

## THE DANUBE RIVER CONTRIBUTION WITH WATER AND SILTS TO THE BLACK SEA

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### ABSTRACT:

On the basis of the processing of the hydrometrical data stock accumulated between 1861-1975, the average multi-annual values of the water discharge and the suspended silts discharged by the Danube river into the Black Sea are presented in the paper. For a period of 115 years the average value of the water discharge was  $6283 \text{ m}^3/\text{s}$  ( $198.14 \times 10^9 \text{ m}^3/\text{yr}$ ) and that of the suspended silts discharge was  $1569 \text{ kg/s}$  ( $49.48 \times 10^6 \text{ t/yr}$ ). It has been found that the tendency of the Danube water turbidity in the past years is its lowering.

### 1. GENERAL

Due to the rich water discharge ceded to the Black Sea, the Danube river influences directly and continuously the composition of the hydrological and biological regime of the sea (2). The thermic regime together with the season level changes, the transparency and colour as well as the morphology of the bottom and shore, the nature and granulometric composition of the silts and the salts dissolved in the sea water are all function of the water and silts discharges contributed by the Danube. The determination of this contribution helps to the better understanding and interpretation of some complex processes taking place in the sea environment.

Taking into account this problem the authors made it their aim to present in this paper a series of new data referring to the runoff and silting of the Danube river at its reaching the Black Sea; these data are obtained by evaluating the hydrometric data previously accumulated. The evaluation method is shortly presented below.

## 2. METHOD OF EVALUATING THE HYDROMETRIC DATA BACKGROUND IN THE LAST CENTURY

Direct data referring to the water discharge measurements during last century are very scarce for the portion at the Danube Delta opening. Professor G.Vasilescu's work "Solid Flow of the Danube" (Debit solide du Danube, évolution recente de son Delta) published in 1928 contains synthetic data of these measurements rendered in table 1.

Professor Gr.Vasilescu drew by means of the previous data, a rating curve at Ceatal Izmail which in its lower part, at levels beyond 200 cm - at Tulcea, coincides practically with the rating curve calculated for a recent period (1) by sistematic measurements of the water discharge. In the case of high levels the rating curve deviates considerably to the right leading to exceedingly high values of the water flows. The lack of measurements, especially those of the high flows periods, did not enable professor Gr.Vasilescu to draw an entirely correct rating curve within the range of high levels. It is this reason that determined the authors of this study to try, starting from the systematic level measurements performed in the previous century for the Tulcea and Galați harbours by the erstwhile European Danubian Commission (CED), to establish the superior branch of the rating curve at Ceatal Izmail with a view to turning the former levels into water discharges.

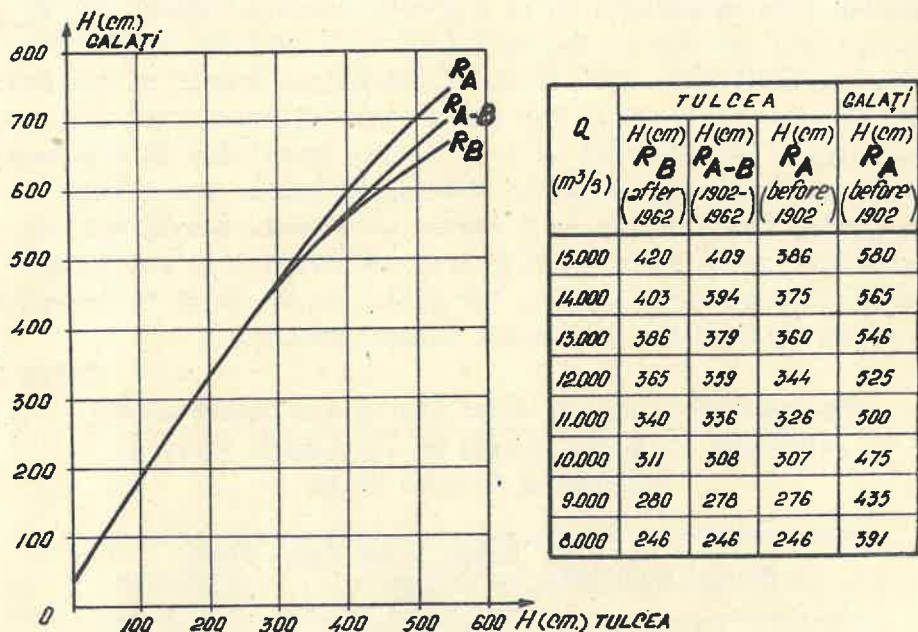
In order to do this it was necessary that the morphologic stability of the Danube river bed and the correctness of the level measurements performed at the Galați and Tulcea harbours during the last century, were tested.

The comparison of the hydrographic survey in the Danube riverbed at the Danube Delta opening show that the upstream morphology of the riverbed at Ceatalu Izmail (the 43<sup>rd</sup> mile) is rela-

tively steady which fact contributes to make possible the analysis of the past level and water flow measurements with a view to drawing a rating curve.

In order to check up the accuracy of the data given by the level measurements, performed at Tulcea, the correlation graphs between the monthly characteristic values (the maximum, the average, the minimum) of the levels on the Tulcea and Galați staff gauges were drawn.

The analysis of the way the correlation points are displayed enabled us to draw a unique line connecting the low levels (in which case the banks are not flooded) and three distinct curves for high levels flooding the Danube river's banks (Fig.1). This characteristic of the level correlations Tulcea-Galați, is to be thus interpreted:



**Fig.1** - The correlation graph of the characteristic monthly values of the levels (maximum average, minimum) on the Tulcea and Galați surveyor's pole for the period 1881-1925.

- the existence of a unique correlation curve for low levels, point to the fact that for the two staff gauges at Tulcea and Galați no modification of the zero point altitude on the staff gauge was recorded with the time. From this formula the conclusion was drawn that the zero point of the CED levels on the staff gauge at Tulcea harbour stick to a constant altitude of 0.56 m as to the reference system at the Black Sea - Sulina within the period 1871-1926. For the period 1861-1870 the altitude corrections make use of the data indicated by the documents of the epoch (4; 5; 6);

- the existence of distinct correlation curves for high levels in a more recent period (since 1962 onward) and in a previous period (before 1902 and between 1902 and 1962), brings forth the hydrotechnic works performed on the Danube riverbed at the reaching point left a determined impact upon the correlations between levels. By careful observations one could establish 3 correlation branches between levels: the  $R_A$  branch valid for the period preceding 1902 considered to be a purely natural regime; the  $R_{A-B}$  branch, valid for the period 1903-1962 of a modified regime due to the regularization activities on the Sulina Branch of the Danube and the  $R_B$  branch valid for the period following 1963 when the levels regime was modified by the damming activities in the Danube meadow and the amendments in the Danube Delta. The rating curves being known in A-B or B regime at Ceatalu Izmail and the characteristics of level correlations between Tulcea and Galați harbours in A and A-B regimes, the rating curve could be drawn for past times in A regime for Ceatal Izmail (Tab.1).

Table 1

The synthetic data of water discharges measurements performed at Ceatal Izmail by the Danube European Commission in past times

Measurement year	Water level (cm) at Tulcea surveyor's pole	Water discharge ( $m^3/s$ )	
1	1871	91	4157
2	1874	244	9180
3	1887	50	3436
4	1891	46	2861

(Table 1 continued )

Measurement year	Water level (cm) at Tulcea surveyor's pole	Water discharge (m <sup>3</sup> /s)	
5	1893	51	3533
6	1896	175	6719
7	1897	267	10030
8	1902	248	9404
9	1904	63	4128
10	1905	279	10141
11	1908	-10	2089
12	1909	284	11456
13	1911	72	4161
14	1912	165	5857
15	1913	231	8113
16	1921	187	6604
17	1925	160	5288
18	1928	231	8113

As it has become common knowledge from the previous period of the 1962, characterized by A and A-B regime, installing hydrotechnic works along the maritime Danube were not performed to modify the levels in the Galați harbour. The modification of the level correlation between the two locations for the 1903-1962 periods was due to the sitting works in the Delta which influenced the levels at Tulcea.

Bearing in mind these elements and making use of the  $R_{A-B}$  and  $R_A$  correlations we could determine the  $H_A$  level at Tulcea on the basis of  $H_{A-B}$  levels at Tulcea. Practically we followed the procedures given below:

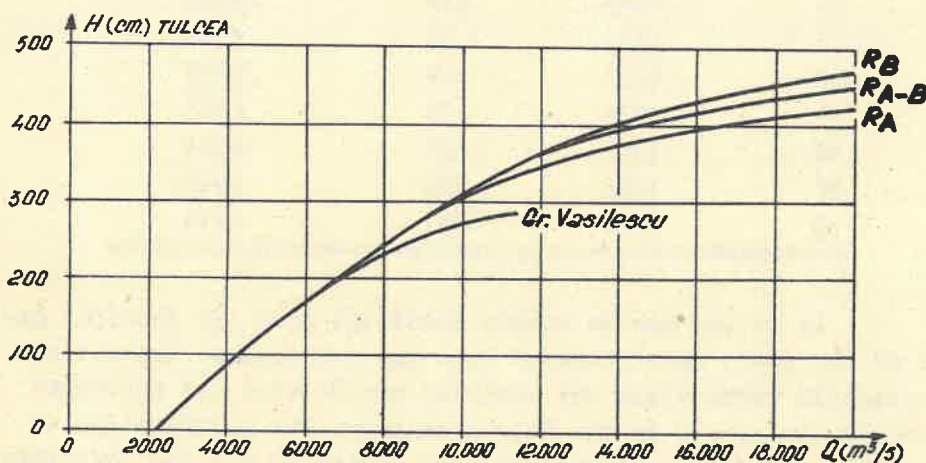
- the  $H_{A-B} = 409$  cm was considered from the rating curve in A-B regime established by measurements (2) corresponding to the water discharge of 15.000 m<sup>3</sup>/s at Ceatal Izmail;

- the level correlation (Fig.1) resulted into a relationship according to which the level at Tulcea  $H_{A-B} = 409$  cm is correspondent to a  $H_{A-B} = 580$  cm level at Galați for the period

1902-1962 and the same level  $H_A=580$  cm for the previous period of the 1902 as the levels in the Galați harbour were practically uninfluenced at all in the previous period of 1962;

- corresponding to the 580 cm levels at Galați there is a  $H_A=386$  cm level at Tulcea representing the natural regime for a water discharge equal to  $15\ 000\ m^3/s$  at Ceatal Izmail.

The above described procedure has been used to rebuild the rating curve at Ceatal Izmail in a purely naturale regime (A) and by means of the level correlations at Tulcea-Galați in the water discharge range of  $9000-15\ 000\ m^3/s$ . The results of the processing were graphically rendered in Fig.2.



**Fig.2** - The staff gauge of the Danube in the delta zone (Ceatal Izmail) considered in comparison to the surveyor's pole at Tulcea harbour.

As far as the silts-runoff data are concerned, systematic measurements have been recorded for Ceatal Izmail since 1968. With reference to the past, only incomplete data are available and they refer to the suspended silts turbidity at the surface of water in Sulina harbour where systematic measurements were performed since as far back as 1857. In order to use the turbidity data obtained at Sulina harbour to determine the mean turbidity in the Danube Delta with a view to evaluating the former silts runoff, the correlation between the turbidities at Sulina and those at

Ceatal Izmail was established. Thus, the direct measurements in the period 1978-1975 resulted in the mean annual surface turbidity at Sulina ( $\rho_{o} PS$ ) and the mean annual section turbidity at Ceatal Izmail ( $\rho_m CI$ ) giving the following relation:

$$\rho_m CI \approx 1,20 \cdot \rho_{o} PS \quad (1)$$

This relation helped to calculate mean annual turbidities of the Danube at Ceatal Izmail if we know the mean annual values of surface water turbidity at the Sulina harbour. The data entered in the 2<sup>nd</sup> and 3<sup>rd</sup> columns of the second table.

### 3. THE WATER CONTRIBUTION

Making use of the data given by level measurements at Tulcea harbour within the period 1861-1920 and the rating curve of A regime in figure 2, the mean annual values of the Danube water flows were obtained for Ceatal Izmail. For the rest of the period (1921-1975) the water discharge data were taken from "Zona de vărsare a Dunării - Monografia hidrologică" (2) (The reaching zone of the Danube - hydrologic monography) and from direct measurements.

The respective data are entered in the fourth column of the second table. Using the data under the heading (Q) in Table 2 the graph in Fig.3 was drawn illustrating the variation with time of the annual water discharge contributed by the Danube to the Black Sea for a 115 years period of time. Within the interval we have analyzed at the reaching point, the annual amount of the Danube water ceded to the Black Sea displays the following characteristics:

Table 2

Mean annual values of surface turbidity in the Danube in the Sulina harbour, as well as the mean section turbidity at Ceatal Izmail section, of the water and the suspended silts discharges at Ceatal Izmail in the period 1861-1975

Year	Sulina-port	Ceatal Izmail		R annual average kg/s
	Q annual average g/m <sup>3</sup>	Q annual average R/m <sup>3</sup>	Q annual average m <sup>3</sup> /s	
1861	228	275	5640	1551
1862	228	275	4560	1252

(Table 2 continued)

Year	Sulina-port		Ceatal Ismail	
	Q annual average g/m <sup>3</sup>	Q annual average g/m <sup>3</sup>	Q annual average m <sup>3</sup> /s	R annual average kg/s
1863	160	192	3340	641
1864	526	630	5240	3301
1865	343	412	5440	2241
1866	114	137	3360	460
1867	297	356	5150	1833
1868	297	356	5500	1958
1870	526	630	7360	4637
1871	457	548	8480	4647
1872	262	314	5870	1843
1873	188	226	4690	1060
1874	192	230	4340	998
1875	160	192	5520	1002
1876	160	192	7630	1465
1877	208	249	6860	1708
1878	249	299	7250	2168
1879	112	134	7620	1021
1880	199	239	5770	1379
1881	237	284	7860	2232
1882	148	178	5440	968
1883	215	258	7040	1816
1884	174	209	5110	1068
1885	165	198	5000	990
1886	265	318	5440	1730
1887	224	269	4780	1280
1888	178	213	6690	1424
1889	228	275	6360	1749
1890	201	241	4960	1195
1891	222	266	5240	1394
1892	228	275	5860	1612
1893	235	282	5840	1647
1894	110	132	4110	543
1895	176	211	6520	1376

(Table 2 continued )

Year	Sulina-port		Ceatal Ismail	
	Q annual average g/m <sup>3</sup>	Q annual average g/m <sup>3</sup>	Q annual average m <sup>3</sup> /s	R annual average kg/s
1896	192	230	6250	1440
1897	253	304	8590	2611
1898	192	230	4810	1110
1899	128	153	4730	724
1900	185	222	7050	1565
1901	290	348	6190	2154
1902	174	209	6130	1281
1903	230	276	5700	1573
1904	151	181	5140	930
1905	212	254	5730	1455
1906	274	329	6240	2053
1907	169	203	6590	1338
1908	162	194	4610	894
1909	313	375	5580	2092
1910	313	375	7720	2895
1911	256	307	5810	1784
1912	384	461	8250	3803
1913	279	335	7530	2523
1914	213	255	8180	2086
1915	235	282	9540	2690
1916	162	329	8050	2648
1917	130	156	7380	1151
1918	175	210	4520	949
1919	274	329	8550	2813
1920	222	266	7180	1910
1921	85	102	4250	433
1922	158	190	7290	1385
1923	151	181	6990	1265
1924	152	182	7620	1387
1925	155	186	5590	1040
1926	185	222	8130	1805
1927	151	181	5970	1081
1928	130	156	5410	844

(Table 2 continued )

Year	Sulina-port		Ceatal Izmail	
	annual average g/m <sup>3</sup>	annual average g/m <sup>3</sup>	Q annual average m <sup>3</sup> /s	R annual average kg/s
1929	176	211	5400	1139
1930	172	206	5210	1073
1931	184	221	6570	1452
1932	112	134	6150	824
1933	241	289	6190	1789
1934	103	124	5650	701
1935	120	144	5570	802
1936	93	112	6330	709
1937	202	242	8170	1977
1938	164	197	6710	1322
1939	321	385	6280	2418
1940	310	372	8940	3326
1941	233	279	9410	2625
1942	135	162	7300	1183
1943	94	113	4520	511
1944	271	325	7480	2431
1945	177	212	6260	1327
1946	114	137	4820	660
1947	116	139	4960	689
1948	191	229	6630	1530
1949	138	166	4410	732
1950	119	143	4550	651
1951	144	172	6350	1092
1952	217	260	5520	1435
1953	321	385	6070	2337
1954	199	239	6040	1444
1955	295	354	8890	3147
1956	153	183	7430	1360
1957	225	270	6060	1636
1958	174	209	6460	1350
1959	164	197	5500	1084
1960	237	284	6600	1874
1961	170	240	5220	1253

(Table 2 continued)

Year	Sulina-port		Ceatal Ismail	
	annual average g/m <sup>3</sup>	annual average g/m <sup>3</sup>	Q annual average m <sup>3</sup> /s	R annual average kg/s
1962	143	218	6560	1430
1963	114	137	6290	862
1964	162	166	5700	946
1965	178	182	8420	1532
1966	116	183	8110	1484
1967	83	115	7640	879
1968	142	183	5680	1040
1969	253	308	6990	2150
1970	153	171	9290	1590
1971	159	212	5560	1180
1972	182	206	6390	1320
1973	203	196	5910	1160
1974	170	157	7150	1120
1975	184	219	7940	1740
<b>Mean</b>	203	247	6283	1569

$$R \begin{matrix} -1970 \\ 1948 \end{matrix} = 1428 \text{ kg/s}$$

$$R \begin{matrix} -1975 \\ 1970 \end{matrix} = 1304 \text{ kg/s}$$

- the mean multiannual value of the water flow is 6283 m<sup>3</sup>/s corresponding to an annual water volume of  $198.14 \times 10^9 \text{ m}^3$ ;

- the years of richest water contribution were: 1915 (9540 m<sup>3</sup>/s); 1941 (9410 m<sup>3</sup>/s) and 1970 (9290 m<sup>3</sup>/s);

- the years of poorest water contribution were 1863 (3340 m<sup>3</sup>/s); 1866 (3360 m<sup>3</sup>/s); 1894 (416 m<sup>3</sup>/s); 1921 (4250 m<sup>3</sup>/s) and 1949 (4410 m<sup>3</sup>/s).

In conformity with the above data we conclude that the annual water contribution of the Danube to the Black Sea varies within the limits of 105 km<sup>3</sup>/year in dry years and 301 km<sup>3</sup>/year in rainy years.

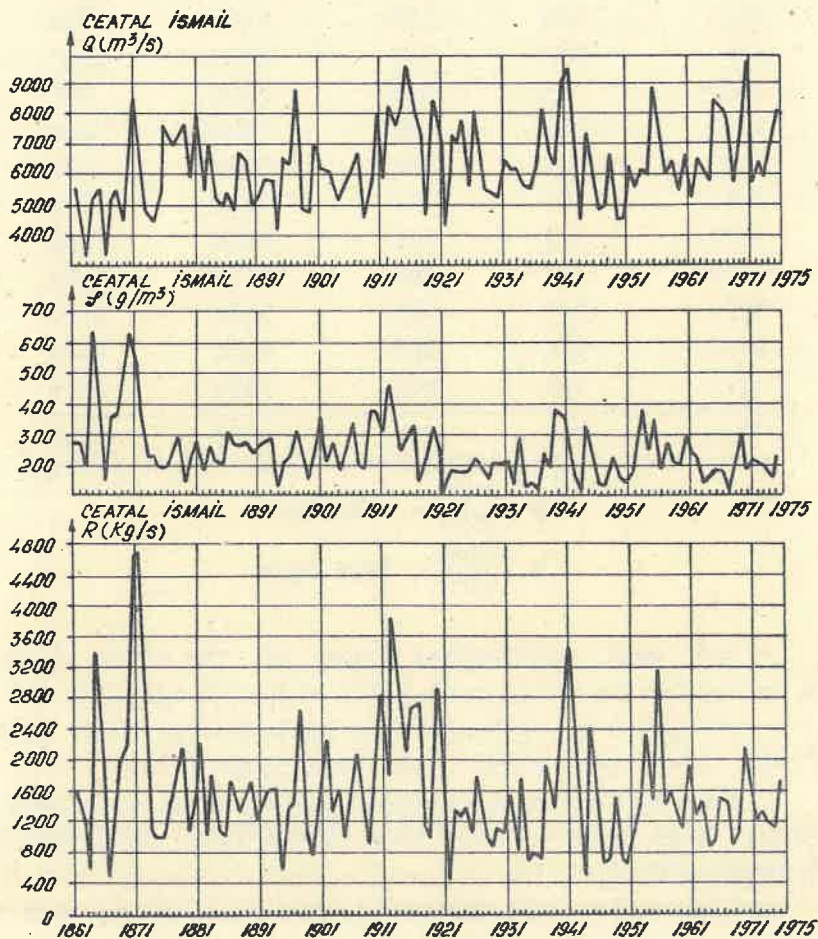
#### 4. THE SILTS CONTRIBUTION

Starting from the values of the mean annual water discharges ( $Q$ ) and of the turbidity ( $\rho$ ) the suspended silts ( $R$ ) were calculated making use of the following relation:

$$R = \rho \cdot Q \quad (2)$$

The resulting data are entered in the 5<sup>th</sup> column of Table 2.

The graphic illustration of the calculating results is



**Fig.3** - The variation graphs of annual mean values of the water flows ( $Q$ ) and turbidity ( $\rho$ ) function of time as well as the suspended silts ( $R$ ) of the Danube at Ceatal Izmail in the period 1861-1975.

given in Fig.3 b and c. From the analysis on the values contained in the tables and variation graphs with time, the characteristics of the silts discharge were put forth for the reaching point of the Danube in the Black Sea:

- the mean multiannual value of the suspended silts is 1569 kg/s corresponding to a mean multiannual turbidity of 249.7 g/m<sup>3</sup> and to an annual amount of 49.48 x 10<sup>6</sup> tons silts;

- the years of richest silts contribution were 1870 (4637 kg/s); 1871 (4647 kg/s); 1912 (3803 kg/s); 1940 (3326 kg/s); 1871 (4647 kg/s); 1912 (3803 kg/s); 1940 (3326 kg/s); 1955 (3147 kg/s) and 1969 (2150 kg/s);

- the years of poorest silts contribution were 1866 (460 kg/s); 1894 (543 kg/s); 1921 (433 kg/s) and 1943 (511 kg/s)

The dry years were concluded to have the poorest silt flow. In Fig.3 it is shown that the turbidity variation of the Danubian waters displays a slight tendency to lower towards the reaching point.

As in 1970 the Danube riverbed was dammed at the Iron Gates (Portile de Fier) by building, in cooperation with Jugoslavia, a hydroenergetic and navigation system, we have used in this paper certain data given by the comparison of discharge values for water and silts at Orșova-Turnu Severin (Fig.3). These data refer exclusively to the period of direct systematic measurements performed on the Orșova (1948-1978) Drobeta Turnu Severin (1971-1975) section of the Danube (Tab.3)

Table 3

The mean annual values of water discharges of the mean turbidity and of suspended silts per section in the Danube at Orșova-Drobeta Turnu Severin for the period 1948 - 1975

Year	Q annual average m <sup>3</sup> /s	ρ annual average g/m <sup>3</sup>	R annual average kg/s
1948	5530	285	1575
1949	3980	185	736
1950	4150	148	615
1951	5380	131	705
1952	5110	160	819
1953	4760	202	963

(Table 3 continued)

Year	Q annual average $m^3/s$	Q annual average $g/m^3$	R annual average $kg/s$
1954	4980	223	1112
1955	7150	310	2215
1956	5900	288	1698
1957	5110	208	1062
1958	5630	227	1278
1959	4900	185	905
1960	5650	184	1042
1961	4390	149	655
1962	5610	199	1105
1963	4840	223	1079
1964	4830	198	956
1965	7220	147	1055
1966	6700	154	1030
1967	5980	107	640
1968	5680	146	830
1969	5690	134	765
1970	7810	171	1335
1971 <sup>x/</sup>	4220	61	257
1972 <sup>x/</sup>	4840	34	164
1973 <sup>x/</sup>	4620	51	235
1974 <sup>x/</sup>	6420	82	526
1975 <sup>x/</sup>	6400	139	890
Mean	5481	169	937

$$x/ \text{ Orşova } \rho_{1948}^{-1970} = 190 \text{ g/m}^3$$

$$x/ \text{ Drobeta TS } \rho_{1971}^{-1975} = 73 \text{ g/m}^3$$

$$x/ \text{ Orşova } R_{1948}^{-1970} = 1051 \text{ kg/s}$$

$$x/ \text{ Drobeta TS } R_{1971}^{-1975} = 414 \text{ kg/s}$$

The comparison of the data listed in Tabs. 2 and 3 gave the following results:

- for the period prior to the damming at The Iron Gates (Portile de Fier), 1948-1970, the mean multiannual value of the suspended silts was 1051 kg/s at Orșova and 1428 kg/s at the reaching point, for a silts concentration of 190 g/m<sup>3</sup> and 218 g/m<sup>3</sup> respectively;

- for the period following the Danube damming, the mean value of multiannual suspended silts was 414 kg/s at Drobeta-Tur-nu Severin downstream the Iron Gates) and 1304 kg/s at the reaching point for a silts concentration of 73 g/m<sup>3</sup> and 199 g/m<sup>3</sup> respectively.

The above data stress the importance of Danube damming at The Iron Gates which influences sensibly the silts runoff upstream the dam; the river is richer in silts in the immediate neighbourhood of the dam and poorer to the reaching point.

The estimation of the liquid and solid measured flows along years, in the delta zone, enabled the correct estimation of the mean multiannual value stressed the maximum amplitude, the general direction and tendency of the runoff variation which allows for a better water management of the available water amount and a better knowledge of the influence the liquid and solid flows bear upon the sea water.

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