DANUBE DELTA HYDROLOGICAL AND WATER QUALITY MODEL

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***Abstract*:** The work presents the first water quality models for Danube delta using the hydro chemical software Sobek-Rural (Delft Hydraulics, Delft, the Netherlands). The background for Danube delta water quality models is the **Danube Delta Hydraulic Model** a sophisticated and at presents the only operational physical hydraulic model for this area (more than 1000 nodes, 1250 branches, 770 cross-sections).

DANUBS_WQ model was made to quantify the sources, pathways and sinks of nutrients in the Danube Basin and their transport from the catchments to the Black Sea. For the Danube Delta aquatic complexes the main process regarding nutrient removal that has been taken into account is the NO3 removal by denitrification in reed beds. Therefore a relation has been derived between the water level at Tulcea in time and a critical level above which inundation occurs. This model was specially created with the purpose to compute the nutrient balance of the Delta area on a relative large spatial scale and for the computation of long time series. The main outputs of the model are: total nitrogen, phosphorus and silica, suspended solids.

SEDIMENTS_WQ model was made to describe the processes of river (suspended) sediments in the channels and lakes of the Danube delta complexes. The main purpose is to get insight to what extend sediments from the river reaches the Danube delta aquatic complexes. One of the main concerns is the annual sedimentation rate in the channels. The model distinguishes five fractions depending on available data regarding the grain size distribution. Estimated sedimentation rates with help of the model could be a useful source of information for the dredging need and frequency in the Danube Delta.The main outputs of the model are: thickness of the sediments in lakes/channels, grain size distribution in sediment layer and transport of suspend solids to Black Sea.

EUTROPHICATION_WQ model is an extended of DANUBS_WQ model for studying eutrophication phenomena in lakes. The model distinguishes the following variables in surface water: dissolved oxygen; inorganic nutrients; adsorbed phosphates; inorganic suspended matter in two fractions; two algae groups (Diatoms and Non-Diatoms); organic detritus; other organic matter. In sediment layer the variables are: adsorbed ortho phosphorus in sediment; inorganic matter in sediment; organic matter in sediment.The main outputs of the model are: algae nitrogen and phosphorus content, chlorophyll a, thickness of sediment layer, Secchi depth, total (including algae) nitrogen, phosphorus and silica.

***Keywords*:** Danube delta, hydrology, hydraulics models, water quality models, GIS.

DAS HYDROLOGISCHE MODELL UND DAS MODELL DER WASSERQUALITÄT DES DONAUDELTAS

Zusammenfassung: Die Arbeit stellt, das erste hydrochemische Modell des Donaudeltas dar, indem sie den spezialisierten Soft Sobek-Rural ver wendet, der vom Institut für Hydraulik Delft und Riza, Holland hergestellt wurde. Der Grund des hydrochemischen Modells wird vom hydraulischen Modell des Donaudeltas, einem komplizierten Modell und bis heute dem einzig phyisischen Operationsmodell für diese Zone (mehr als 1000 knoten, 1259 trassen, 770 Querschnitte) dargestellt.

Das erste hydrochemische Modell DANUBS_WQ wurde erzeugt, um den Nahrungsstoffetransport zum Schwarzen Meer und ins Donaudelta zu quantifizieren. Für die Wasserkomplexe im Donaudelta ist der bedeutendste Vorgang, die Befreiung (treilassung) von NO_3 zu betrachten; dieser Vorgang hat als Folge die Entnitrifikation der Schilfwälder. Dafür war es notwendig, damit eine Beziehung zwischn dem Wasserspiegel der Station Tulcea und dem Wasserspiegel, wo das Űberschwemmen der Schilfflächen entsteht, festgestellt wird. Deises hydrochemische Modell ist insbesondere für das Rechnen des Wiegens der Nahrungsstoffe im Donaudelta in einem grőßeren Mass und für einen längeren Zeitabschnitt dargestellt worden. Die Hauptergebnisse des Modells gestatten das Fődern des Transportes des Stickstoffes, des Phosphors und des Siliziums.

Das zweite hydrochemische Modell SEDIMENTS_WQ wurde hergestellt, um die Sedimentationsvorgänge der Kanäle und der Seen im Donaudelta zu simulieren. Der Hauptzweck war, der Sedimentationsvorgang der Wasserkomplexe im Donaudelta, der aus dem Transport der Sedimente der Donau entstand, und also des Festsellens der jährlichen Sedimentationsrate der Kanäle der Donaudeltas zu beschreiben. Das Modell besitzt fünf Bruchteile, die gemäss der Dimensionen der Partikeln klassifiziert, werden. Das Schätzen der Sedimentationsraten durch das Verwenden hydrochemischen Modells gestattet das Festtegen eines wirksamen Ausbaggerungsplans der Kanäle im Donaudelta. Die Hauptergebnisse gestaten das Simulieren der Sedimentedicke in Seen/Kanälen, das Verteilen der Bruchteile in der Sedimentechicht, den festen Transport zum Schwarzen Meer.

Das dritte hydrochemische Modell EUTROPHICATION_WQ (das Ausbauen des Modells DANUBS_WQ) wird zwecks des Simulierens der Eutrophieerscheinungen der See des Donaudeltas erzeugt. Das Modell verwender zwei Algentypen (Diatomite und Nondiatomite). Die Hauptergebnisse, gestatten den Stickstoff – und Phosphorinhalt in den Algen, das Chlorophyll “a”, den Stickstoff, das Siliyium (idem man die Algen einbezicht) zu simulieren.
Schlüsselwörter: hydraulisches Modellieren, Wasserqualität, GIS, Hydrologie.

1. Introduction

The Danube Delta is a complex hydrological system and is still in a quite natural state. However, the system has been subject to considerable changes during the last centuries. Especially canalisation works have influenced the hydraulic infrastructure. The actual topography of the delta can be described as riverine system with extended lake complexes and limited marine influence. In most parts of the year the Danube flows in riverbeds. During high water periods it flows in floodplains. These flow patterns enable the use of a one-dimensional flow modelling programme to simulate the water flow in the hundreds of canals in the delta. Danube Delta Hydrological Model offers a powerful tool for the Danube Delta Biosphere Reserve Administration (DDBRA) managers able to:

- Simulate and evaluate the impact of hydro-technical works (block or open new channels);
- Compute the water budgets of the Danube Delta and aquatic complexes;
- Determine residence time of the lakes as factor in the prediction of the chance on algae blooming;
- Provide background information for water quality modelling (nutrients, heavy metals, pollutants, eutrophication process).

2. Method

The Danube Delta Model is an integrate application of GIS processing and hydraulic modelling (Sobek_Rural software). The general approach of Danube delta model is shown below (Figure 1).

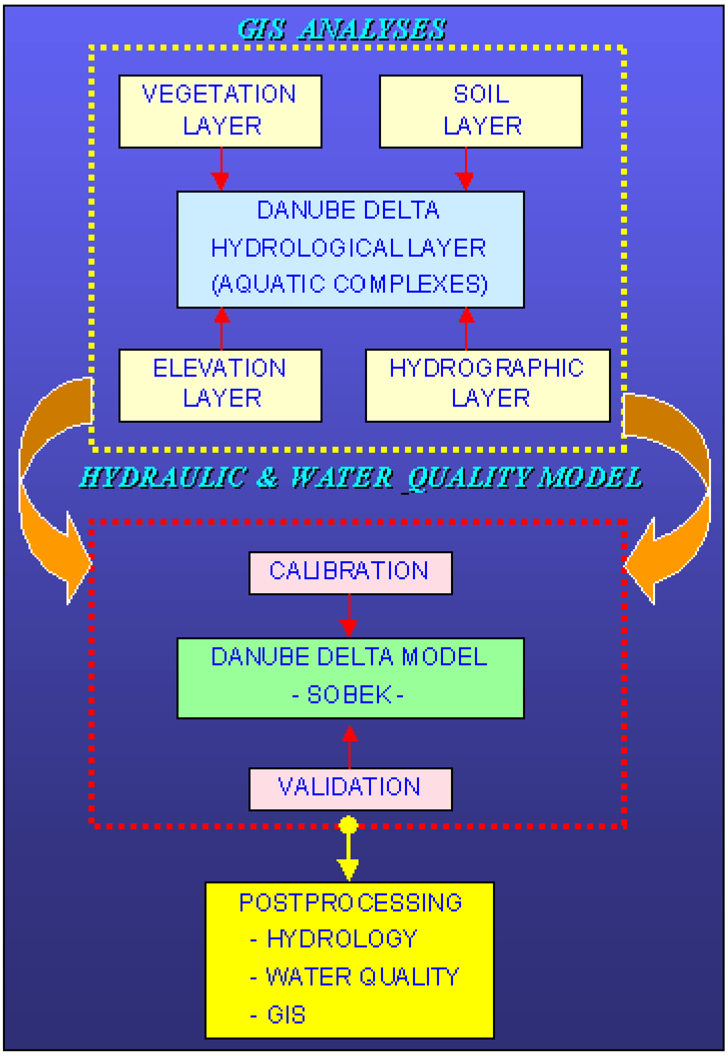
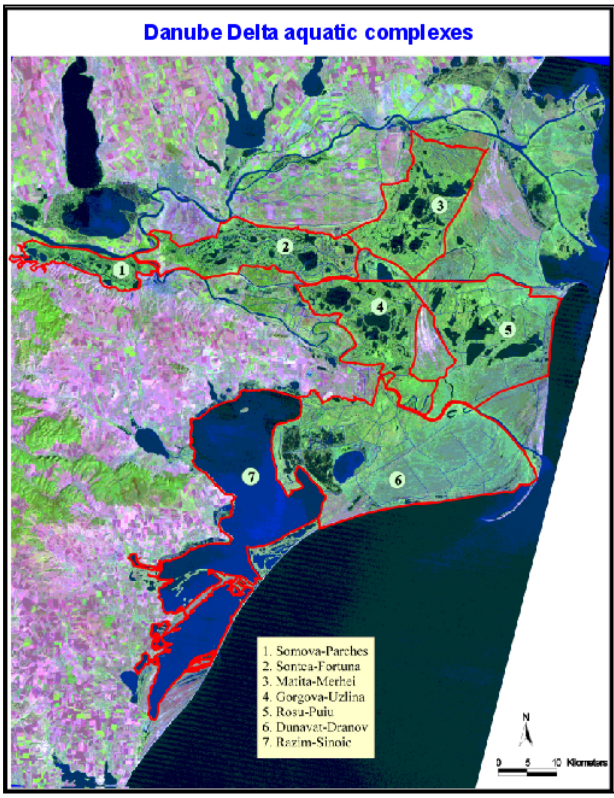


Figure 1. Structure of the Danube Delta Model

The GIS layers used are the channel net of the aquatic complexes (Figure 2), elevation map (Figure 3), vegetation map (Hanganu and Drost, 1994), (Figure 4) and soil map (Munteanu and Curelariu, 1996) (Figure 5) of the Danube delta. The results of the GIS analyses have provided spatial information about hydrographical net of the channel (coordinates of the nodes, channel arcs), surface of the lakes, surfaces of the flooding areas, all being used as background inputs for the hydraulic schematisation (Constantinescu 1998).

The model used is Sobek_Rural (Manual, 2000), a product developed by Delft Hydraulics in partnership with Institute for Inland Water Management and Waste Water Treatment (Riza) of the Netherlands government. Sobek is a software package, which in concise technical terms is a one-dimensional open-channel dynamic numerical modelling system. It is capable of solving the equations that describe unsteady water flow, salt intrusion, sediment transport, morphology and water quality. Sobek is also a physical model, using physical dimensions of canals and lakes and standard hydraulic formulas, as opposed to empirical or black box models, which try to predict outcome results purely on mathematical basis. The primary building parts are branches and nodes. Simply said, in the branches the water flows and in the nodes the balances are computed.



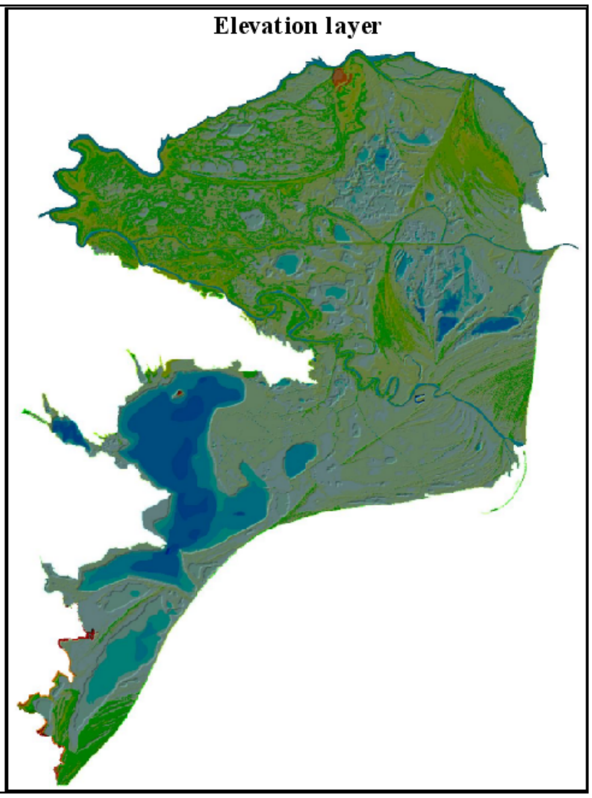
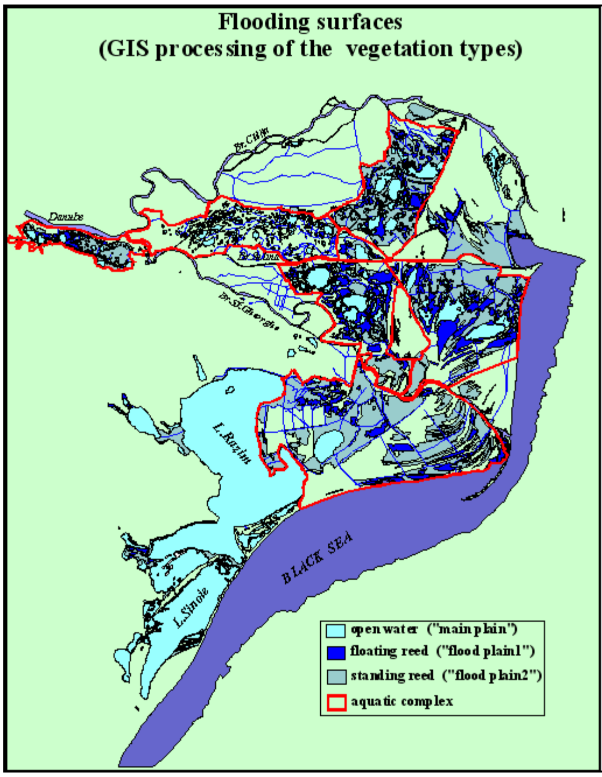


Figure 2. Danube delta aquatic complexes

Figure 3. Danube delta elevation map



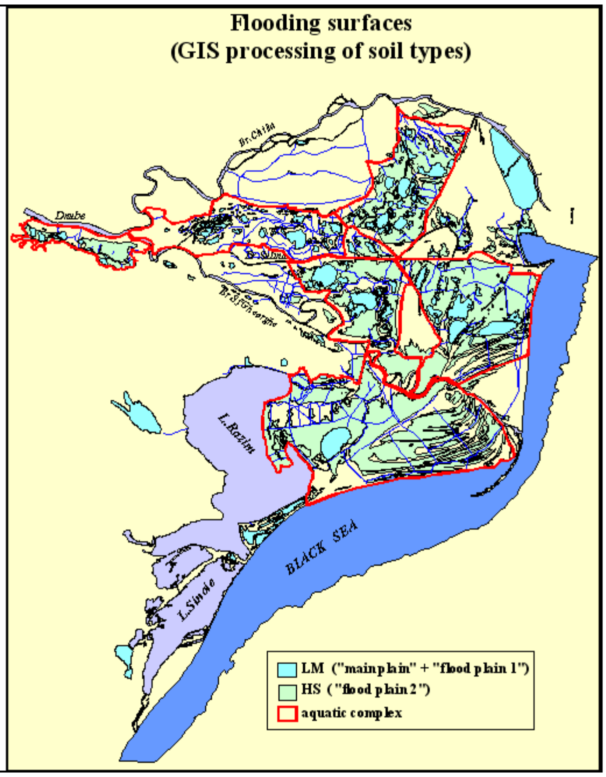


Figure 4. Danube delta vegetation

Figure 5. Danube delta soil map

2.1 Danube delta hydrologcal model

As with all modelling programmes, the main challenge is to fit the real world of canals, branches lakes etceteras into a schematisation with which Sobek can compute. As a one-dimensional model the flow of water must be expressed as a flow through a canal from one point to another point. These are the branches and nodes of the numerical model. Also a lake must be expressed as a (very wide) canal or combination of canals. To be able to include wind effects, it is a good habit to schematise a lake as a combination of at least three canals. Because Sobek was designed to schematise rivers, also floodplains of rivers can be incorporated in the model. Sobek considers floodplain as canals, which run parallel to the main canal. The floodplain can be given a different roughness than the main canal. In the floodplain itself a distinction is made between the part with flow closest to the main canal and a part without flow. The latter part only stores water with rising water tables and releases it again when the water table lowers.

As long as a river or delta can be expressed in above mentioned combination of nodes and branches and annexing floodplains, than a numerical representation of the physical world can be made, in which the water transport formulas describe correctly the flow. However a big burden is still the input of all physical dimensions of rivers, lake and canals. Also the boundary conditions, the time series of water tables and water levels at the begin end the end of the delta, must be provided. These data must be consistent concerning the use of the correct base level (mMNS) and the accuracy of the flow and level data.

A specific hydraulic situation in the Danube delta is the existence of floating reed beds (Constantinescu and Menting 2000). The canals have been schematised according to their measured cross-section (Figure 6).

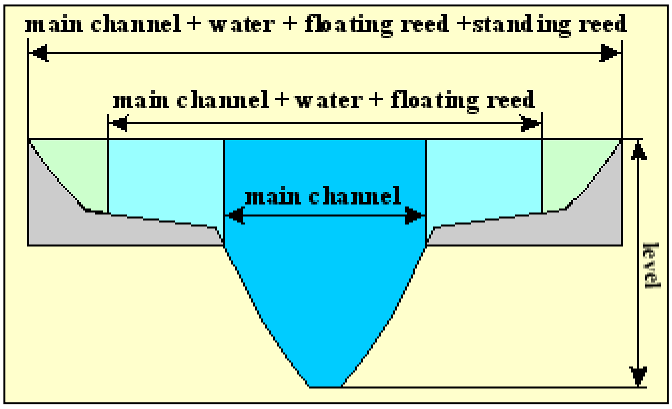


Figure 6. Cross-section schematisation

If necessary floodplains have been schematised parallel to the main channel (Figure 7).

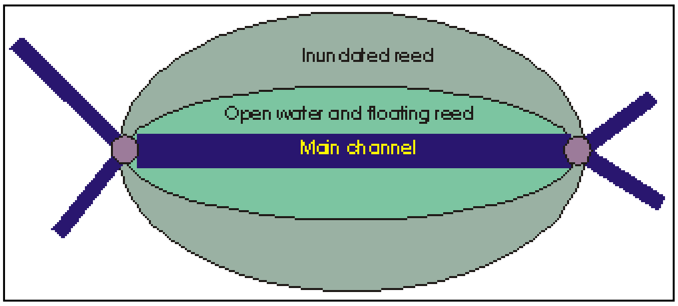


Figure 7. Channel schematisation

The lakes or lake complexes have been schematised as a system of connected canals (Figure 8). The total surface area of these connected canals is made equal to the surface of the lake and the floating reed. The area of standing reed is equal to the non-flowing part of the floodplain schematisation. The inlet and outlet canals of the lake (or lake complex) are the nodes at the circumference of the lake or lake complex.

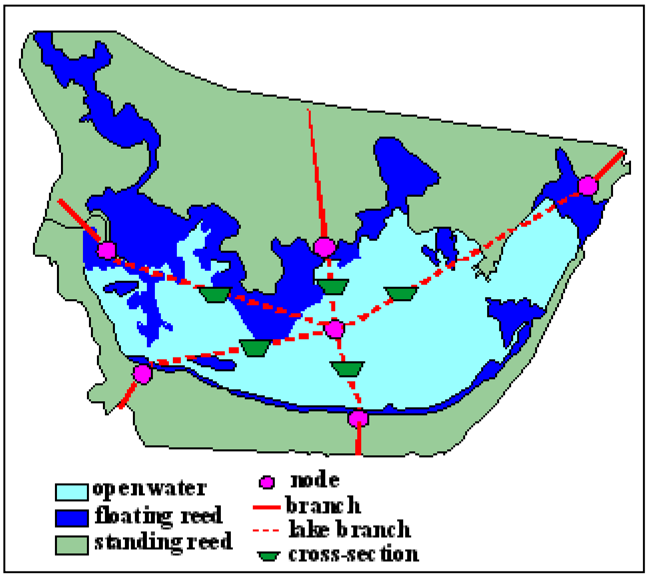


Figure 8. Lake schematisation

The dimensions of the cross-sections of the lakes include the GIS results of the spatial processing of the elevation, vegetation and soil maps (surface of the open water, floating reed, standing reed, depth). The final schematisation of the Danube delta model is shown in Figure 9.

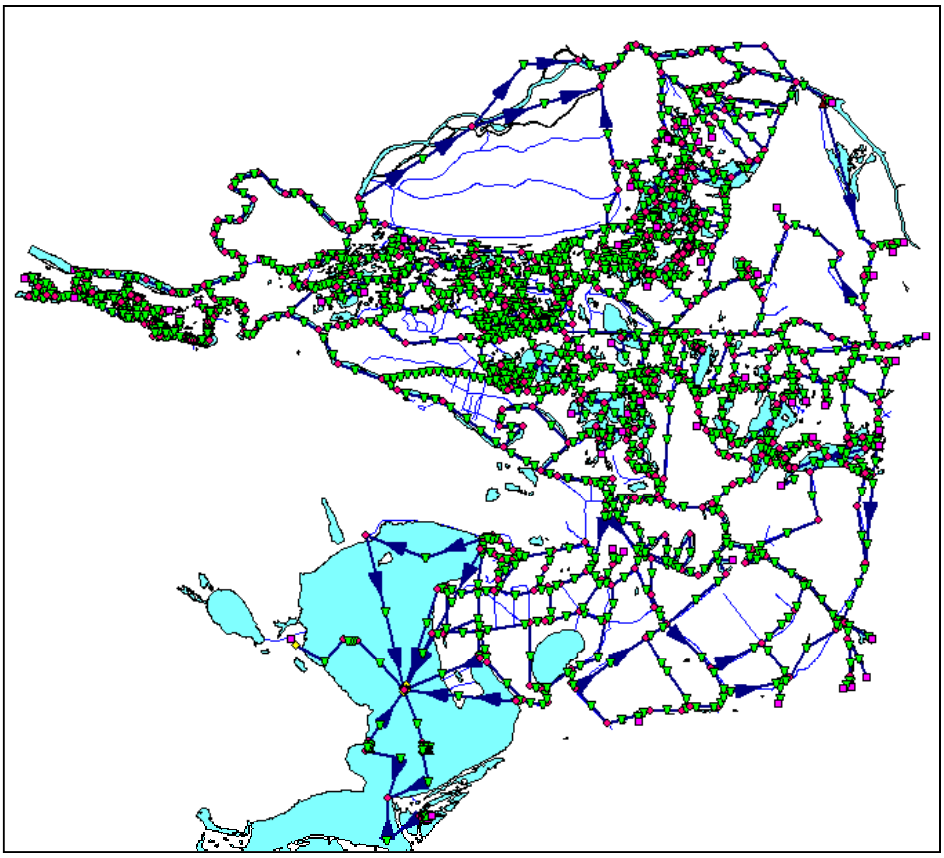


Figure 9. Schematisation of Danube delta model

2.2 Danube delta water quality models

The water quality models are built based on the hydraulic model and the specialised library from Sobek_Rural software. The hydro chemical processes are organised in "groups of substance" (Figure 10) each group containing a set of selectable substances (Figure 11).

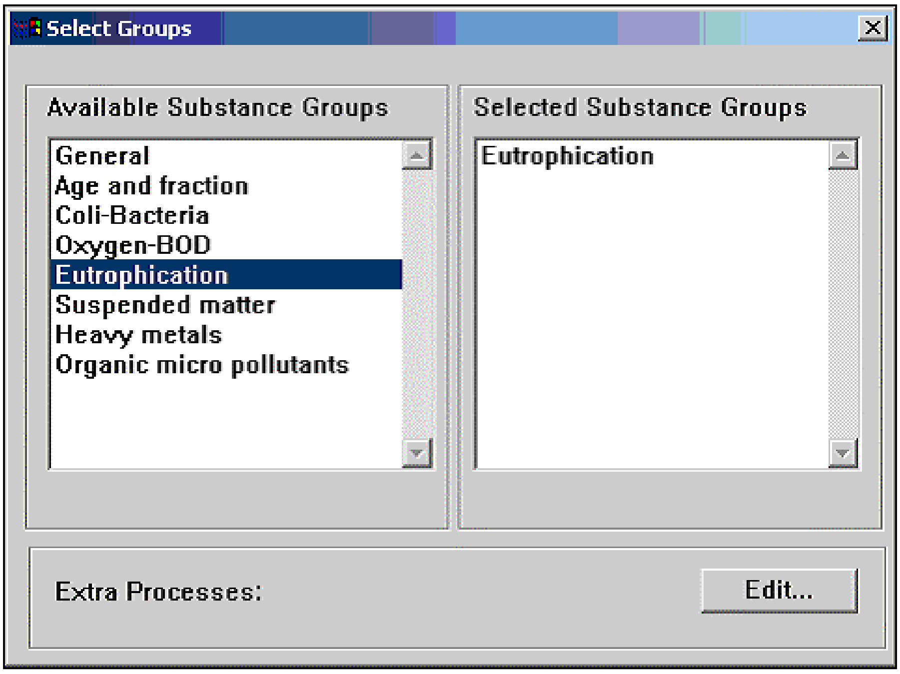


Figure 10. Sobek library – groups of substances

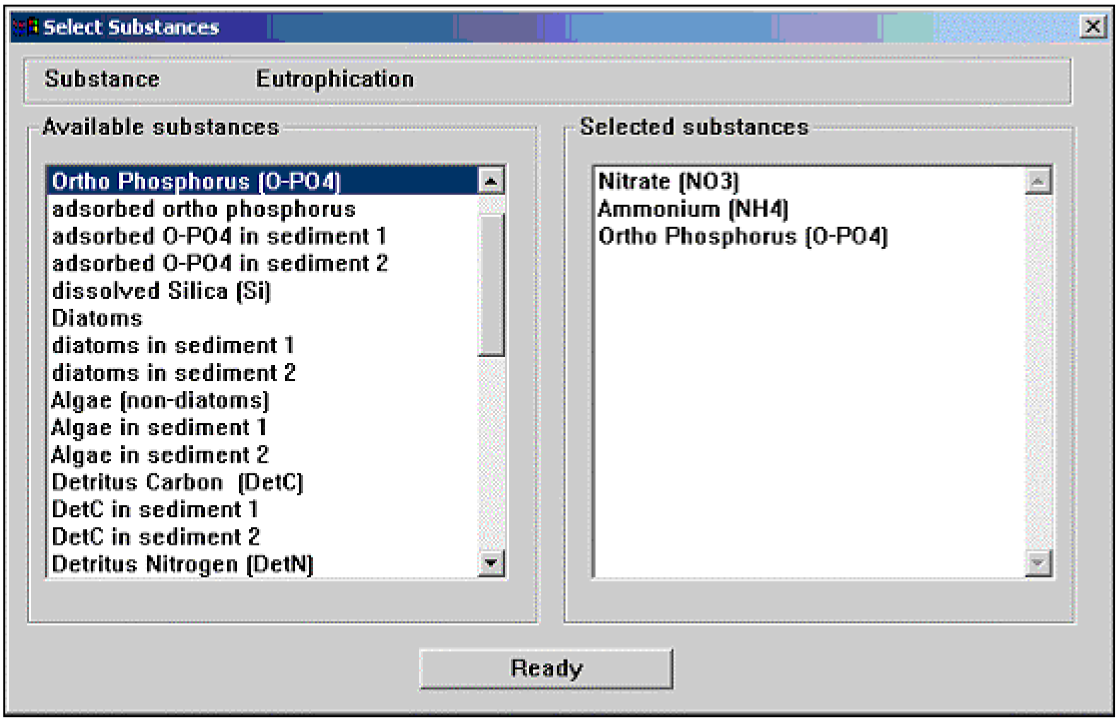


Figure 11. Sobek library - substances

For the Danube Delta aquatic complexes the main process regarding nutrient removal (Suciu and Constantinescu 2000) that has been taken into account is the NO3 removal by denitrification in reed beds (Figure 12, 13). Therefore a relation has been derived between the water level at Tulcea in time and a critical level above which inundation occurs (Figure 14).

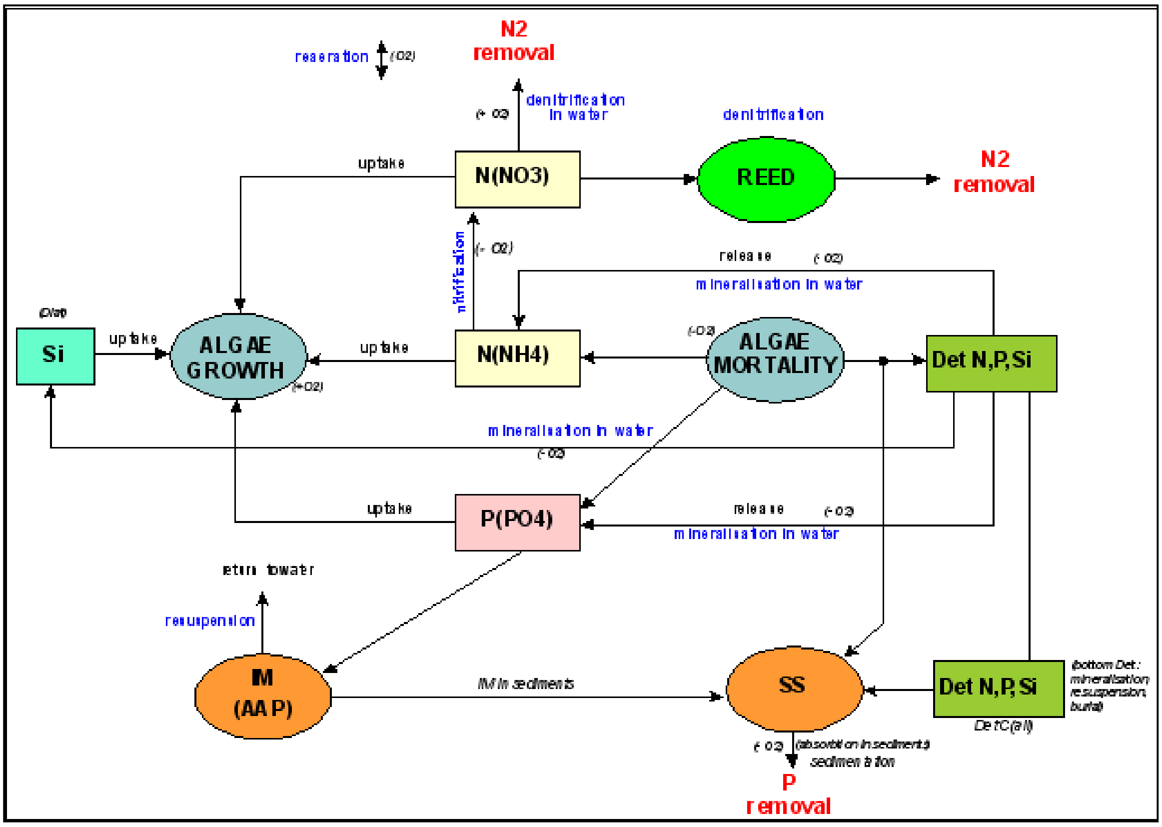


Figure 12. Nitrogen and phosphorus cycle

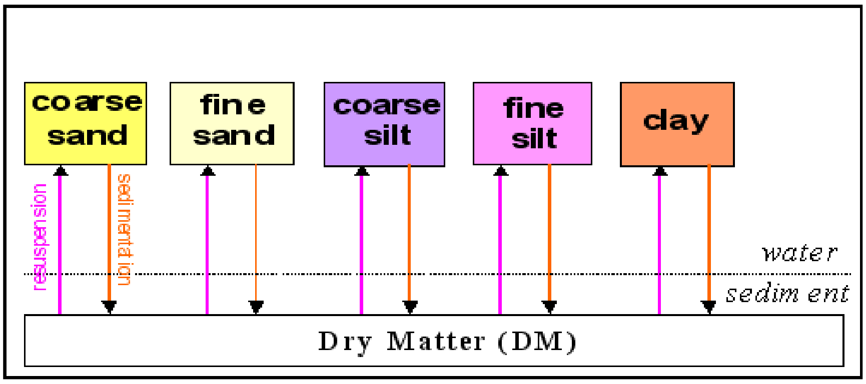


Figure 13. Sediments cycle

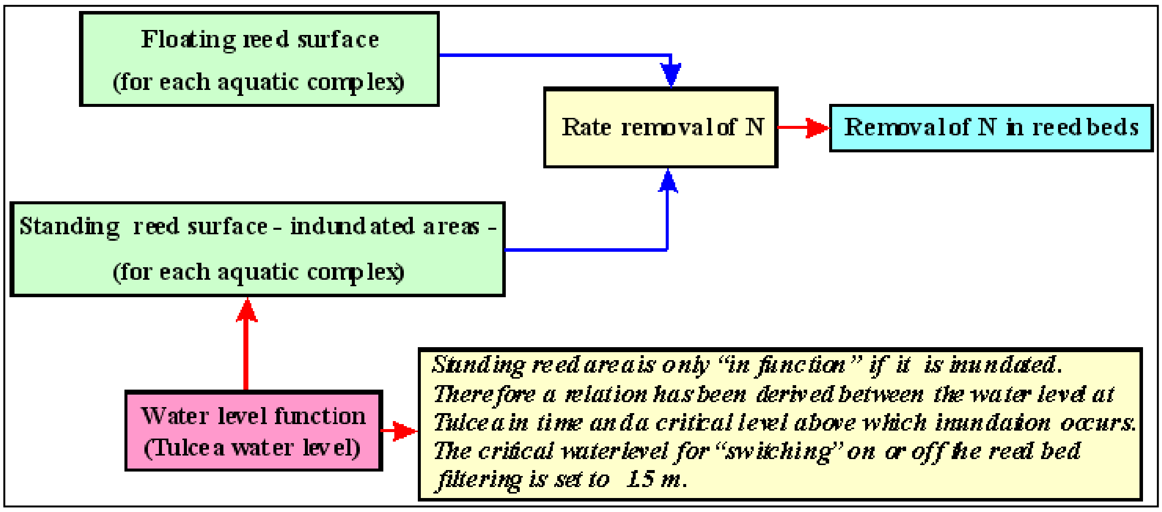


Figure 14. Relation between water level at Tulcea station and flooding areas

Using these relation were developed the following water quality models:

- DANUBS_WQ model was made to quantify the sources, pathways and sinks of nutrients in the Danube Basin and their transport from the catchments to the Black Sea. This model was specially created with the purpose to compute the nutrient balance of the Delta area on a relative large spatial scale and for the computation of long time series. The main outputs of the model are: total nitrogen, phosphorus and silica, suspended solids. The model is used in “daNUbs” FP V project;
- SEDIMENTS_WQ model was made to describe the processes of river (suspended) sediments in the channels and lakes of the Danube delta complexes. The main purpose is to get insight to what extend sediments from the river reaches the Danube delta aquatic complexes. One of the main concerns is the annual sedimentation rate in the channels.

The model distinguishes five fractions depending on available data regarding the grain size distribution. Estimated sedimentation rates with help of the model could be a useful source of information for the dredging need and frequency in the Danube Delta. The model has to be calibrated and validated;

- EUTROPHICATION_WQ model is an extended of DANUBS_WQ model for studying eutrophication phenomena in lakes. The model distinguishes the following variables in surface water: dissolved oxygen; inorganic nutrients; adsorbed phosphates; inorganic suspended matter in two fractions; two algae groups (Diatoms and Non-Diatoms); organic detritus; other organic matter. In sediment layer the variables are: adsorbed ortho phosphorus in sediment; inorganic matter in sediment; organic matter in sediment. The model is the most complex and has to be refining, calibrated and validated.

3. Results

The Danube delta model was used to run simulations for some restoration project concerning Danube delta Biosphere Reserve. The goal was to analyse the hydrological changes due to the hydro technical works and to choose the best solution. The scenarios for three of them are presented bellow (Figures 15, 16, 17).

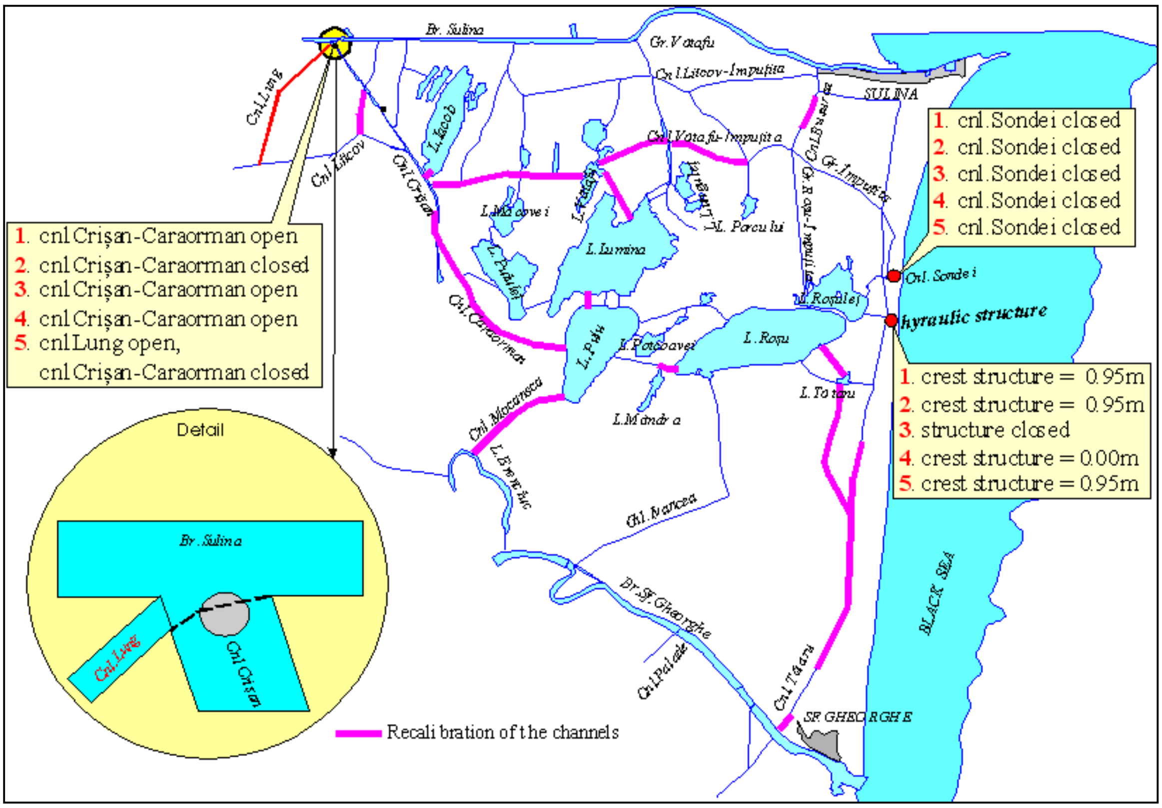


Figure 15. Hydrological scenarios for improving the water circulation in Rosu-Puiu complex

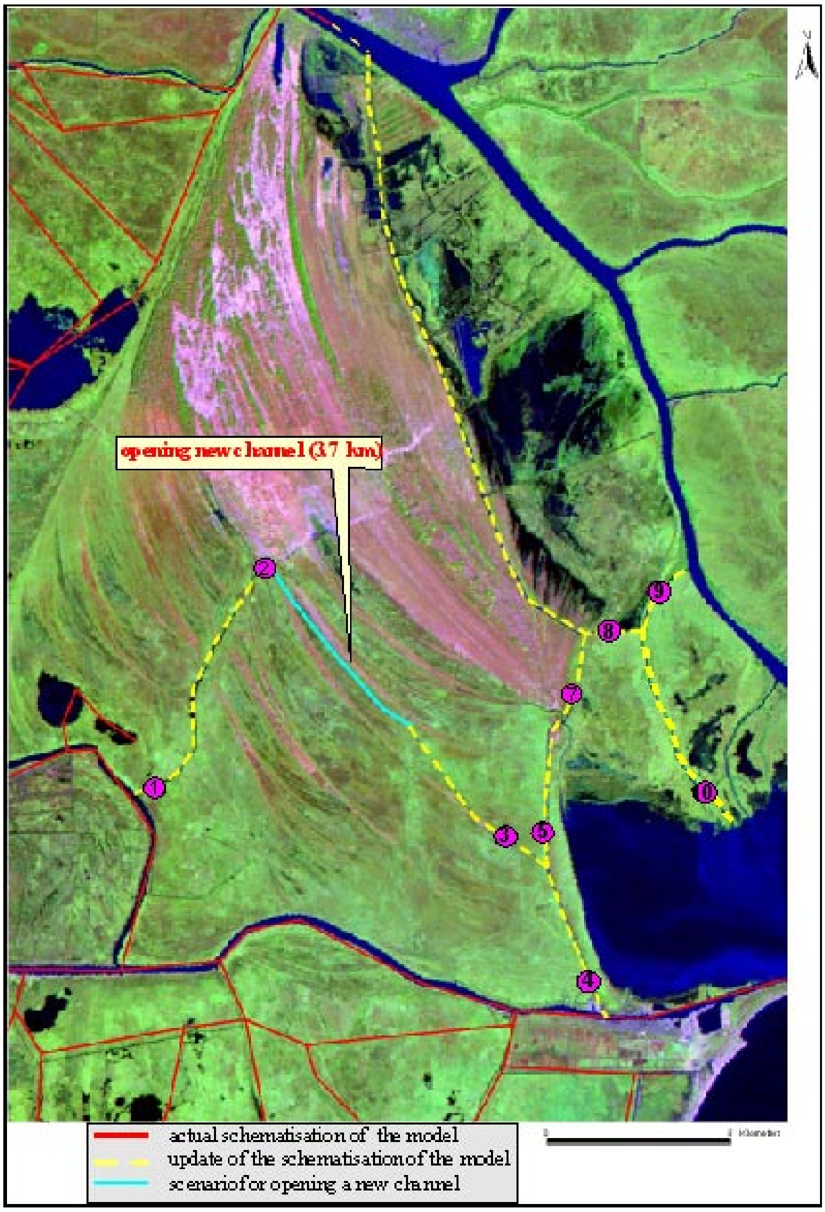


Figure 16. Hydrological scenarios for the restoration of Popina zone

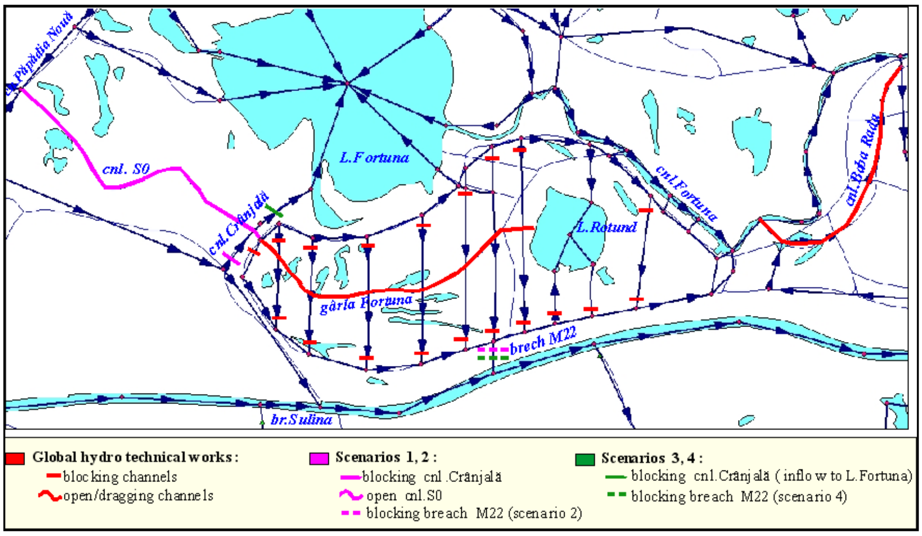


Figure 17. Hydrological scenarios for the restoration of Fortuna zone

SEDIMENTS_WQ model can be used to support dredging management decisions. The outputs of these model are the evaluation of thickness of the sediments in lak ... to Bl...

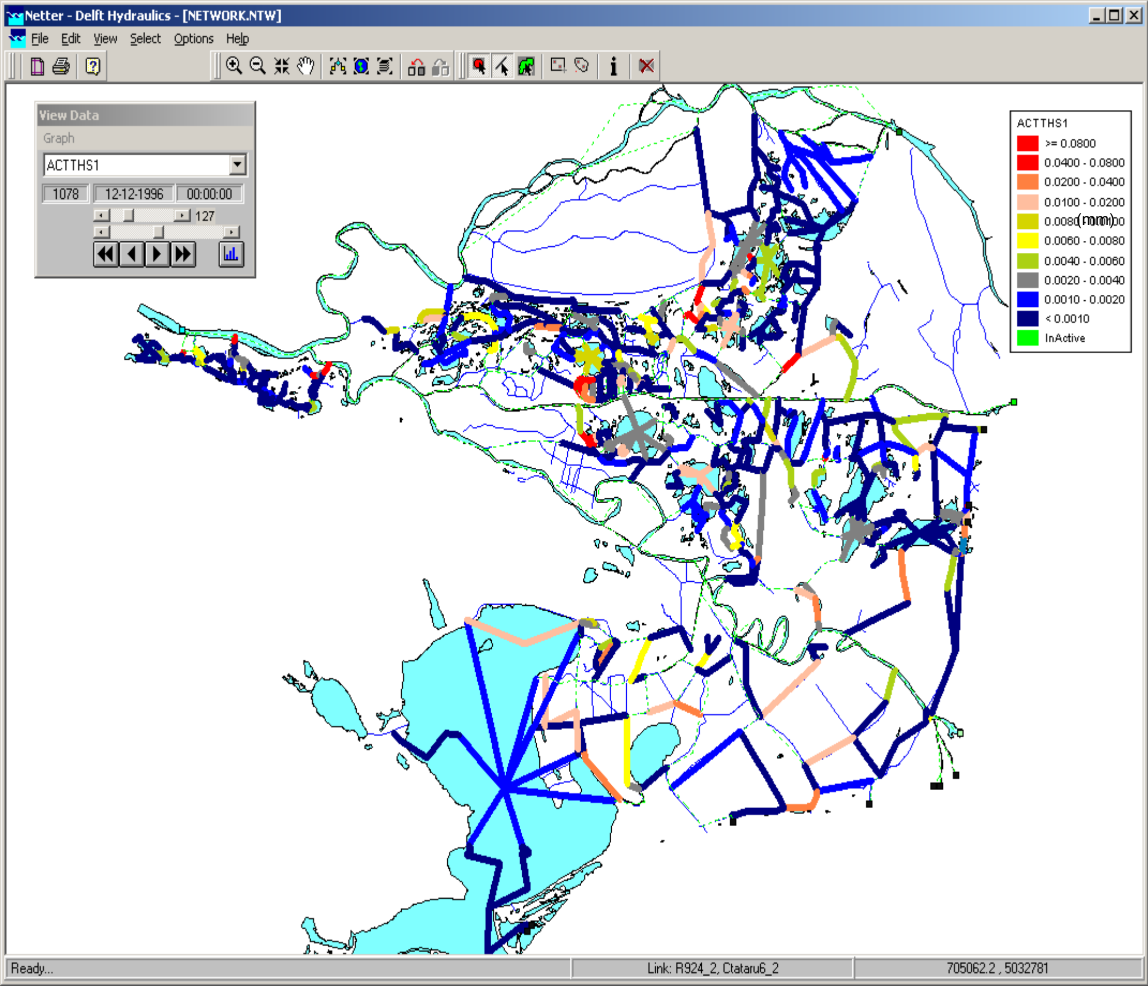


Figure 18. Distribution of the actual sediment thickness in Danube delta

From the decision point of view (Danube Delta Biosphere Reserve Administration) it is very important to know the channels that should be dragged for a better circulation of the water in the aquatic complexes (Figure 19).

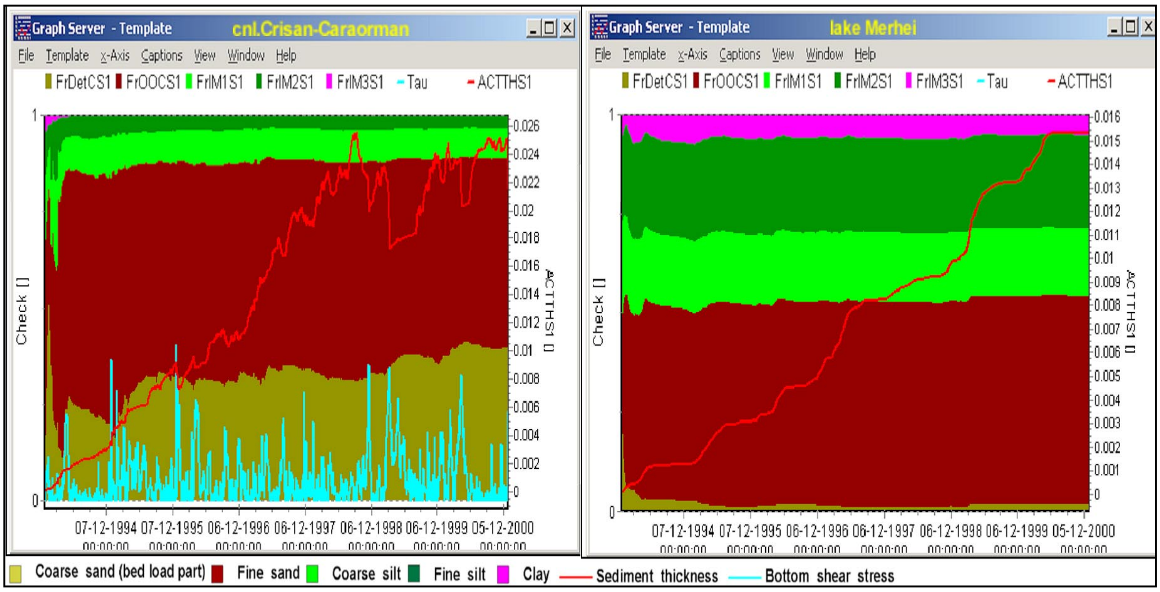


Figure 19. Sediment thickness & fraction distribution in sediment

DANUBS_WQ model is used in the "daNUbe " (Nutrient Management in the Danube Basins and its Impact on the Black See) FP V project (Figure 22). The main outputs of the model are: total nitrogen (Figure 20), phosphorus (Figure 21) and silica, suspended solids.

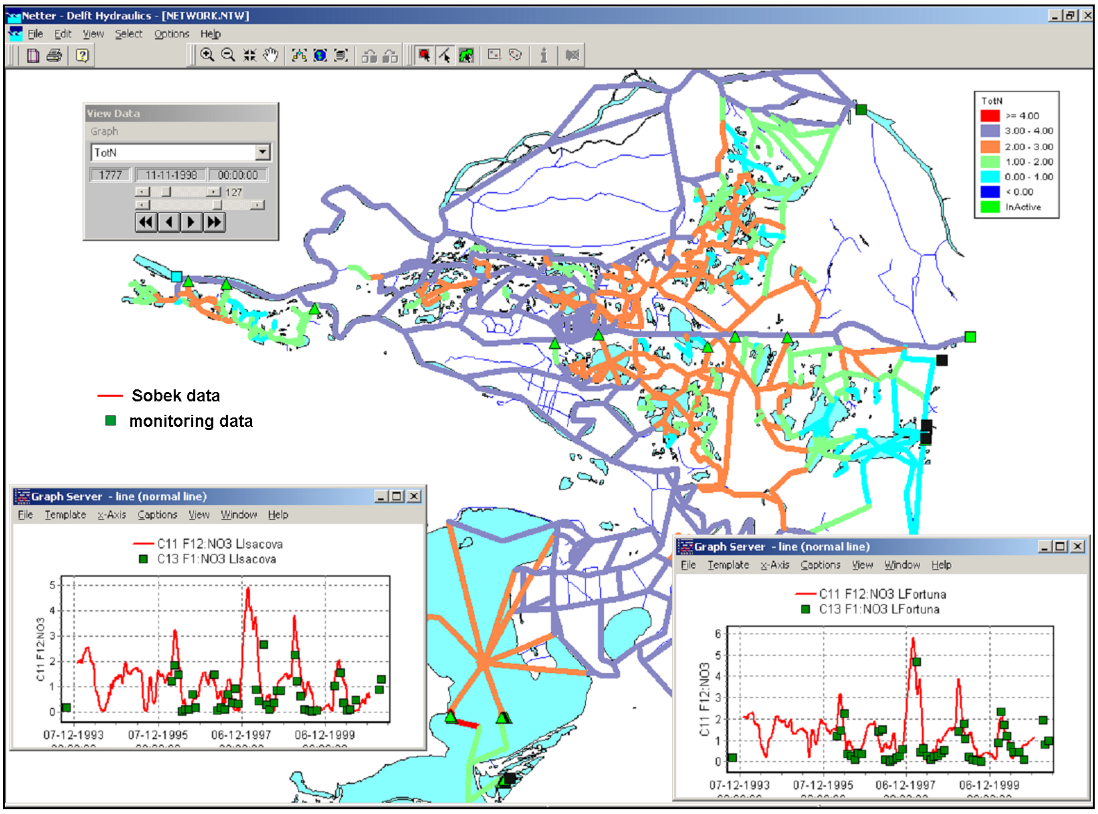


Figure 20. Total nitrogen concentration

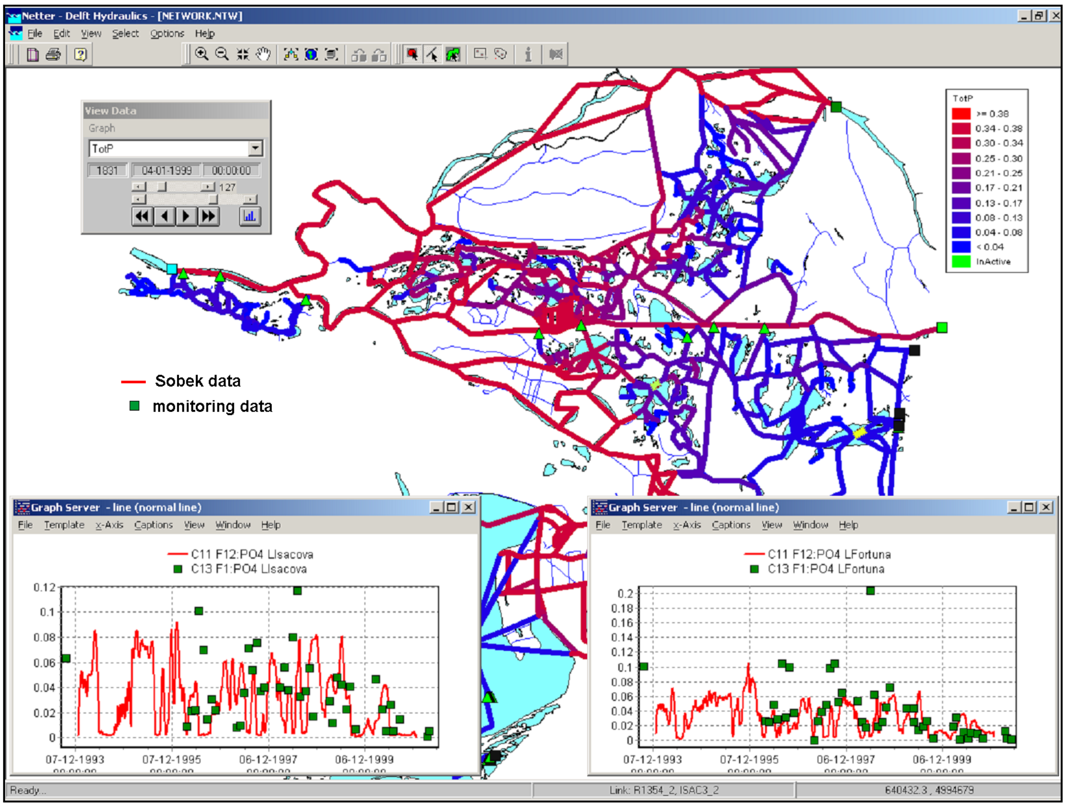
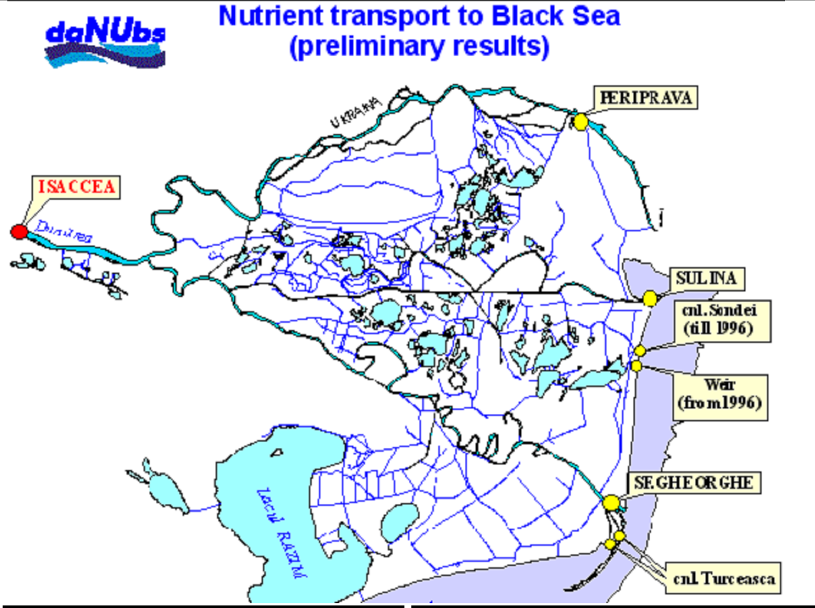


Figure 21. Total phosphorus concentration



	Total N	(10^3 tons/year)		
	ISACCEA	Periprava	Sulina	Sf.Gheorghe
1994	524	289	101	116
1995	542	302	101	116
1996	597	332	114	128
1997	548	308	102	120

	Total P	(10^3 tons/year)		
	ISACCEA	Periprava	Sulina	Sf.Gheorghe
1994	35	19	7	8
1995	41	23	8	9
1996	55	30	10	12
1997	51	28	9	11

	Total Si	(10^3 tons/year)		
	ISACCEA	Periprava	Sulina	Sf.Gheorghe
1994	469	260	93	104
1995	526	293	100	113
1996	602	336	117	130
1997	562	317	108	125

	Nutrients	(10^3 tons/year)	
	Isaccea	BlackSea	Aquatic complexes
1994	1028	998	2.94%
1995	1109	1064	4.05%
1996	1254	1210	3.46%
1997	1160	1129	2.68%

Figure 22. Nutrients transport to Black Sea

4. References

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