IWRŚ
Warsaw Agricultural University Department of Hydraulic Engineering and Environmental Recultivation
Center Of Excellence In Wetland Hydrology "WETHYDRO"

Workshop 1
"MEASUREMENT TECHNIQUES AND DATA ASSESSMENT IN WETLANDS HYDROLOGY"

Biebrza Wetlands Goniadz, 12-14 June 2003

ASSESSMENT AND PREDICTION MATHEMATICAL MODEL FOR THE DANUBE DELTA BIOSPHERE RESERVE HYDROGRAPHIC NETWORK MORPHOLOGICAL CHANGES. THEIR EFFECTS ON WETLANDS AND COASTAL ZONE HABITAT BIODIVERSITY

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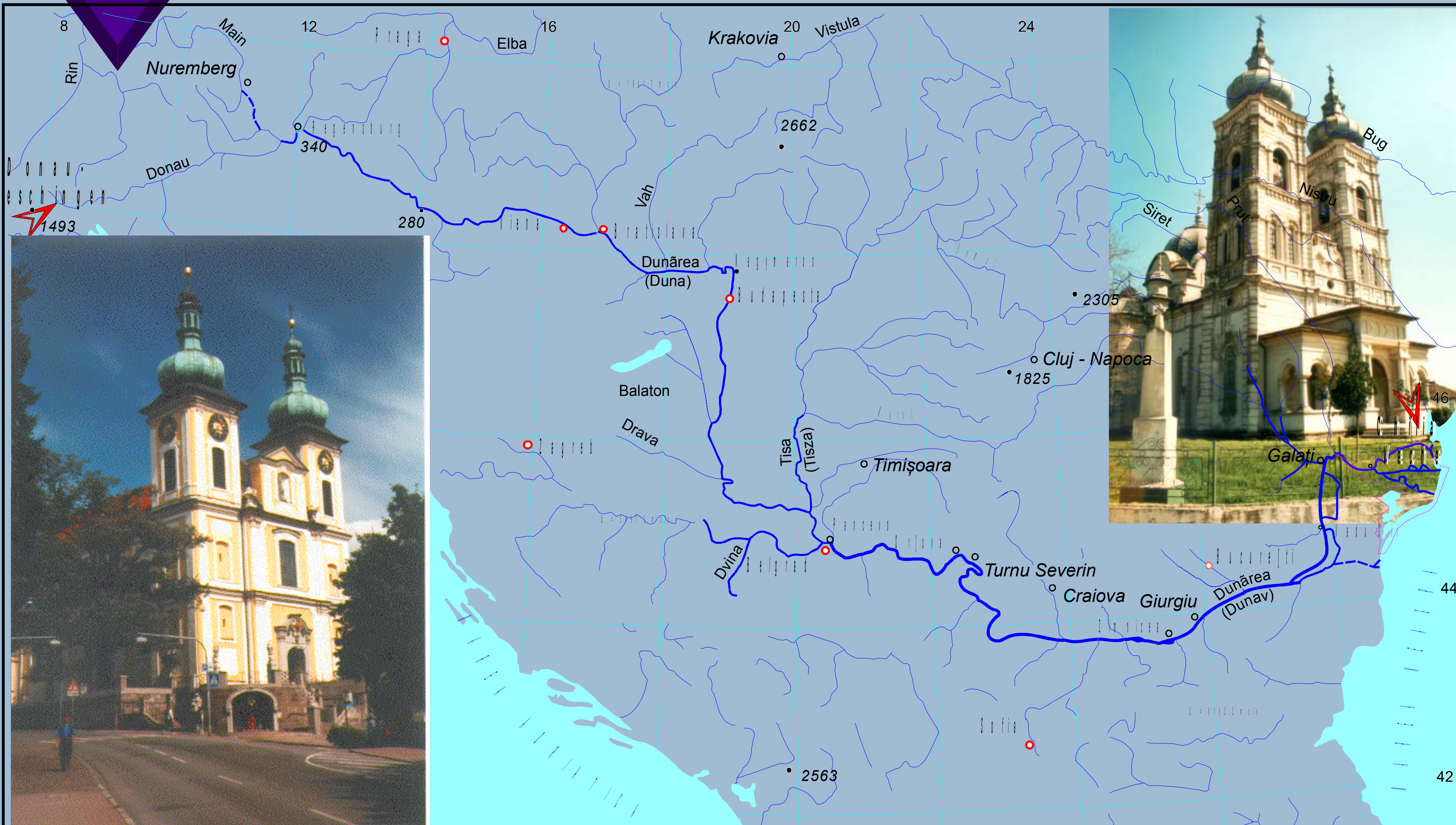
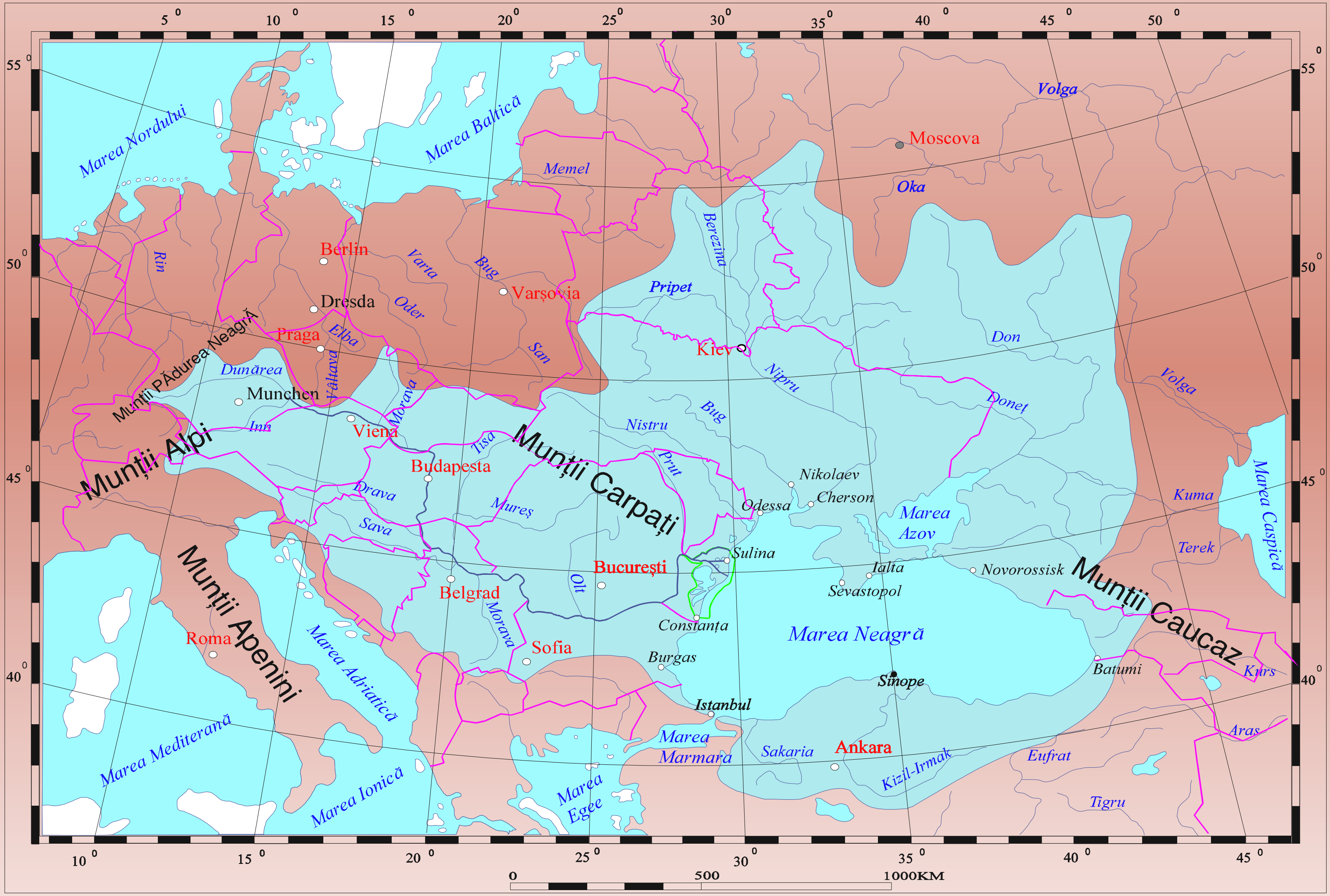
DANUBE RIVER: 2,840 Km length
HYDROGRAPHIC BASIN - 817,000 Km^2



Black Sea hydrographic basin

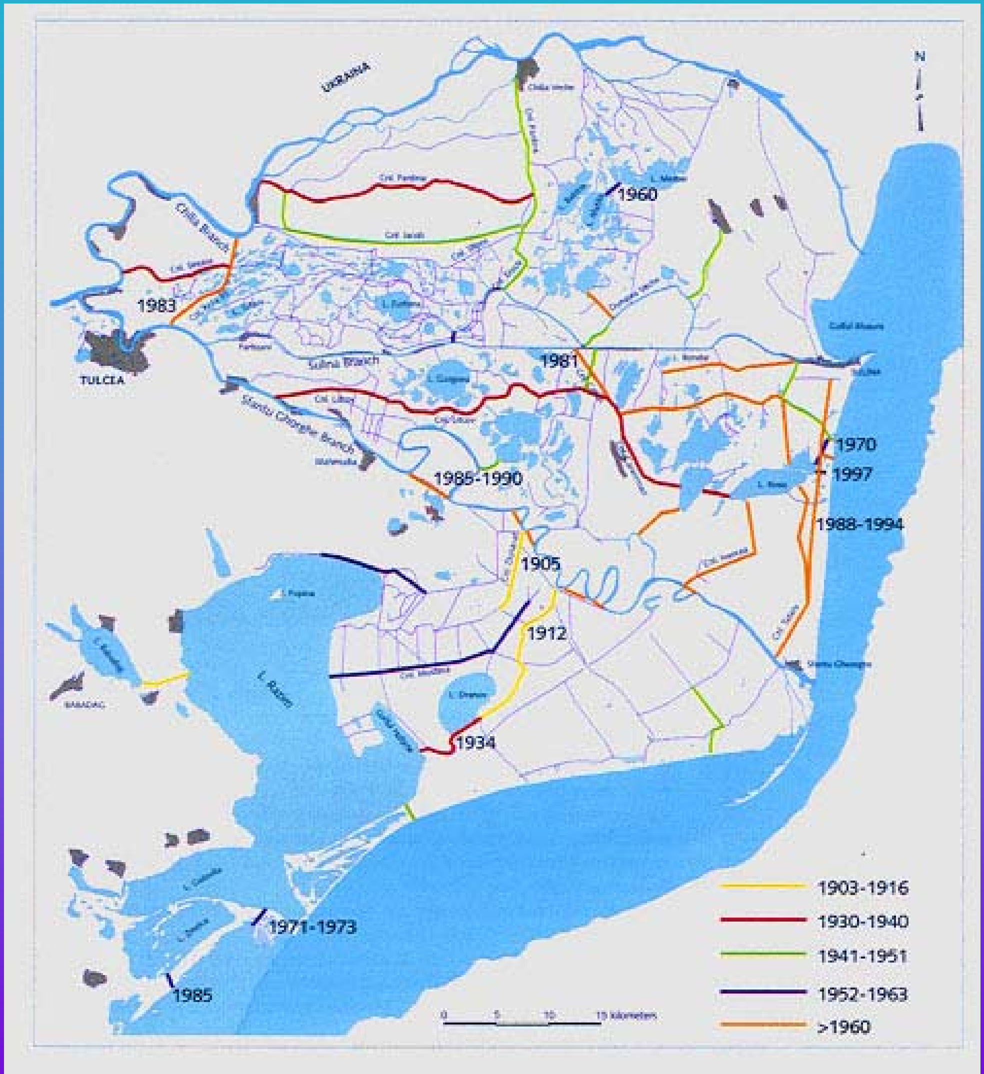
BAZINUL HIDROGRAFIC AL MĂRII NEGRE

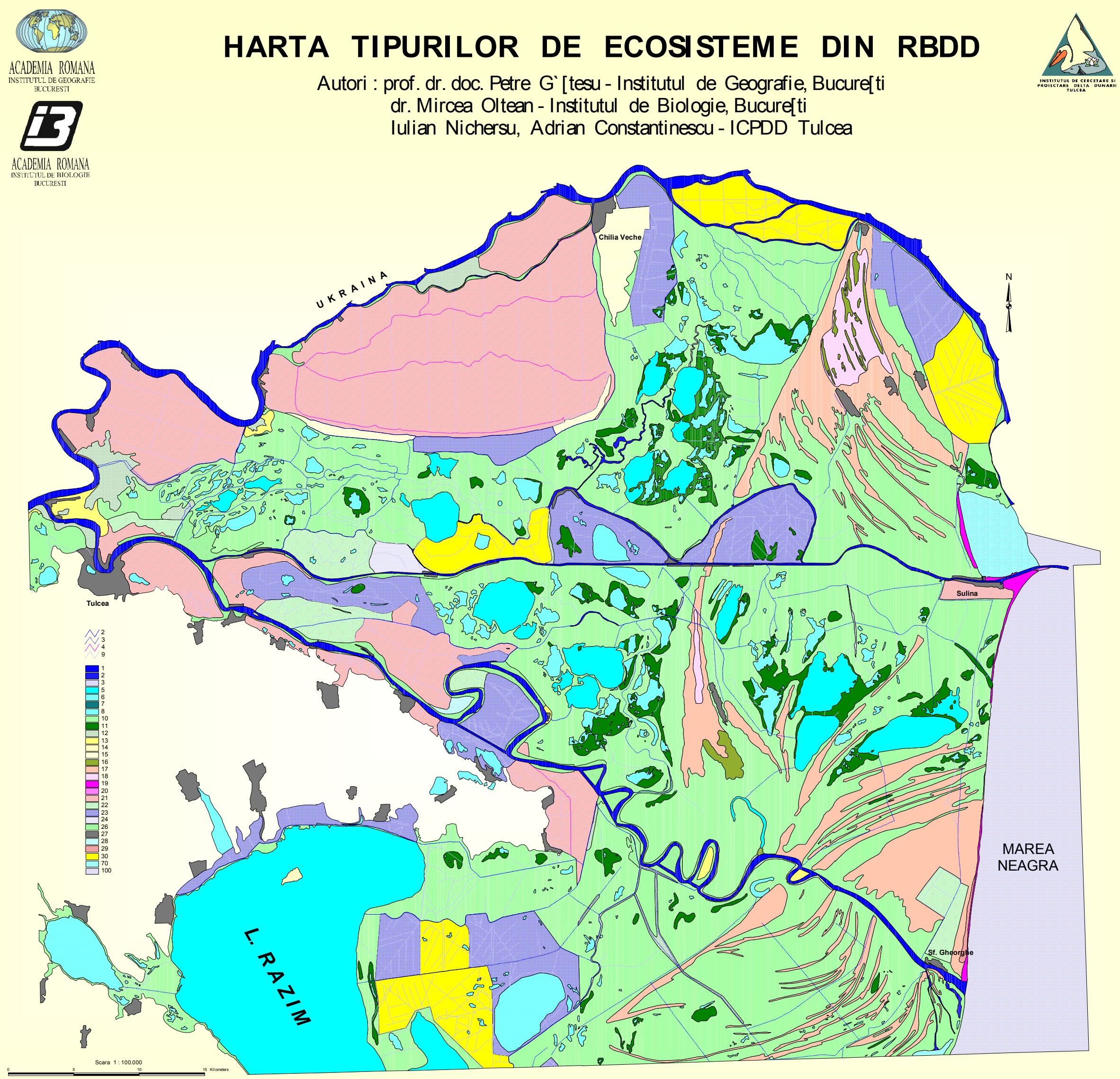


area ver a

Surface 8 / 000 km

Main Danube Delta hydrographic network modifications made within 1903 - 1997

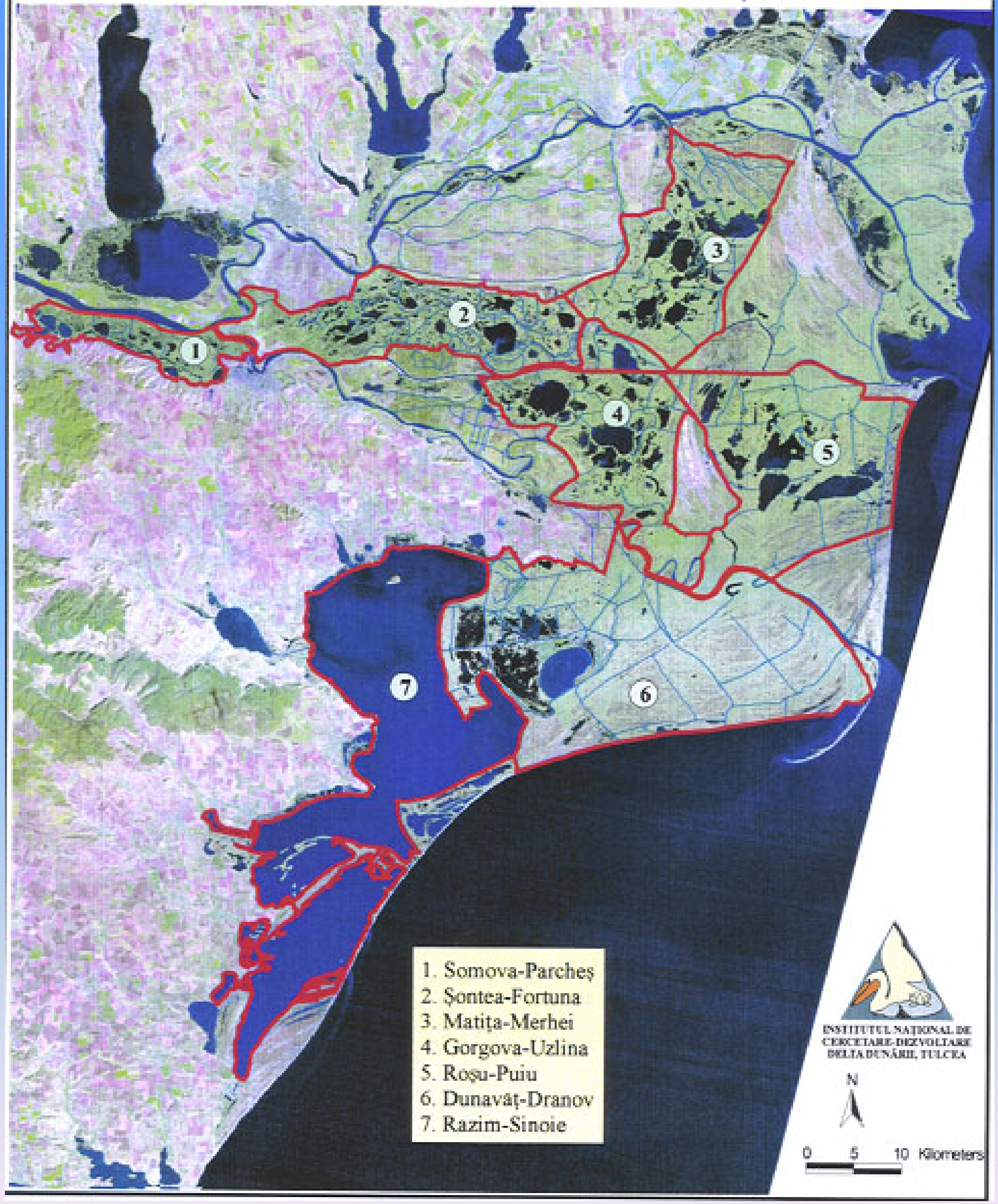




Ecosystems map

The establishmng ecosystems types have been made using the methodology of CORINE program.

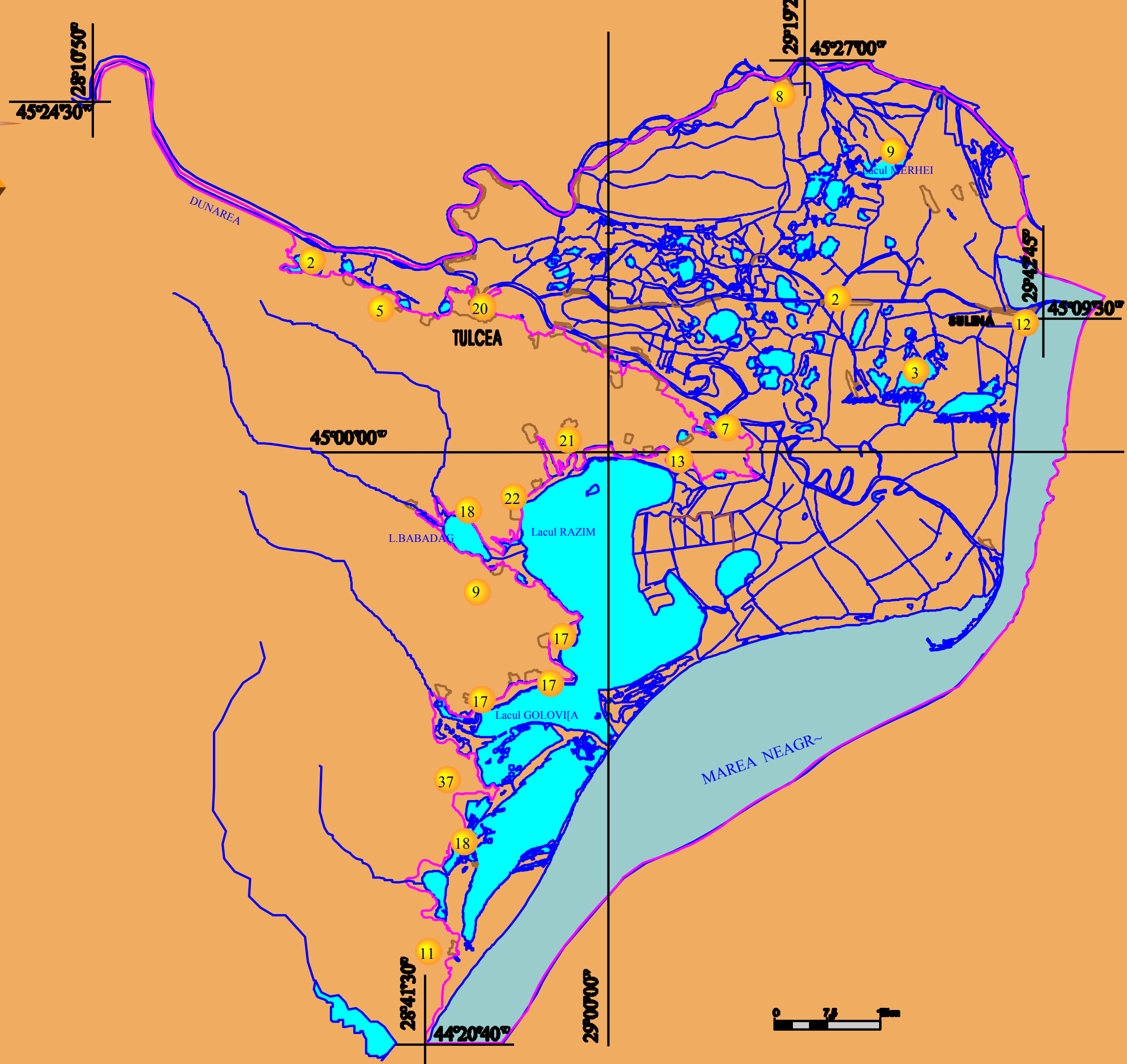
Complexele acvatice din Delta Dunării
(imagine satelitară LANDSAT - October 1995)



1. Generalities

The DANUBE RIVER has its spring within the Black Forest Mountains (Germany) and after 2,857 km reaches the Black Sea (Romania), by means of a huge DANUBE DELTA (DD).
It crosses and connects western, central, south-eastern and eastern parts of the European continent and as much as 17 countries, collecting water and sediments from a hydrographic basin of 817,000 sq.km.
The Danube Delta Biosphere Reserve (DDBR) was declared aa World Heritage since 1990. Its area is of 5,800 sq.km. This is one of the greatest wetlands in the world.

The Danube Delta Biosphere Reserve hydrographic network is constituted of more than 3,500 km of canals (natural and artificial) and more than 500 lakes (about 200,000 ha).
By its particular physical and geographical genesis and evolution conditions, the Danube Delta represents a world unique natural geographic zone.
A very great quantity of water and alluvia are carried by the Danube River, partly deposited within the Danube Delta and the most part (95%) is transported and discharged into the Black Sea.



Danube Delta Biosphere Reserve hydrographic network

I. HYDRODYNAMICS LAWS

Water flow in streams is governed by the two hydrodynamics laws:

1. **the fluid mass preservation principle – the water discharge (Q) is constant in all cross sections of a channel sector with no tributaries:**

$Q = A_1*V_1 = A_2*V_2 = ... An*Vn = constant$

2. the fluid energy preservation principle – energy equation applied for real liquids (Bernoulli equation) between two cross sections of a channel:

$Z_1 + P_1/ \gamma + V_1^2/2g = Z_2 + P_2/\gamma + V_2^2/2g + hr$

$Z_1 + P_1/\gamma$, $Z_2 + P_2/\gamma$ - potential energy (m);$V_1^2/2g$, $V_2^2/2g$ – kinetic energy (m)
hr - head loss due to liquid friction flowing through the two cross sections.

II. WATER DISCHARGE: Q (m3/s)

Q = A*V
A – cross section area (m^2)
V – water velocity (m/s)
V = Cv RI
C = $1/nR^y$ – C - Chezy coefficient id dependent on the cross section roughness;
The stream cross-section is divided into a main channel and a maximum of two floodplains with different roughness formulation. In each of those sections (main channel, floodplain 1 and floodplain 2) the local Chézy coefficient may be computed in different ways depending on your preference and selection.

R - hydraulic radius: wetted cross-sectional area divided by the wetted perimeter.

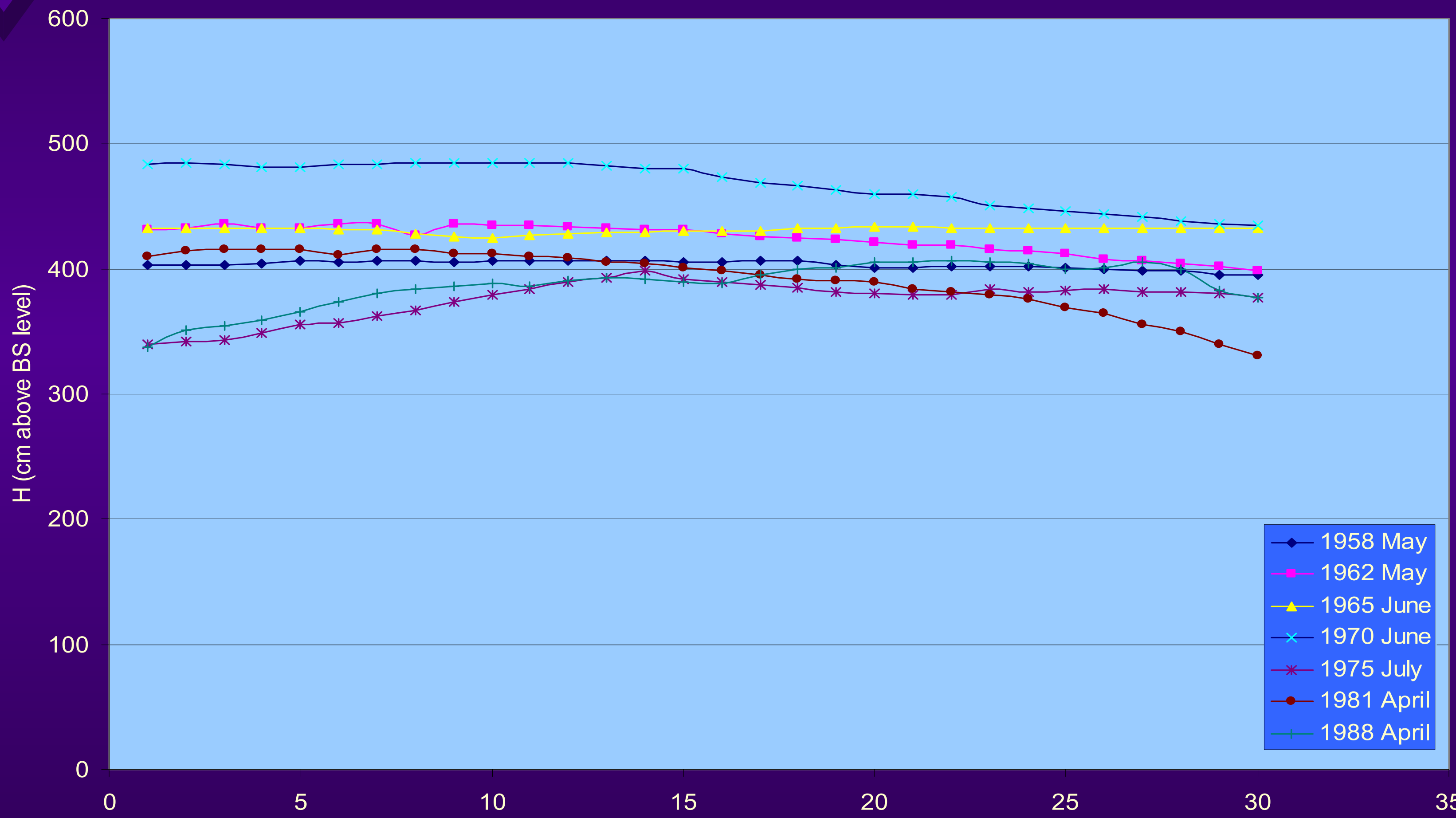
I – energy gradient
Q = A C v RI

III. Water suspended sediment load: R (kg/s)

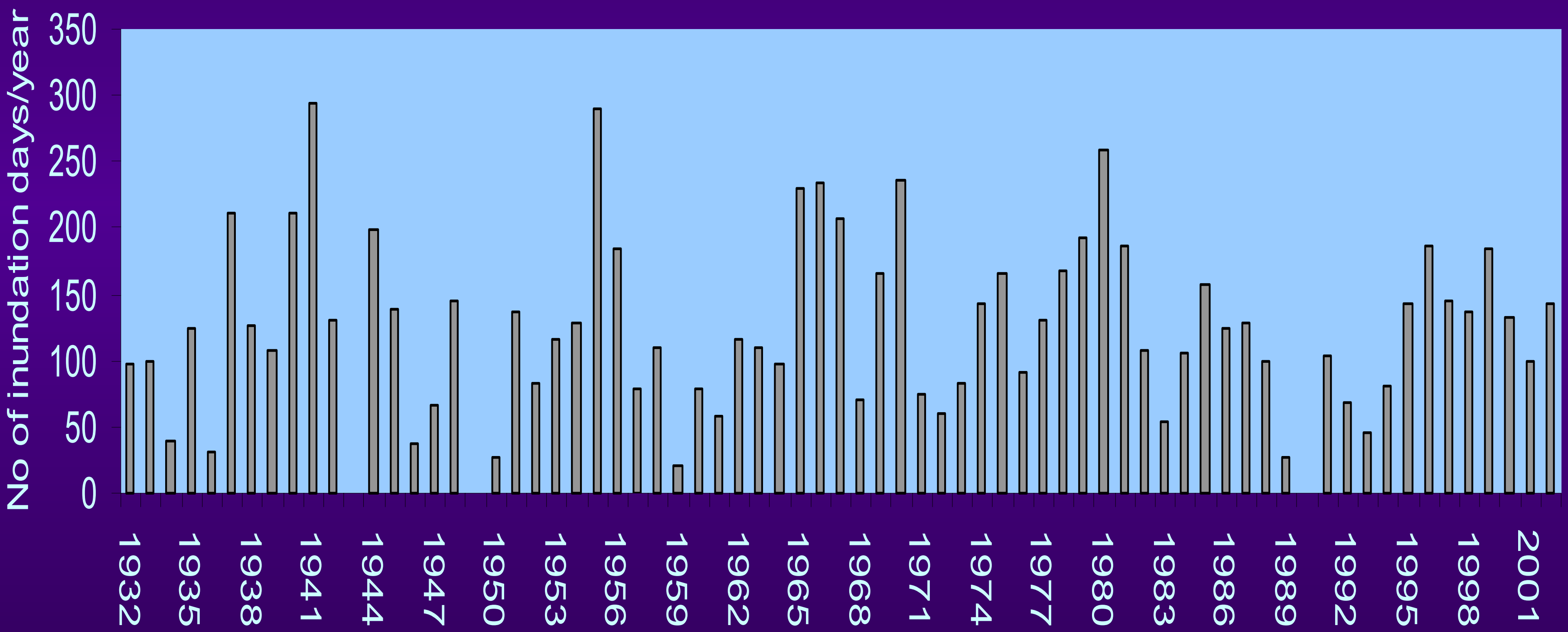
$R = Q^{*} \rho$

Q – water discharge (m^3/s)
ρ - water turbidity (g/m^3)

The highest Danube River levels (H) recorded at Tulcea harbour - Danube Delta's upstream zone. Interval study: 1932-2002

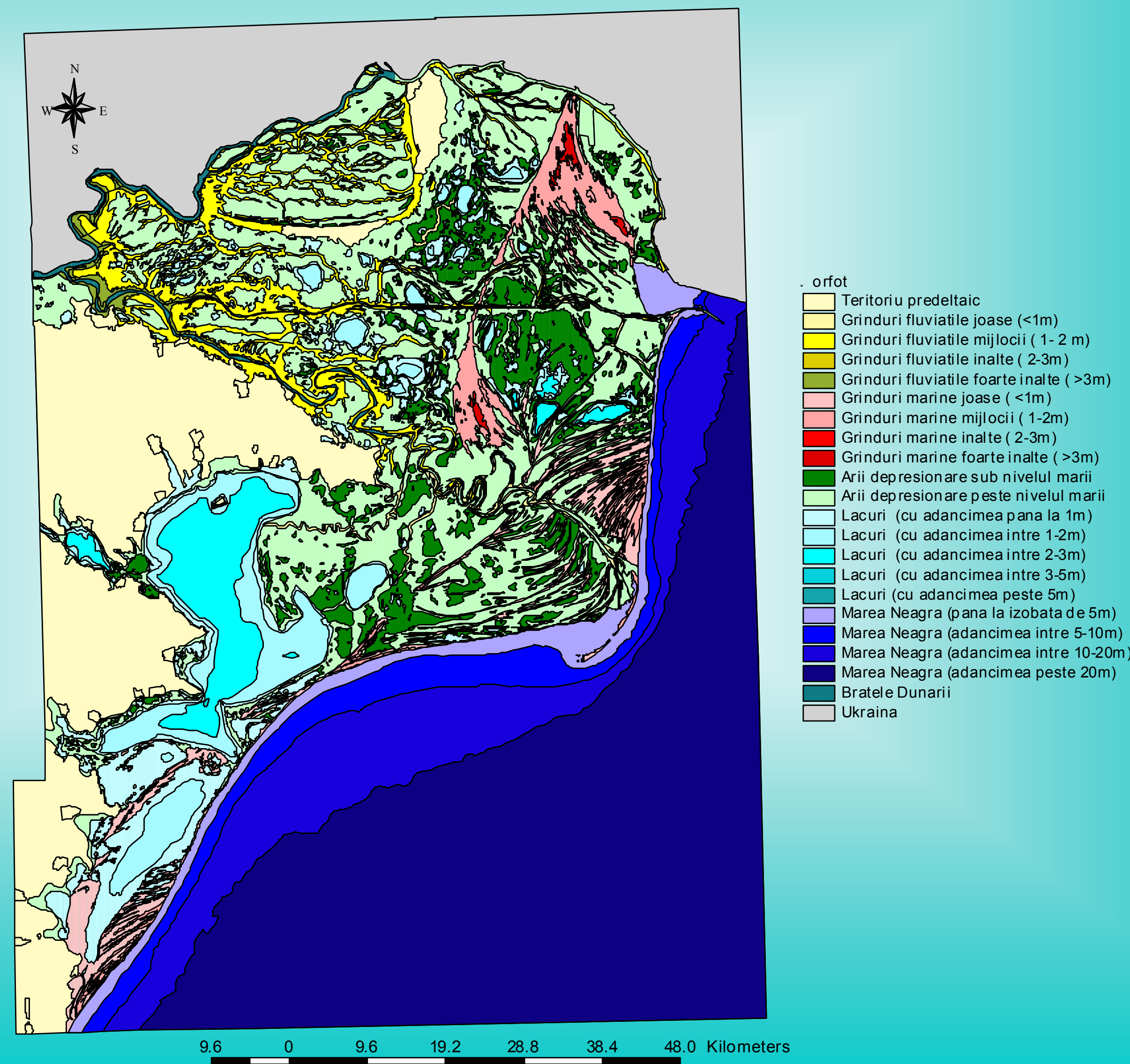


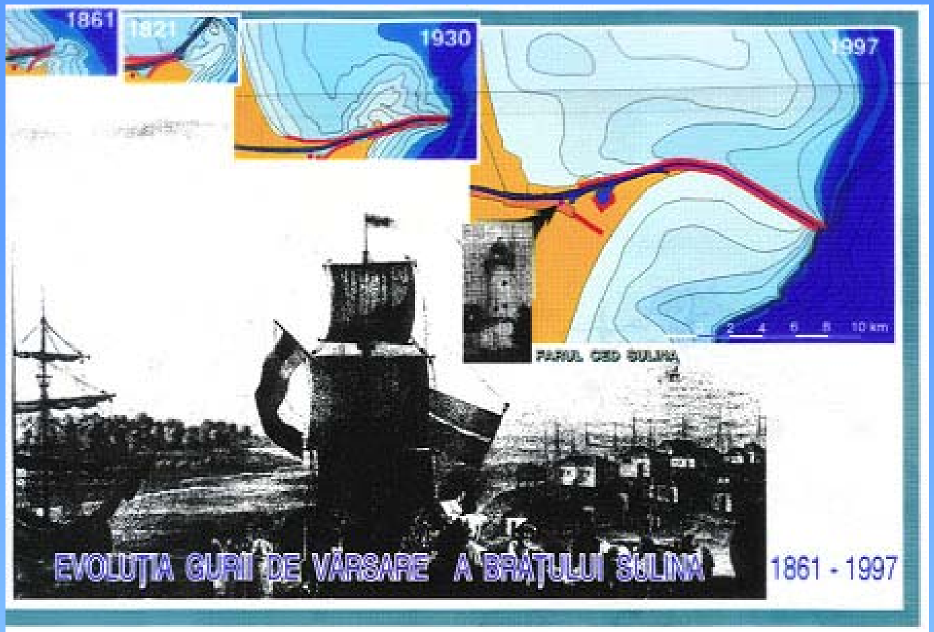
Inundation days for the Danube Delta inner zones - Danube River water levels > 290 cm, Q > 10,000 m3/s

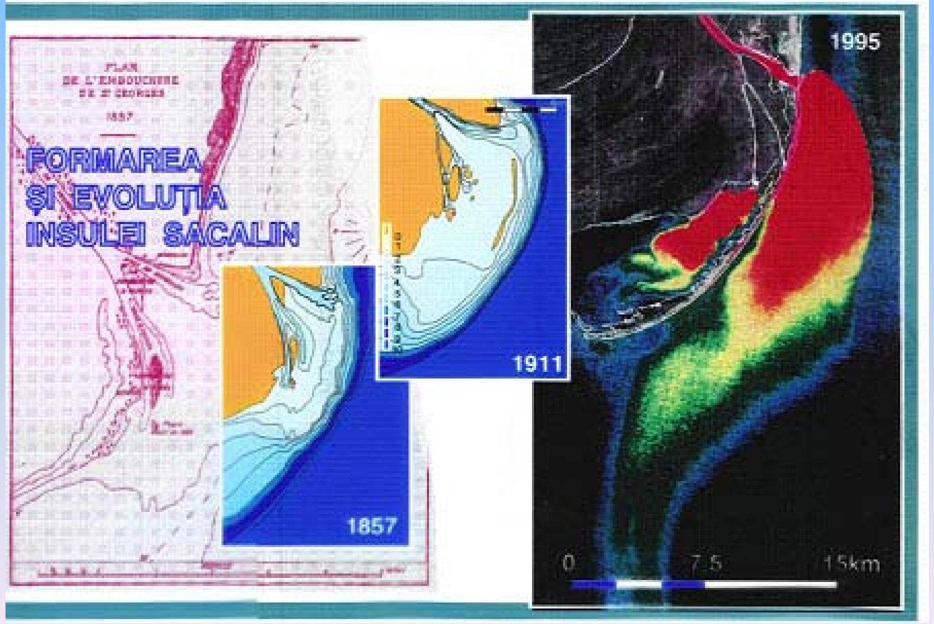


Hypsometrical model of Danube Delta Biosphere Reserve

Modelul hipsometric
- Rezervatia Biosferei Delta Dunarii -




1861
1821
1930
1997
2 4 6 8 10 km
EVOLUȚIA GURII DE VĂRSARE A BRAȚULUI SULINA
1861 - 1997


FORMAREA
ȘI EVOLUȚIA
INSULEI SACALIN
1857
1911
1995
0
7.5
15km

In these conditions, along with significant human being interference, the morphological changes, both within the Danube Delta hydrographic network and coastal zones, have a very rapid rhythm (satellite images in between 1975-2000).
A great impact on Danube Delta morphohydrographical changes and environment quality has the Danube River hydrologic regime (from the Danube Delta entrance). It takes place based on water and its solid matter load quantity and quality. The DDBR human population, flora, fauna and coastal zone existence and evolution depend on these elements.

Project objective

To build a mathematical model for assessment and prediction the DDBR morphohydrographical changes.

Purpose

1.To develop a practical instrument which has to work in the frame of the decision-making process for a sound management of the hydrographic network functions:

- refreshment water supply for protection and conservation of natural habitats;
- development of natural resources;
- human population health control (water and sediment pollutant contents evaluation).

2. To up-date the DDBR hypsometry evolution map.

3. To extend this mathematical model use for any variable of the aquatic environment (flora and fauna elements) due to the fact their behaviour depends on the Danube River water discharge.

Methodology

The independent variable is the Danube River water discharge (Q, m^3/s), measured at the Danube Delta Biosphere Reserve entrance cross section (Tulcea port hydrometric station).

Morphologic balance of water and its suspended solid matter contents

Two kinds of database sources are available:

1. Hydrologic data: quantities of water and alluvia which entered the inner Danube Delta hydrographic network (within 1858-2002) and;
2. Topohydrographic surveys (from: 1911, 1960, 1980-2002 for a part of DD)

Results

Based on these data (topohydrographic and hydrologic data), one can determine the morphologic balance through two different ways:

1. **the volumetric evaluation of the hydrographic network changes (based on topohydrographic data);**

the mass evaluation of the hydrographic network changes (based on hydrologic data).

Results

Using the two ways, it will allow to mediate data and go on to elaborate the morphologic model.

This model can simulate, by means of a resulted function (dependent on hydrologic elements), the evolution, in time and in different (natural or man-made) conditions, the hydrographical network morphological changes.

The morphologic evolution model will be made separately for the 7 hydrographic units of the DDBR, naturally delimited by their geomorphologic features.

The model will be an instrument to evaluate the rhythm of the morphologic evolution and to find out the optimum hydrologic regime to diminish the sedimentation or erosion processes.

MONTHLY MULTIANNUAL CHARACTERISTIC VALUES FOR DANUBE RIVER WATER DISCHARGE (Q, m3/s)

Measurement station: Tulcea port Study interval: 1840 - 1990

Water discharge	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I - XII
characteristics:				MONTHLY MAXIMUM DISCHARGE									
MAXIMUM	13870	15690	16110	14500	15540	20940	20940	12250	11350	11940	11800	11700	20940
MEAN	6640	7370	8390	8870	9320	9040	8160	6470	5400	5300	5690	6420	10480
MINIMUM	2120	2481	4180	4390	5340	4800	3500	2690	2580	2030	2250	2470	6200
				MONTHLY MEAN DISCHARGE									
MAXIMUM	11200	11840	12300	13290	14320	15480	15970	11710	10530	9490	10890	9580	9400
MEAN	5470	6030	7010	8160	8610	8270	7150	5510	4590	4380	4748	5480	6280
MINIMUM	1890	2450	3020	3910	4390	3980	3000	2250	2270	1750	2000	2110	3810
				MONTHLY MINIMUM DISCHARGE									
MAXIMUM	9600	10770	11490	12850	13600	12730	12090	11000	3900	8790	9640	9140	6270
MEAN	4400	4810	5620	7430	7910	7400	6040	4600	3810	3550	3880	4580	2780
MINIMUM	1820	1840	2200	3110	3770	3120	2650	1960	2000	1350	1450	1750	1350

WATER SALTS DISCHARGE BALANCE (M, kg/s)

MEAN VALUES FOR WATER MINERALIZATION

Study interval: 1858 - 1990

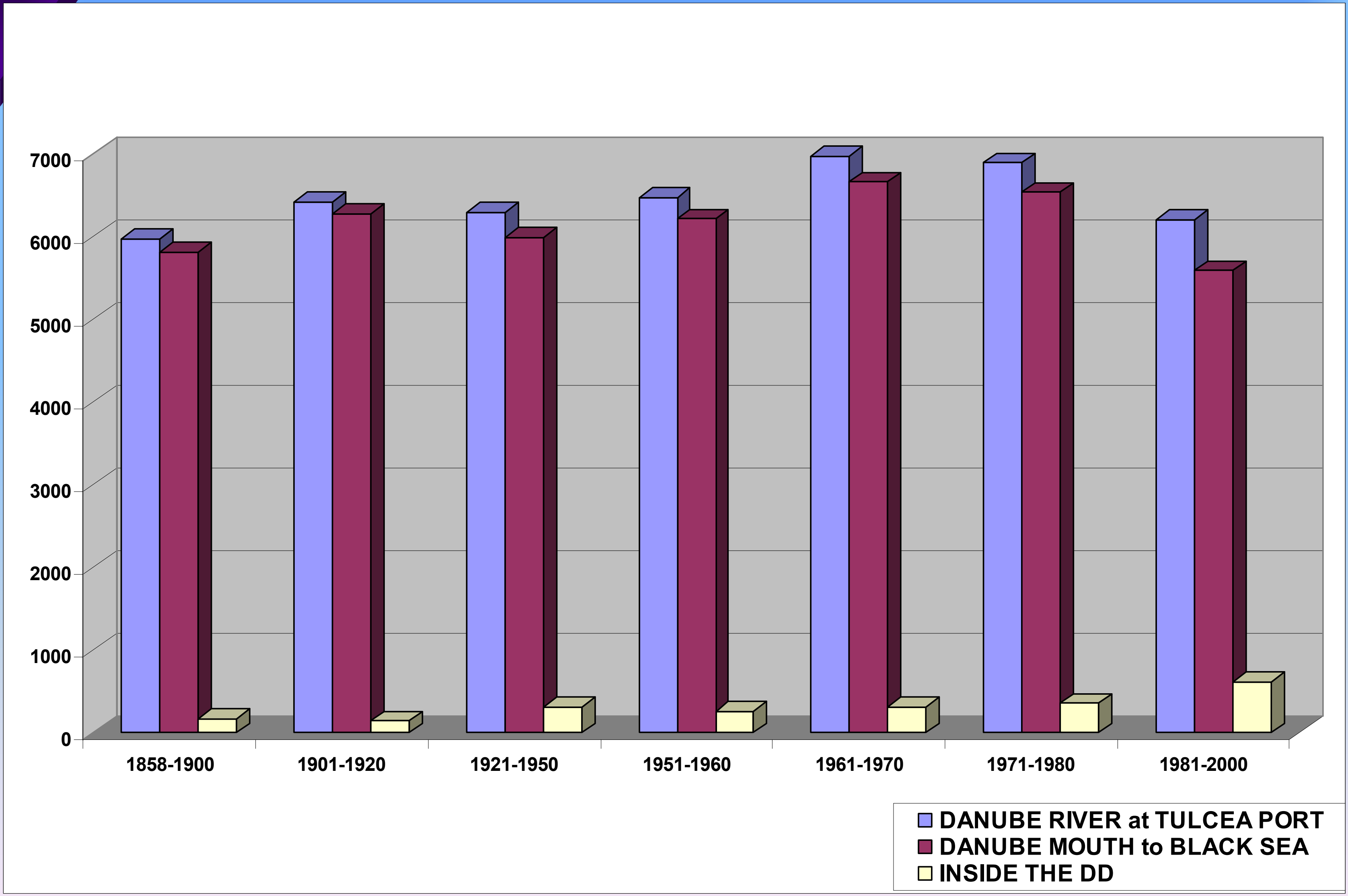
	1858-1900	1901-1920	1921-1950	1951-1960	1961-1970	1971-1980	1981-1990
			I. CHILIA ARM				
INLET	674,58	932,40	1033,80	1260,50	1468,40	1569,20	1537,20
OUTLET (Black Sea)	656,79	912,03	1000,60	1217,20	1424,80	1535,50	1379,90
INSIDE THE DD	14,79	20,37	33,20	43,30	43,60	60,70	157,30
			II. TULCEA ARM				
INLET (Mm 43)	353,63	414,54	585,87	743,18	945,62	1102,70	1109,70
OUTLET (Mm 34)	358,96	414,45	551,14	728,02	886,79	1096,10	1122,90
INSIDE THE DD	-5,33	0,00	34,73	15,16	58,82	6,60	-13,20
			III. SULINA ARM				
INLET (Mm 33)	75,51	127,26	233,11	327,96	408,63	504,77	526,48
OUTLET (Mm 0, Black Sea)	84,64	146,37	253,44	345,91	436,31	498,90	484,28
INSIDE THE DD	-9,11	-19,11	-20,33	-17,95	-27,68	5,87	42,20
			IV. ST. GEORGE ARM				
INLET (KM 108)	283,46	287,28	318,02	400,05	478,17	591,32	596,39
OUTLET (KM 8, Black Sea)	255,08	258,51	286,12	359,83	442,19	524,35	518,38
INSIDE THE DD	28,38	28,77	31,90	40,22	35,98	66,97	78,01
			DANUBE DELTA GENERAL "M" BALANCE				
DANUBE RIVER at TULCEA PORT	1028,20	1346,90	1619,70	2003,70	2414,00	2698,90	2646,90
DANUBE MOUTH to BLACK SEA	999,49	1316,90	1540,20	1922,90	2303,30	2558,70	2382,60
INSIDE THE DD	28,71	30,00	79,50	80,80	110,70	140,20	264,30

WATER DISCHARGE BALANCE: Q (m^3/s)

Mean values within study year intervals

	1858-1900	1901-1920	1921-1950	1951-1960	1961-1970	1971-1980	1981-2000
I. CHILIA ARM							
INLET	3922	4440	4018	4074	4244	4076	3606
OUTLET (Black Sea)	3836	4343	3889	3934	4118	3921	3237
INSIDE THE DD	86	97	129	140	126	155	369
II. TULCEA ARM							
INLET (Mm 43)	2056	1974	2277	2402	2732	2816	2603
OUTLET (Mm 34)	2087	1974	2142	2353	2563	2799	2634
INSIDE THE DD	-31	0	135	49	170	17	-31
III. SULINA ARM							
INLET (Mm 33)	439	606	906	1060	1181	1289	1235
OUTLET (Mm 0, Black Sea)	492	697	985	1118	1261	1274	1136
INSIDE THE DD	-53	-91	-80	-58	-80	1599	
IV. ST. GEORGE ARM							
INLET (KM 108)	1648	1368	1236	1293	1382	1510	1399
OUTLET (KM 8, Black Sea)	1483	1231	1112	1163	1278	1339	1216
INSIDE THE DD	165	137	124	130	104	171	183
GENERAL "Q" BALANCE							
DANUBE RIVER at TULCEA PORT	5978	6414	6295	6476	6976	6892	6209
DANUBE MOUTH to BLACK SEA	5811	6271	5986	6215	6657	6534	5589
INSIDE THE DD	167	143	309	261	319	358	620

WATER DISCHARGE BALANCE - Mean values in interval study Q(m3/s)



SEDIMENT LOAD DISCHARGE BALANCE (R, kg/s)

MEAN VALUES

Study interval: 1858 - 1990

	1858-1900	1901-1920	1921-1950	1951-1960	1961-1970	1971-1980	1981-1990
I. CHILIA ARM							
INLET	1252	1405	988	1260	864	757	538
OUTLET (Black Sea)	1225	1374	907	1157	810	688	535
INSIDE THE DD	27	31	81	104	54	69	-3
II. TULCEA ARM							
INLET (Mm 43)	671	619	480	596	529	551	263
OUTLET (Mm 34)	673	616	521	722	503	517	401
INSIDE THE DD	-2	3	-41	-126	26	34	-148
III. SULINA ARM							
INLET (Mm 33)	141	187	219	324	235	230	183
OUTLET (Mm 0, Black Sea)	150	198	268	377	286	242	137
INSIDE THE DD	-9	-11	-49	-53	-51	-12	46
IV. ST. GEORGE ARM							
INLET (KM 108)	532	429	302	398	268	287	218
OUTLET (KM 8, Black Sea)	456	386	281	370	257	214	123
INSIDE THE DD	76	43	21	28	11	73	95
DANUBE DELTA GENERAL "R" BALANCE							
DANUBE RIVER at TULCEA PORT	1923	2024	1468	1857	1893	1308	795
DANUBE MOUTH to BLACK SEA	1851	1958	1456	1904	1353	1144	795
INSIDE THE DD	72	66	12	-48	40	164	0

Danube Delta Biosphere Reserve Hydrogrometric stations

Hydrographic object: DANUBE River at Isaccea (ISC), Ceatal Izmail (CID)

No	Date	Water level	Water discharge	Cross section	Water velocity med	Water velocity max	Width	Water depth med	Water depth max	Suspended load	Mean turbidity
		H	Q	A	Vm	Vmax	B	hm	hmax	R	rom
		(cm)	(m^3/s)	(m^2)	(m/s)	(m/s)	(m)	(m)	(m)	(kg/s)	(g/m^3)
1994ISC1	22,03	232	6570	8040	0,817	1,2	779	10,3	17,8	256	0,039
1994ISC2	25,04	356	10200	9020	1,13	1,98	802	11,2	19	840	0,082
1994ISC3	6,05	389	11200	9470	1,18	1,81	806	11,7	19,4	1120	0,1
1994ISC4	15,06	255	6600	8190	0,806	1,25	781	10,5	17,9	386	0,058
1994ISC5	11,07	143	4610	7310	0,631	1,07	768	9,5	16,7	147	0,032
1994ISC6	23,08	30	2630	6640	0,405	0,653	751	8,8	16	102	0,038
1994ISC7	1,09	50	3140	6780	0,463	0,781	760	8,9	15,8	192	0,061
1994ISC8	4,11	52	2890	6630	0,436	0,66	760	8,7	16	38,4	0,013
1994ISC9	10,11	112	4240	7170	0,591	0,919	767	9,3	16,6	279	0,066
1995ISC1	***6,05***	***344***	***8660***	***8950***	***0,968***	***1,5***	***797***	***11,2***	***19***	***771***	***0,089***
1995ISC2	***20,06***	***333***	***8050***	***9030***	***0,891***	***1,21***	***798***	***11,3***	***18,7***	***783***	***0,097***
1995ISC3	***22,06***	***341***	***8400***	***8950***	***0,938***	***1,35***	***800***	***11,2***	***18,5***	***312***	***0,037***
1995ISC4	***24,07***	***238***	***5810***	***8170***	***0,711***	***1,09***	***782***	***10,1***	***17,6***	***282***	***0,05***
1995ISC5	***14,08***	***107***	***3740***	***7190***	***0,52***	***0,864***	***769***	***9,3***	***16,4***	***92***	***0,024***
1995ISC6	***19,09***	***254***	***7020***	***8450***	***0,831***	***1,34***	***782***	***10,8***	***17,8***	***732***	***0,104***
1995ISC7	***16,1***	***149***	***4820***	***7540***	***0,639***	***0,975***	***773***	***9,8***	***16,6***	***272***	***0,056***
1995ISC8	***24,1***	***104***	***3720***	***7100***	***0,524***	***0,78***	***762***	***9,3***	***15,4***	***47***	***0,013***

Danube Delta hydrologic regime characteristics

Hydrometric station: Tulcea port

1. Mean multiannual water discharge, within 1840-2002, is 6300 m3/s.
2. Maximum value: 20,940 m3/s (July 1897)
3. Minimum value: 1,350 m3/s (October 1921)
4. Annual values are between 3,610 – 9,420 m3/s
5. Linear tendency of Q to increase, as a function of time:

Q (t) = 5986+3.91(t-1839)

Each annual value adds 3.9 m3/s

Danube Delta hydrologic regime characteristics

6. For Q>9,100 m3/s (inundation conditions) and for 1970-2000 database interval: H=171.8+2.78423v (Q-7297.2);

7. For Q<9,100 m3/s (no inundation conditions):
H=-619.6+7.9809v (Q+3888.5)
8. For H Tulcea < 290 cm (above Black Sea water level):
Q=9,100+(H-290)(28.56+0.0154(H-290))
9. For H>290 cm:

- **Q=9,100+(H-290)(30.5+0.129(H-290))- flood Q value;**

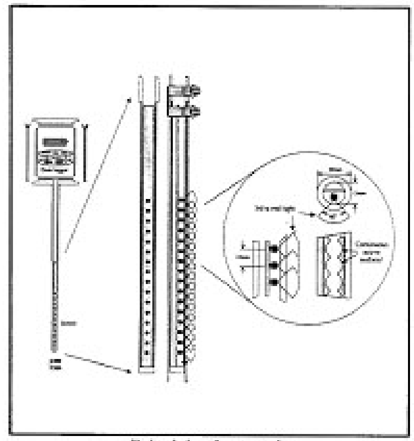
- **Q=9,100+(H-290)(30.5+0.065(H-290) – inner Danube Delta hydrographic network**

Danube Delta water solid matter load: R (kg/s)

1840 – 2000 interval study

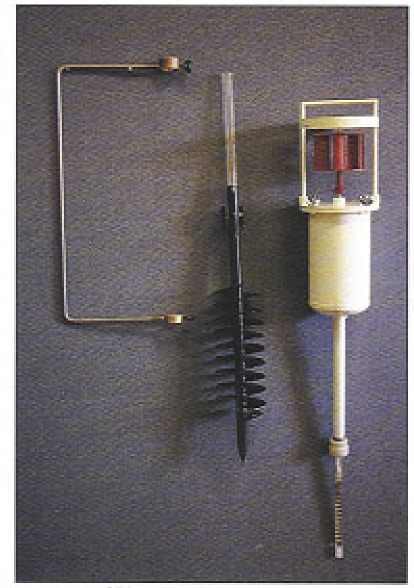
1. Mean multiannual value: 1737 kg/s
2. Annual values: 224 (1990) – 4780 (1871)
3. Decrease tendency with a annual value of 7.8 kg/s:

   R(t) = 2,339-7.8(t-1839



Principle of operation

In - situ installation



SEDIMETER with accessories

SEDIMETER.

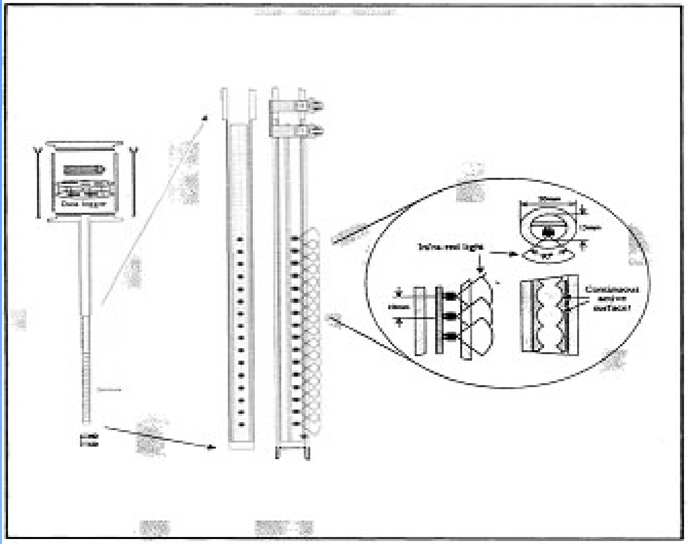
A SENSOR FOR MEASURING EROSION AND SEDIMENTATION OF SEA BEDS.

* A simple and versatile tool to detect sediment transport.

* Indicates bottom level as well as sediment concentration in the sea water above the sea bed.

* Current speed and sea water temperature sensors are optional extras.

PRINCIPLE OF OPERATION.



MAIN FEATURES:

- A simple and versatile tool to detect sediment transport.
- Indicates bottom level as well as sediment concentration in the sea water above the sea bed.
- Very little disturbance of natural flow patterns.
- Very high resolution.
- Easy to install and recover.
- In - situ programmable with portable PC.
- Data logger versions and direct reading versions available.
- Data output via RS 232 port
- Current speed and sea water temperature sensors are optional extras.

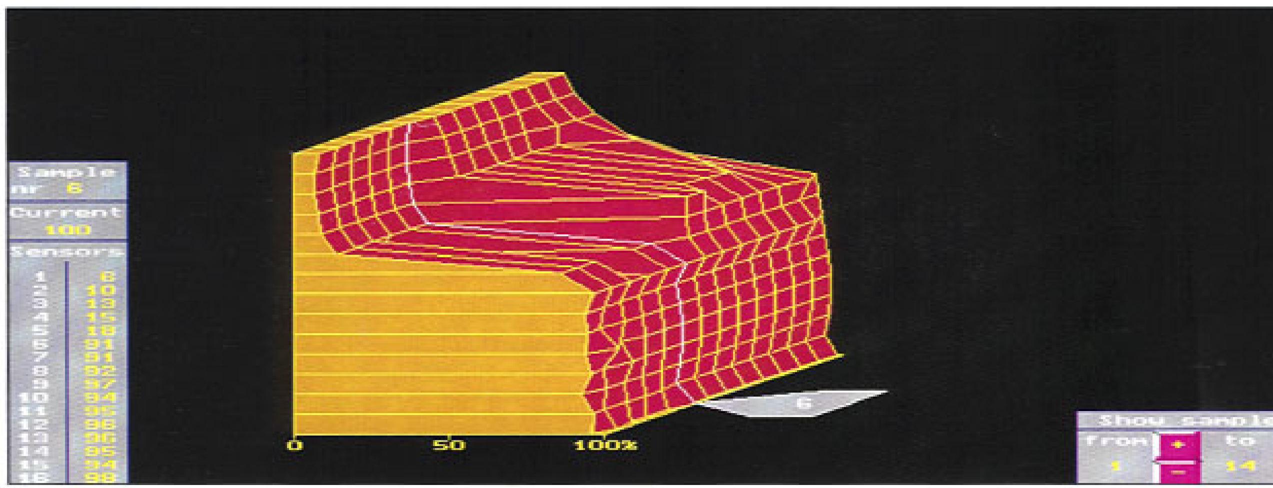
The sensor in the SEDIMETER is a transparent tube equipped with infra-red optical backscatter detectors at 9 mm intervals, so as to give overlapping measurement zones. The elevation of the sea bed in the spot where the instrument is placed, is measured at a desired time -interval and registered by the data-logger.

The detectors each contain an infra-red LED and a photo-transistor with an IR-filter, to avoid disturbance from visible light. By activating each LED separately and registering the back - scattered light from each overlapping phototransistor, the sensor will detect minute changes on the bottom besides the sensor. The returned signal is a function fo the reflecting properties of the sediments, and their concentration. A plot of the registered data will therefore indicate both the level of the bottom, and the approximate concentration of sediments immediately above the sea bed. When several measurements are plotted together in 3D-plot, minute changes in elevation, as well as turbidity, will easily be detected by visual inspection.

The SEDIMETER is an optical system in that it uses light as an information-carrier, but due to its operating principle, is not dependant on the visibility.
It has a constant though very small disturbance of the flow pattern associated with it.

DATA CAPTURE - SOFTWARE.

The SEDIMETER has an internal data logger with storage capacity of 255 samples. The data is output via a standard RS 232 port, and may be read by any PC or similar device.
The SEDI software package is a graphic presentation software which displays in a three - dimensional plot the measured value of each individual sensor. In addition each sample can also be read as numeric values.
The SEDI software package will run on any PC with VGA graphics installed.



APPLICATION EXAMPLES

* **SEDIMENT TRANSPORT AND DEPOSITION RESEARCH**, for measuring the freqency of transport, the threshold of transport, the migration of transport forms and the temporal nature of sediment deposition.

* **PORTS AND INDUSTRIAL OUTLETS**, for measuring sediment build - up and absolute level.

* **TOXIC AND DANGEROUS SEA DEPOSITIONS**, for measuring potential instability or transportation risks.

Contact manufacturer for further information on suitability for specific applications or for customer specified versions.

Ceratophyllum demersum growing close to the 'plaur'

Extensieve development of filamentous algae in Lake Baclanesti.

Hydrotechnics works for navigation stream cross-section improvement

Dredging canals in the Danube Delta.