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The State of the Danube riverbed along the Romanian-Bulgarian border

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Abstract

According to the Work Program of the international PHARE Project OSS 98-5303.00 "Morphological changes and abatement of their negative effects on a selected Danube reach", the expert group performed a research trip with a Romanian ship on the Danube along the Romanian-Bulgarian border.
In order to evaluate the state of the banks and islands of the Danube riverbed, among the field objectives a visual examination was performed along the route that the expedition took. During the field trip the experts observed the different types of the morphological processes that affect the banks of the Danube riverbed, between km 375 and km 845.5. Finally a list was made of the “hot points” where the protection works are necessary.

The following conclusions were drawn:
- The balance of the transport of fine and coarse sediments through the downstream riverbed of the Danube presents a deficit, resulting into a general erosion of the riverbed;
- The balance of the transport of coarse sediment presents a surplus, resulting into deposits of sediments on the bottom of the riverbed, in the areas with great widths of the Danube riverbed;
- The erosions of the Danube riverbed have mainly been generated under the action of the water currents, waves, ice and due to the forests existing on the riverbed banks;
- In the areas of the riverbed where its width is greater than 1050 m a decrease appeared of the transport capacity of the coarse sediments, leading to a loss of stability of the riverbed bottom and the occurrence of some bars, and even to the formation of islands;
- In order to ensure good navigation conditions, the dredging works are necessary in the areas where the stability of the riverbed bottom was lost (the annual volumes depend on the hydrological status of the Danube, the natural riverbed width and the navigation channel dimensions -depth and width).

It is important to define a set of common benchmarks, agreed and balanced on the Danube banks for a mutually free use by both countries. It is necessary to complete with benchmarks the current levelling and geodetic networks along the Danube riverbed, determining their positions in the new European systems - EUREF and EUVN. Based on these new systems, it will be possible to carry out the positioning of all hydrographical surveys of the Danube riverbed as well as periodic verifying of the heights of all the hydrometric gauges along the Danube.

1. Problem setting and existing database.

The present day international economic and environmental requirements have made necessary the study of the riverbed conditions along the Danube inferior sector, downstream of the Iron Gages energetic and navigation system (km 863).
One of the major issues of this study is related to the improvement of navigation conditions on the Danube, with a view to establishing a permanent naval traffic during the periods with low waters.

Fig.1

Solving this problem requires a complex analysis of the physical state of the Danube, of the banks, widths and depths as well as of the interactions between the water flow and the riverbed. Some processing of the map drawing resource of the hydrographic navigation maps and of the hydrological resource of water flow measurements carried out on the Danube after the second world war have been done with this view. The respective processing allowed for the highlighting of the variation in time and of the dependence of the riverbed morpho-hydrographic parameters on the hydrographic mechanism as well as for learning about the interacting hydraulic mechanism of the water stream and the riverbed along the inferior Danube sector.

The performed investigations formed the main part of the object of an International Study and PHARE Project OSS 98-5303 called "Morphological changes and abatement of their negative effects on a selected Danube reach" processing data over two intervals, between 1996-1997 and 1998-2000. Participants in the respective Project were Austria, as a guarantor country of the European Union through the Vienna Technical University as the international coordinator, Romania through the National Institute of Marine Geology and Geoecology (GeoEcoMar) as the titular of contract and the National Institute of Meteorology and Hydrology (NIMH) as the associate partner, Bulgaria through the Sofia Technical University and Yugoslavia through the Belgrade Water Management Institute.

In order to update the information on the physical state of the Danube riverbed banks, during the third decade of September 1999 the experts of the Project partner countries performed a recognition field trip (RFT) along the Romanian-Bulgarian border of the Danube between Chiciu Calarasi-Silistra (km 375) and the mouth of the Timok river (km 845.4) (Fig.1).

Two Austrians, one Yugoslav, three Bulgarians and three Romanians represented the expert group of RFT. This group was joined by the International coordinator of the PHARE Project, professor dr.ing. Dieter Gutkhnecht from the Vienna Technical University and the national coordinators, from Romania the expert dr. ing. Constantin Bondar of GeoEcoMar Bucharest and from Bulgaria the expert dr.ing. Stefan Modev from the Sofia Technical University. The Yugoslav representative of the group was the expert professor dr.ing. Slobodan Petcovici (Fig.2).

The water expedition of the expert group was prepared by the GeoEcoMar Institute with the help of the Coast Guard in the activity framework of the General Inspectorate of Border Police with the Romanian Ministry of the Interior, which provided a fluvial ship (Fig.3).

Fig.2

Fig.3

During the five days of RFT from the beginning of the expedition visual observations were made regarding:

- The physical state of the Danube riverbed banks and islands, making observations and notes on the spot .
- The state of the hydrometrical gauges, presenting construction and location sketches and cross bathymetric profiles in the hydrometrical sections as well as the water discharges curves.

At the end of the RFT on the Danube a minute was drafted mentioning the accomplishment of the expedition objectives and the processing method used in order to obtain the field data for the Project.
The Bulgarian expert team prepared a compact disk with the images and charts indicating the bank positions in different years and the "hot points" of the banks that need protection works.

The results outlined in this work are obtained by processing the hydrographic and hydrologic data fund cumulating the Romanian and Bulgarian measurements throughout the XXth century /1,2,5,7/ and the RFT findings regarding the physical state of the Danube riverbed in September 1999.

In order to point out the variation in time and the dependence on the hydrologic status of the riverbed morpho-hydrographic parameters in the fluvial sector between Iron Gates 2 (km 863) and the entrance in Ialomita Marsh at Chiciu-Calarasi (km 375) the measurements were performed only on the main Danube riverbed sections (without branches and islands) whose average widths and depths on the talveg had been previously established in 1962 and 1992. In order to get a bird's eye view of the processes along the whole Danube section between km 942 and km 375, not taking in account the secondary branches and the islands, the hydrographic map of 1909 was taken into account. Thus three hydrographic situations of the Danube riverbed were considered at intervals of 53 and 30 years respectively. Table 1 shows the results of the detailed calculus done for 11 riverbed sections without secondary branches and without islands.

In order to understand the hydraulic mechanism between the water stream and the riverbed 5,136 measurements of water discharges were processed by the Romanian and Bulgarian teams in 31 hydrometric sections of the Danube inferior sector after the second world war, with the help of a special program made up of three modules. The results obtained have been centralized in Table 2. The results of the analysis of tables 1 and 2 are discussed below.

2. Results of the hydrographic maps processing.

The data resulting from processing the 1909, 1962 and 1992 navigation hydrographic maps (Table 1) allowed for noticing some hydrodynamic effects induced by the water stream on the Danube riverbed all along the inferior section as well as on different sections from the Iron Gates 1(km 942) up the Ialomita pond at Chiciu-Calarasi (km 375):

- All along the inferior Danube, the riverbed becomes wider at an average of 83 m between 1909-1962 and at an average of 47 m between 1962-1992;
- All along the Danube and between the same comparison years the Danube riverbed decreased its depths on the talveg from 10.6 m in 1909, to about 6.6 m in 1962 and to about 6.5 in 1992;
- Along the unique riverbed, without secondary branches and without islands, the Danube riverbed enlarged at an average of 58.3 m between 1962 and 1992. The decrease of the depths on the talveg of about 0.21 m took place at the same time.

Table 1

Averages values from 1962 and 1992 of the morphographic parameters of the Danube riverbed in the inferior section, along unique sections, without branches or islands.

No.	Riverbed sections, km upstream, km downstream	Y e a r s				Mean values in 1962-1992		Variation for 30 years	
		1962		1992					
		B(m)	he(m)	B(m)	he(m)	mB(m)	mhe(m)	varB (m/yr)	varhe (m/yr.)
1.	820-810	841	6,39	906	6,57	873,5	6,48	2,17	0,006
2.	712-704	724	8,38	754	9,09	739,0	8,73	1,00	0,024
3.	689-673	966	5,48	1021	6,39	993,5	5,93	1,83	0,030
4.	660-654	829	7,69	843	6,46	836,0	7,08	0,47	-0,040
5.	636-631	1218	4,68	1335	3,87	1276,5	4,28	3,90	-0,027
6.	600-594	907	5,93	964	5,67	935,5	5,80	1,90	-0,0087
7.	557-547	906	6,73	966	6,10	936,0	6,41	2,00	-0,021
8.	522-512	844	7,00	914	7,36	879,0	7,18	2,33	0,012
9.	434-428	841	8,07	881	7,90	861,0	7,98	1,33	-0,0057
10.	420-412	860	7,27	955	6,70	907,5	6,98	3,17	-0,019
11.	401-395	828	7,47	966	6,71	897,0	7,09	460	-0,025

The significance of the data in the columns of Table 1 is the following:

B (m) - the average width of the Danube riverbed for the water mirror,
he (m) - the average depth on the talveg as to zero of the hydrometric gauges,
mB (m) - the mean of the average width in the interval 1962-1992,
mhe (m) - the mean of the average depth on the thalveg in the interval 1962-1992,
varhe (m/year) - the variation in time of the average depth on the talveg in the interval

1962-1992.

Fig.4

Table 2

Hydromorphologic data along the Danube riverbed in the hydrometric sections of water and alluvia discharge measurements in 1956-1998 years.

No.	Section hidrom.	No. mas.	qm m2/s	bm m	adm m	Q0 m3/s	b0 m	adm0 m	H0 cm	bhm	ahe m	bhe	che	Hm cm	dshe m	dsH cm
1.	Drobeta T.S 1970-1984	104	3.90	788	6.70	3348	727	4.26	-740	.739	4.39	-.218	.025	300	.127	-71
2.	Tiganasi 1982-1984	12	5.03	679	6.70	2106	471	5.66	-1035	.426	5.66	.0412	.048	264	-.307	-84
3.	Gruia 1970-1987	57	2.68	910	6.58	2448	881	3.72	-573	.807	3.71	-.163	.033	318	-.086	7
4.	Novo Selo 1956-1973	100	4.28	767	7.84	2205	695	5.33	-895	.730	5.47	-.141	.028	323	.017	18
5.	Calafat 1969-1998	196	4.24	782	7.84	2401	736	5.52	-855	.784	5.58	-.121	.026	280	.033	-13
6.	Lom 1956-1973	81	5.51	710	8.27	2204	606	6.40	-954	.639	6.58	-.112	.021	298	-.014	10
7.	Bechet 1970-1998	114	4.08	756	7.83	2407	722	5.28	-763	.836	5.36	-.101	.026	287	-.002	-4
8.	Oriahovo 1967-1973	35	4.89	695	8.68	2352	666	6.19	-1024	.797	6.32	-.153	.022	292	-.068	-7
9.	Corabia 1967-1998	282	4.06	914	6.39	2407	770	4.64	-841	.643	4.91	-.168	.025	265	.008	-22
10	Turnu Mag. 1967-1998	303	5.80	673	8.60	2403	640	6.60	-1015	.781	6.63	-.108	.023	246	-.023	-10
11.	Zimnicea 1966-1998	295	3.83	874	7.24	2405	823	4.88	-797	.774	4.94	-.147	.028	285	.027	-1
12.	Svistov 1956-1997	205	3.76	860	7.49	2509	816	5.02	-851	.786	5.16	-.152	.029	290	.021	12
13.	Giurgiu 1966-1998	339	4.26	801	7.76	2834	773	5.64	-1014	.787	5.68	-.150	.028	252	.022	-22
14.	Ruse	188	4.67	763	8.47	2826	741	6.22	-1027	.819	6.28	-.130	.025	258	.001	-22

1958-1997															
15. Oltenita 1970-1998	292	5.07	714	8.22	2586	683	5.93	-886	.816	6.03	-.116	.023	267	-.006	13
16. Silistra 1956-1973	72	4.40	778	7.21	2891	740	5.06	-856	.839	5.14	-.078	.038	237	.000	-8
17. Chiciu-Cal. 1966-1998	290	5.22	748	8.33	3108	718	6.37	-945	.827	6.38	-.096	.024	228	.044	-12
18. Vadu Oii 1956-1998	402	8.36	563	12.4	2731	526	10.4	-1510	.708	10.5	-.085	.015	280	.044	2
19. Braila 1956-1998	498	8.15	643	12.0	2163	565	10.4	-1706	.523	10.6	-.118	.015	298	.002	-1
20. Grindu 1966-1998	301	6.85	679	10.7	2162	637	8.39	-1060	.788	8.35	-.059	.015	289	-.088	-6
21. Isaccea 1959-1998	241	6.15	781	10.5	2148	753	8.55	-1559	.806	8.58	-.072	.024	228	-.001	3
22. Ceatal Izm. 1964-1998	313	12.9	440	16.5	1964	422	15.0	-2372	.798	15.0	.075	.018	191	-.038	1
23. Smardan 1996-1998	23	1.33	291	5.16	121	262	2.35	-334	.778	2.47	-.171	.026	338	-.011	51
24. Calarasi 1995-1998	20	2.47	193	4.36	228	149	3.28	-772	.453	3.62	-.338	.025	233	-.034	28
25. Socarici 1950	8	1.16	220	4.05	260	171	2.83	-461	.853	2.89	-.169	.044	143	.186	154
26. Oltina 1950-1951	66	1.13	198	3.71	145	184	1.90	-340	.825	1.93	-.098	.074	193	.017	-88
27. Jigalia 1951	25	6.55	320	10.6	1709	275	8.51	-1343	.861	8.51	.031	.029	243	-.603	-361
28. Bala.am 1950	29	2.98	410	5.74	1590	366	4.77	-717	.680	4.74	-.084	.036	143	.237	154
29. Bala.av 1950-1989	67	3.71	313	7.35	1672	302	5.77	-860	.822	5.73	-.041	.034	185	.270	-12
30. Caragheor. 1950-1951	87	2.81	441	6.08	1013	423	4.28	-703	.863	4.30	-.060	.045	193	-.058	-124
31. Parjoaia 1950-1998	91	3.91	1017	5.6	2712	979	3.86	-616	.785	3.87	-.153	.035	205	.145	-98

The significance of the data in the columns of the Table 2 is the following:

Section
hidrom. - hydrometric section name and the interval of the years with measurements carried out,
No. mas. - number of measurements of water discharges carried out in each hydrometric section,
qm - the average specific water discharge resulting from the measurements mean,
bm - the average width of the riverbed resulting from the measurements mean,
adm - the cross average depth on the riverbed resulting from the measurements mean,
Q0 - the water discharge at the zero level of hydrometric gauge,
b0 - the width of the riverbed at the zero level of hydrometric gauge,
adm0 - the cross average depth on the riverbed at the zero level,
H0 - the average depth on the talveg in report to the zero level,
bhm - the constant value in the correlation adm = ahm + bhm.H, where H is the level of the water at the hydrometric gauge,
ahe, hhe
and che - constant values in the correlation he = ahe + bhe.H + che.H^2, where he is the average cross depth at the zero level and H is the water level at hydrometric gauge,
Hm - the average level at the hydrometric gauge resulting from the water discharge measurements,
dshe - the average variation in time of the average depth for two days period,
dsH - the average variation in time of the water level for two days period.

In conclusion the riverbed of the Danube inferior section degrades physically in time by the erosion of the banks and the diminishing of the depths. These effects have a negative effect on the economic activities and on the environment (Fig.4).

3. Results of the water discharges data processing.

On the basis of the hydrologic data base obtained from the water discharges measurements carried out yearly and repeatedly in fixed cross sections on the Danube riverbed a special processing was carried out having as results hydromorphologic elements regarding the interaction between the water stream and the riverbed. This data is shown in table 2 and leads to the following conclusion:

- The width and depth of the Danube riverbed in different sections changes in time under the action of the natural factors (water stream, sediment transport, waves and frost);
- There is a dependence between the cross morphological elements of the riverbed and the elements of the hydrological state. This dependence will be mathematically modeled in the following paragraph;
- Due to the continuity of the water flow along the Danube riverbed, the widths and depths of the riverbed in different cross sections are in a reverse interdependence - in the narrow areas of the riverbed there are great depths and in the wide areas there are small depths;
- In the riverbed sections having great widths the most intense process of erosion takes place on the banks and on the sediment setting on the bottom of the bed.

The above conclusions are analyzed below in order to determine the laws governing the respective phenomena.

4. Empirical functions describing the dependence of the hydrographic parameters by the hydrologic state.

The following empirical functions resulted following the conclusions obtained from the processing of the hydrographical maps.

- The equation with finite differences regarding the tendency of widening in time of the Danube riverbed width, expressed by the empirical function,

$$dB/dt = hm*(- 1.5728 + 0.002442*B)^2 \qquad (1)$$

where: dB/dt is the gradient of the annual variation of the width of the riverbed at a mean level expressed in (m/year),
B - the width of the riverbed at a mean level of the water mirror, expressed in (m),
hm - the cross mean depth of the riverbed, expressed in (m).

- The equation with finite differences regarding the tendency of diminishing or increasing in time of the Danube riverbed depth, expressed by the empirical function,

$$dh/dt = 0.0257*hm - 0.000176*B \qquad (2)$$

where: dh/dt is the gradient of the annual variation of the cross mean depth of the riverbed, expressed in (m/year),
hm and B have the same significance as those in equation (1).

Based on the conclusions drawn from the processing of the hydrological data from the water discharges measurements in fixed cross sections the following empirical functions resulted:

- The function of the riverbed mean depth;

$$hm = 2.803 + 1.0961*qm \qquad (3)$$

where hm (m), is the riverbed cross mean depth, reported at the water mirror, qm (m^2/s) is the cross mean specific water discharge on the riverbed.
The hydromorphologic function (3) is valid both for the unique Danube riverbed and for the riverbeds of the secondary branches in the area with islands.

- The function of the average width for the unique riverbed;

$$bm = 2591/hm^{0.06} *\exp(- 0.148*qm) \qquad (3.1)$$

- The function of the average widths for the secondary branches between islands;

$$bm = 70 + 112*qm \qquad (3.2)$$

where bm (m) is the width of the riverbed at the water mirror, qm (m^2/s) is the cross mean specific water discharge on the riverbed.

- The function of the depth on the riverbed talveg;

$$H0 = 1.695 + 1.677*qm \qquad (4)$$

where H0 is the riverbed depth on the talveg reported to the zero of hydrometric gauge and qm is the cross mean specific water discharge on the riverbed.

- The function of the cross average depth at the low water;

$$he = ahe + bhe*H + che*H^2 \qquad (5)$$

where: he (m) is the cross average depth on the riverbed, reported to the zero of the hydrometric gauge,
H (m), the level of water reported to the zero of the hydrometric gauge,
ahe, bhe and che, parameters dependent on the average cross specific water discharge qm (m^2/s) on the riverbed,

$$ahe = 0.817 + 1.1*qm \qquad (5.1)$$

$$bhe = - 0.2 + 0.01895*qm \qquad (5.2)$$

$$che = (0.253 - 0.0405*qm^{0.5})^2 \qquad (5.3)$$

The hydromorphologic functions (4) and (5.1)-(5.3) are valid both for the secondary branches in the areas with islands.

The analysis of the empirical function system (2)-(5) and of the respective parameters leads to specific morpho-hydrologic characteristics of the Danube riverbed.

- For example, of the equation with finite differences (2), it comes out that the hydromorphologic processes in the Danube riverbed can be stopped when there is the relation B = 146*hm between the width (B) and the average depth (hm) of the riverbed.

- The morphometric elements of the Danube unique riverbed and of the secondary branches riverbeds are dependent on the specific water discharge (qm) across the riverbed as follows:
  - The cross average depth on the riverbed as well as the depths on the talveg are linearly dependent on the average specific water discharge (functions 3 and 4).
  - The widths of the unique Danube riverbed and of the secondary branches at the average level of the water mirror, show differences dependent on the specific water discharge, thus;
    - for the unique Danube riverbed, the widths vary exponentially - decreasing with the increase of the specific water discharge (function 3.1),
    - for the secondary branches riverbeds, the widths vary linearly with the specific water discharge (function 3.2).
- The average depth at the low water (function 5), dependence on the water mirror level, is characterized by parameters dependent on the specific water discharge, expressed by the empirical functions (5.1)-(5.3).

An analysis and discussion of the empirical function (5), together with the parameters expressed by the empirical functions (5.1)-(5.3), shows the following:
- First of all, the function (5.1) of the parameters ahe, shows at what depth is situated the medium bottom of the riverbed relative to the line of the zeroes of the hydrometric gauges. Of the respective function it results that for a very low water of the Danube, the medium bottom of the riverbed is to be found at a depth of 0.82 m.
- Function (5.2) of the bhe parameter, shows the direction and the vertical variation intensity of the average bottom of the riverbed as to the zero line of the hydrometrical gauges. Of the respective function it results that for specific water discharges lower than 10.55 m^2/s, a rising of the medium bottom takes place in the riverbed due to the alluvial sedimentation processes. For specific water discharges greater than 10.55 m^2/s, a lowering of the medium bottom of the riverbed took place due the erosion process. It results that within the Danube water flow variation there is a water flow for which there are no more morphological variations in the riverbed. This water flow characterized by the medium specific water discharge equal to 10.55 m^2/s, separates the states of the morphological processes in the riverbed, representing an extremely important hydromorphologic criterion.
- Function (5.3) of the che parameter and of the bhe parameter allows for the determination of the water level (Hm) at which the hydro morphological state changes in the riverbed or of the level at which no hydro morphological change takes place. This fact results from the annulment of the differentiation as to the (H) of the empirical function (5). By differentiation as to the H of the function (5) the expression (6) was obtained and further on equaling it to zero the relation (7) was obtained.

$$dhe/dH = bhe + 2*che*H \tag{6}$$

$$Hne = - bhe/2/che \tag{7}$$

Taking into account the functions (4.2) and (4.3), the relation (6) becomes,

$$Hne = - (-0.2 + 0.01895*qm)/2/(0.253 - 0.0405*qm^{0.5})^2 \tag{8}$$

Function (8) allows for a maximum of 2.14 m for a medium specific water discharge equal to 2.8543 m^2/s. In conclusion on the Danube inferior section, the riverbed hydromorphologic stability state settles when the water levels get values of about 214 m.

The above mentioned facts point to the practical utility of the empirical functions (2)-(7), in view of understanding the mechanisms of the riverbed hydromorphologic processes as well as choosing of a riverbed cross morphometry corresponding to the requirements of the navigation depth.

5. Findings of the recognition field trip (RFT) of the Danube riverbed between Chiciu Calarasi-Silistra (km 375) and the mouth of the Timok river (km 845.4).

During the recognition field trip the Danube was in a small water state with water discharges varying between 4400 m^3/s at Chiciu Calarasi-Silistra (km 375) and 3800 m^3/s at Cetate (km 811).
The field notes made by the experts during the expedition from their direct observations on the physical state of the Danube riverbed, of the banks, of the sandbanks and of the islands were presented in the Table 3. In view of the field notes processing the expert group elaborated a morphological type of the banks. On the basis of this morphological type they compiled a statistics of the length of the bank types (Table 4). From the table and the statistics of the bank types came out the following findings:

- From a total length of 471 km of the expedition route the erosion of the Danube banks was observed on 244.1 km and deposits on 120.4 km. From the length of the banks erosion, 95.9 km were on the left riverbed, 51.5 km on the right riverbed and 96 km along the islands. From the length of the banks with deposits 28.1 km were on the left riverbed, 11.1 km on the right riverbed and 32 km along the islands.
- The forests along the eroded banks have the trees inverted in the riverbed.
- On the investigation of the riverbed reach the Danube width exceeds 1000 m on a length of about 65 km, from which on a length of 1.6 km it is greater than 1500 m, on 16.3 km it has widths between 1500 and 1200 m, on 30 km it has widths between 1199 and 1100m and on 17 km the widths are between 1099 m and 1000 m. In the large riverbed (with widths greater than 1000 m) the navigation channel it characterized by small depths (under 2.0m).

Tabel 3

The Danube banks state data of the riverbed and of the islands on the common Romanian Bulgarian border (between km 373 and km 845), obtained during the recognition field trip (RFT) performed between 20 and 24 September 1999 by the international group of experts (AU, YU, RO and BG) of the PHARE Project "Morphological changes and abatement of there negative effect on a selected Danube reach".

No	km	Left bank	Right bank	Islands and others observations
1.	375	d6	port	-
2.	376.5	Romanian dredging for extraction of ballast (1/18-20)		
3.	377	e1	ep1(1/21)	-
4.	379.5	Hydrometrical section		-
5.	380	A great island and a one small		-
6.	380	e1	-	-
7.	382.5	e1	e1	Ciaica mare
8.	383	e1(1/22)	-	-
9.	385	e1	-	-
10.	386	e1	-	-
11.	387.7	Canal for the pump left bank		-

12.	388	e1	e1	-
13.	389	d6	e1	-
14.	390	Romanian greifer for extraction of ballast (1/23-24)		
15.	391	e2	e1	Ciocanesti
16	394.5	s	ep1	Ciocanesti
17.	395	Water plug on the left bank		-
18.	395.5	e1	d6	-
19.	396	Turistic point, right bank	-	
20.	398	-	-	Low end of Island Varasti
21.	399	Island Varasti(1/25)	e1	Varasti
22.	400	Up end Island Varasti, great width > 1 km		
23.	401	ep1	-	-
24.	403	Kaolin exploitation right bank-		
25.	404	e3	-	Island in formation (2/4)
26.	407	-	-	Gorvan(2/5,6)
27.	408	d6	e1	Depth little
28.	409	e1	-	Great width
29.	412	e1	d6	-
30.	413	Floating station pump.		Pump station.
31.	414	e1	-	-
32.	416	e1	d6	-
33.	417.5	-	-	Island
34.	418	Breadth riverbed(2/8)	-	-
35.	419	e1	-	-
36.	423	e1(hot spot)	-	Great width, Irrigation canal
37.	424	e1	-	-
38.	426	e1	-	-
39.	428	e1	-	-
40.	430	e1	-	Water level at Oltenita 69 cm.
41.	431	s	s	-
42.	432	New mouth Arges	-	Radelskii
43.	434	e1	-	-
44.	435	e1	-	-
45.	436	e1	-	-
46.	438	d6	e1	-
47.	440	e1	e1	-
48.	443	e1	e1	-
49.	442.5	Pump station left bank	-	
50.	445	-	-	Vajaetoarea
51.	446	e2	e1	Vajaetoarea
52.	450	e1	e1	Briclian
No	**km**	**Left bank**	**Right bank**	**Islands and others observations**
53.	453.7	e1	-	e.am Brichilian
54.	455	-	-	Large riverbed, a new island
55.	457	-	d6	-
56.	458	d6	d6	-
57.	460	e1	-	-
58.	461	d6	-	Bulgarian dredge for extraction ballast
59.	462	-	s	-
60.	464	-	s	e.av Island
61.	465.5	-	-	d.am Island
62.	468	s	-	Follows a lot Islands(2/13)
63.	470	s	s	-
64.	475	e1	d6	-
65.	477	e1	-	-
66.	479.2	Water plug, left bank		-
67.	479.6	-	-	e.am Island Alco
68.	479.8	e1	-	-
69.	481	s	s	-
70.	485	d6	-	e.am si d.av Litlle Island
71.	496	e1	-	-

72.	500	d6	-	-
73.	501	d6	s	Liuliak, small depth
74.	503.4	e1	e1	-
75.	505	e1	e1	-
76.	507	e5	s (rock)	Dinu with e.am
77.	510	e1	s	d.am Cama Island, large riverbed
78.	511	Large riverbed	-	-
79.	514	e1	s (rock)	-
80.	516	e1	s	-
81.	517	e1	s (protected)	-
82.	518	e1p	s (protected)	Romanian dredge,extraction ballast
83.	520	e1-2	s (protected)	-
84.	522	e1-2	s	Large riverbed, Pump Station m.s
85.	523	e1p	e1p	-
86.	527	e1	s	-
87.	529	e1	e1p	-
88.	530	e1	s	-
89.	533	e3	e1	-
90.	534	e3	e1	-
91.	536	e1p	e3	-
92.	538.8	e1-2	e1	Gasca, The Monument Haiduc right bank
93.	540	e1	s	e.am, Gasca
94.	545	e6	s	-
95.	555	e1	port	Water level Zimnicea 77 cm.
96.	555.5	Water plug	-	Island in formation, large riverbed
97.	556	e5	s	-
98.	558	e1p	Mouth for water evacuation	
99.	559	e1	e1	-
100.	560	e3	e6	-
101.	561	e3	e3	A lot sand bars
102.	562	e3	-	e.av Island
103.	563	e6	e3	-
104.	564	e1	e1	large riverbed
105.	567	e1	s	-
106.	568	s	e6	-
107.	569	e1	e1p	Canal for water plug
108.	569.5	s	e1	-
109.	570	s	e1	-
110.	571	e1	e1	-
111.	573	e6	e1	Large riverbed
112.	573.5	e1p	e1p	-
113.	575	e1	s	The Crossing Breaza, Failed Ship 2/18)
No	**km**	**Left bank**	**Right bank**	**Islands and others observations**
114.	579	e1	s	-
115.	580.5	e1 (concrete dig)	-	-
116.	582	e6	e1	Island
117.	587	e1	e6	e.am Island
118.	591	e1	e6	-
119.	594	e6	s (Rock)	2/19
120.	595.5	e6	s (Rock)	Water level at Turnu Magurele 128 cm.
121.	600	e1	s	-
122.	602	e5	s (concrete dig)	
123.	605	e1	s (concrete dig)	
124.	608	s	s	Large riverbed, small depths
125.	610	s	s	-
126.	612	s	s	-
127.	614	s	s	Island, large riverbed
128.	616	s	s	Large riverbed
129.	618	e6	s	-
130.	620	-	-	e.am Island
131.	623	s	s	-

132.	626	e2	e2	-
133.	628	e1	e1	-
134.	630	s (port) Water plug	d.am Island,Water level Corabia 46 cm	
135.	631	e1	e1	Large riverbed
136.	632	e1	s	Large riverbed
137.	634	e1	s	Large riverbed
138.	636	e6	s	-
139.	637	e1p	s	-
140.	639	e6	s	-
141.	642	e1	s	-
142.	644	e6	s	-
143.	645	e6	s	-
144.	646	e1p	s	-
145.	648	e1p	s	-
146.	650	s	s	-
147.	652	e1p	s (Rock)	-
148.	655	s	s	-
149.	656	e1	s	-
150.	659	e1	s	-
151.	661	e1p	s	-
152.	663	e1p	s	-
153.	665	e1p	s	-
154.	667	e1p	s	e.am Island Papadia
155.	670	e1	s	-
156.	671	s	e1	-
157.	673	s	e6	-
158.	675	e1p	s	-
159.	677	e1	s (port)	-
160.	680	s	s	-
161.	681	s	s	-
162.	684	s	e1	-
163.	687	s	e1	-
164.	688	s	s	-
165.	689	s	s	-
166.	691	s	e1	Tributary Jiul at km 691.5
167.	692	e1	e1	-
168.	693	e1	e1	-
169.	695	s	e6	-
170.	697	e1	e6	Pump station
171.	699	s	e6	-
172.	703	s	s	-
173.	703.5	e1	s	-
174.	706	e1	s	Hight tension electrical line
No	**km**	**Left bank**	**Right bank**	**Islands and others observations**
175.	707	e1	s	Floating pump station
176.	713	e1	s	-
177.	714	e6	e1(hot spot)	-
178.	715	s	e1	-
179.	717	e1	s	-
180.	720	s	s	Large riverbed
181.	722	s	e1p	-
182.	726	e1p	s	-
183.	731	e6	s	-
184.	734	e6	s	-
185.	736	e1	s	-
186.	740	e1	s	-
187.	744	e1	s	-
188.	746	s	s	-
189.	747	e1	e1	-
190.	759	e1	e1	Bulgarian dredge extraction of ballast
191.	762	e1	s	-

192.	764	e6	s	-
193.	774	s	s	-
194.	777	s	s	-
195.	778	s	s	-
196.	780	s	s	-
197.	783	s	e1	-
198.	786	s	s	-
199.	799	s	e1	-
200.	801.5	s	e6	Pump station
201.	804	s	s	-
202.	807	s	s	Dredge NZ 20
203.	813	s	s	3/13,14, water level Cetate 100 cm.
204.	814	e1	s	Pump station
205.	815	e1	s	-
206.	817	e1p	s	-
207.	819	e1	s	Pump station
208.	822	e1	s	Dangerous bar
209.	823	e1p	s	-
210.	825	e1	s	Floating Pump Station
211.	828	e1	e1	-
212.	832	s	s	Pump station
213.	833	s	s	-
214.	835	e1	s	-
215.	840	s	e1	-
216.	841	e1	s	-
217.	844	s	e1	-

The attached letters with the numbers from column 3 and 4 have the followings significations regarding the type of the bank erosions:

e1 - erosion terrace type (Fig.5 and Fig.6),
e2 - lowland type erosion,
e1-2 - mixture type erosion,
e3 - ledge type erosion,
e4 - sliding type erosion,
e5 - steep slope erosion,
e6 - alternating deposition / erosion,
d6 - slope-bank deposition,
s - stable bank,
ep - erosion accompanied of fallen forest (Fig.7),
e.am - erosion in upstream of island (Fig.8),
e.av - erosion in downstream of island,
d.am - upstream deposition,
d.av - downstream deposition.

The parenthesis with interior numbers indicates the number of photo.

Table 4

Statistical data of the length (km) of the morphological types of riverbed bank of Danube from the common Romanian-Bulgarian border (September 1999)

km 370 - km 844.5

Bank	Types			of		the		bank		
	e1	e1p	e2	e1-2	e3	e4	e5	e6	d6	s	Total
Left	94.3	34.9	7.3	2.0	8.5	0.0	6.3	40.0	18.9	117.9	430.0
Right	89.3	10.3	2.5	0.0	4.4	0.0	0.0	21.5	10.8	235.7	374.4

Total	283.6	45.1	9.8	2.0	12.9	0.0	6.3	61.5	29.7	353.5	804.3

km 370 - km 484

Bank			Types			of		the		bank	
	e1	e1p	e2	e1-2	e3	e4	e5	e6	d6	s	Total
Left	52.1	0.0	4.8	0.0	2.0	0.0	0.0	0.0	7.3	11.4	77.5
Right	21.3	1.5	0.0	0.0	0.0	0.0	0.0	0.0	10.8	10.4	43.9
Total	73.4	1.5	4.8	0.0	2.0	0.0	0.0	0.0	18.0	21.7	121.3

km 484 - km 630

Bank			Types			of		the		bank	
	e1	e1p	e2	e1-2	e3	e4	e5	e6	d6	s	Total
Left	63.9	8.9	2.5	5.5	6.5	0.0	6.3	20.0	11.7	17.3	142.5
Right	21.3	5.8	2.5	0.0	4.4	0.0	0.0	10.0	0.0	73.1	117.0
Total	85.2	14.6	5.0	5.5	10.9	0.0	6.3	30.0	11.7	90.3	259.5

km 630 - km 844.5

Bank			Types			of		the		bank	
	e1	e1p	e2	e1-2	e3	e4	e5	e6	d6	s	Total
Left	78.3	26.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	89.3	213.5
Right	46.8	3.0	0.0	0.0	0.0	0.0	0.0	11.5	0.0	152.3	213.5
Total	125.0	29.0	0.0	0.0	0.0	0.0	0.0	31.5	0.0	241.5	427.0

The letters from the top of the table, have the following signification regarding the type of the bank erosion:

e1 - terrace type erosion,
e1p - terrace type erosion, accompanied of fallen forest,
e2 - lowland type erosion,
e1-2 - mixture type erosion,
e3 - ledge type erosion,
e4 - sliding type erosion,
e5 - steep slope erosion,
e6 - alternating deposition-erosion,
d6 - slope-bank deposition,
s - stable bank,
e.am - erosion in upstream of island,
e.av - erosion in lowstream of island,
d.am - upstream deposition,
d.av - lowstream deposition.

Fig.5 Terrace type erosion (I)

Fig.6 Terrace type erosion (II)

Fig.7 Erosion accompanied by fallen forest

Fig.8 Erosion in upstream of island

Fig.9 Longitudinal sand bank

- In the Danube riverbed between Chiciu Calarasi-Silistra (km 375) and Drobeta Turnu Severin (km 931) the number of islands formed and developed in the riverbed is in a continuous increase: from 93 islands in 1934 with a total length of 283 km to135 islands in 1992 with a total length of 353 km. Among these islands 62 are placed on the left bank (Fig.9), 16 are situated in the central part of the riverbed and 54 are placed on the right of the riverbed.
- The natural tendency towards an increase in the islands number on the Danube riverbed will lead to the formation of new secondary branches with sure consequences of loss of navigable riverbed stability.

During the expedition a selection was made of the “hot points” of the riverbed where the banks require urgent actions of anti-erosion protection on the Romanian-Bulgarian border. In these “hot points” the widths of the riverbed exceeds the limit value of 1050 m. In order of urgency those riverbed reaches are presented as “0”, “I”, “II” and “III” (Table 5).

In conclusion:

- The total length of the “hot points” of riverbed on the Romania-Bulgarian border sectors is of 53 km from which:
    - in urgent “0” 1.6 km where the average width of the riverbed is of 1775 m and where the left riverbed erosions put in danger the dike for defense against the great flows.
    - in urgent “I” 15 km where the average width of the riverbed varies between 1483 and 1200 m.
    - In urgent “II” 24 km where the average width of the riverbed varies between 1173 and 1122 m.
    - In urgent “III” 14 km where the average width of the riverbed varies between 1094 and 1072 m.

Table 5

The riverbed parts of the Danube from common romanian-bulgarian border selected as “hot spots” from morphological point view.

No.	From (km) - to (km)	Length of part (km)	Mean width (m)	The “hot” length (km)
0	425.0 - 423.4	1.6	1775	1.6
			Total 0	1.6 km
1	764.8 - 763.5	1.3	1483	2.0
2	630.5 - 629.2	7.3	1344	7.0
3	463.5 - 461.0	2.5	1274	3.0
4	458.3 - 455.3	3.0	1215	2.0
5	617.2 - 615.0	2.2	1200	1.0
			Total I	15.0 km
6	675.1 - 673.0	2.1	1173	1.0
7	716.2 - 714.9	1.3	1169	2.0
8	713.6 - 712.3	1.3	1160	2.0
9	541.6 - 540.5	1.1	1153	2.0
10	620.5 - 619.2	1.3	1137	2.0
11	806.1 - 802.0	4.1	1132	3.0
12	756.9 - 751.3	5.6	1131	5.0
13	538.6 - 529.6	9.0	1124	4.0
14	522.9 - 518.7	4.2	1122	3.0
			Total II	24.0 km
15	782.0 - 778.0	4.0	1094	4.0
16	566.0 - 564.0	2.0	1090	2.0
17	449.2 - 448.0	1.2	1088	2.0
18	689.9 - 684.1	6.8	1087	5.0
19	578.6 - 575.6	3.0	1072	1.0
			Total III	14.0 km
			General total	53.0 km


Fig.10 Zimnicea hydrometric gauge.

The physical state of the hydrometric gauges presents an advanced degree of attrition and some of them lost the last inferior piece of measurement of level (Fig.10).

The Danube riverbed in the hydrometric sections presents relative morphometric stability. The graphs of water discharge curves present the tendency of clockwise gyration over time.

6. Concluding remarks and recommendations.

The morpho-hydrographic study of the Danube riverbed on the inferior section downstream the Iron Gates hydro-energetic and navigation system shows a slow riverbed physical degradation due to natural hydro-morphologic processes.

The analysis of the data supplied by the water flow measurements has allowed for highlighting the hydro-morphologic process in the riverbed and their dependence on the Danube hydrological state.

Processing the navigation hydrographical maps led to the conclusion that the Danube riverbed widens and in time it gradually reduces its depth.

The widening of the riverbed takes place by the banks erosion under the natural action of the stream, waves and icebergs.

The riverbed depth decrease takes place under the natural action of the sediment deposition in the areas where the riverbed widening exceeds the width limit, which allows the sediments flowing.

The hydrographic and hydro-morphologic data have made it possible to define the empirical functions of the hydro-morphologic processes in the riverbed necessary for establishing the riverbed cross morphometry which should ensure the riverbed stability in time.

In order to calibrate a steady riverbed and to stop the natural erosion of the bank, based on the results of this study, hydro-technical works are recommended so as to regulate the riverbed and protect the banks.

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