	5.91	30.01(MN75)
		Vwater (m/s)	0.15	1.51	1.69	1.61	1.65	1.59	1.43	1.06	1.56
		Vcr.(m/s)		1.34	1.45	1.40	1.43	1.39	1.30	0.97	1.33
		Vcr-Vwater		-0.17	-0.24	-0.21	-0.22	-0.20	-0.13	-0.09	EROD.II-VIII
13300	Qmax 2010 (Qmax.10%)	Hwater (m)	0.40	11.70	13.90	12.80	13.40	12.70	10.90	4.80	28.90(MN75)
		Vwater (m/s)	0.07	1.37	1.54	1.46	1.49	1.44	1.28	0.91	1.41
		Vcr.(m/s)		1.28	1.40	1.34	1.37	1.33	1.33		1.34
		Vcr-Vwater		-0.09	-0.14	-0.12	-0.12	-0.11	0.05		EROD:II-VII
5590	Qmed.m.year (Qmed.50%)	Hwater (m)	0	7.39	9.59	8.49	9.09	8.39	6.59	0.49	24.59(MN75)
		Vwater (m/s)	0	0.98	1.10	1.00	1.05	0.98	0.82	0.55	0.98
		Vcr.(m/s)		1.06	1.18	1.12	1.15	1.11	1.02		1.11
		Vcr-Vwater		0.08	0.08	0.12	0.10	0.13	0.20		STABIL

For Bechet gauging station, the alternative phenomena recorded during the studied period are verified in respect of the mobility range of the riverbed bottom: degradation for high flows in flood conditions and stability/ aggradation phenomena for the medium and small flows.

## 5. THE SWOT ANALYSIS TYPE

The SWOT analysis (Strengths, Weaknesses, Opportunities and Threats) of the present study on the alluvial transport and the estimation of changes in the riverbeds morphology includes the following aspects:

### 5.1. Strengths

The study takes into account the complexity of processes and phenomena specific to that sector, it highlights the local processes of the studied section; it can draw the attention to certain problems of local interest which can still influence the whole works. For example, for this study, there have been elaborated detailed studies related to the completion of the data bases necessary for the phenomena modeling and application of mathematical models recognized worldwide for the accuracy of these morphological evolution processes of the riverbed and the estimation of possible developments of phenomena on a more extended sector.

### 5.2. Weaknesses

The results of this detailed study of local interest would be necessary to be integrated in an existing broad study of the Danube with this specific nature; or in other words, to achieve a broad picture of the morphological processes outlined in a particular sector. On this purpose, it is necessary to update and develop general studies of the Danube on the basis of mathematical models and a separate summary. The current data on the morphological evolution of the riverbed by sectors are based on the comparative study of periodic topographic surveys generally performed at the hydrometric stations located at very great distances of about 50 km (an example for this area: Calafat – km 795; Bistreț-km 725; Bechet–km 679; Corabia–km 625) and it does not apply to local processes where the aggradation and degradation phenomena can alternate depending on the specific characteristics.

### 5.3. Opportunities

Whereas there is a data stock from several fields accumulated over time and for a more extensive sector, it is useful to have and systematize these data in The Danube's extended sector, in order to develop this kind of study with zonal and / or extended application (using this study as a pilot database).

### 5.4. Threats

If this type of study is not elaborated with application to the studied section according to the necessary data for the mathematical models, there is the threat to neglect certain zonal phenomena or processes that may evolve over time, and on the other hand, if the study is not also completed with a summary view, other processes of the sector as a whole, called synergistic processes may be ignored.

This study meets these conditions and the presented results can be applied with minimal threats.

### **5.5. Applications and opportunities for expending the research**

- The Danube River under-crossing works. Application: the Bechet area;
- The Danube River under-crossing works. Application: cross-border bridges;
- Estimates on the clogging phenomena in the reservoirs. Applications: the Olt River – Frunzaru reservoir; the Arges River – Mihailesti reservoir.
- Morphological evolutions of the Danube riverbed in the area of ports;
- Analysis of the instability areas of the Danube waterway;
- Research on the active mobility areas in the riverbeds.

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