NUTRIENT EMISSIONS FROM DIFFUSE AND POINT SOURCES INTO THE RIVER DANUBE AND ITS MAIN TRIBUTARIES FOR THE PERIOD OF 1998-2000 – RESULTS AND PROBLEMS.

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ABSTRACT

Nutrient emissions by point and diffuse sources were estimated for 388 sub-catchments of the Danube river basin for the period 1998-2000 by means of the Model MONERIS. For nitrogen total emissions of 684 kt/a N were estimated for the Danube basin. 80% of these emissions were caused by diffuse sources (mainly groundwater, urban areas and tile drainage). For phosphorus the emission was 57 kt/a P, with a contribution of diffuse sources to this sum of 58%. The comparison of calculated and observed loads shows that the mean deviation for the investigated sub catchments of the Danube river basin is 20% for dissolved inorganic nitrogen and 34% for phosphorus. The spatial resolution of the emission calculations allows the identification of regional hot spots and the derivation of specific regional measures to reduce the emissions into the Danube and consequently into the Western Black Sea.

INTRODUCTION

The Danube river basin covers an area of about 802,890 km² and includes thirteen countries (small portions of five other countries also belong to the watershed) with a total population of 83 million people. The Danube is the largest river discharging into the Black Sea, with an average annual outflow of 6800 m³/s. It also provides the highest sediment and nitrogen load (Jaoshvili, 2002; GEF, 1996). The nutrient discharges increased manifold from the early sixties up to the late eighties (Somlyody *et al.*, 1999) causing the eutrophication of rivers and, especially, the Western Black Sea and its coastal areas, which are strongly influenced by the Danube. Effective measures to reduce nutrient inputs needs the knowledge of quantities, sources and regional distribution within the sub-basins. The nutrient state of a river system depends on natural characteristics, the level and structure of the nutrient emitted into the river system, caused by both geogenic background and anthropogenic activities. The analysis of the present state of input and load at different scales within the river basin is an important prerequisite for deriving quality criteria and management plans.Estimations of nutrient emissions in the Danube river basin have been carried out at a national level using different databases and methods (EU/AR102A91, 1997; Haskoning, 1994). A highlighted shortcoming of the improved emissions estimates is the approach for quantification of the fluxes is not the same of all countries involved (Zessner and Gils, 1999). The main objectives of the present study were: (i) to develop harmonised modelling tools for quantification of nutrient emissions (nitrogen and phosphorus) from point and diffuse sources into surface waters of a large international river system at a catchment scale, (ii) to identify the regional distribution of nutrient influx in relation to input pathways and river basins, (iii) to compare the emissions and immissions for investigated river basins and quantification of retention within the surface waters, and (iv) to assess the potential of different management options to reduce nutrient loads. This paper discusses selected results and problems related to these aspects of research.

METHODS

The model MONERIS (MOdelling Nutrient Emissions into RIver Systems) was applied to estimate the nutrient inputs by point and diffuse sources into the Danube River. This GIS oriented model was developed for the estimation of nutrient inputs by various point and diffuse sources into German river basins larger than 500 km² (Behrendt *et al.*, 2000; Behrendt *et al.*, 2002). The basic input into the model are data on discharges, data on water quality and a Geographical Information System integrating digital maps and statistical information for different administrative levels. Whereas inputs from municipal wastewater treatment plants and industrial discharges enter the river system directly, diffuse nutrient inputs arise from a number of different pathways (see Figure 1). Distinction among the inputs from the different runoff components is necessary because the nutrient concentrations within the runoff components and the processes within these runoff components are different. Consequently, MONERIS takes seven pathways into account: point sources, atmospheric deposition, erosion, surface runoff, groundwater, tile drainage and paved urban areas.

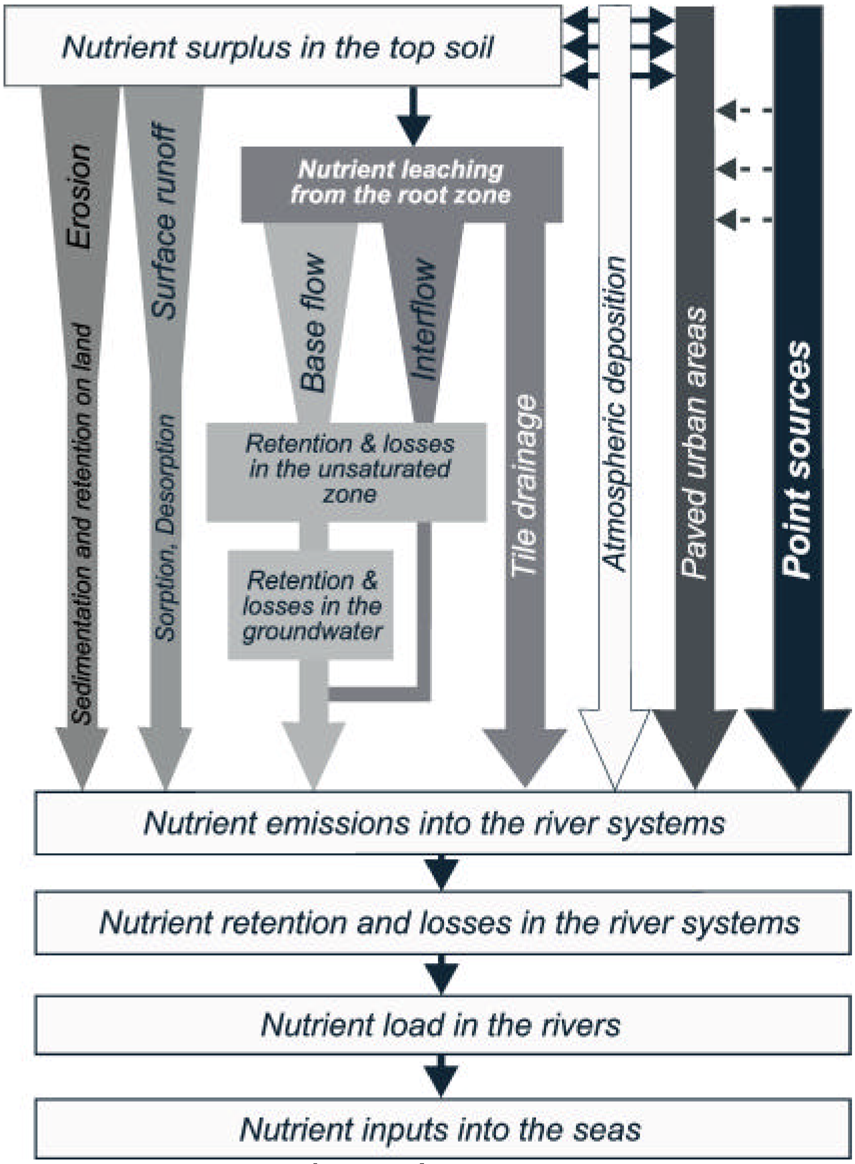

Figure 1: Pathways and processes in MONERIS.

Along the pathway from the source of the emission into the river, substances are governed by manifold processes of transformation, retention and loss. To quantify and forecast the nutrient inputs in relation to their source requires knowledge of these transformation and retention processes. The use of a Geographical Information System allows a regional differentiated quantification of nutrient emissions into river systems. Therefore, estimates were not only carried out for large river basins. Within the present study the estimations were performed with the same methodology for 388 catchments, with minor adaptations of the MONERIS model, within the whole Danube river basin. The size of the catchments varies between 70 km² to 10,000 km². The calculation was done for the time period 1998 to 2000. Information used for the emission calculations were derived by GIS-analysis, from digital maps such as land use, elevation, soil types, hydrogeology, administrative boundaries, river net and boundaries of sub-catchments within the Danube basin. Maps on land use intensity, indicated by nitrogen surplus for example, were created on an administrative level by linking statistical data with the best available resolution, respectively. Information on municipal waste water treatment plants and direct industrial discharges were also implemented in the GIS. The results of calculations are presented aggregated for the major sub-basins grouped according to the International Commission for the Protection of the Danube River (ICPDR, 2000) (Figure 2).

RESULTS AND DISCUSSION

The total phosphorus (P) emissions into the Danube river basin were about 57,220 t/a P in the period 1998-2000 (Table 1). These were dominated by point sources, which accounted for 42% of the total phosphorus emissions. Erosion (32%), urban areas (15%) and groundwater (8.5%) were the main diffuse sources of P in the Danube basin. The other pathways, atmospheric deposition, tile drainage and surface runoff, contribute together only about 3% to the total phosphorus emissions.

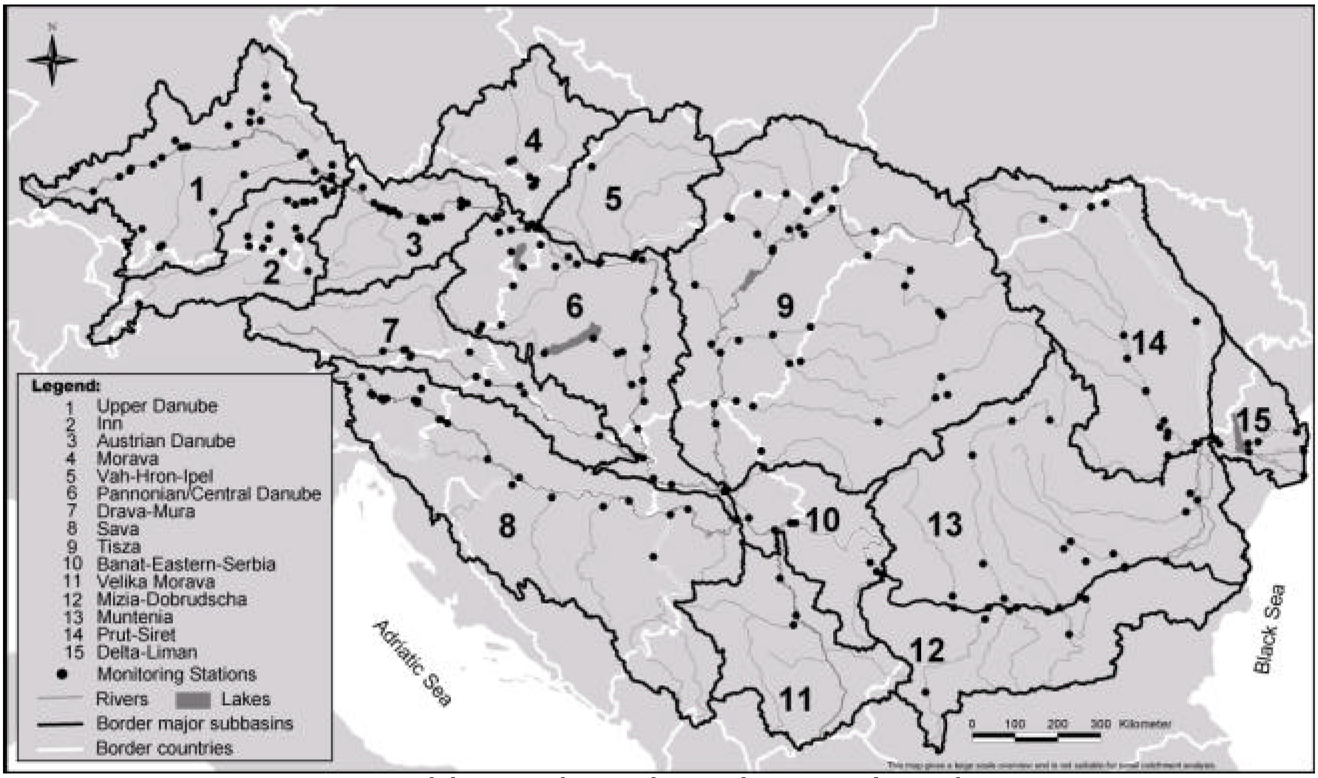

Fig. 2: Major sub-basins in the Danube river basin according to the ICPDR.

Table 1: Nutrient emissions by point and diffuse sources into the Danube river basin in the period 1998-2000.

		E_{Gw}	E_{Dr}	E_{Dep}	E_{Ero}	E_{Ro}	E_{Urb}	E_{Point}	Sum
Phosphorus	t/yr	4860	410	600	18170	660	8520	24000	57220
	%	8.5	0.7	1.1	31.8	1.1	14.9	41.9	100
Nitrogen	t/yr	358650	66970	18800	19800	13990	69320	136670	684200
	%	52.4	9.8	2.8	2.9	1.2	10.1	20.0	100

Total nitrogen (N) emissions into the river basin of the Danube were about 684,200 t/a N in the period 1998-2000. Groundwater (52%) and point sources (20%) were identified as the main sources of nitrogen emissions. The contribution of urban areas and tile drainage (10% each) were similar. Only about 7% of the nitrogen emissions come from other pathways.

Table 2 gives an overview of the specific nutrient emissions of the Danube and its tributaries in the period 1998-2000 and the share of diffuse sources at the total phosphorus and nitrogen emissions. The highest specific P-inputs were in the Inn (1150 g/ha· yr) and Banat-Eastern Serbia (1110 g/ha· yr) sub-basin; these have nearly the same populations (Table 2) but differ greatly in the portion of agricultural land (32%, 61% respectively) and surface runoff (931 mm/m²· a, 142 mm/m²· a respectively). In comparison with the other Danube river sub-basins, the portion of diffuse sources in Banat-Eastern Serbia was, with 36%, the lowest. This means that the P-inputs were mainly from point sources. The diffuse P-inputs in the Inn sub-basin e.g. have a share on the total of 54%. This underlines the fact that the P-inputs per inhabitant are much higher in the Banat-Eastern Serbia than the Inn sub-basin.

The highest specific N-inputs came from the Upper Danube (19.5 kg/ha· yr) and the Austrian Danube (12.7 kg/ha· yr). The latter followed closely by the Inn (11.8 kg/ha· yr) and Morava (10.8 kg/ha· yr) sub-basins. Whereas the portion of agricultural land in the Morava sub-basin is about 63%, the Inn sub-basin had only about half (32%) of this. The diffuse portion of N-inputs, at 94%, was the highest in the Inn sub-basin and is well above the average for the total Danube river basin (80%). The lowest portion of diffuse N-emissions (52%) was detected in the Pannonian Danube. The specific phosphorus and nitrogen inputs (710 g/ha· yr P, 8.5 kg/ha· yr N respectively) calculated by MONERIS in the Danube river basin were lower than those estimated by the same method for the river basins of the Rhine, Elbe or Odra. For the period 1993-1997 (Behrendt *et al.* 2000; Behrendt *et al.* 2002; Table 2), the specific phosphorus emissions in the Danube are estimated to be about 65% of the specific P-emissions in the Rhine and Odra basin, whereas the specific nitrogen emissions were about only 39% of the Rhine and 50% of the Elbe basin. The portion of diffuse P-inputs in the Danube river basin was 58%, which is comparable with the findings for the Elbe but much higher than in the Odra (38%) and in the Rhine for the period 1993-1997. The contribution of diffuse N-inputs of 80% in the Danube river basin was greater than the Elbe (72%), Rhine (63%) or Odra (63%).

Table 2: Major features of sub-basins and calculated specific nitrogen (N) and phosphorus (P) emissions into surface waters, the relative share of total N and P emissions by diffuse sources within the Danube and its tributaries, the Rhine, the Elbe and the Odra river basins in the periods 1998-2000 or 1993-1997.

Basin[1]	Population	Runoff	Area	Portion agricult. area	Specific emissions		Portion diffuse emissions	
					TP	TN	TP	TN
	[1000 Inh]	[mm]	[km²]	[%]	[g/ha· yr]	[kg/ha· yr]	[%]	[%]
Upper Danube	8498	480	49940	55.7	640	19.5	73.1	88.0
Inn	2344	931	26070	32.1	1150	11.8	54.3	93.8
Austrian Danube	2539	529	26240	46.3	610	12.7	83.5	87.2
Morava	3116	107	26650	63.2	730	10.8	68.2	79.6
Vah & Hron & Ipel	3204	190	29840	51.3	630	7.9	73.2	79.5
Pannonian Danube	8916	78	60370	67.1	970	7.8	44.1	52.0
Drava	3237	438	40310	40.6	700	8.6	70.2	85.3
Sava	8605	434	95890	39.8	840	8.7	51.7	81.3
Tisa	13457	218	151780	57.8	510	6.8	66.6	83.2
Banat-East.Serbia	2392	142	28940	60.6	1110	8.2	35.6	61.7
Velika Morava	3954	159	37630	33.0	720	5.0	42.8	74.3
Mizia-Dobrudscha	3760	163	54060	55.2	820	8.2	52.4	78.8
Muntenia	9947	311	82250	63.8	740	8.4	49.1	76.2
Prut-Siret	6976	167	73470	56.6	530	5.4	81.8	84.6
Delta-Liman	1213	8	19450	71.3	410	3.1	68.4	74.0
Danube total	82158	269	802890	53.7	710	8.5	58.1	80.0
Rhine²*	45767	530	159710	48.6	1270	50.9		63.1
Elbe*	21043	158	134860	60.2	908	60.1		72.3
Odra*	15836	148	118580	62.0	1080	37.9		63.6

**investigation period 1993-1997; [1]Basins according to ICPDR (2000); [2] Station Bimmen/Lobith at the German-Dutch Border.*

Figure 3 presents the portion of the pathways to the total phosphorus and nitrogen emissions by sub-basins of the Danube river system in the period 1998-2000. The highest proportional inputs from point sources for both P and N were found in the Pannonian Danube and Banat-Eastern Serbia. A high percentage of nearly 60% of nitrogen inputs by point sources originates also in the Velika Morava sub-basin. The diffuse source, which contributes in all sub-basins with a high percentage to the phosphorus emissions, is erosion. The highest portions were observed in the upper part of the Danube river basin in the Upper Danube, Inn, Austrian Danube, Morava, and Drava sub-basins as well as in the Prut-Siret sub-basin. These are sub-basins with a high portion of arable land at the total catchment area and/or with high slopes in the catchment area. High P-contents in the topsoil are also responsible for the occurrence of high P-inputs by erosion where the share of arable land at the total catchment area is high. P-inputs from urban areas contribute also to a high percentage to the total P-emissions. This pathway dominates especially in the Pannonian Danube, the Tisa and the Velika Morava.

The dominant pathway for diffuse N-inputs is groundwater for all sub-basins, with the exception of the Delta-Liman where atmospheric deposition was highest contributor. This is because of the high water surface area in this sub-basin. The share of N-inputs by groundwater is also very low in the Pannonian Danube, due to the long residence time and high retention capacity in the Pannonian lowlands. The highest N-inputs by groundwater occur in the Upper Danube, Inn and Austrian Danube with a share of more than 65% from the total. Whereas in the Morava, Delta-Liman and Tisa sub-basin an important source of the total N-inputs is by tile drainage, in the Pannonian Danube and Velika Morava the share by urban areas dominates for N-inputs. The other pathways are of minor importance; only the surface runoff has some relevance in the Inn, Austrian Danube and Drava sub-basin because of the high runoff rates in those catchments.

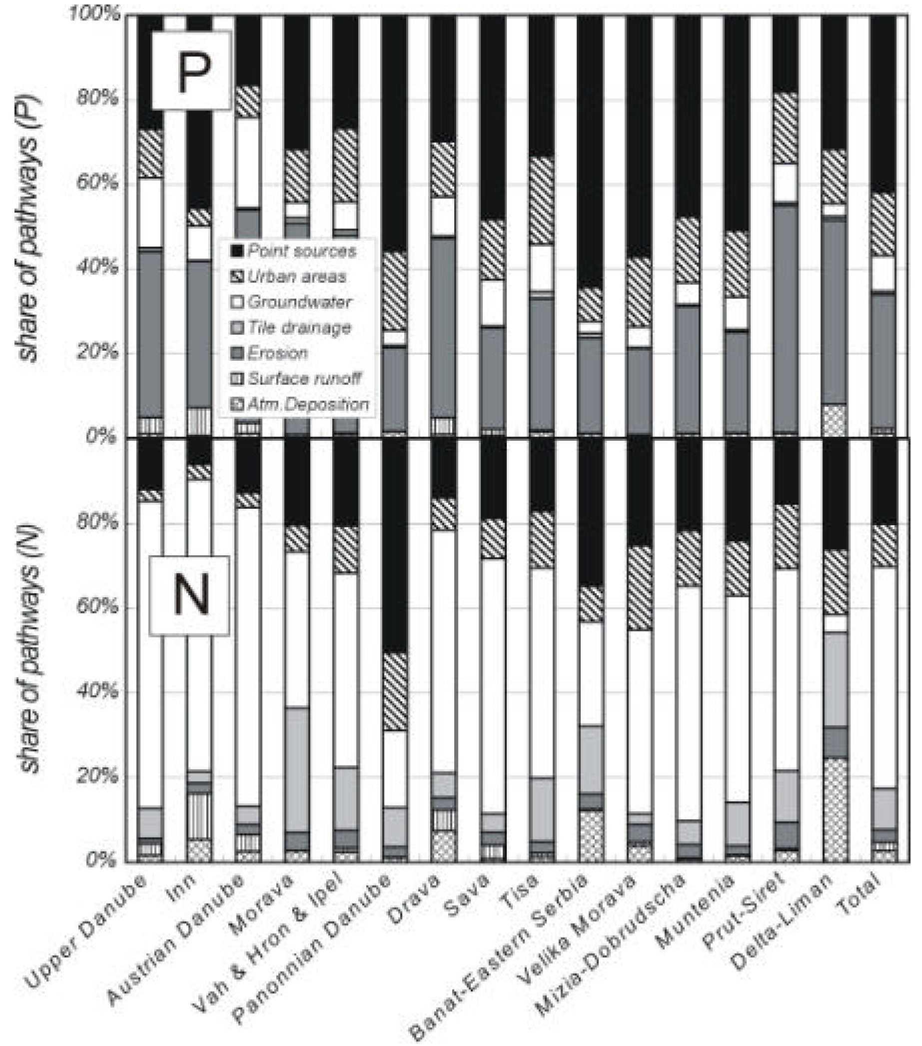

Figure 3 Portion of pathways to the total phosphorus and nitrogen emissions in the Danube river system by sub-basins in the period 1998-2000.

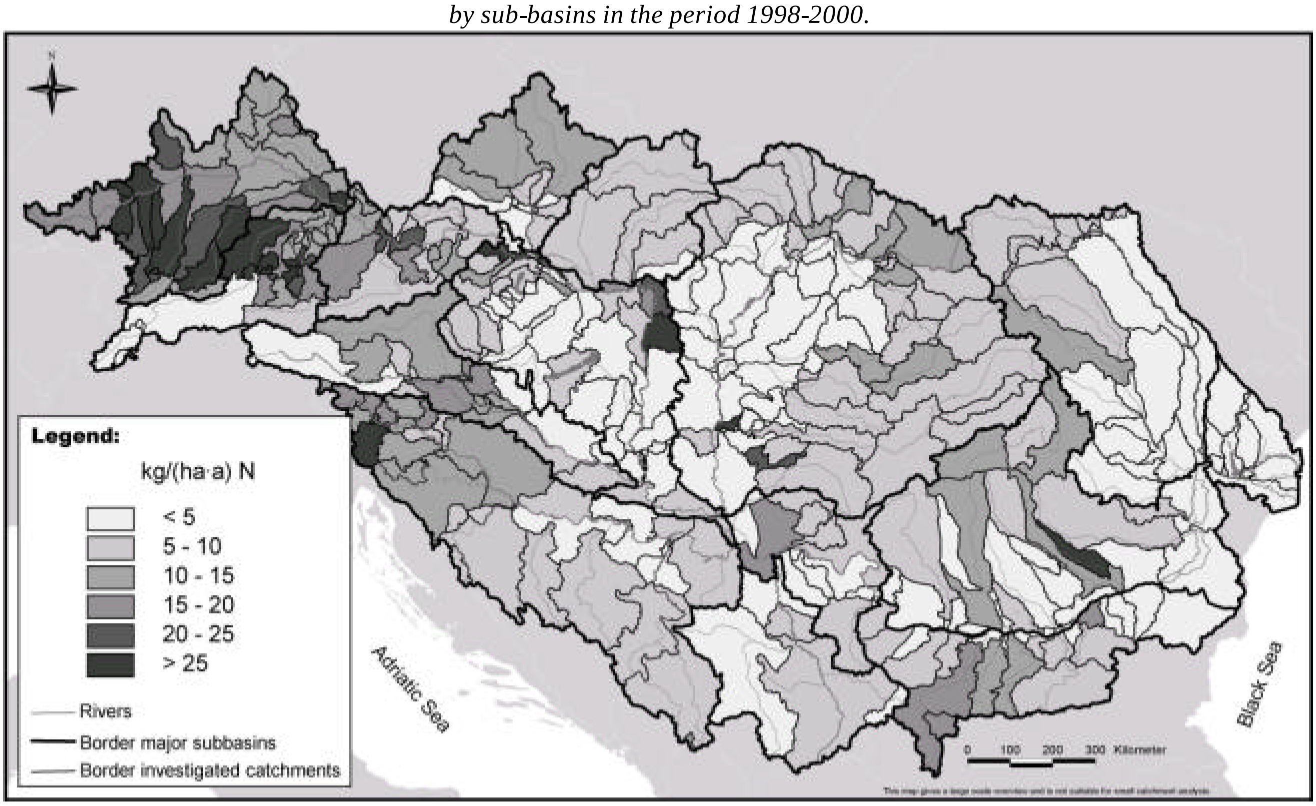

Figure 4:Regional distribution of mean specific nitrogen emissions into surface water in the Danube river basin calculated with MONERIS for the period 1998-2000.

Figure 4 presents the regional distribution by catchments of specific nitrogen emissions into surface water in the Danube river basin calculated for the period 1998-2000. The highest specific N-emissions originates from the catchments in the upper part of the Danube, as well as in the Morava, upper Sava, in the tributaries to the Tisa and upper Siret and Prut catchments ranging between 15 kg/(ha· yr) N to more than 25 kg/(ha· yr) N. High nitrogen emissions resulted also for those catchments were major cities are located like in the Danube catchments of Vienna, Bratislava, Budapest, the Iskar catchment (Sofia) and Arges catchment (Bucharest).

By application of the retention functions of MONERIS for nitrogen and phosphorus the load within the river systems of the Danube could be calculated and compared with the observed loads at 91 monitoring stations (for dissolved inorganic nitrogen, DIN) and 63 monitoring stations (for total phosphorus, TP) within the river system (Figure 5). It was found that the mean deviation between the calculated and observed nitrogen loads was 20% for dis solved inorganic nitrogen and 34% for total phosphorus. For nitrogen this deviation is comparable with the results found for the Odra basin (mean deviation DIN 23%; Behrendt *et al*. 2002) and for the German river basins (22%; Behrendt *et al*. (2000). In contrast to this, the deviation between observed and calculated total phosphorus loads was 31% for the Odra and 27% for the German river basins. From this, it is concluded that some data inputs or model approaches have to be revised for the next step of the modelling.

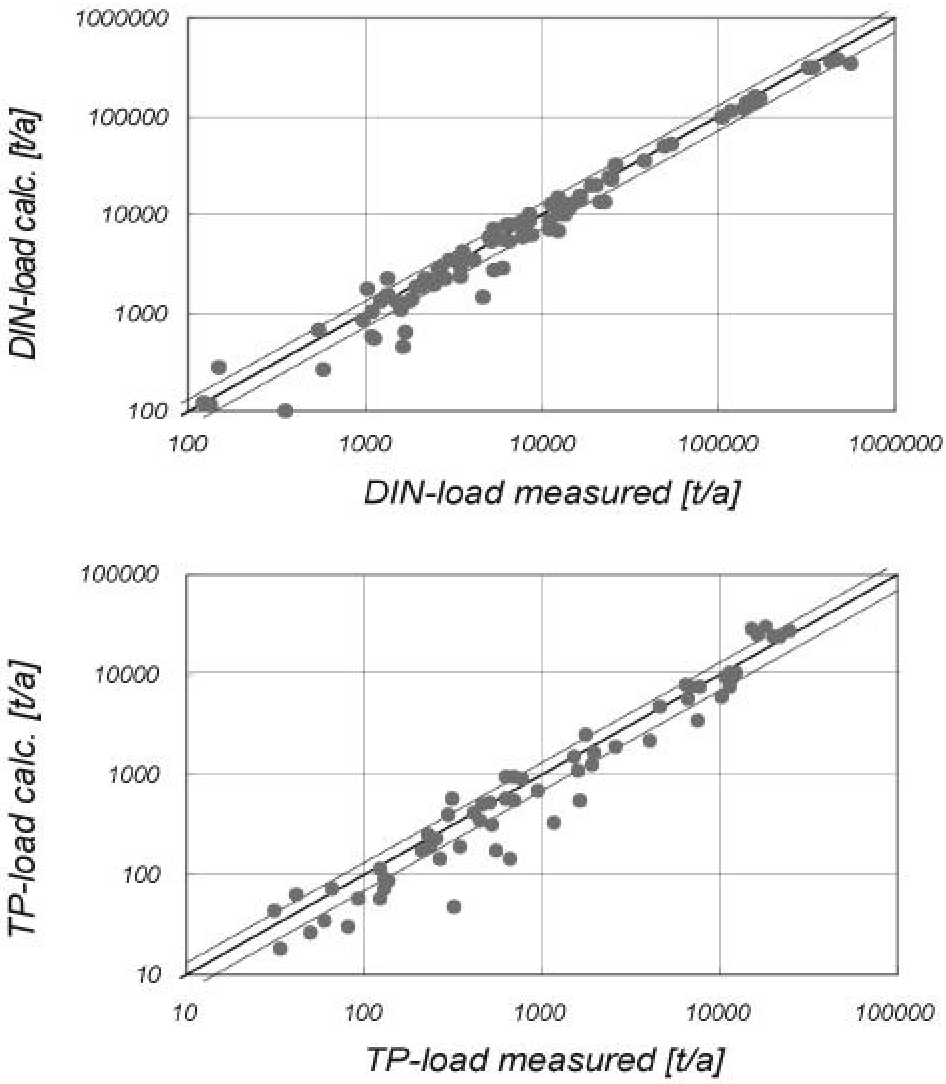

Figure 5:Comparison of observed and calculated total phosphorus loads (TP, bottom) and dissolved inorganic nitrogen (DIN, top) in the Danube and its sub catchments for the period 1998-2000.

CONCLUSIONS

The results of calculations allow the identification of regional hot spots, and the derivation of specific regional measures to reduce the emissions into the Danube and consequently into the Black Sea. Problems and uncertainties in the results are mainly caused by insufficient spatial resolution of information on erosion and hydrogeology (basin wide) and land use for Croatia, the Federal Republic of Yugoslavia, Bosnia-Herzegovina and the Ukraine. Better resolution of land use and statistical data could improve the reliability of these calculations. For derivation of best effective management measures the future research should focus on scenario calculations. In order to show possible effects of different measures on nutrient emission reductions by sources and sub-catchments, targets have to be set for the ecological status of the river system of Danube itself as well as for the Black Sea. The aimed targets for such scenario calculations should also take into account the European Water Framework Directive and the European Waste Water Directive to ensure the close connection of research results with policy and management stemming from the Danube River Protection Convention (DRCP).

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