Environmental Research of the Federal Ministry
of the Environment, Nature Conservation and Nuclear Safety

Water Research Project

Research Report 200 22 232

Harmonised Inventory of Point and Diffuse Emissions of Nitrogen and Phosphorus for a Transboundary River Basin

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Im gesamten Einzugsgebiet der Donau wurden für 388 Flussgebiete die Nährstoffemissionen von punktuellen und diffusen Quellen für den Zeitraum 1998-2000 mit Hilfe des Modellsystems MONERIS quantifiziert. Das Modell erlaubt die Abschätzung von 6 verschiedenen diffusen Eintragspfaden und berücksichtigt darüber hinaus die Einträge aus kommunalen Kläranlagen und durch industrielle Direkteinleiter. Für Stickstoff konnten für den Zeitraum 1998-2000 im Donaugebiet Einträge von insgesamt ca. 690 kt/a ermittelt werden, davon 80 % aus diffusen Quellen. Für Phosphor betrugen die Einträge im gleichen Zeitraum 67,2 kt/a, wovon 64 % auf diffuse Quellen entfielen. Der Vergleich von gemessenen und beobachteten Frachten für die untersuchten Flussgebiete zeigt eine mittlere Abweichungen von 21 % für Stickstoff und 30 % für Phosphor. Die regionale Auflösung der Eintragsberechnungen erlaubt die Identifikation von Schwerpunkten der Nährstoffbelastung und die Ableitung gebietsspezifischer Maßnahmen.</td></tr>
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Stickstoff- und Phosphoreinträge, Emissionsmethode, MONERIS, Punktquellen, diffuse Quellen, Donau, Nährstofffrachten, Retention, kommunale Kläranlagen, industrielle Direkteinleiter, atmosphärische Deposition, Abschwemmung, Erosion, Dränage, Grundwasser, urbane Flächen</td></tr>
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16. Abstract

The nutrient emissions from point and diffuse sources were estimated for 388 subcatchments of the Danube river basin for the period 1998-2000 with the model system MONERIS. The model distinguishes between six diffuse pathways and point source emissions from waste water treatment plants and direct industrial discharges. It was estimated that the total nitrogen emission into the Danube river system amounts about 690 kt/a in the period 1998 to 2000, with 80 % from diffuse sources. For phosphorus the emissions accounted for the same time period 67.2 kt/a, with a share of diffuse sources of 64 %. The comparison between measured and observed loads in the investigated subcachments shows a mean deviation of 21 % for nitrogen and 30 % for phosphorus. The spatial resolution of the emission calculations allows the identification of regional hot spots and the derivation of specific regional measures for emission reduction.

17. Keywords
nitrogen and phosphorus inputs, emission method, MONERIS, source apportionment, point sources, diffuse sources, river basins, Danube, nutrient loads, retention, municipal wastewater treatment plants, direct industrial discharges, atmospheric deposition, surface runoff, erosion, tile drainage, groundwater, urban areas

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Abbreviations

Addr.	Adress
A_{EZG}	Catchment area
AD_N	Portion of diffuse nitrogen emission
AD_P	Portion of diffuse phosphorus emission
AL	Albania
AP_N	Portion of nitrogen emission from point sources
AP_P	Portion of phosphorus emission from point sources
AT	Austria
BA	Bosnia-Herzegovina
BAV	Bavaria
BG	Bulgaria
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe
BOD	Biological oxigen demand
BUTE	Budapest University of Technology and Economics
BÜK	general soil map of Germany (Bodenübersichtskarte)
B-W	Baden-Wuerttemberg
CCC	Chemical Cordination Centre
CH	Switzerland
CLC	CORINE-land cover
COD	Chemical oxigen demand
CORINE	Coordination of information of the Environment
CZ	Czech Republic
DCW	Digital Chart of the World
DE	Germany
DEM	digital elevation model
DIN	dissolved inorganic nitrogen
DOC	dissolved organic carbon
DRPC	Danube River Protection Convention
DSMW	Digital Soil Map of the World
DWD	German Weather Service (Deutscher Wetterdienst)
$EAD_{N,P}$	nutrient emissions via atmospheric deposition
$EAD_{N,Pspec}$	area specific nutrient emissions via atmospheric deposition
$EAG_{N,P}$	nutrient emissions by agricultural impacts
$EAG_{N,Pspec}$	area specific nutrient emissions by agricultural impacts
EAG_{NIMP}	Portion of nitrogen emission caused by agricultural impact
EAG_{PIMP}	Portion of phosphorus emission caused by agricultural impact
$EBACK_{N,P}$	nutrient emissions for background conditions
$EBACK_{N,Pspec}$	area specific nutrient emissions for background conditions
$EDIF_{N,P}$	nutrient emissions via diffuse sources
$EDIF_{N,Pspec}$	area specific nutrient emissions via diffuse sources
$EDR_{N,P}$	nutrient emissions via tile drainage
$EDR_{N,Pspec}$	area specific nutrient emissions via tile drainage
EEA	European Environment Agency
$EER_{N,P}$	nutrient emissions via erosion

$EER_{N,Pspec}$	area specific nutrient emissions via erosion
$EGW_{N,P}$	nutrient emissions via groundwater
$EGW_{N,Pspec}$	area specific nutrient emissions via groundwater and natural interflow
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
EMIS	Emission (Expert Group)
$EP_{N,P}$	nutrient input via point sources
$EP_{N,Pspec}$	area specific nutrient input via point sources
$ESR_{N,P}$	nutrient input via surface runoff
$ESR_{N,Pspec}$	area specific nutrient input via surface runoff
ESRI	Environmental Research Systems Institute
$ESUM_{N,P}$	total nutrient input
$ESUM_{N,Pspec}$	area specific total nutrient input
$EURB_{N,P}$	nutrient input via urban areas
$EURB_{N,Pspec}$	area specific nutrient input via urban areas
EU	European Union
EW	population equivalent
FEA	Federal Environmental Agency
FAO	Food and Agricultural Organization of the United Nations
GIS	Geographic Information System
GLCC	Global Land Cover Characterization
GPCC	Global Precipitation Climatology Center
HU	Hungary
HR	Croatia
ICPDR	International Commission for the Protection of the Danube River
IGB	Institute of Freshwater Ecology and Inland Fisheries
IT	Italy
LfW	Landesamt für Wasserwirtschaft (State office of water management)
LfU	Landesamt für Umweltschutz (Environmental agency)
MD	Moldova
MLIM/EG	Monitoring, Laboratory and Information Management/Expert Group
MONERIS	MOdelling Nutrient Emissions in RIver Systems
N	Nitrogen
NH4-N	Nitrogen as Ammonia
NILU	Norwegian Institute for Air Research (Norsk institutt for luftforskning)
NO2-N	Nitrite as nitrogen
NO3-N	Nitrate as nitrogen
NOx-N	Nitric oxides as nitrogen
OECD	Organization for Economic Cooperation and Development
ORNL	Oak Ridge National Laboratory
P	Phosphorus
PL	Poland
PO_4	Phosphate
PO4-P	Phosphorus as phosphate
RIVM	National Institute of Public Health and the Environment (Rijksinstituut voor Volksgezondheid en Milieu)
RO	Romania

SI	Slovenia
SK	Republic of Slovakia
SS	Suspended solids
TNMN	Trans National Monitoring Network
TOC	Total organic carbon
TOT-N	Total nitrogen
TOT-P	Total phosphorus
TP	Total phosphorus
TPE	Total population equivalents
UA	Ukraine
UNESCO	United Nations Scientific, Educational and Cultural Organization
U.S.	United States
USGS	United States Geological Survey
USLE	uniformed soil loss equation
VITUKI	Water Resources Research Centre (Vízgazdálkodási Tudományos Kutató Rt.)
WFD	(EU) Water Framework Directive
WWTP	waste water treatment plant
YU	Yugoslavia (Serbia and Montenegro)

Abbreviations used in Formulas

a	unit conversion factor
a, b	model coefficients (formula 3.46)
A_{AG}	agricultural area
A_{AL}	arable land
A_{AR}	area of arable land
A_{B}	area of bog soil
A_{CA}	catchment area
a_{COM}	proportion of total urban area in commercial use
A_{DR}	drained area
A_{DRB}	area of drained bog soil
A_{DRF}	area of drained fen soil
A_{DRL}	area of drained loams
A_{DRS}	area of drained sandy soil
A_{EZG}	catchment area
A_{FOR}	area of forest
A_{F}	area of fen soil
a_{IMP}	share of precipitation realized as surface runoff from impervious urban areas
A_{L}	area of loamy soil
A_{GRAS}	grassland area
A_{HRT}	area of different hydrogeologically rock types
A_{IMP}	impervious urban area
A_{IMPC}	impervious urban area connected to combined sewer system
A_{IMPN}	impervious urban area connected neither to a sewer nor to a wastewater treatment plant
A_{IMPS}	impervious urban area connected to separated sewer system
A_{IMPSO}	urban area connected only to sewers
A_{L}	area of loamy soil
A_{LN}	agricultural area
A_{M}	mountain area
A_{OP}	open area
A_{RO}	areas of relevant surface runoff
A_{S}	area of sandy soil
A_{URB}	total urban area
A_{W}	total water surface area
A_{WCLC}	water surface area from CORINE-Landcover
A_{WOOP}	woodland and open area
b	model coefficient for denitrification
$C_{C_{N,P}}$	nutrient concentration in combined sewers during overflow
$C_{COM_{N,P}}$	nutrient concentration in commercial wastewater
$C_{DR_{N,P}}$	drainage water nutrient concentration
$C_{DR_{NO3-N}}$	nitrate concentration in drainage water
$C_{DRB_{N,P}}$	drainage water nutrient concentration for bog soil
$C_{DRB_{P}}$	drainage water phosphorus concentration for bog soil

$C_{DRF_{N,P}}$	drainage water nutrient concentration for fen soil
$C_{DRF_{P}}$	drainage water phosphorus concentration for fen soil
$C_{DRL_{N,P}}$	drainage water nutrient concentration for loamy soil
$C_{DRL_{P}}$	drainage water phosphorus concentration for loamy soil
$C_{DRS_{N,P}}$	drainage water nutrient concentration for sandy soil
$C_{DRS_{P}}$	drainage water phosphorus concentration for sandy soil
$C_{GW_{N}}$	nitrogen concentration in groundwater
$C_{GWAG_{SRP}}$	groundwater SRP concentration for agricultural land
$C_{GW_{NO3-N}}$	nitrate concentration in groundwater
$C_{GW_{SRP}}$	SRP concentration in groundwater
$C_{GWB_{SRP}}$	groundwater SRP concentration for bog soil
$C_{GWF_{SRP}}$	groundwater SRP concentration for fen soil
$C_{GWL_{SRP}}$	groundwater SRP concentration for loamy soil
$C_{GWS_{SRP}}$	groundwater SRP concentration for sandy soil
$C_{GWB_{N,P}}$	groundwater nutrient concentration for bog soil
$C_{GWF_{N,P}}$	groundwater nutrient concentration for fen soil
$C_{GWL_{N,P}}$	groundwater nutrient concentration for loamy soil
$C_{GW_{N,P}}$	nutrient concentration in groundwater
$C_{GWS_{N,P}}$	groundwater nutrient concentration for sandy soil
$C_{GW_{SRP}}$	SRP-concentration in groundwater
$C_{GW_{TP}}$	TP-concentration in groundwater
$C_{GWWOOP_{SRP}}$	groundwater SRP conc. for woodland and open areas
$C_{GWWOOP_{N,P}}$	groundwater nutrient concentration for woodland and open areas
c_i	measured concentration
$C_{LWPOT_{NO3-N}}$	potential nitrate concentration in leakage water for the total area with base flow
$C_{RO_{N,P}}$	nutrient concentration in surface runoff
$C_{ROAR_{N,P}}$	nutrient concentration in surface runoff from arable land
$C_{ROARABPj}$	dissolved P-concentration in surface runoff from arable land in the country j
$C_{ROFOR_{N,P}}$	nutrient concentration in surface runoff from forest
$C_{ROGRAS_{N,P}}$	nutrient concentration in surface runoff from grassland
$C_{ROOP_{N,P}}$	nutrient concentration in surface runoff from open land
$C_{ROPASTPj}$	dissolved P-Concentration in surface runoff from agricultural pasture in the country j
$C_{SW_{N}}$	nitrogen concentration in groundwater
$C_{SW_{N,P}}$	nutrient concentration in leakage water
CLS	correction factor for the long-term changes in surpluses
$DEP_{N.P}$	area specific deposition
DR	exponent for denitrification
$EAD_{N,P}$	nutrient emissions via atmospheric deposition
$ED_{N,P}$	nutrient input via diffuse sources
$EDR_{N,P}$	nutrient emissions via tile drainage
$EER_{N,P}$	nutrient input via erosion
$EGW_{N,P}$	nutrient emissions via groundwater

$EIN_{N,P}$	inhabitant specific nutrient output
$EIN_{D_{N,P}}$	inhabitant specific output of dissolved nutrients
$EP_{N,P}$	nutrient input via point sources
ER	enrichment ratio
$ER_{N,P}$	enrichment ratio for nitrogen and phosphorus
$ERO_{N,P}$	nutrient input via surface runoff
ES_{IMP}	specific nutrient emissions from impervious urban areas
$ESR_{N,P}$	nutrient input via surface runoff
$ET_{N,P}$	total nutrient input
$EUC_{N,P}$	nutrient emissions via combined sewer overflows
$EUN_{N,P}$	nutrient input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants
$EUS_{N,P}$	nutrient inputs via separate sewers
$EUSO_{N,P}$	nutrient input via impervious urban areas and from inhabitants connected only to sewers
HL	hydraulic load
h_M	mean elevation of the catchment
IN_C	number of inhabitants connected to combined sewer system
IN_N	inhabitants connected neither to sewers nor to wastewater treatment plants
IN_{SO}	inhabitants connected only to sewers
k_1	model coefficient
k_2	model coefficient
l_{CSO}	length of the combined sewer overflows
l_{SAS}	length of the sanitary sewers
L_p	average annual nutrient load in the studied period
$L_{N,P}$	nutrient load
L_y	annual load
LW	leakage water quantity
n	number of data
N	nitrogen
N_{DEP}	atmospheric nitrogen deposition
N_J	annual precipitation
N_{SOIL}	nitrogen content in topsoil
N_{SUR}	nitrogen surplus of agricultural areas
N_{TSUR}	total nitrogen surplus
p	number of years with measuring data in the study period
P	phosphorus
P_{ACCj}	long term P-Accumulation in the country j
P_{SOIL}	phosphorus content in the top-soil
P_{SU}	average precipitation in the summer half year
P_{WI}	average precipitation in the winter half year
P_Y	average annual precipitation
POP_{DEN}	population density
q	specific runoff
q_i	measured flow
Q	average runoff
Q_y	mean annual flow

Q_{AD}	atmospheric input flow
q_{COM}	specific runoff from commercial areas
Q_{COMC}	runoff from commercial areas connected to combined sewers
Q_{COMSO}	annual runoff from commercial areas only connected to sewers
Q_{DR}	tile drainage flow
q_{DR}	specific drain water flow
q_G	average yearly specific runoff
Q_{GW}	base flow and natural interflow
q_{IMP}	specific surface runoff from impervious urban areas
Q_{IMPC}	storm water runoff from combined sewer system
q_{IN}	daily wastewater output per inhabitant
q_R	rainfall runoff rate
Q_{RO}	surface runoff from non-paved areas
q_{RO}	specific surface runoff
Q_{URB}	surface runoff from urban areas
RE	discharge rate of combined sewer overflows
$R_{L_{N,P}}$	load weighted nutrient retention
$R_{N,P}$	loss or retention of nutrients
$R_{S_{N,P}}$	nutrient retention in soil
SDR	sediment delivery ratio
SED	sediment input
SER	sewage system ratio
SL	slope
SL_{CA}	mean slope of the catchment (from USGS-DEM)
SRP	soluble reactive phosphorus
SOL	soil loss
t_{RES}	mean residence time for the natural subsurface flow
V_S	storage volume
W_{TR}	proportion of dissolved human nutrient output transported to wastewater treatment plants
Z_{NST}	effective number of storm water days

Summary

The model **MONERIS** (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) was applied to estimate the nutrient emissions into the Danube river basin by point sources and various diffuse pathways. The model is based on data of river flow and water quality as well as a geographical information system (GIS), which includes digital maps and extensive statistical information.

Whereas point emissions from waste water treatment plants and industrial sources are directly discharged into the rivers, diffuse emissions into surface waters are caused by the sum of different pathways, which are realised by separate flow components (see Figure 1). This separation of the components of diffuse sources is necessary, because nutrient concentrations and relevant processes for the pathways are mostly very different. Consequently seven pathways are considered:

- point sources (discharges from municipal waste water treatment plants and direct industrial discharges)
- atmospheric deposition
- erosion
- surface runoff
- groundwater
- tile drainage
- paved urban areas

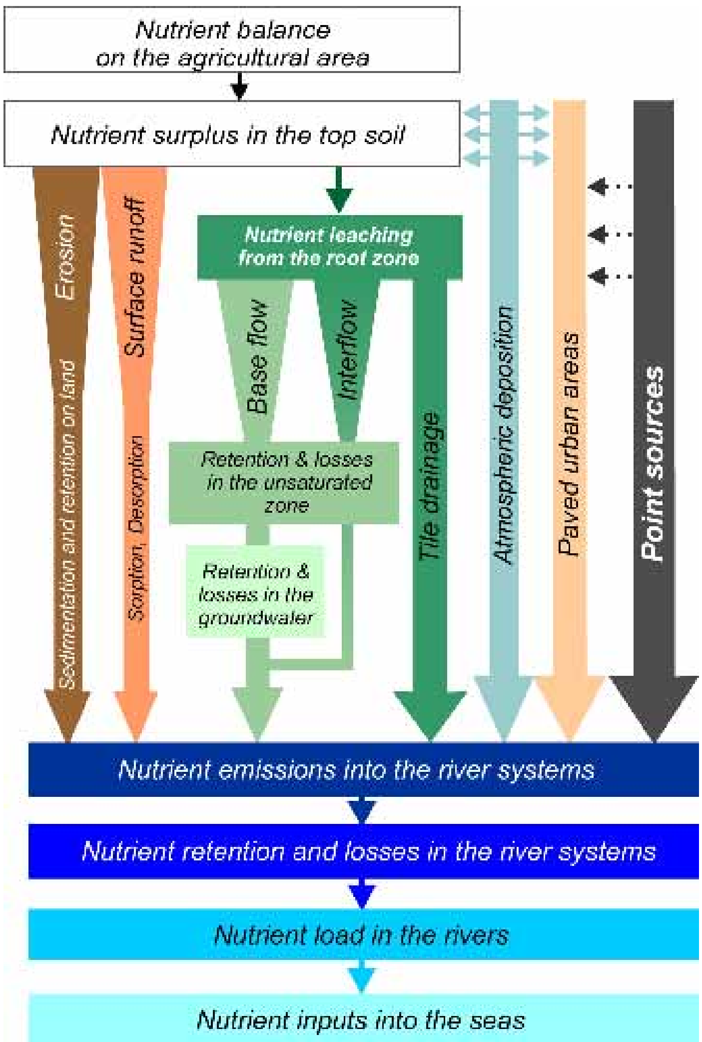


Figure 1: Pathways and processes within MONERIS.

Along the pathway from the source of the emission into the river substances are governed by manifold processes of transformation, retention and loss. Knowledge of these processes of transformation and retention is necessary to quantify and to predict nutrient emissions into the rivers in relation to their sources. The establishment of a harmonised database, the application and the adaptation of the model to the special conditions in the Danube river basin was a main task within this project and focused on the following:

- To test the application of the model for 388 subcatchment areas with a size between 10 and 16000 km².

- Establishment of a harmonised database for digital maps and statistical data for the whole Danube river basin
- Calculation of the point source discharges within the subcatchment based on the inventory of ICPDR and additional country data if available.
- To test and to adapt modules of the model regarding applicability for the Danube basin. This was necessary especially for the approaches for surface runoff.
- Introduction of a new approach for the calculation of the retention of total nitrogen within the surface waters of a catchment.

The estimation of the nutrient emissions was carried out for 388 different catchment areas covering the whole Danube river basin. For all catchments the same method was applied. The calculations were done for the time period 1998-2000.

The results of the calculations of the nutrient emissions into the largest tributaries (Drava, Sava, Tisza, upper Danube) and the whole basin of the Danube, as well as for the Danube countries are presented in Tables 1 to 2 and Figures 2 to 3.

Nitrogen emissions into the Danube river basins were about 687 kt/a N in the period 1998-2000. The input via groundwater is with 47 % the dominant pathway. The share of point sources in nitrogen emissions amounts to about 20 %. The contributions of erosion, surface runoff and atmospheric deposition to the total nitrogen emission are for the whole Danube basin below 6 % for each of these pathways.

The total phosphorus emissions into the Danube river basins were about 67.8 kt/a P in the period 1998-2000. In spite of the enormous reduction of phosphorus discharges from point sources these sources remain one dominant pathway of phosphorus emissions with 35 % in the period 1998-2000. Among the diffuse pathways, emissions by erosion dominate and represent 37 % of the total input.

Amongst the individual Danube countries and the whole Danube river basin the nutrient emissions as well as the share in the various emission pathways vary to a relatively large extent as shown in Tables 1 to 2 and Figures 2 to 3.

The highest specific nitrogen emissions within the Danube basins were detected with 19.2 kg/(ha·a) N for the Upper Danube due to high emissions from agricultural sources and low retention of nitrogen in the unsaturated zone and in groundwater. For phosphorus the tributaries with the highest specific emissions are the Iskar (1.8 kg/(ha·a) P) and the Arges (2.1 kg/(ha·a) P mainly due to the large point source emissions of the capitals Sofia and Bucharest. The area with the lowest specific nitrogen and phosphorus emissions is the Delta-Liman with 0.35 kg/(ha·a) P and 3.2 kg/(ha·a) N.

The nutrient loads, calculated from the measured flow and nutrient concentrations, show similar changes as the nutrient emissions for the period 1998-2000 for the investigated river basins. The nutrient emissions estimated with MONERIS compare well with the results of other authors as well as with the results of other methods of source apportionment. The deviation between the estimated diffuse nutrient emissions are in a range of 21 % for nitrogen and 29 % for phosphorus. Whereas the mean deviation between the measured and calculated nitrogen loads is in the same range as found for other river catchments the deviation for the P-loads is about 5 % higher. The reason for this higher deviation could be a higher error in the measured loads as well as insufficient estimations of the P-emissions.

The estimated nutrient loads from the Danube into the Black Sea are 390 kt/a N for dissolved inorganic nitrogen, 451 kt/a N for total nitrogen and 22 kt/a P for phosphorus, if an additional retention of 8.3 kt/a P is assumed within the Iron Gate reservoir.

From the comparison of the nutrient emissions with the estimated loads a retention in the surface water systems of 237 kt/a N for nitrogen and 46 kt/a P for phosphorus was calculated. This is mainly due to denitrification for nitrogen and sedimentation of phosphorus within the river or in the floodplains and reservoirs.

In general, the analysis has shown that a modelling of the nutrient emissions and loads is possible for such a large transboundary river system like the Danube. The quality of the results allow the conclusion that the model can be used for scenario analysis for the reconstructions of changes in the past and the

Figure 2: Phosphorus and Nitrogen emissions via the various pathways into the Danube river basins and its main tributaries in the time periods 1998-2000.

effect of measures on the nutrient loads in the future. Beside the reached consistency and quality of the model results a further need for the improvement of the database is necessary. This should be focused on the following topics:

- Enlargement of the point source inventory by all cities of 2000-10000 inhabitants including more data on the existing sewer systems.

- Increase of the spatial resolution for the estimation of the nutrient surplus of agricultural areas by consideration of agricultural statistics for the district or regional level (SI, HR, BA, YU, BG, MD and UK).

- Establishment of a CORINE-landcover map for Croatia, Yugoslavia (Serbia & Montenegro), Ukraine and Moldova.

- Use of existing maps with higher spatial resolution especially for the soil properties and the hydrogeology.

- Establishment of a harmonized soil erosion map for the whole Danube river basin.

- Implementation of further data and results of analysis from the region into the model.

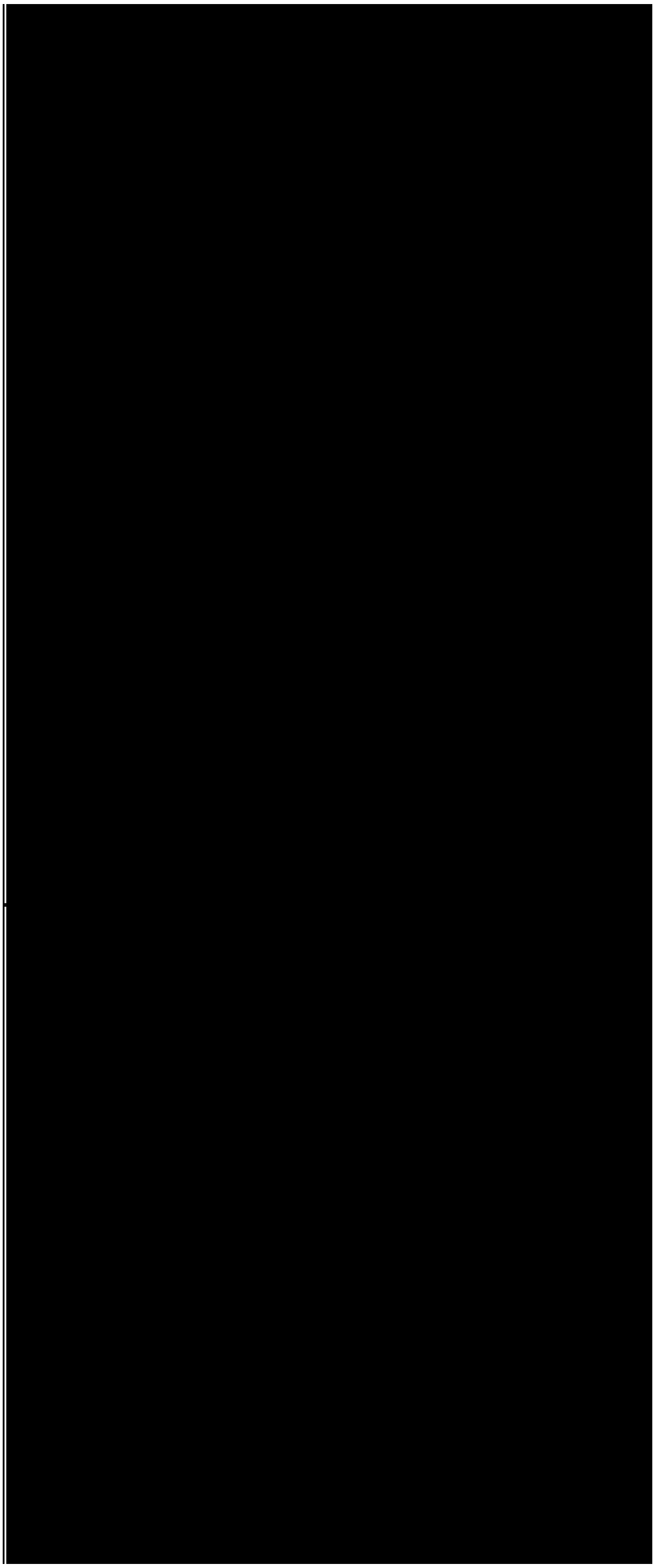


Figure 3: Phosphorus and Nitrogen emissions via the various sources into the Danube river basins and its main tributaries in the time periods 1998-2000.

Table 1: Nitrogen emissions via various pathways, their contributions to the total emissions for the Danube and the parts of the countries within the Danube river basin for the period 1998-2000.

		DE	AT	CZ	SK	HU	SI	HR	BH	YU	RO	BG	UK	MD	Rest	Danube
Groundwater	[t/a]	80540	31870	10050	16650	5580	14280	17010	14740	18720	73250	22910	300	18580	310	324780
	[%]	71,4	39,5	36,5	41,4	12,3	59,8	59,3	57,6	33,6	44,8	51,1	6,9	63,6	16,1	47,2
Tile drainage	[t/a]	7510	3370	8060	6090	5820	810	0	690	2710	22390	2450	1490	2070	10	66970
	[%]	6,7	4,2	29,3	15,2	12,9	3,4	0,0	2,7	4,9	13,7	5,5	34,4	7,1	0,5	9,7
Erosion	[t/a]	1870	2880	1540	2200	1840	540	1180	1870	2830	7340	2040	820	1440	130	28520
	[%]	1,7	3,6	5,6	5,5	4,1	2,3	4,1	7,3	5,1	4,5	4,6	18,9	4,9	6,8	4,1
Surface runoff	[t/a]	4620	20750	220	1030	150	1350	1090	1560	1540	5420	1150	0	2230	1360	42480
	[%]	4,1	25,7	0,8	2,6	0,3	5,7	3,8	6,1	2,8	3,3	2,6	0,0	7,6	70,8	6,2
Atmospheric deposi-tion	[t/a]	2310	1830	500	820	3630	280	660	370	1790	4070	1070	190	1130	50	18680
	[%]	2,0	2,3	1,8	2,0	8,0	1,2	2,3	1,4	3,2	2,5	2,4	4,4	3,9	2,6	2,7
Urban areas	[t/a]	3170	3850	1660	4170	12260	2460	2390	2750	7860	20280	5760	740	1940	40	69320
	[%]	2,8	4,8	6,0	10,4	27,1	10,3	8,3	10,7	14,1	12,4	12,9	17,1	6,6	2,1	10,1
Sum diffuse sour-ces	**[t/a]**	100020	64550	22030	30960	29280	19720	22330	21980	35450	132750	35380	3540	27390	1900	550750
	[%]	88,7	80,1	80,0	77,1	64,8	82,6	77,8	85,9	63,7	81,2	79,0	81,8	93,7	99,0	80,1
Background	[t/a]	19430	30110	3190	8660	4080	6340	7620	10960	14330	37480	9840	250	9750	1380	163430
	[%]	17,2	37,4	11,6	21,6	9,0	26,5	26,6	42,8	25,7	22,9	22,0	5,8	33,4	71,9	23,8
Agricultural diffus sources	[t/a]	76500	29860	16980	17800	11490	10810	12060	8120	12540	73370	19350	2470	15250	460	310550
	[%]	67,8	37,0	61,7	44,3	25,4	45,3	42,0	31,7	22,5	44,9	43,2	57,0	52,2	24,0	45,2
Sum of point sources	**[t/a]**	12780	16050	5500	9210	15930	4160	6370	3610	20220	30780	9420	790	1830	20	136670
	[%]	11,3	19,9	20,0	22,9	35,2	17,4	22,2	14,1	36,3	18,8	21,0	18,2	6,3	1,0	19,9
Sum of all sources	**[t/a]**	112800	80600	27530	40170	45210	23880	28700	25590	55670	163530	44800	4330	29220	1920	687420
	[%]	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

Table 2: Phosphorus emissions via various pathways, their contributions to the total emissions for the Danube and the parts of the countries within the Danube river basin for the period 1998-2000.

		DE	AT	CZ	SK	HU	SI	HR	BH	YU	RO	BG	UK	MD	Rest	Danube
Groundwater	[t/a]	611	458	56	202	315	193	243	304	375	1119	222	19	331	6	4455
	[%]	12,8	6,4	2,7	5,0	4,5	9,5	7,4	8,8	4,0	7,0	4,3	2,3	13,6	2,8	6,6
Tile drainage	[t/a]	30	17	23	44	50	4	0	9	32	137	16	8	17	0	407
	[%]	0,6	0,2	1,1	1,1	0,7	0,2	0,0	0,3	0,3	0,9	0,3	1,0	0,7	0,0	0,6
Erosion	[t/a]	1935	3256	1177	1925	1776	475	905	1375	2138	7016	1899	551	1005	164	25597
	[%]	40,7	45,7	55,7	48,0	25,4	23,4	27,6	39,8	23,0	43,8	36,4	66,6	41,4	77,0	37,8
Surface runoff	[t/a]	610	832	41	173	46	192	254	263	206	921	246	0	375	35	4194
	[%]	12,8	11,7	1,9	4,3	0,7	9,5	7,8	7,6	2,2	5,8	4,7	0,0	15,4	16,4	6,2
Atmospheric deposition	[t/a]	38	43	12	23	121	7	22	15	69	163	41	7	42	1	604
	[%]	0,8	0,6	0,6	0,6	1,7	0,3	0,7	0,4	0,7	1,0	0,8	0,8	1,7	0,5	0,9
Urban areas	[t/a]	422	412	223	505	1689	339	421	402	968	2189	691	77	179	5	8522
	[%]	8,9	5,8	10,6	12,6	24,2	16,7	12,8	11,6	10,4	13,7	13,3	9,3	7,4	2,3	12,6
Sum diffuse sources	**[t/a]**	3646	5018	1532	2872	3997	1210	1845	2368	3788	11545	3115	662	1949	211	43779
	[%]	76,6	70,4	72,5	71,6	57,2	59,6	56,3	68,6	40,7	72,1	59,7	80,0	80,2	99,1	64,6
Background	[t/a]	580	1738	57	215	151	226	236	351	387	1190	233	11	308	165	5848
	[%]	12,2	24,4	2,7	5,4	2,2	11,1	7,2	10,2	4,2	7,4	4,5	1,3	12,7	77,5	8,6
Agricultural diffus sources	[t/a]	2606	2825	1240	2129	2036	638	1166	1600	2364	8003	2150	567	1420	40	28805
	[%]	54,8	39,6	58,7	53,1	29,1	31,4	35,6	46,3	25,4	50,0	41,2	68,6	58,5	18,8	42,5
Sum of point sources	**[t/a]**	1113	2108	580	1140	2994	819	1432	1086	5523	4462	2099	165	480	2	24004
	[%]	23,4	29,6	27,5	28,4	42,8	40,4	43,7	31,4	59,3	27,9	40,3	20,0	19,8	0,9	35,4
Sum of all sources	**[t/a]**	4759	7126	2112	4012	6991	2029	3277	3454	9311	16007	5214	827	2429	213	67783
	[%]	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0

1 Introduction

The European Water Framework Directive (WFD) demands for all river systems and the coastal zones of the European seas to reach a good ecological status within the next decade. In addition to the fact that there is an urgent need for the definition of "good ecological status", one of the most important tasks will be to evaluate the present status of the ecosystems and the point and diffuse sources of the polluting emissions into these systems. Based upon this analysis of the present state and comparison with the target state, appropriate measures have to be developed in order to reach the necessary good ecological status. Costs can then be estimated for the implementation of the measures.

During the last decade significant progress was made with this process for national rivers, especially for the nutrients phosphorus and nitrogen. However, it has been unclear which tools and models can be used for the analysis of large transboundary river systems where it is especially necessary to establish far as possible a unified database and harmonised model approach. Without this unification and harmonisation there is a risk that evaluation of the present situation, and the subsequent development of proposed measures, will differ greatly due to the application of different tools for the individual regions of the river system.

An analysis of the Odra river basins (Behrendt et al., 2003) showed that the MONERIS model for the estimation of the point and diffuse nutrient emissions into medium and large river systems can be used also for such a task outside of German river systems. But the Odra is a relatively simple example of a European transboundary river system since the basin is dominated by one country (Poland) and the hydrological conditions are actually similar to some river systems of Eastern Germany.

The analysis of the point and diffuse emissions within the Danube basins is, compared to the Odra, a much more difficult task since the Danube is the second largest river system in Europe and about 7 times larger than the Odra. Furthermore, a total of thirteen countries have to be taken into account with a wide range of socio-economic conditions, while the hydrological situation differs very much in parts of the Danube basin in comparison to German river basins.

In order to address these issues a project funded by the German Environmental Agency was started in 2000. The project was focused on three objectives. Firstly, the tools and models that have been developed for each emission source needed to be tested in the Danube basin for their description of the nutrient flow from the emission sources to the riverine transport systems. Secondly, a harmonised spatial digital database for the whole Danube basin was to be prepared which could be used by the International Commission for the Protection of Danube River (ICPDR) for further analysis. Thirdly the established harmonised database was to be used in combination with the model to estimate possible changes of the nutrient state of the Danube river based on upon different scenarios for diffuse and point emissions.

For the achievement of these objectives it was necessary to incorporate scientists from the most of the Danube countries into the study team and to cooperate very closely with the different working groups of the ICPDR as EMIS and TNMN.

One year after the begin of this project the EU-project daNUbs ("Nutrient management in the Danube Basin and its impact on the Black Sea"; EVK1-CT-2000-00051) was started. Within the daNUbs project our group has the task of the estimation of the nutrient emissions by point and diffuse sources within the different subcatchments of the Danube and the nutrient load within the main river system as the input for the Danube Water Quality Model (DWQM). The estimation of the nutrient emissions should be done for the present state but also for different scenarios for the further development. The cooperation within the framework of the daNUbs project and the financial support of this project was an urgent help for us to solve the manifold problems in relation to the database as well as the modification of the model approaches to such a large river basin with different climatic, hydrological and socio-economic conditions. Especially the application of the model MONERIS to different case studies in the Danube river basin by different national groups and coordinated by the University of Technology Vienna was and will be very helpful also for the modelling of the whole river basin.

Therefore we can conclude that the results presented in this report were only be possible in relation to the spatial resolution as well as the quality of the calculations by the combination of the work within both projects.

The following research report shows all of the results, which may be interesting for other scientists working in this field as well as the further work of the International Commission for the Protection of Danube River. Additionally we will derive tasks for further developments regarding the database and the modelling tools to get a better description of the present status of the nutrient emissions into the river system of Danube and availability to estimate changes of the status in the past and in the future.

2 Database

2.1 Spatial input data

For the research project the following data were made available as geo-referenced datasets that could be integrated into the GIS. For GIS presentation of these data and the calculation results, the Lambert Equal Area Azimuthal projection was used with the central meridian 20° E and the latitude of reference 55° N.

- The **river network** was taken from the *Environmental Research Systems Institute* (ESRI) "Digital Chart of the World" (1:1 Million, 1991/1992).

- The **catchment boundaries** were constructed according to the position of the river monitoring stations from the Trans National Monitoring Network (TNMN, Water Quality in the Danube River Basin 1997, TNMN Yearbook) published by the *International Commission for the Protection of the Danube River* (*ICPDR*, 2000) as well as from the position of selected monitoring stations of the Danube countries. Additionally, the catchment area boundaries from digital databases from Hungary (*Institute of Water Pollution Control, VITUKI*), Romania *(Romanian Waters, National Administration*) and Slovenia (*Environmental Agency*) were used for delineation of the catchments. The geographical location of the monitoring stations in the river network was derived from sources of very different content and quality. The primary information came either as stored coordinates in various geographic reference systems and/or as verbal descriptions of the location relative to water bodies and towns. In some individual cases, existing information about the location on the left or right river-bank was not considered because of the small scale of the river network map. Map 2.1 gives an overview of the 388 investigated catchments. This Map shows selected catchments grouped after major sub-basins according to the ICPDR and additional selected catchments for the major rivers. Table 2.1 gives an overview of selected sub-basins, respective catchments, according to the position of the monitoring stations. The size of the sub-catchments, between two monitoring stations, is normally more than 100 km² and only a few sub-catchments in border regions are smaller. The largest sub-catchment considered in this analysis is the Velika Morava at Varvarin occupying about 16,000 km². The overall catchment size of the Danube is 802,888 km².

- The **digital elevation model** (DEM) GTOPO30 from the *United States Geological Survey* (*USGS*) has a resolution of 30 arcsec (about 925 m × 570 m, resampled to 200 m × 200 m) and was used for the delineation of the catchment borders and to give an overview of the relief in the Danube river basin (Map 2.3).

- For **land use** classification, data from CORINE Land Cover (CLC) (*European Environment Agency* (EEA 1995) with a resolution of 100 m x 100 m were used, as well as data from CORINE Land Cover (CLC) (Land Cover, *European Commission*, 1996, CORINE Land Cover of Europe, *European Topic Centre on Land Cover*, Kiruna, Sweden, 1997) with a spatial resolution of 250 m x 250 m for the part of Switzerland. This data includes land use data from satellite images for the years 1989-1992 for Switzerland from the *State Statistics Offices*, the PHARE-Program of the European Union and the *European Topic Centre on Land Cover*. The original classes were aggregated for calculation to eight classes as shown in Map 2. and chapter 3.1.2.2 Table 3.5. As the information on land use is missing from CORINE for Croatia, FR Yugoslavia (Serbia and Montenegro), the Republic of Moldova and Ukraine, additional information on land cover was taken from the USGS (*United States Geological Survey,* GLCC - Version 2, 1997) (Map2.5) and used to identify land use classes in these countries according to CORINE land cover (see chapter 3.1.2.2). The spatial resolution of the USGS land cover map is 1000 m x 1000 m (based on 1-km AVHRR data spanning April 1992 through March 1993). An overview of the land use distribution in the investigated catchments is given in Table 2.. The portions in the sub-catchments in the Danube river basin differ significantly, for example for agricultural land between 61.9 % in the Morava and 14.6 % in the Inn sub-basin, and for forest between 45.4 % in the Drava-Mura, 65.9 % in the Velika Morava and 3.7 % in the Delta Liman catchments. In the catchments of Mizia-Dobrudscha and Muntenia 5.8 % are occupied by urban area, in the Austrian Danube 1.4 %.

- The Digital **Soil Map** of the World (DSMW, FAO 1997) based on the FAO/UNESCO Soil Map of the World. The original scale of 1:5 000 000 was used in terms of physico-chemical parameters such as soil texture, drainage class and nitrogen content in the upper soil layer. Map 2.6 gives an overview of the soils in the Danube River Basin grouped according to the major soil types.

- A **hydrogeological map** of Europe from the *National Institute of Public Health and the Environment (RIVM)* was used for the differentiation of consolidated and unconsolidated rock regions within the Danube catchment area (Map 2.7).

- Several **hydrometeorological** input data digital maps were created. Map 2.8 was obtained from interpolated distribution of precipitation data (monthly values, 1998-2000, spatial resolution of one arc/degree) available from the *Global Precipitation Climatology Centre* (GPCC) of the *German Weather Service* (RUDOLF et al., 2003). Map 2.9 (mean annual precipitation) and Map 2.10 (mean annual runoff) were made available by *Geodaten, Analyse & Integration* and are derived from maps at the scale 1: 200 000 published by the *Regional Co-operation of the Danube Countries (Regionale Zusammenarbeit der Donauländer)*, 1986, in "Die Donau und ihr Einzugsgebiet" part 3, Map III/3. These maps are based on meteorological and discharge data recorded mainly for the period 1931-1970. Map 2.10 was used for the calculation of the specific runoff for those catchments without data on runoff.

- Data on **atmospheric deposition** of nitrogen oxides and ammonium with a resolution of 50 km for the year 1999 were derived from the results of the *Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP)* coordinated by the *Chemical Coordinating Centre (CCC) (Norwegian Institute* *for Air Research, NILU*) and were used for calculating the total nitrogen deposition in the investigated area (Map 2.11).

The data input for **soil erosion** was provided by a digital map from *National Institute of Public Health and the Environment (RIVM)* (1995) based on the Universal Soil Loss Equation (USLE) with a resolution of 1 km was used (Map 2.12).

- The borders of the **administrative areas** (districts, regions, and countries) in the Danube Basin were available for the year 1999 from MACON, "Professional Maps and Data Sets", (1:1 Million, 1999), (Map 2.13).

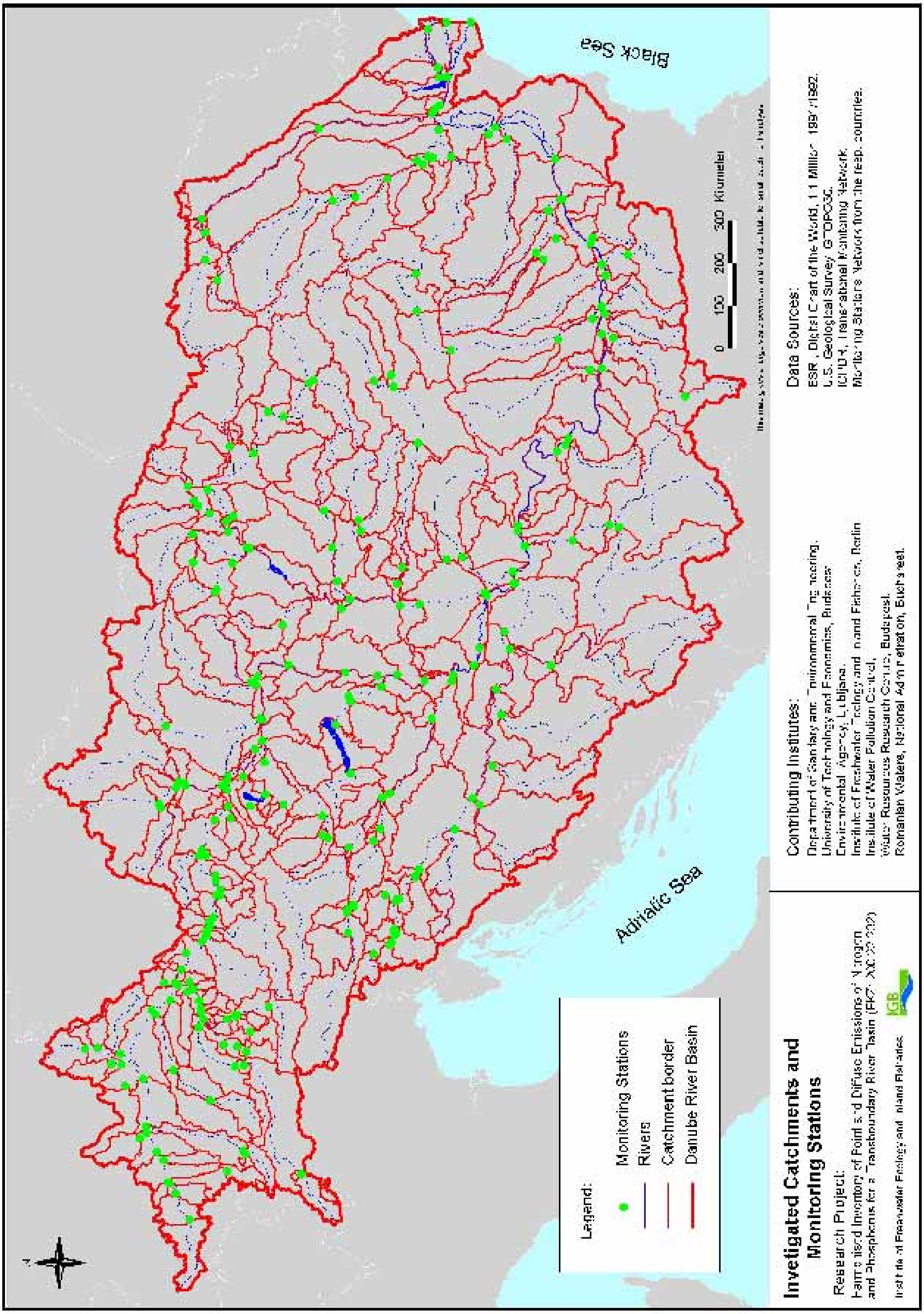
- For **population density** a digital map was created with the information on population figures (for the year 1999) available from the different national statistical offices (internet) and completed with the information from national statistical offices supplied by the national consultants (Austria) (Map 2.14). In addition a further map (Map 2.15) of population density was created from the LandScan 2000 Global Population Database developed by *Oak Ridge National Laboratory* (ORNL). The LandScan data set is a worldwide population database compiled on a 30" X 30" latitude/longitude grid. Census counts (at subnational level) were apportioned to each grid cell based on likelihood coefficients which are based on proximity to roads, slope, land cover, night time lights, and other data sets. The LandScan files are available via the internet in ESRI (*Environmental Research Systems Institute*) grid format.

- A digital map with the location of waste water treatment plants (**WWTP**) (Map 2.16) from the WWTP Inventory 2000 of the *ICPDR* was created for the calculation of the input of point sources (municipal waste water treatment plants and industrial dischargers) in the river system of the investigated catchments. The ICPDR Inventory includes for each country only the largest point sources and about 75% of the total point source emissions into the river system of the Danube. This inventory was supplied by national inventories of Germany (*LfW Bavaria,* München *and LfU Baden-Württemberg,* Karlsruhe), Slovakia (by the *Water Research Institute,* Bratislava), Hungary (by the *Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics, BUTE*) and from the inventory (former study within the PHARE-Project EU/AR102A/91 (1997) "Nutrient Balances for Danube Countries") supplied by the *Institute for Water Quality and Waste Management, University of Technology Vienna*. The latter was used to supply information on WWTP for Austria, the Czech Republic, Slovakia, Hungary, Slovenia, Bulgaria, Romania and the Ukraine which are not included in the inventories mentioned above. Map 2.17 shows the location of all point sources considered for the calculations.

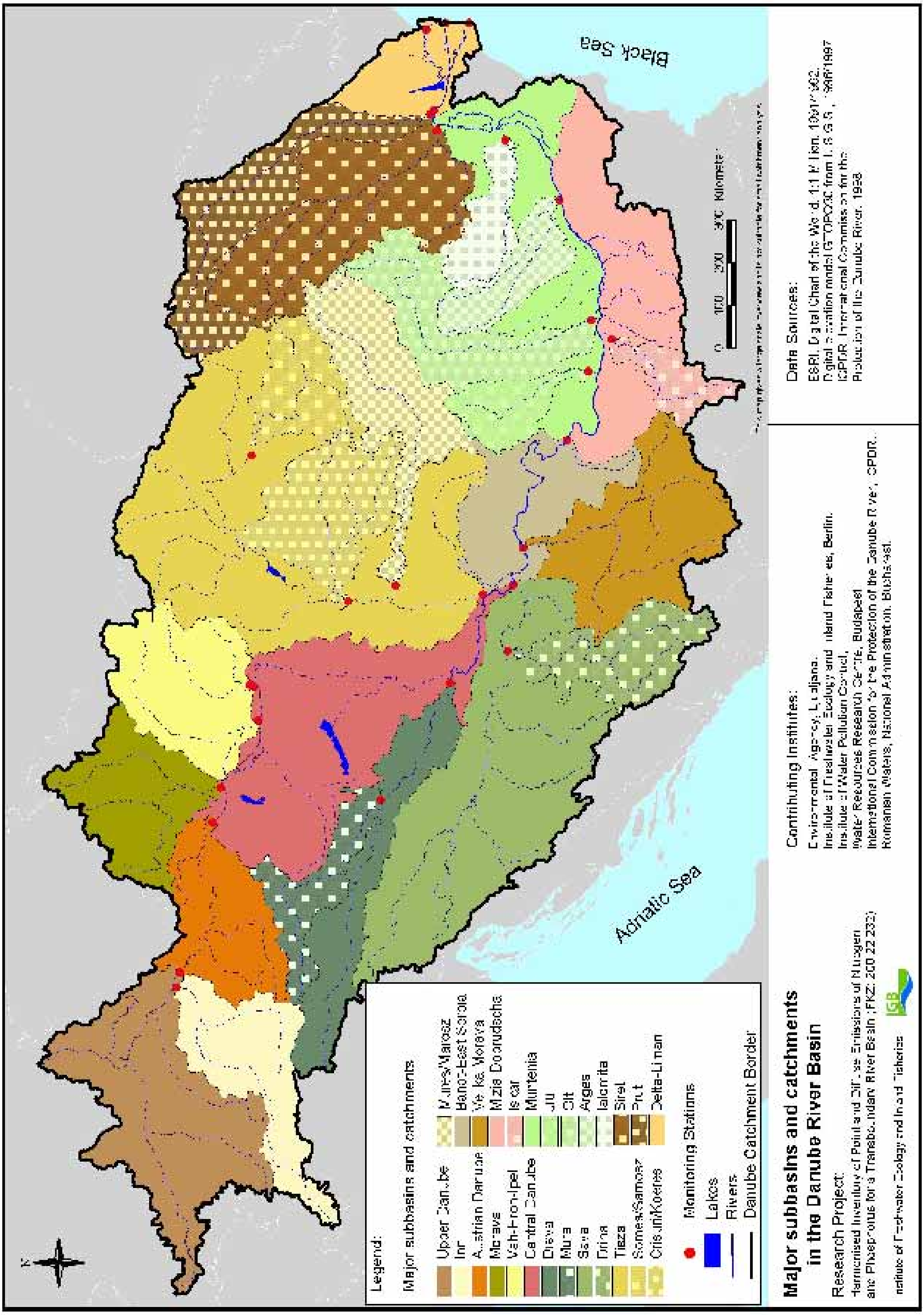
Table 2.1: Selected catchments, total catchment area, percentage of total catchment area in the different countries.

River	Station	Short name	Area	
			Catchment	country
			km²	%
Upper Danube	Jochenstein	Dan_Joc	77347	68,7 – DE; 16,1 - AT; 15,2 - CZ
Inn	Passau-Ingling	Inn_Pas	26074	31,0 - DE; 54,5 - AT; 7,1 - CH; 1,0 IT
Austrian Danube	Wien-Nussdorf	Dan_Nus	24792	100,0 - AT
Morava	Marchdorf	Mor_Mar	26645	8,8 - AT; 77,9 - CZ; 8,3 - SK
Vah-Hron	Vah-Komarno	Vah_Kom	29845	94,2 - SK; 5,8 - PL
Pannonian Central Danube	Zemun (before Belgrade)	Dan_Bel	60893	19,7 - AT; 4,0 - HR; 8,6 - YU; 2,2 SK; 65,5 - H
Drava-Mura	Osijek	Dra_Osi	40315	0,9 - IT; 55,1 - AT; 11,5 - SI; 17,3 - HR; 15,1 - H
Drava	Osijek	Dra_Osi	26250	45,5 - AT; 25,2 - HR; 12,5 - SI; 16,2 - H; 0,6 - IT
Mura	mouth section	Mur_Mouth	14065	73,6 - AT; 3,2 - HR; 9,9 - SI; 13,3 - H
Sava	Belgrad	Sav_Bel	95885	25,4 - HR; 12,3 - SI; 39,9 - BA; 22,3 - YU; 0,2 - AL
Sava	Belgrad	Sav_Bel	76271	15,4 - SI; 31,9 - HR; 11,9 - YU; 40,7 - BA
Drina	Crna Bara	Dri_Crn	19614	0,8 - AL; 62,5 - YU; 36,7 - BA
Tisa	Titel	Tis_Tit	151775	8,0 - UA; 10,0 - SK; 28,5 - H; 48,3 - RO; 5,2 - YU
Somes/Szamos	Oar (Border)	Som_Oar	15374	100,0 - RO
Crisuri/Koeroes	Magyartes	Koe_Mag	25414	45,5 - H; 55,5 - RO
Mures/ Maros	Mako	Mar_Mak	28650	1,9 - H; 98,1 - RO
Banat-Eastern Serbia	Prahovo	Dan_Pra	28940	33,4 - RO; 66,6 - YU
Velika Morava	mouth section	Vel_Luc	37634	97,0 - YU; 3,0 - BG
Mizia-Dobrudscha	Silistra/Chiciu	Dan_Chi	54060	100,0 - BG
Iskar	Orechovitza	Isk_Ore	8256	100,0 - BG
Muntenia	Conf. Danube Giurgiulesti	Dan_Giu	82250	100,0 - RO
Jiu	Zaval	Jiu_Zav	9964	100,0 - RO
Olt	Izbiceni	Olt_Izb	24253	100,0 - RO
Arges	Clatesti/Conf. Dan	Arg_Cla	12576	100,0 - RO
Ialomita	Tandarei	Ial_Tan	10287	100,0 - RO
Prut-Siret	Conf. Danube Giurgiulesti	Pru_Giu	73470	10,7 - MD; 73,7 - RO; 15,6 - UA
Prut	Conf. Danube Giurgiulesti	Pru_Giu	28581	31,9 - UA; 38,5 - RO; 27,8 - MD
Siret	Sendreni	Sir_Sen	44892	100,0 - RO
Delta-Liman	Sulina	Dan_Sul	19450	29,3 - RO; 28,6 - MD; 42,3 - UA

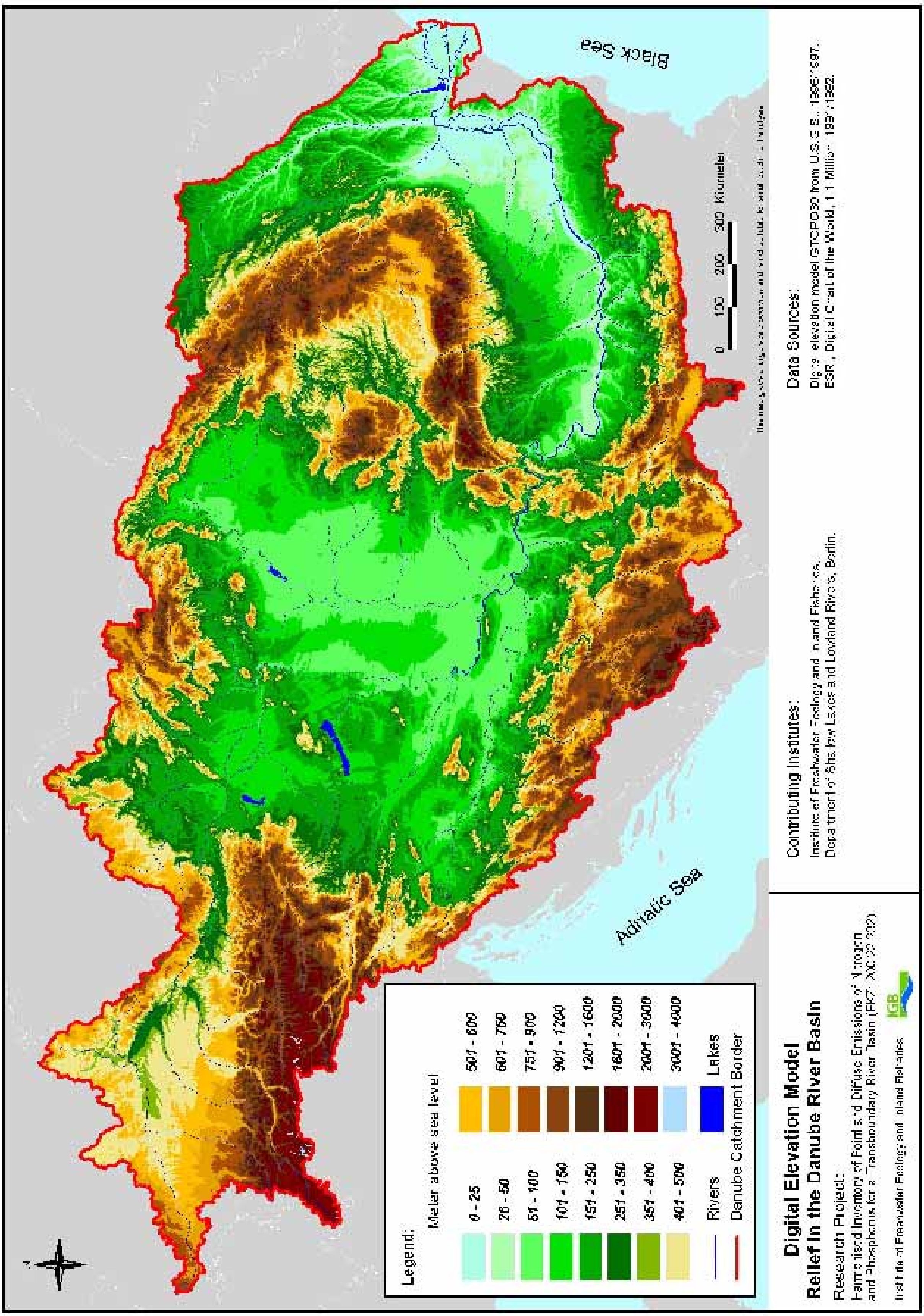
DE - Germany, AT - Austria, CZ - Czech Republic, SK - Republic of Slovakia, H - Hungary, SI - Slovenia, HR - Croatia, BA - Bosnia-Herzegovina, YU – Yugoslavia (Serbia and Montenegro), BG - Bulgaria, R - Romania, UA - Ukraine, MD - Moldova, IT - Italy, CH - Switzerland, PL - Poland, AL - Albania.



Map 2.1: Investigated catchments and monitoring stations.



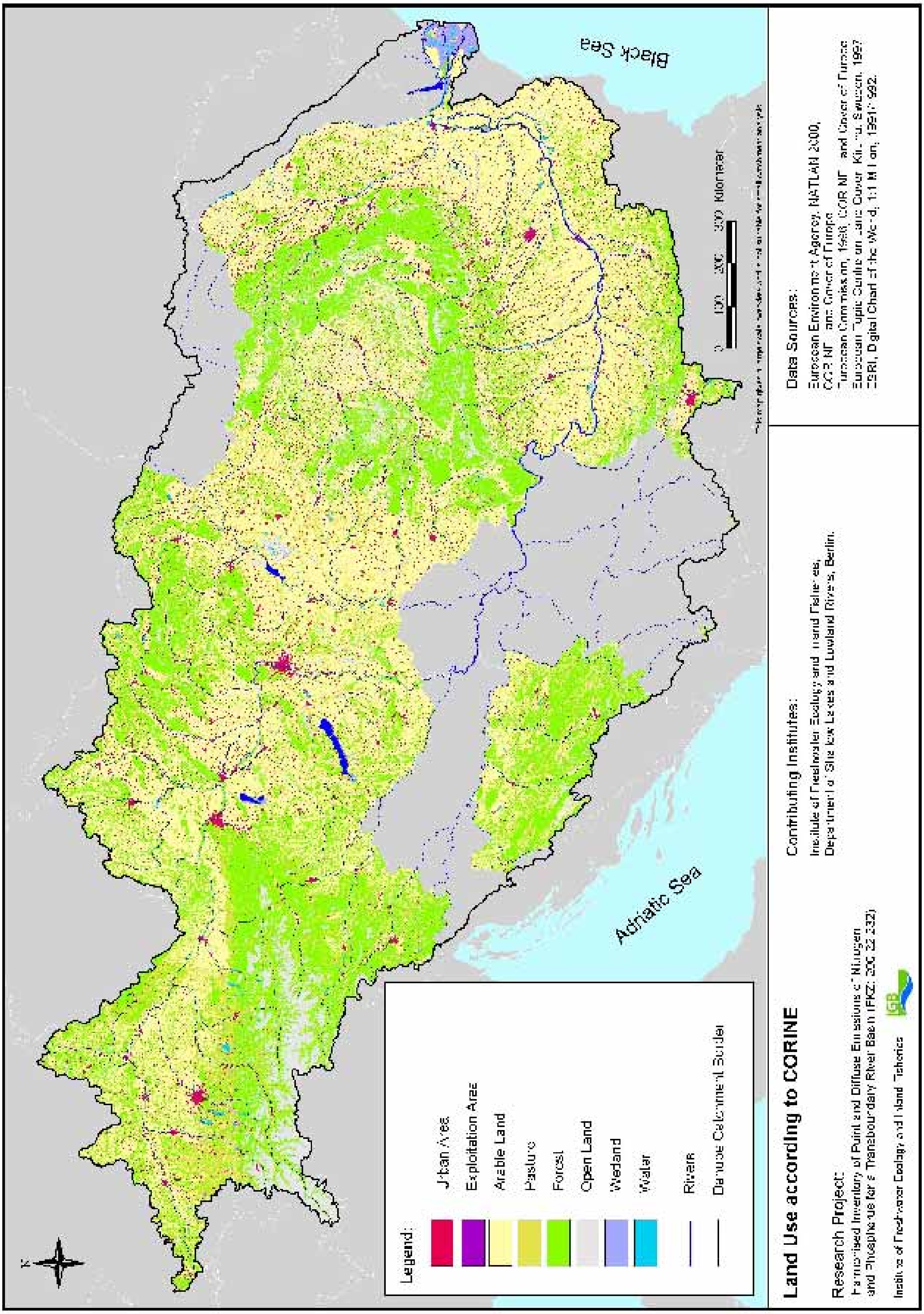
Map 2.2: *Major subbasins and catchments in the Danube River Basin.*



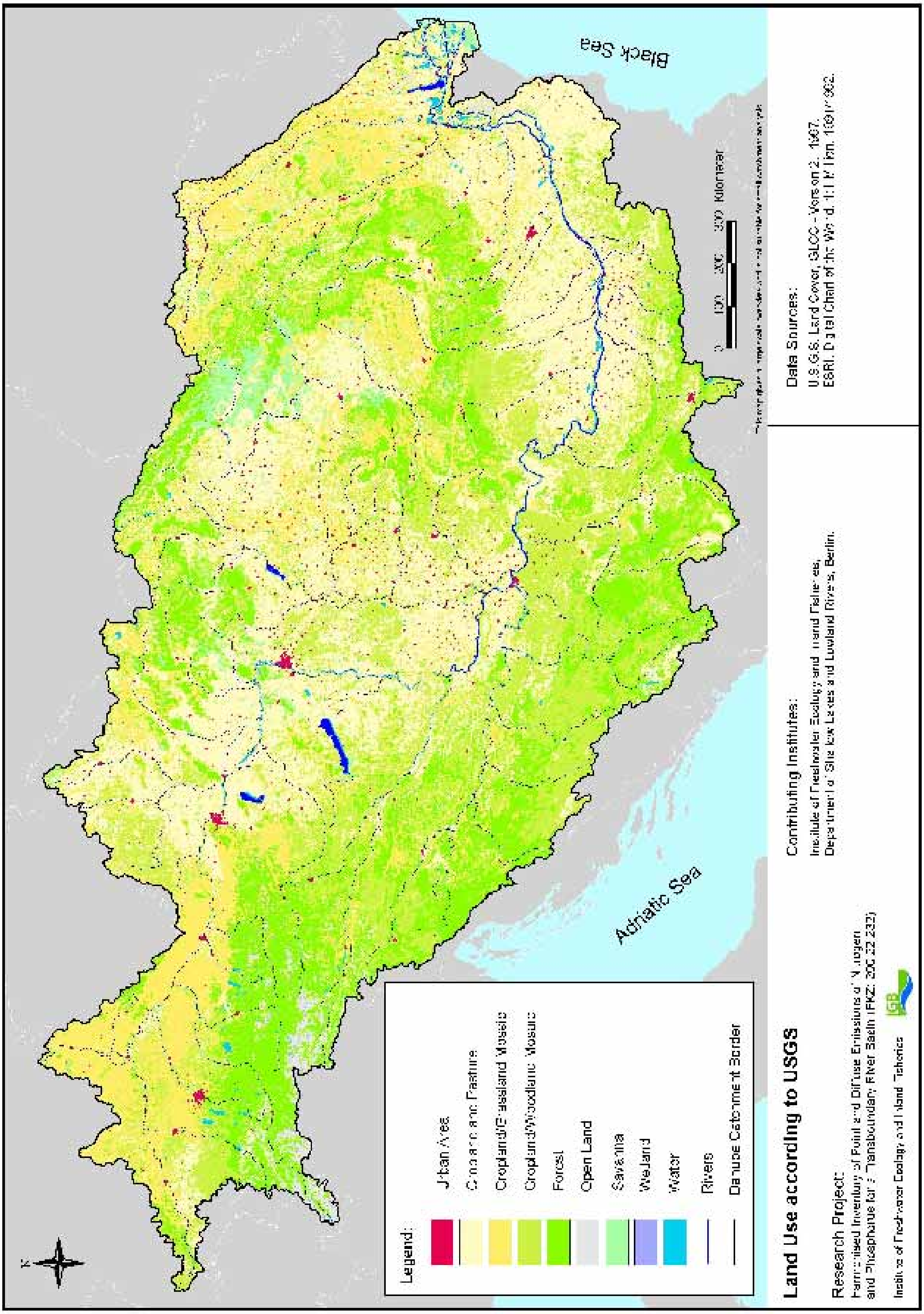
Map 2.3: Digital elevation model (USGS GTOPO30).

Table 2.2: Land use distribution in the Danube River Basin for selected subbasins.

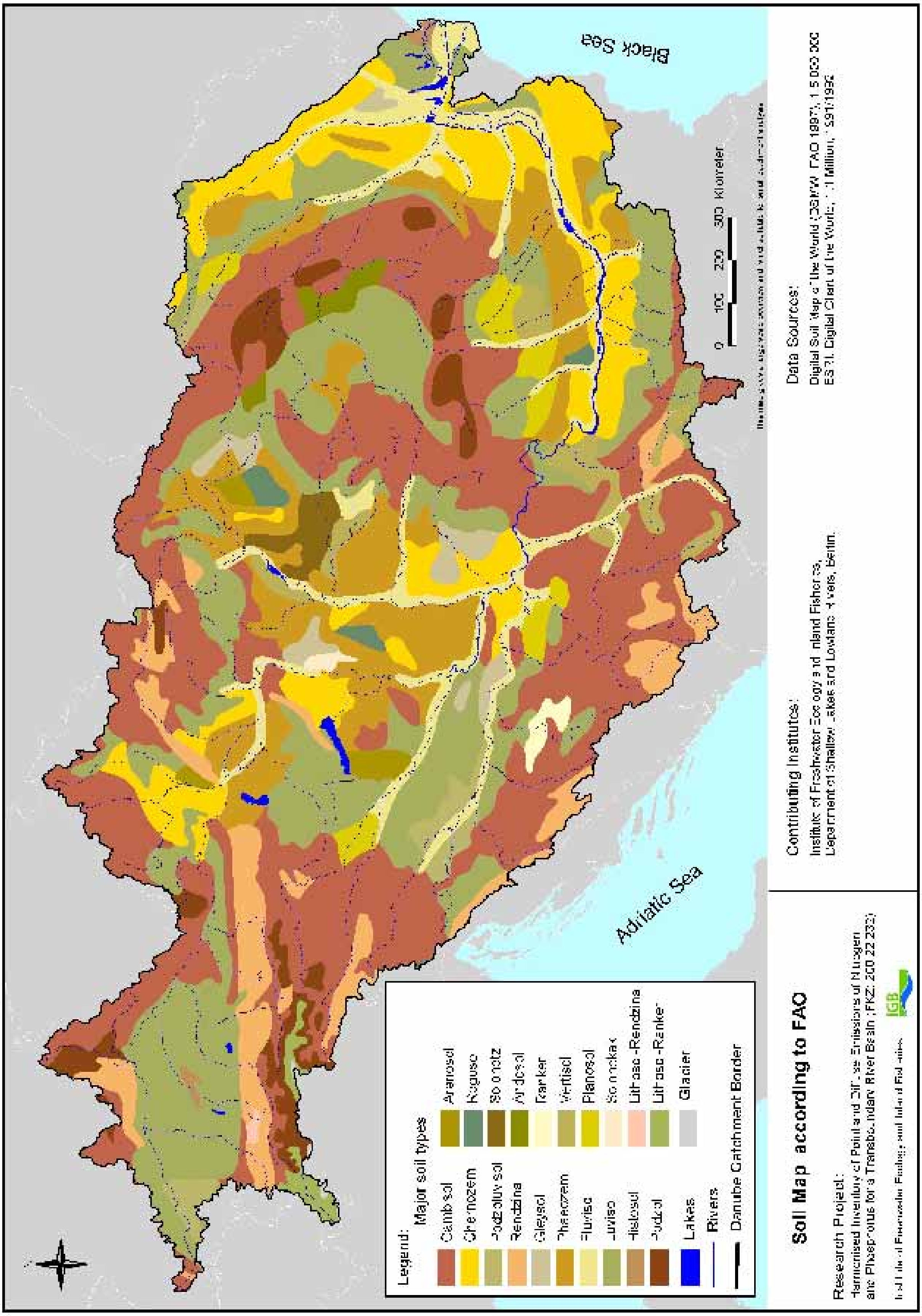
Name (countries) subbasins	Urban area	Arable land	Pasture	Forest	Water	Exploitation area	Open land	Wetlands
	%							
Upper Danube (DE, AT, CH, IT)	4.9	40.4	15.1	34.1	0.6	0.2	4.1	0.7
Inn (DE, AT, CZ)	1.9	14.6	17.4	34.1	0.9	0.0	30.8	0.3
Austrian Danube (AT)	1.4	35.2	10.9	44.5	1.0	0.1	7.0	0.0
Morava (CZ, AT, SK)	4.9	61.9	1.3	29.2	0.4	0.1	2.2	0.0
Vah-Hron (SK, CZ, H)	5.4	46.6	4.7	39.1	0.3	0.1	3.6	0.1
Pannonian Central Danube (AT, SK, H, HR, YU)	5.4	61.0	6.1	22.0	2.5	0.2	1.7	1.0
Drava-Mura (AT, SI, HR, H)	1.6	31.7	8.9	45.4	0.6	0.1	11.5	0.4
Mura	1.9	27.1	9.6	50.6	0.1	0.1	10.4	0.2
Drava	1.4	34.1	8.5	42.6	0.8	0.1	12.0	0.4
Sava (SI, HR, BA, YU)	0.9	34.3	5.4	56.7	0.4	0.1	1.9	0.3
Sava	1.1	39.1	4.4	52.7	0.4	0.1	1.8	0.3
Drina	0.2	15.5	9.5	71.9	0.3	0.1	2.4	0.0
Tisa (SK, UA, RO, H, YU)	4.4	51.5	5.9	26.6	0.5	0.1	8.9	2.0
Somes/Szamos	5.3	40.7	2.6	33.3	0.4	0.1	17.6	0.0
Crisuri/Koeroes	4.7	57.4	7.9	19.6	0.6	0.1	9.2	0.5
Mures/Maros	4.1	36.2	2.0	36.0	0.3	0.1	21.3	0.0
Banat-Eastern Serbia (YU, RO)	1.7	56.2	5.3	31.0	1.8	0.0	3.8	0.1
Velika Morava (YU, BG)	0.5	28.2	4.6	65.9	0.1	0.0	0.7	0.0
Mizia-Dobrudscha (BG)	5.8	57.5	4.9	23.0	0.8	0.1	5.7	0.1
Iskar	6.7	41.2	5.9	32.3	0.4	0.5	12.8	0.1
Muntenia (RO)	5.8	58.6	1.6	22.8	1.2	0.2	10.4	0.4
Jiu	5.6	40.2	0.9	37.3	0.2	0.9	14.9	0.0
Olt	4.9	39.0	2.3	35.8	0.7	0.1	17.1	0.1
Arges	8.2	55.1	1.0	26.6	0.8	0.1	7.9	0.2
Ialomita	7.7	57.7	0.6	23.5	0.7	0.1	9.5	0.2
Prut-Siret (UA, MD, RO)	5.4	51.2	4.5	27.1	0.6	0.0	9.1	0.8
Prut	3.9	67.5	8.8	13.1	0.7	0.0	4.4	1.6
Siret	6.4	41.9	1.9	36.6	0.5	0.0	12.3	0.3
Delta-Liman (MD, UA, RO)	2.1	62.3	7.0	3.7	8.7	0.0	2.2	13.9



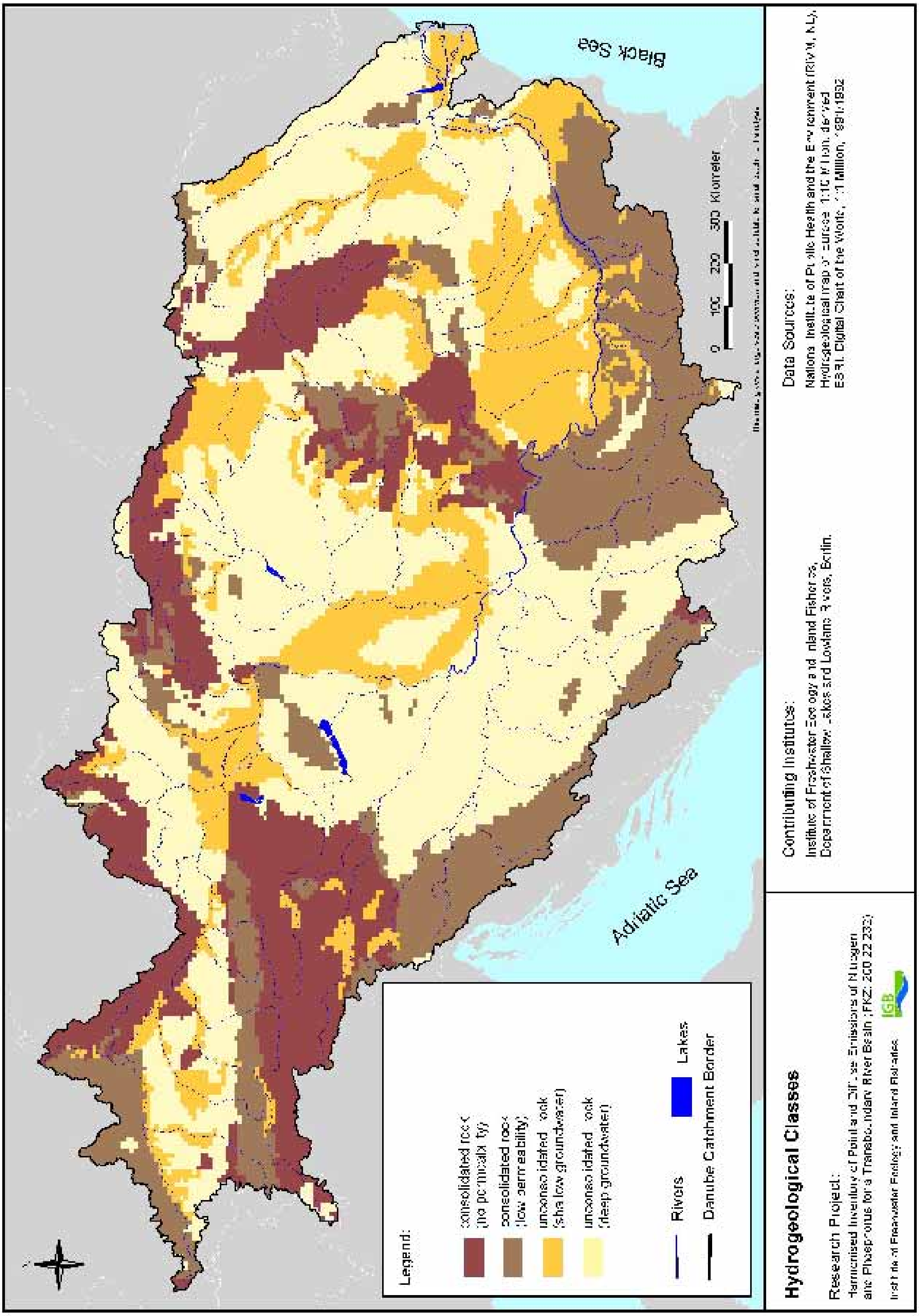
Map 2.4: Land use according to CORINE landcover.



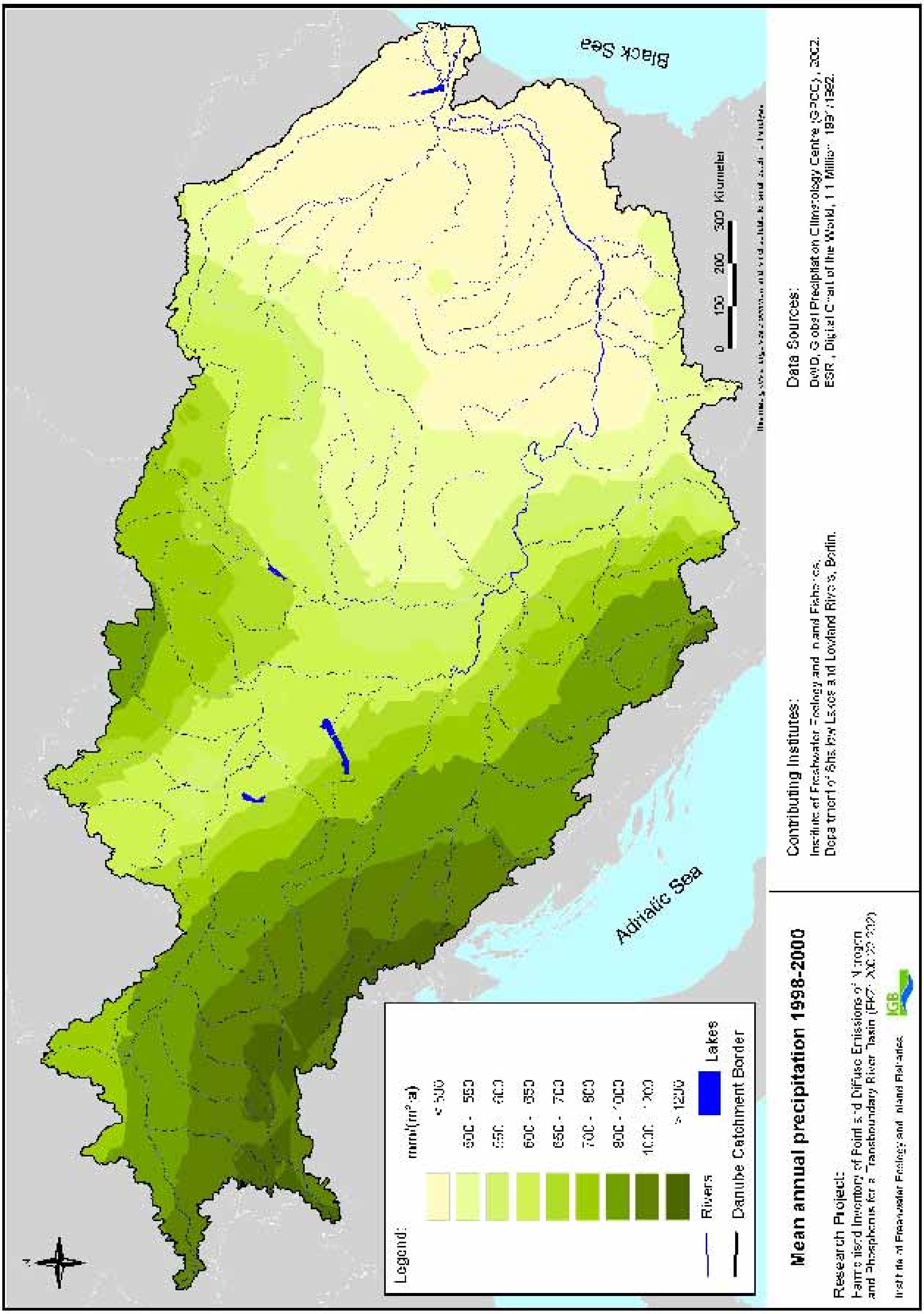
Map 2.5: Land use according to USGS landcover map of the world.



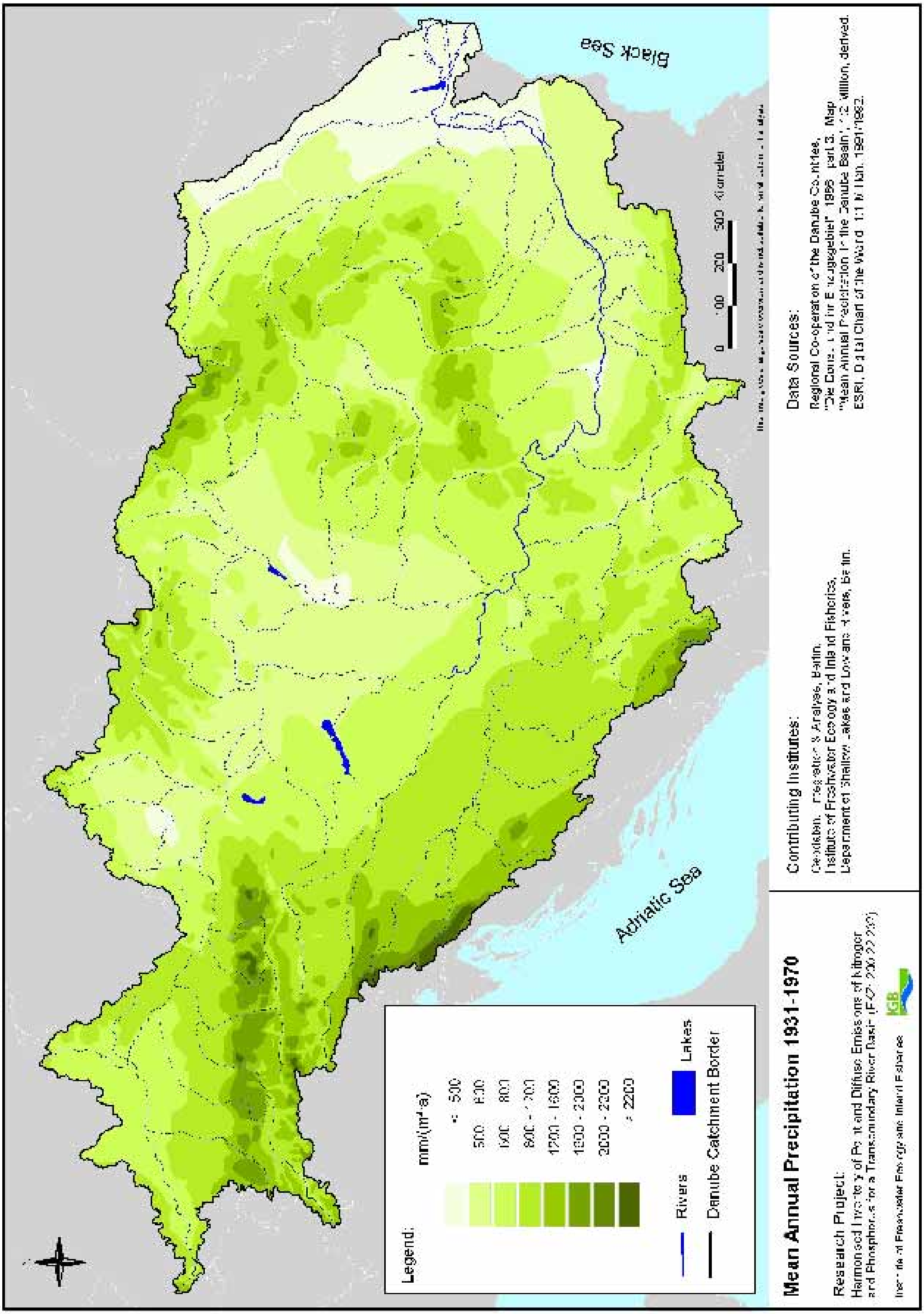
Map 2.6: Soil map according to FAO soil map of the world.



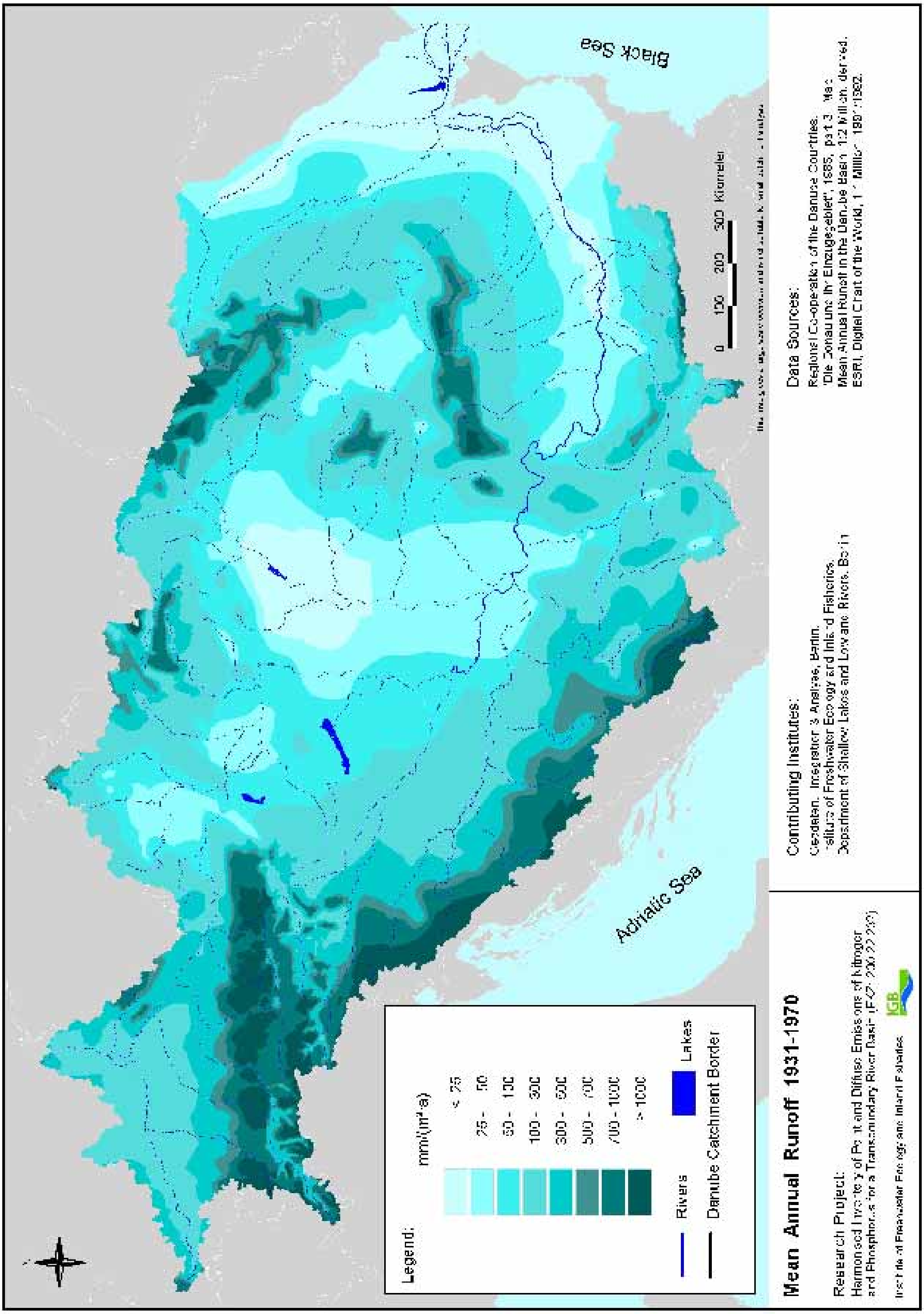
Map 2.7: Hydrogeological map.



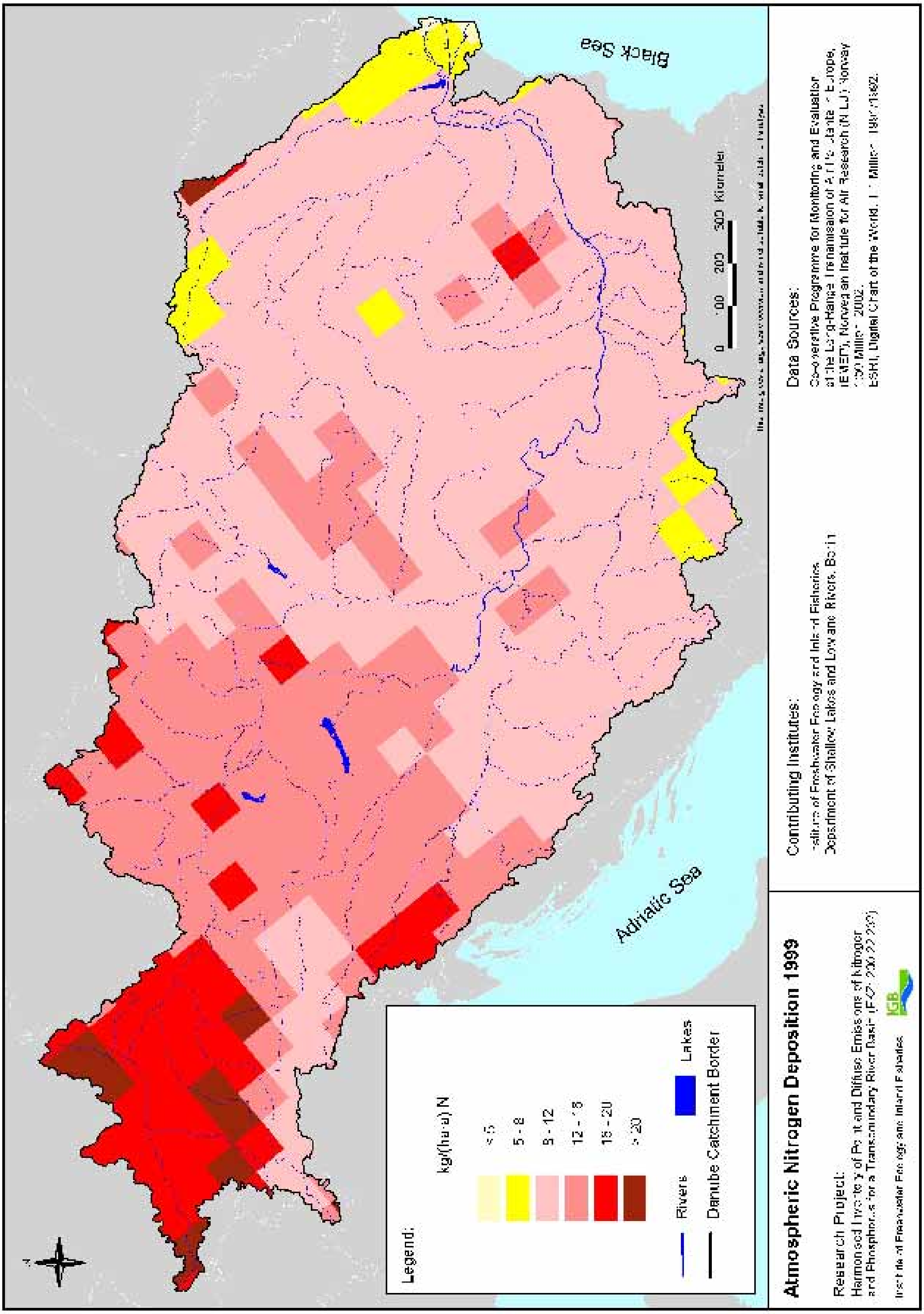
Map 2.8: Mean annual precipitation 1998-2000, DWD.



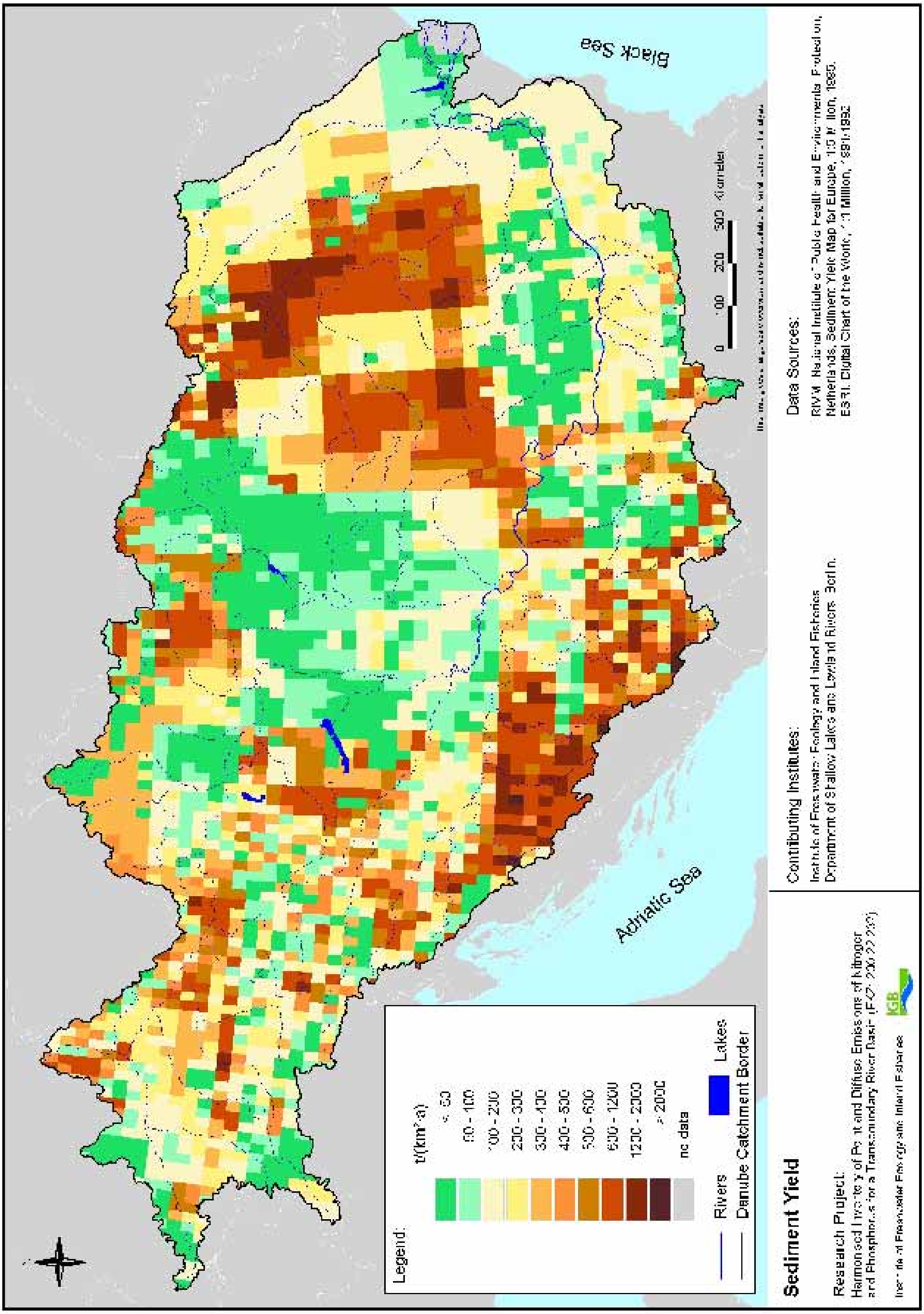
Map 2.9: Longterm mean annual precipitation.



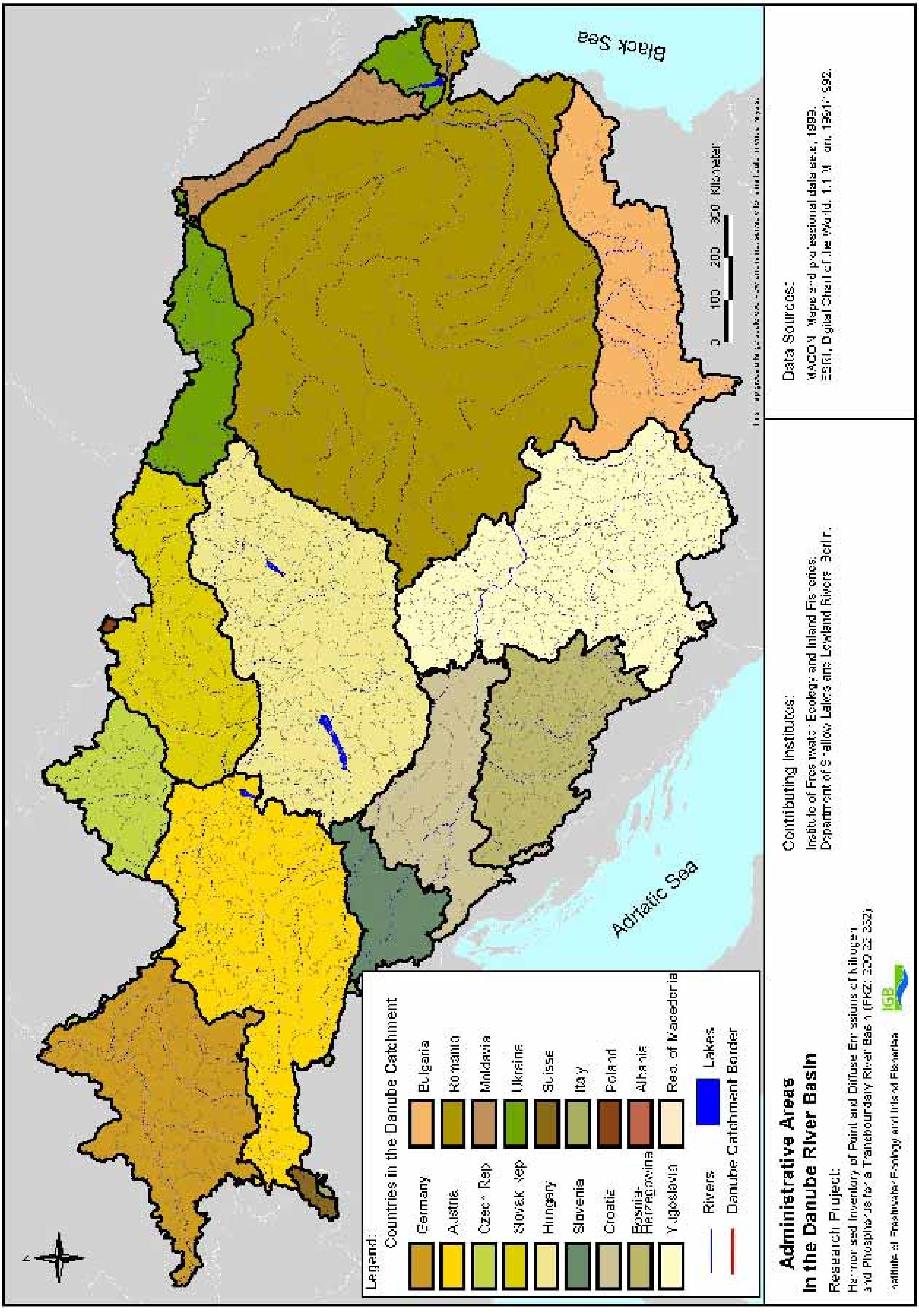
Map 2.10: Longterm mean annual runoff.



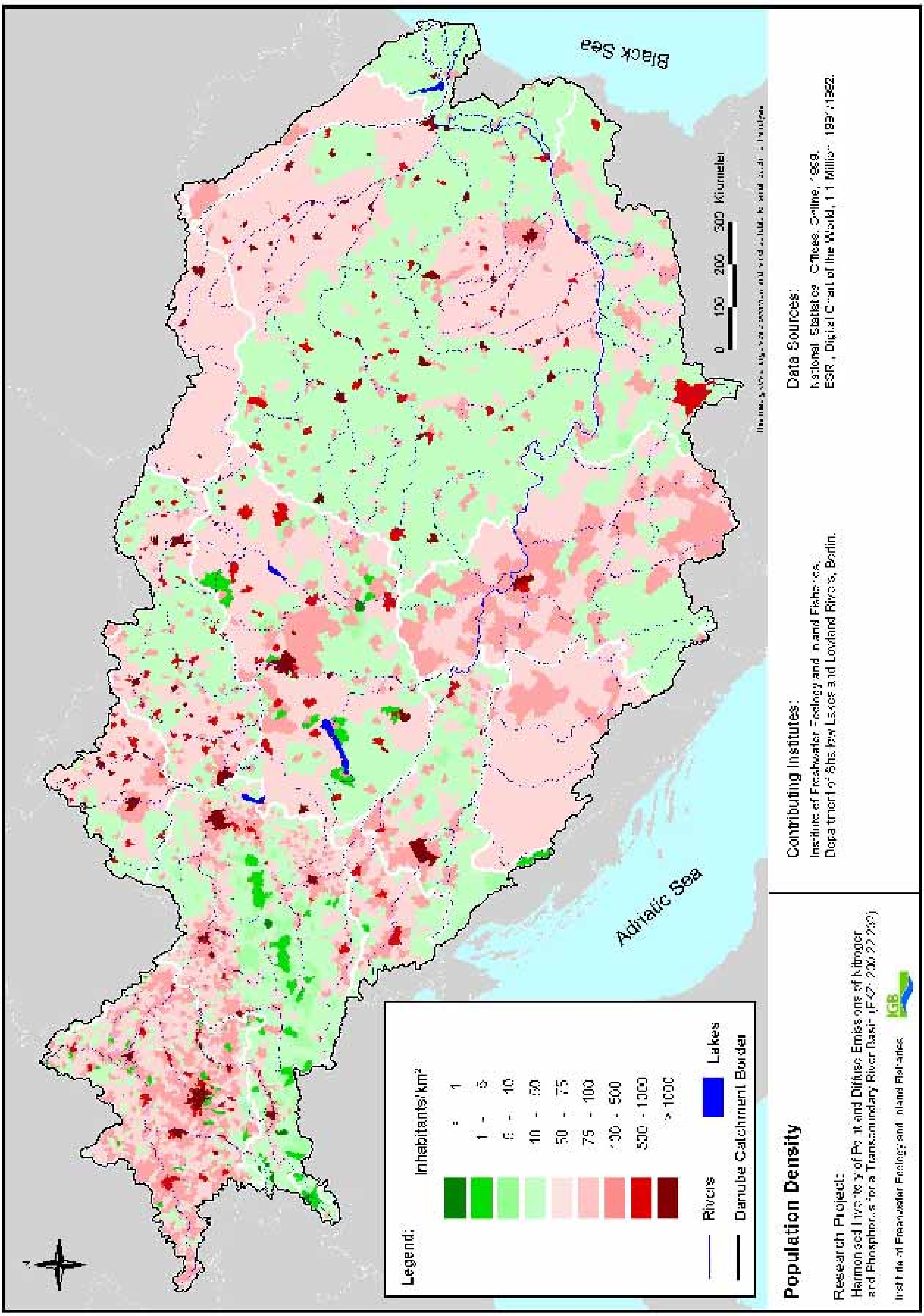
Map 2.11: *Atmospheric nitrogen deposition.*



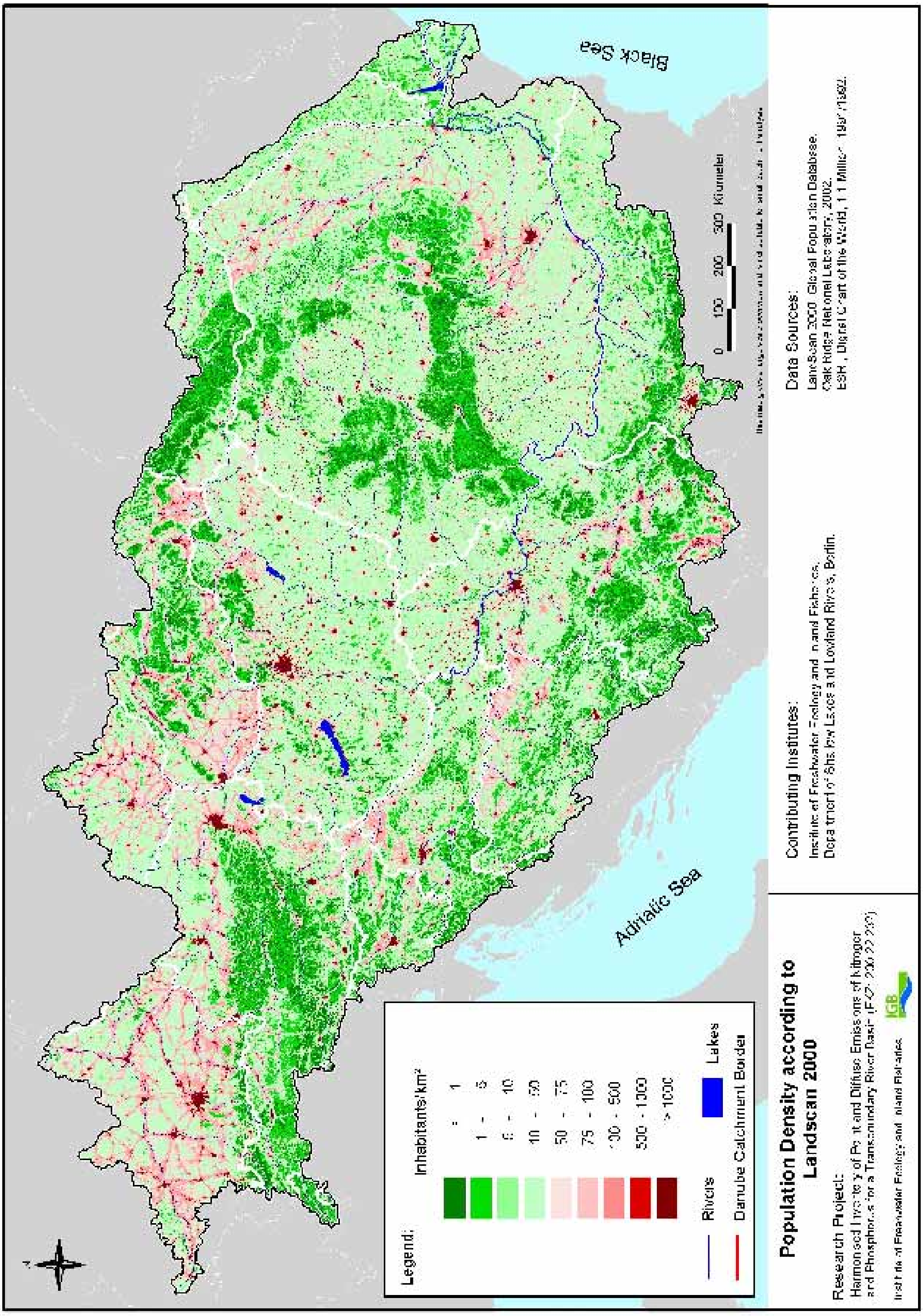
Map 2.12: Sediment yield.



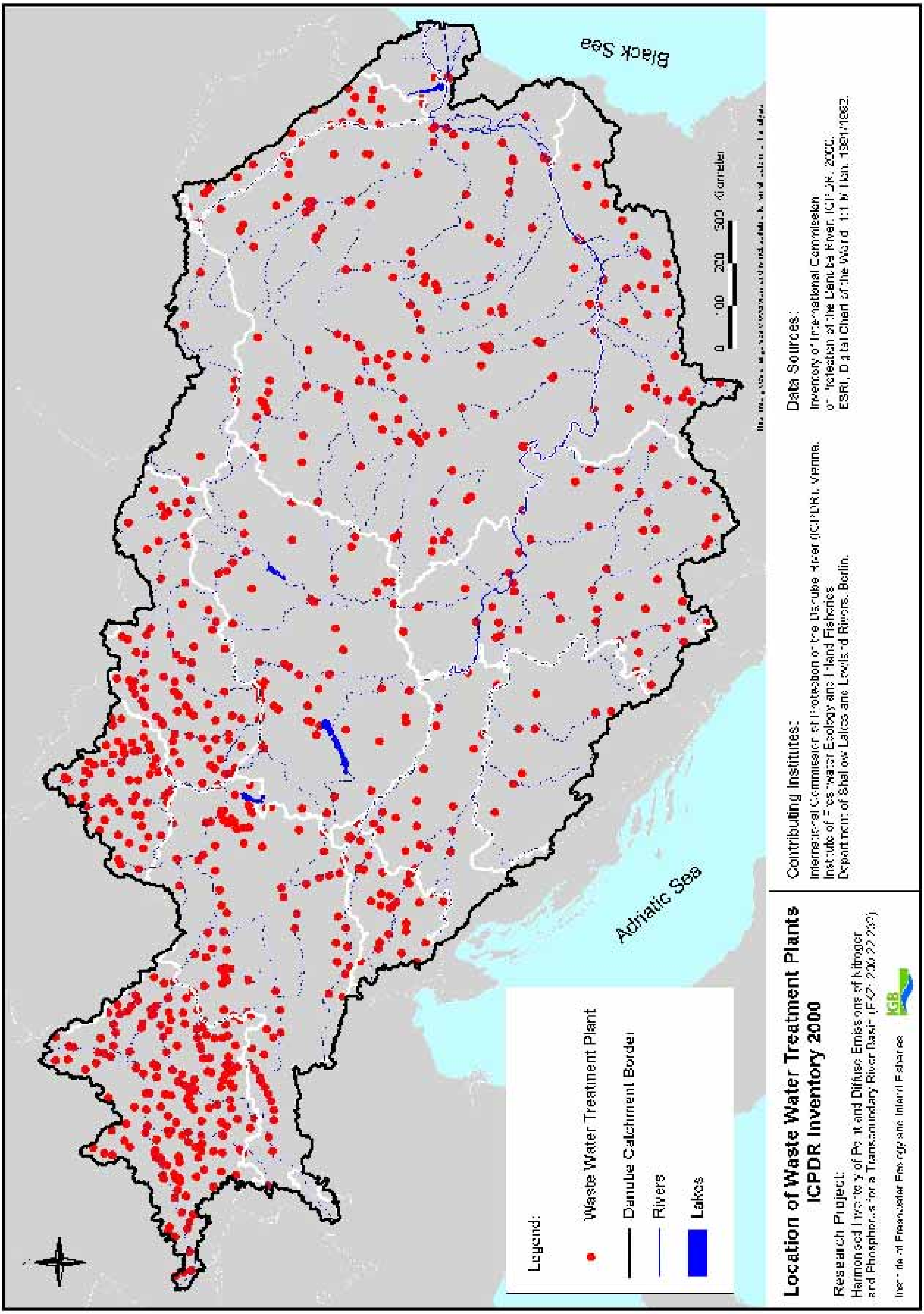
Map 2.13: Administrative areas.



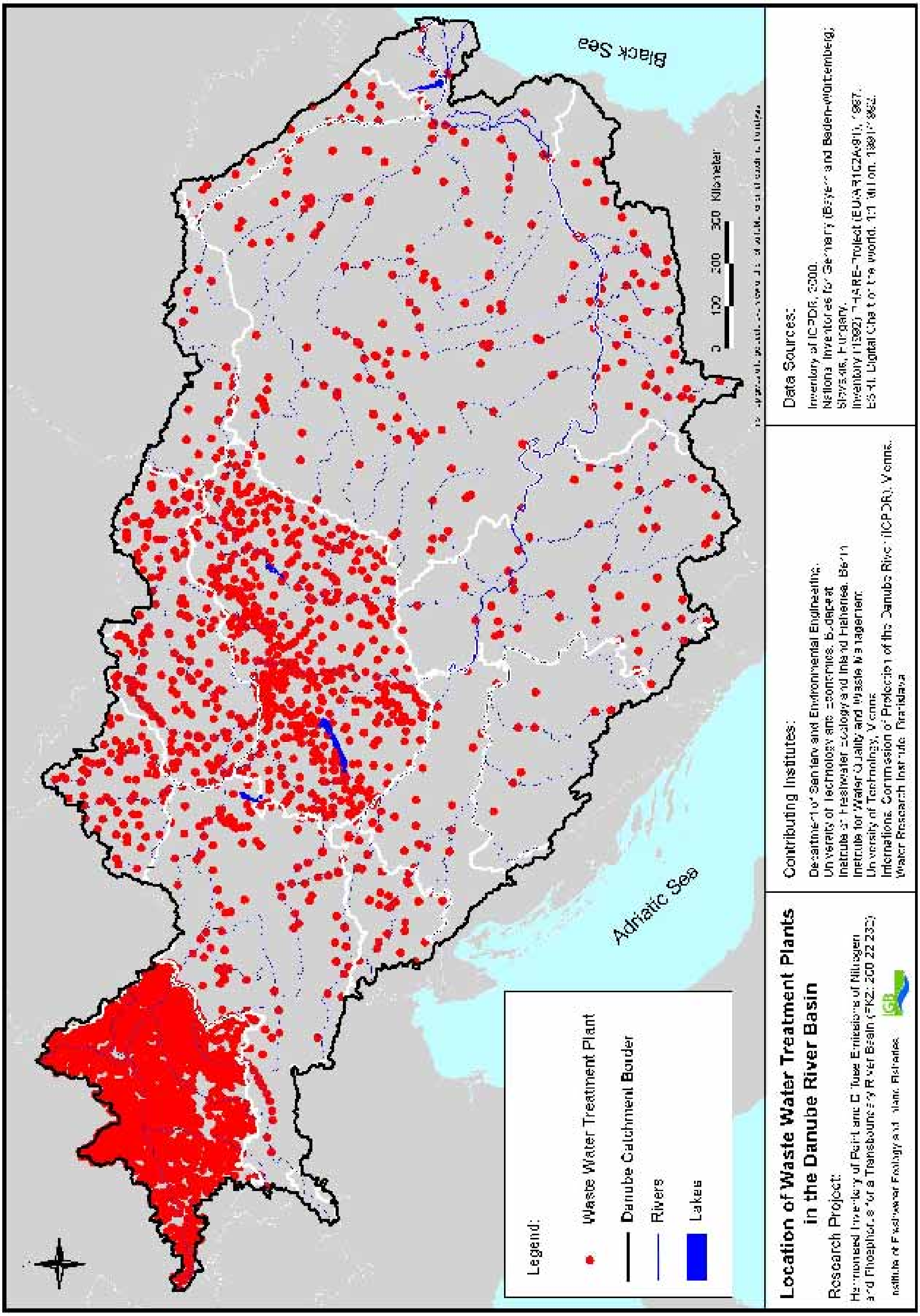
Map 2.14: Population Density based on statistical data within administrative boundaries.



Map 2.15: *Population Density according to Landscan2000.*



Map 2.16: Location of Waste Water Treatment Plants according to ICPDR Inventory 2000.



Map 2.17: Location of Waste Water Treatment Plants in the Danube Basin.

2.2 Data for calculating point source emissions

For the emission from point sources data from the ICPDR Inventory together with data of the reference year 2000 were used. The inventory of municipal discharges includes emissions which total at least about 75 % of the national COD loads transported in sewers and discharged into the riverine environment, irrespective of the type of treatment. The type of treatment ranges from no treatment at all to mechanical treatment, the removal of organic carbon and up to the removal of phosphorus and nitrogen. For the Federal Republic of Yugoslavia (Serbia and Montenegro) the inventory only contains the data on municipal discharges for the year 1996. This is due to the fact that at the time of compilation of the ICPDR inventory the Federal Republic of Yugoslavia (Serbia and Montenegro) did not yet actively participate in, and contribute data to, the ICPDR. The inventory of industrial discharges includes the most relevant types of industry: food-, chemical-, pulp and paper-, fertilizer-, mining-, iron and steel-, metal surface treatment-, textile-, leather industry and large agricultural plants. In each case only the best data available were included, but inevitably the 'quality' of the data varies according to the methods used by national experts for identifying emissions from individual plants. Depending upon the country and source of emission, the values in the emission inventories of the respective countries may be based upon continuous or periodical measurements; permit values, or values estimated by some other means. Typical values included in the emission inventory of municipal discharges alongside the information regarding name of discharger, geographical location, river basin and main river are:

- raw water load (TPE)
- current treatment
- current capacity of WWTP (TPE)
- volume of wastewater discharge (Tm^3/a)
- total load discharged into receiving waters (BOD, COD, N, NH_4-N, P) (t/a).

Typical values included in the emission inventory of industrial discharges alongside the information on name of the plant, geographical location, river basin, main river and sector are:

- raw water load (TPE)
- volume of wastewater discharge (Tm^3/a)
- discharged pollutants in t/a (e.g. COD, BOD5, NH_4-N, NO_2-N, NO_3-N, TN, PO_4-P, TP, SS) (t/a).

In addition to the ICPDR inventory database the national WWTP inventory of Bavaria and Baden-Württemberg was used to calculate the total nutrient discharges by point sources for the German part of the Danube. For the recorded WWTP similar information and typical values to those of the ICPDR are included in the database, such as:

- Plant capacity as inhabitant equivalents

- Treated wastewater volume per year
- Nitrogen parameters (concentration, yearly load)
- Phosphorus parameters (concentration, yearly load)

Table 2.3: Nitrogen and phosphorus discharges by country according to the point source inventory

Country	P	N
	[t/a]	[t/a]
DE	1113	12780
AT	2108	16050
CZ	580	5500
SK	1140	9210
HU	2994	15930
SI	819	4160
HR	1432	6370
BA	1086	3610
YU	5523	20220
RO	4462	30780
BG	2099	9420
MD	165	790
UA	480	1830
Other	2	20

Additional information on waste water treatment plants (WWTP) (164 locations, values for the year 2000) was also supplied by national consultants for Slovakia (*Water Research Institute*, Bratislava), as well as information on major direct industrial discharger (1996 to 2000, summarized for major subbasins in Slovakia). For Hungary information on 495 WWTP was supplied by *Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economic (BUTE*). For the other countries (Austria, Czech Republic, Slovenia, Bulgaria, Moldava, Ukraine) additional information was made available by the national consultant for Austria (*Institute for Water Quality and Waste Management, University of Technology Vienna)* from former studies within the framework of the PHARE-Project EU/AR102A/91 (1997) "Nutrient Balances for Danube Countries".

Calculation of the missing point source discharges was carried out as described in chapter 3.1.1. The loads for nitrogen and phosphorus taken into account for the respective Danube country are totalled and summarised in Table 2.3.

2.3 Monitoring data for surface water

The **water quality** database from the *Trans National Monitoring Network* (*TNMN*) established by the *ICPDR* (*International Commission for the Protection of the Danube River*) comprises concentration and discharge values for the period 1996-2000. Under the Danube River Protection Convention (DRPC), the *Monitoring, Laboratory and Information Management Expert Group* (MLIM/EG) is "operating" the *Trans National Monitoring Network* for water quality in the Danube River Basin. The TNMN has sampling and measuring locations in all countries starting from the source of the river in Germany downstream to the three mouths in the Danube Delta where the river discharges into the Black Sea. Within the present structure of the TNMN there are 61 sampling stations in total that are selected from the national monitoring networks and based on criteria and objectives agreed between the countries. Of these, 31 are situated on the Danube river and 30 on the tributaries of the Danube. For the years 1996-1997 the data on discharge and river load varies between bimonthly and monthly values for the different stations, while for some stations data is even more irregular. The available values per year therefore vary from 3 to 12 for this time period. Starting from 1998-2000 daily discharge values are available from the TNMN database, and biweekly to monthly values for the river load (with exceptions of some stations, e.g. in Bosnia-Herzegovina). For the calculation of the river loads the period of 1998-2000 was considered. Investigated pollutants which were determined according to TNMN are Ammonia (NH_4), Nitrite as Nitrogen (NO_2), Nitrate as Nitrogen (NO_3), Phosphates (PO_4), Total Phosphorus (TP) and other pollutants were not considered for the calculations. Data on suspended solids (SS), temperature, DOC, TOC were also available from this database.

For this study, a total of 35 monitoring locations in the **German Danube catchment** area were chosen (including the 4 stations also monitored in the TNMN, see Table 2.4 underlined with grey). If the discharge was measured at another station from the water quality, then some conversion is necessary. To calculate the discharge at the water quality station the flow at the discharge monitoring station is multiplied with a conversion factor (see Table 2.4). If the conversion factor is not known, it was determined from the relationship of the catchment areas of water quality monitoring and discharge monitoring stations. This conversion procedure was also applied for the flows at the water quality monitoring stations of the other Danube countries according to the catchment areas determined by GIS (Geographical Information System) and the data supplied by the national consultants. The size of the catchment areas of the 35 monitoring points in the German part of the Danube river basin ranges from 804 to 77347 km^2. Table 2.4 shows the water quality and discharge data in the German part of the Danube river which could be used. The calculations for this study are based on the data for the period 1998 – 2000.

For the **Austrian** part of the **Danube catchment** another 49 monitoring stations were chosen for this study in addition to the 4 stations in the TNMN. An overview of the stations and the available data of discharge and water quality is given in Table 2.5. Bimonthly measurements of nutrient concentration (Ammonia (NH_4), Nitrite as Nitrogen (NO_2), Nitrate as Nitrogen (NO_3), Phosphates (PO_4), Total Phosphorus (TP)), suspended solids (SS) and temperature were (basically) available from June 1993. Monthly values for the same parameters were available from 1996 until June/July 2001. Daily discharge data were available for 21 stations for the time period 1971-1999.

Of the 35 stations selected within this study for the **Hungarian** part of the **Danube catchment,** data on water quality and discharge were provided for 30 monitoring stations by the *Institute of Water Pollution Control* at *VITUKI* in Budapest. The data were monitored weekly to biweekly (nutrients), runoff, temperature, suspended solids, chlorophyll (as well as other parameters) and are available for the period 1995-2000. An overview of the stations and the available data of discharge and quality data is shown in Table 2.6.

Table 2.4: Monitoring stations, discharge and water quality data in the German part of the Danube catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG} [km²]	Conversion factor	Quality data from	Quality data to	Daily discharge data from	Daily discharge data to
11304	Danube	Hundersingen	Hundersingen	2896.8	1.00			1987	1996
11301	Danube	Oepfingen	Berg	4500.0	1.05			1987	1996
11404	Iller	Kempten	Kempten	1056.6	1.00	1983	2000	1980	2000
11402	Iller	Wiblingen	Wiblingen	2321.3	1.00	1983	2000	1981	2000
11503	Danube	Ulm	Neu-Ulm	7858.5	1.00	1983	2000	1981	2000
11501	Danube	Boefinger Halde	Neu-Ulm	8255.2	1.00	1983	2000	1981	2000
11602	Mindel	Offingen	Offingen	927.7	1.00	1983	2000	1981	2000
11702	Danube	Dillingen	Dillingen	11442.5	1.00	1983	2000	1981	2000
11802	Woernitz	Ronheim	Harburg	1605.2	1.00	1983	2000	1981	2000
11901	Danube	Schaefstall	Danubewoerth	15149.0	1.00	1983	2000	1981	2000
12303	Lech	Fuessen	Fuessen	1414.2	1.00	1983	2000	1981	1999
12901	Lech	Feldheim	Feldheim	4357.0	1.00	1983	2000	1982	1999
13302	Danube	Neustadt	Kehlheim	22645.5	1.00	1983	2000	1982	2000
13401	Altmuehl	Groegling	Beilngries	2572.4	1.00	1984	2000	1984	2000
14302	Naab	Unterkoebelitz	Unterkoebelitz	2097.5	1.00	1983	2000	1981	1999
14402	Schwarzach	Warnbach	Warnbach	830.8	1.00	1983	2000	1981	2000
14601	Vils	Dietldorf	Dietldorf	1112.1	1.00	1983	2000	1981	1999
14902	Naab	Heitzenhofen	Heitzenhofen	5554.0	1.00	1983	2000	1981	2000
15202	Regen	Regenstauf	Regenstauf	2707.7	1.00	1983	2000	1981	2000
15901	Danube	Deggendorf	Pfelling	38350.0	1.00	1983	2000	1981	2000
16502	Isar	Baierbrunn	Muenchen	2855.5	1.00	1983	2000	1981	2000
16601	Amper	Moosburg	Inkofen	3299.1	1.00	1983	2000	1983	2000
16902	Isar	Plattling	Plattling	9094.7	1.00	1983	2000	1981	2000
17202	Vils	Grafenmuehle	Grafenmuehle	1385.9	1.00			1981	2000
17301	Danube	Passau	Passau	49938.2	1.00			1978	2000
17402	Ilz	Kalteneck	Kalteneck	804.4	1.00	1983	2000	1981	2000
18101	Inn	Kirchdorf	Oberaudorf	9978.2	1.00	1983	2000	1981	2000
18302	Inn	Eschelbach	Eschelbach	13402.3	1.00			1981	1995
18402	Alz	Seebruck	Seebruck	1442.2	1.00	1983	2000	1981	2000
18404	Tiroler Achen	Staudach	Staudach	970.7	1.00	1983	2000	1981	2000
18602	Salzach	Laufen	Laufen	6143.1	1.00	1983	2000	1981	2000
18603	Saalach	Freilassing	Staufeneck	1150.0	1.04	1983	2000	1981	2000
18802	Rott	Ruhstorf	Ruhstorf	1016.9	1.00	1983	2000	1981	2000
18902	Inn	Passau-Ingling	Passau-Ingling	26073.7	1.00	1983	2000	1981	2000
19101	Danube	Jochenstein	Achleiten	77346.7	1.00	1983	2000	1980	2000

Table2.5: Monitoring stations, discharge and water quality data in the Austrian part of the Danube catchment area.

Addr.	River	Quality monitor-ing station	Discharge monitoring station	A_{EZG} [km²]	Conver-sion factor	Quality data from*	Quality data to	Daily discharge data from	Daily discharge data to
72100967	Lech	Weisshaus	Lechaschau	1199	1.18	7/1993	8/2001	1971	1999
73100007	Inn	Martinsbruck	Kajetansbrücke	2011	0.93	12/1993	8/2001	1971	1997
75000987	Inn	Kirchdorf/Erl	Kirchbichl	9978		12/1991	8/2001	1971	1999
73390967	Achen	Kössen	Kössen-Hütte	855	1.11	10/1991	8/2001	1993	1999
52110087	Salzach	Werfen	Werfen	2934	1	1/1992	5/2001	1995	1997
54110127	Salzach	Salzburg	Salzburg	4439	1	1/1991	5/2001	1971	1999
51210087	Saalach	Unken	Weissbach bei Lofer	865	1.52	1/1992	10/2001	1971	1999
54110117	Saalach	Salzburg	Siezenheim	1150	1	1/1992	5/2001	1976	1999
40401017	Salzach	Ueberackern	Ach	6771	1.1	12/1991	1/2001	1991	1999
40502017	Inn	Braunau	Schärding	22755	0.88	9/1991	1/2001		
40503037	Mattig	St. Peter a Haag	Jahrsdorf	430	0.96	6/1993	6/2001	1971	1999
40504017	Muehlheimer Ache	Altheim	Mamling	3346	1	6/1993	6/2001	1976	1997
40505037	Antiesen	Antiesenhof	Haging	288	1.7	6/1993	6/2001	1971	1999
	Osternach		Osternach					1971	1999
40506027	Pram	Taufkirchen	Pramerdorf	322	0.94	6/1993	6/2001	1976	1999
40502037	Inn	Schardenberg	Schärding	26074		9/1991	1/2001		
40607017	Danube	Jochenstein		77346.7		7/1991	6/2001	1998	2000
40608037	Grosse Muehl	Neufelden	Teufelmühle	664	1.14	6/1993	6/2001	1971	1999
40607027	Danube	Linz/Margarethen	Kienstock	79912		6/1993	6/2001	1976	1999
40709117	Traun	Ebelsberg	Wels Lichtenegg	4244	1.01	3/1991	8/2001	1980	1997
40907037	Danube	Luftenberg/ Abwinden	Abwinden-Asten	84332		7/1991	6/2001	1997	2000
40916017	Gusen	St. Georgen	St. Georgen	244	0.94	6/1993	6/2001	1979	1999
40814047	Enns	Enns	Steyr Ortskai	6081	1.02	12/1991	6/2001	1971	1999
40917017	Aist	Schwertberg	Schwertberg	705	1.16	6/1993	6/2001	1976	1999
40918027	Naarn	Mitterkirch	Haid	317	1.04	6/1993	6/2001	1993	1997
30900057	Danube	Ybbs-Persenbeug	Kienstock	92840		7/1991	6/2001	1976	1999
30900047	Ybbs	Neumark an der Ybbs	Greimpersdorf	1349	1.02	12/1991	6/2001	1971	1999
	Ybbs	Greimpersdorf	Greimpersdorf			5/2001	4/2002		
30900077	Erlauf	Petzenkirchen	Niederndorf	624	1.04	9/1993	6/2001	1971	1999
30900087	Melk	Zelking/ Matleinsdorf	Matzleinsdorf	270	0.94	9/1993	6/2001	1971	1999
30900107	Pielach	Loosdorf	Hofstetten	590	2.03	9/1993	6/2001	1971	1999
30900147	Traisen	St Andrae	Windpassing	896	1.22	9/1993	6/2001	1971	1999
31000067	Kamp	Duernstein /Grundorf	Stiefern	1729	1.15	9/1993	6/2001	1971	1999
92001017	Danube	Wien-Nussdorf	Wien	104782	1	7/1991	6/2001	1971	2000
31000167	Triesting	Achau	Hirtenberg	850	2.96	9/1993	6/2001	1977	1999
31000177	Fischa	Fischamend	Fischamend	870	1	9/1993	6/2001	1971	1999

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from*	to	from	to
31000017	Danube	Deutsch Altenburg	Wien Reichsbrücke	104782		1995	2001	1993	1997
31100037	Thaya (Dyje)	Bernhardsthal/ Rabensburg	Hardegg	12554		9/1991	6/2001	1977	1999
31100047	March/Morava	Markthof	Angern an der March	26645	1.03	7/1991	6/1998	1971	1999
31000027	Danube	Wolfsthal	Wien Reichsbrücke	132098		7/1991	6/2001	1997	2000
10000077	Leitha	Nickelsdorf	Nickelsdorf	1899	0.86	9/1991	6/2001	1984	1997
10000087	Raab	Jennersdorf	Neumarkt	953	0.96	11/1991	6/2001	1991	1999
10000097	Lafnitz	Eltendorf	Eltendorf	1991	1	11/1991	6/2001	1979	1999
10000107	Strem	Heiligenbrunn	Heiligenbrunn	1284	1	11/1991	6/2001	1971	1997
-	Wulka	Schuetzen	Schuetzen	408	1	1995	2001	1992	2000
21500087	Drau	Lavamuend	Spital	11055		12/1991	7/2001	1993	1997
21560297	Lavant	Lavamuend	Krottendorf	964	0.99	12/1991	7/2001	1971	1999
61400147	Mura	Radkersburg	Mureck	10190	1	1/1992	12/2000	1974	1999

*Number before slash gives the month from which measured values are available.

For 14 monitoring stations of the 16 stations selected for the **Slovenian** part of the **Danube catchment**, data on water quality and discharge were provided by the national consultant**.** The data were monitored for some stations bimonthly in major parts irregularly (nutrients). Daily discharge values were available from runoff monitoring stations for the period 1994-1998 and for some of the stations also for the year 2000 and 2001. An overview of the stations and the available data of discharge and water quality measurements is shown in Table 2.7.

For this study a total of 46 monitoring stations were chosen for the **Romanian** part of the **Danube catchment**. In the TNMN 11 monitoring stations are included. For the remaining 35 stations selected additionally from the national monitoring network, daily discharge values were available for the period 1994-1999 as well as monthly values on nutrient concentrations, temperature, and in some parts on suspended solids for the same period. Table 2.8 gives an overview of water quality and discharge data in the Romanian part of the Danube river which could be used.

Table 2.6: Monitoring stations, discharge and water quality data in the Hungarian part of the Danube catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG} [km²]	Conversion factor	Quality data from	Quality data to	Daily discharge data from	Daily discharge data to
1	Danube	Medvedov	Medvedov	132724	1	1995	2000	1993	2001
2	Repce	Repcevis	Repcevis	578	1	1995	2000	1993	2001
3	Neusiedler See/F	Fertoerakos	Fertoerakos	1402	1	1995	2000		
4	Rabca	Lebenmymiklos	Lebeny	4195	1	1995	2000	1993	2001
5	Raba	Gyoer	Arpas	17317	1.52	1995	2000	1993	2001
6	Danube	Komarom	Komarom	151751	1	1995	2000	1993	2001
7	Danube	Szob	Nagymaros	183437	0.99	1995	2000	1993	2001
8	Danube	Nagyteteny	Budapest	185023	1	1995	2000	1993	2001
9	Danube	Dunafoeldvar	Dombori-puszta	188816	0.99	1995	2000	1993	2001
11	Zala/Balaton	Fenekpuszta	Zalaapati	2691	3.77	1995	2000	1993	2001
13	Kapos	Pincehely	Kurd	3227	1.51	1995	2000	1993	2001
15	Sio	Szekszard-Palank	Simontornya	14927	1.44	1995	2000	1993	2001
17	Danube	Hercegszanto	Mohacs	209386	1	1995	2000	1993	2001
18	Drava	Dravaszabolcs	Dravaszabolcs	37251	1	1995	2000	1993	2001
19	Tisza	Tiszabecs	Tiszabecs	9688	1	1995	2000	1993	2001
20	Szamos	Csenger	Csenger	15374	1	1995	2000	1993	2001
21	Tisza	Zahony	Zahony	33582	1.02	1995	2000	1993	2001
22	Lonyai Canal	Buj	Kotaj	2080	1.18	1995	2000	1998	2001
23	Bodrog	Felsoeberecki	Felsoeberecki	12886	1	1995	2000	1993	2001
24	Bodrog	Bodrogkeresztur	Felsoeberecki	13445				1993	2001
25	Sajo	Sajopuspoki	Sajopuspoki (SK/H)	3233	1	1995	2000	1993	2001
26	Sajo	Kesznyeten	Onod	12874	1.08	1995	2000	1993	2001
27	Tisza	Szolnok	Szolnok	69434	1	1995	2000	1993	2001
28	Zagya	Szentloerinckata	Szentloerinckata	2008	1	1995	2000	1993	2001
29	Tisa	Tiszaug	Martfü	77221		1995	2000		
30	Sebes-Koeroes	Koeroesladany	Koeroesladany	8315	1	1995	2000	1993	2001
32	(Harmas)-Koeroes	Magyartes	Kunszentmarton	25414	1	1995	2000	1993	2001
33	Maros	Nagylak	Mako	28113	0.93	1995	2000	1993	2001
34	Maros	Mako	Mako	28650	1	1995	2000	1993	2001
35	Tisza	Tiszasziget	Szeged	139997	1	1995	2000	1993	2001

Table 2.7: Monitoring stations, discharge and water quality data in the Slovenian part of the Danube catchment area.

Addr	River	Quality monitoring station	Discharge monitoring station	A_{EZG} [km²]	Conver-sion factor	Quality data from	Quality data to	Daily discharge data from	Daily discharge data to
-	Drava	Ormoz	Ormoz	15329	1	1996	2000	1998	2000
3450	Sava	Otolec	Radovljica	968	1.08	1994	1998	1994	1998/2000
4208	Sora	Medvode	Suha I automatic	640	1.13	1994	1998	1994	2000
	Sora		Medvode I		0.99			1994	1998
3530	Sava	Medno	Medno automatic	2160	0.98	1996*	2000	1994	1998/2000
3570	Sava	Sentjakob	Sentjakob-automatic	2279	1	1994	1998	1994	1998/2000
4470	Kamniska Bistrica	Bericevo	Vir	539	2.59	1994	1998	1994	1998
5110	Ljubljanica	Zalog	Moste-automatic	1881	1.06	1994	1998	1994	1998/2000
3590	Sava	Dolsko	Litija I	4739	1	1994	1998	1994	1998
3725	Sava	Hrastnik-automatic	Hrastnik-automatic	5223	1		2000*	1994	1998/2000
6120	Savinja	Medlog	Celje II	1190	1	1994	1998	1994	1996
6210	Savinja	Veliko Sirje-autom.	Veliko Sirje-autom.	1847	1	1994*	2000	1994	1998/2000
3744	Sava	Radece				1994	1998		
3860	Sava	Jesenice	Jesenice	10647	1	1999	2000	1999	2000

* lack of data for periods between the years

Table 2.8: Monitoring stations, discharge and water quality data in the Romanian part of the Danube catchment area.

Addr.	River	Quality monitor-ing station	Discharge monitor-ing station	A_{EZG} [km²]	Conver-sion factor	Quality data from	Quality data to	Daily discharge data from	Daily discharge data to
1	Somesul Mic	Salatiu	Salatiu	3582	1	1994	1999	1994	1999
2	Somes	Vad	Rastoci	8832	1	1994	1999	1994	1999
3	Somes	Ulmeni	Ulmeni	11618	1	1994	1999	1994	1999
4	Lapus	Busag	Lapusel	1799	1.04	1994	1999	1994	1999
5	Somes	Oar (border)	Satu Mare	15374	1	1994	1999	1994	1999
6	Crisul Repede	Cheresig	Cheresig	2342	1	1994	1999	1994	1999
7	Crisul Negru	Zerind	Zerind	3932	1	1994	1999	1994	1999
8	Crisul Alb	Varsand	Chisinau Cris	4136	1	1994	1999	1994	1999
9	Mures	Ocna Mures	Ocna Mures	10100	1	1994	1999	1994	1999
10	Tarnava Mica	Petrisat	Blaj	2028	1.05	1994	1999	1994	1999
11	Tarnava	Mihalt	Mihalt	6222	1	1994	1999	1994	1999
12	Mures	Branisca	Branisca	24547	1	1994	1999	1994	1999
13	Mures	Nadlac / border	Nadlac / border	27848	1	1994	1999	1994	1999
14	Bega	Otelec	Timisoara/Remetea	1347/1940	1	1994	1999	1994	1999
15	Timis	Graniceri	Graniceri/Sag	7743	1	1994	1999	1994	1999
16	Danube	Bazias	Bazias	565766	1	1994	2000	1994	2000
17	Danube	Pristol/Novo Selo Harbour	Pristol/Novo Selo Harbour	578882	1	1994	2000	1994	2000
18	Jiu	Zaval	Zaval	9964/10046	1	1994	1999	1994	1999

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG} [km²]	Conversion factor	Quality data from	Quality data to	Daily discharge data from	Daily discharge data to
19	Olt	Caineni	Caineni	13396	1	1994	1999	1994	1999
20	Oltet	Falcoiu	Bals	2421		1994	1999	1994	1999
21	Olt	Izbiceni	Stoenesti	24253		1994	1999	1994	1998
22	Vedea	us confl. Danube	Alexandria	5432				1994	1999
23	Arges	Malu Spart	Malu Spart	3795	1	1994	1999	1994	1999
24	Neajlov	Vadu Lat (Neajlov)	Vadu Lat (Neajlov)	1300	1				2000
25	Neajlov	Calugareni	Calugareni	3446	1	1994	1999	1994	1999
26	Dambovita	Clatesti	Budesti	1703		1994	1999	1994	1999
27	Danube	us. Arges	us. Arges	666922	1	1996	2000	1996	2000
28	Arges	Clatesti / Conf. Danube	Clatesti / Conf. Dan	12576	1	1996	2000	1999	2000
29	Danube	Chiciu/Silistra	Chiciu/Silistra	685140	1	1996	2000	1998	2000
30	Ialomita	Tandarei	Tandarei	10287	1	1994	1999	1994	1999
31	Siret	Dragesti	Dragesti	11903	1	1994	1999	1994	1999
32	Siret	Galbeni	Adjudu Vechi	19402		1994	1999	1994	1999
33	Trotus	Adjud	Vranceni	4417		1994	1999	1994	1999
34	Birlad	Umbraresti	Tecuci	7242		1994	1999	1994	1999
35	Putna	Botirlau	Botirlau	2476	1	1994	1999	1994	1999
36	Siret	Lungoci	Lungoci	36048	1	1994	2000	1994	1999
37	Rimnicu Sarat	Maicanesti	Tataru	1092		1994	1999		
38	Buzau	Racovita	Racovita	5198	1	1994	1999	1994	1999
39	Siret	Conf. Danube Sendreni	Conf. Danube Sendreni	44893	1	1996	2000	1998	2000
40	Prut	Darabani	Radauti	8787		1994	1999	1994	1999
41	Prut	Dranceni	Dranceni	23062	1	1994	1999	1994	1999
42	Prut	Conf. Danube Giurgiulesti	Conf. Danube Giurgiulesti	28581	1	1994	1999	1998	2000
43	Danube	Reni-Chilia	Reni-Chilia arm	788113	1	1994	1999	1998	2000
44	Danube	Vilkova-Chilia arm	Vilkova-Chilia arm		1	1996	2000	1998	2000
45	Danube	Sulina-Sulina arm	Sulina-Sulina arm	802888	1	1996	2000	1998	2000
46	Danube	Sf.Gheorghe-Gheorghe arm	Sf.Gheorghe-Gheorghe arm		1	1996	2000	1998	2000

2.4 Administrative data

Administrative data were collected at the municipality or district level. With the help of GIS datasets of the administrative units, this information was used in the GIS on an area basis and could be aggregated for the various catchment areas.

Data on population, land use, cultivation, and livestock numbers for municipalities or districts for the year 1999 were available in tabular form. Data were supplied by the national consultants as well as by the IGB from the information of different statistical offices via the internet.

2.5 Agricultural data

The top soil **nutrient surplus** at the agricultural area for the German part of the Danube Basin has been taken for the period 1950-1999 from BEHRENDT et al. (2002a). For the Czech part, the nutrient surplus was supplied for the year 2000 on a district basis by the *Water Research Institute, branch BRNO.* For Austria, Slovakia, Hungary and Romania the nutrient surplus was calculated on a district level for 1999 by IGB according to the OECD methodology (OECD, 1997) and based on the statistical data on district level provided by the national consultants of the respective countries. For the other Danube countries (Slovakia, Slovenia, Croatia, Bosnia-Herzegovina, Yugoslavia, Bulgaria, Moldavia and the Ukraine) the nutrient surplus at the agricultural area was calculated on a country basis for the period 1961-2000 according to the OECD methodology (OECD, 1997) based on data from FAO statistics (*FAOStat 98 – 1961-1998* and for the period 1999-2000 based on data available from statistics of the FAO homepage via internet: http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture).

Information on **tile drainage** was made available from different sources. Partly the national consultants provided the information on the extend of tile drainage at total land in agricultural use by administrative units (different levels) or as major basin wide figures on the extend of tile drainage. Only for Slovenia the exact location as well as the extent of tile drained areas were available. For those countries where such information was missing, the percentage of tile drained areas was estimated on the basis of the FAO soil map and figures given in this database on drainage capacity for the different soils (see chapter 3.1.2.5). Based on the figures from different sources the percentage of tile drained areas on the total land in agricultural use was aggregated for each investigated catchment as an area weighted mean according to CLC and the catchment boundaries. An overview of which data were used for the respective countries is given in Tabel 2.9.

Table 2.9: Figures and sources used for the estimation of the percentage of tile drained areas in the investigated catchments.

Country	Available Figures	Sources used
Germany	Percentage of tile drained area on agricultural land for the sub-catchments	BACH et al. (1978)
Austria	-	FAO digital database, CLC
Czech Republic	percentage tile drained area on district unit; resp. map	district data, CLC
Slovakia	extend of tile drained area on land in agricultural use (ha) by regional units	region data, CLC
Hungary	extend of tile drained area on land in agricultural use (ha) by regional units	region data, CLC
Slovenia	digital map on tile drained areas	digital map, CLC
Croatia	-	FAO digital database, CLC
Bosnia-Herzegovina	-	FAO digital database, CLC
Rep. of Yugoslavia	-	FAO digital database, CLC
Bulgaria	-	FAO digital database, CLC
Romania	extend of tile drained area on land in agricultural use (ha) by major subbasin	subcatchment data, CLC
Ukraine	-	FAO digital database, CLC
Moldova	extend of tile drained area on land in agricultural use (ha) by district units	district data, CLC

3. Methodology

3.1 Nutrient Emissions

The GIS oriented Model MONERIS (**MO**deling **N**utrient **E**missions in **RI**ver **S**ystems) was developed for the estimation of nutrient inputs by various point and diffuse sources into German river basins larger than 1000 km² for the periods 1983 to 1987, 1993 to 1997 and 1998-2000 (BEHRENDT et al., 2000; BEHRENDT et al., 2002). Within this project the model was applied to 388 sub-basins of the Danube river. The estimations were made for the period 1998 to 2000.

The basic input into the model are data on discharges, data on water quality of the investigated river basins and a Geographical Information System integrating digital maps as well as statistical information for different administrative levels.

Whereas the inputs of municipal waste water treatment plants and of direct industrial discharges enter the river system directly, the sum of the diffuse nutrient inputs into the surface waters is the result of different pathways realized by several runoff components (see Figure 3.1).

The distinction between the inputs from the different runoff components is necessary, because the concentrations of substances within the runoff components and the processes within these runoff components are very different. Therefore MONERIS takes seven pathways into account:

- discharges from point sources
- inputs into surface waters via atmospheric deposition
- inputs into surface waters via groundwater
- inputs into surface waters via tile drainage
- inputs into surface waters via paved urban areas
- inputs into surface waters by erosion
- inputs into surface waters via surface runoff (only dissolved nutrients)

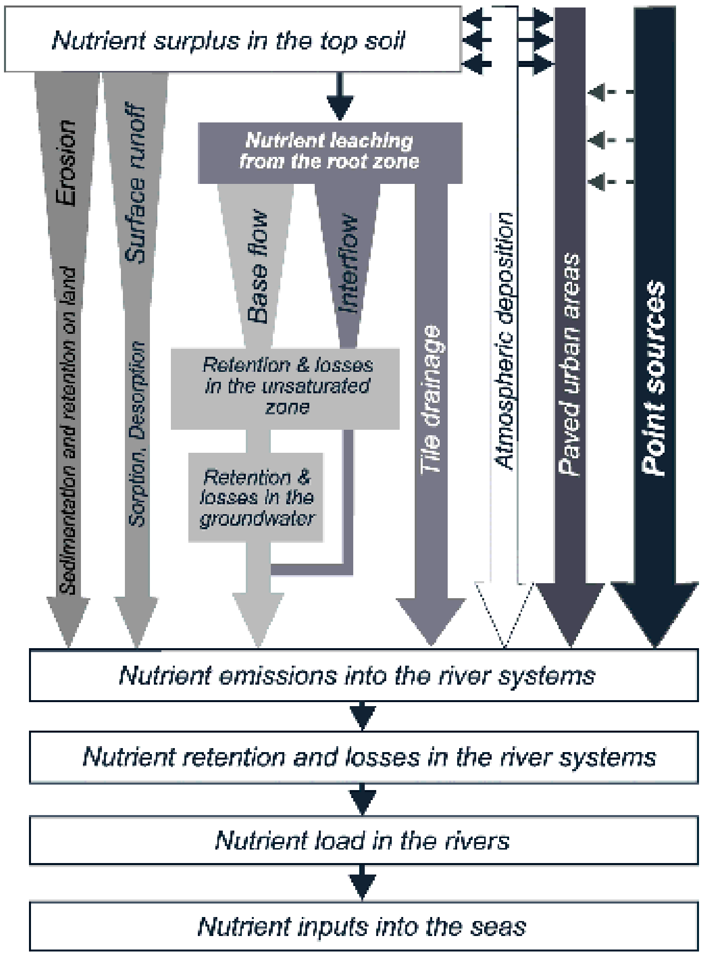


Figure **3.1:** Pathways and processes in MONERIS.

Within the diffuse pathways, various transformation, loss and retention processes are identified. To quantify and forecast the nutrient inputs in relation to their cause knowledge of these transformation and retention processes is required. This is not yet possible through detailed dynamic process models because the current state of knowledge and existing databases is limited for medium and large river basins. Therefore, existing approaches of macro-scale modeling will be complemented and modified and, if necessary, attempts will be made to derive new applicable conceptual models for the estimation of nutrient inputs via the individual diffuse pathways.

An important step in the development of the individual sub-models was to validate these models by comparing the results with independent data sets. For example, the groundwater sub-model was validated with measured groundwater concentrations.

The use of a Geographical Information System gives the possibility for a regionalized estimation of nutrient inputs. The estimations were made with the same methodology for 388 different river basins. The calculation was carried out for the time period 1998 to 2000.

The following chapters present a short description of the methodology of MONERIS. Detailed information is presented in BEHRENDT et al. (2000).

3.1.1 Nutrient discharges from municipal waste water treatment plants and industry

For the estimation of the nutrient inputs by municipal waste water treatment plants and by industrial discharges the ICPDR inventory for the year 2000 was used. This inventory includes only the largest point sources and represents for each country about 75% of the total point source emissions into the river systems of Danube.

To estimate the total nutrient discharges by WWTP and direct industrial inputs, a correction based on the available database for each country was made.

For Germany the national WWTP inventory of Bavaria and Baden-Württemberg was used to calculate the total nutrient discharges by point sources within the German part of the Danube. For Slovakia and Hungary the WWTP database collected by the consultants was also used. Since this was larger than the ICPDR inventory, it was assumed that the inventory for these both countries was nearly complete.

For the other countries the missing 25% of point source discharges were calculated from the inventory (includes 75% of discharges). This amount was divided by the population of the catchments within the countries investigated where information on WWTP`s was not available. This specific point source emissions per inhabitant and country is overlayed by the remaining population within the sub-basins to calculate the total nutrient emissions by point sources.

One problem encountered was that the assumption that the ICPDR inventory includes about 75% of the total point source emissions of each country is not actually well defined in relation to specific nutrients and could differ for nitrogen and phosphorus.

3.1.2 Nutrient Emissions from Diffuse Sources

3.1.2.1 Nutrient Balances

For all countries in the Danube basin the nutrient surplus of agricultural areas was estimated using the OECD method (OECD, 1997). The ***soil surface balance*** calculates the difference between the total quantity of nutrient inputs entering the soil and the quantity of nutrient outputs leaving the soil annually. The calculation of the soil surface balance, as defined here, is a modified version of the so-called *"gross balance"* which provides information about the complete surplus (deficit) of nutrients into the soil, water and air from an agricultural system.

The calculations for the different countries are based on the agricultural statistics and nutrient equivalents for livestock and crops. Because the result of the balance depends on the selected numbers of the nutrient equivalents, the same equivalents were used for the calculations in all countries. These harmonized nutrient equivalents are mainly based on those used in the Czech Republic and published in the database of the OECD (1999) as well as by BEHRENDT et al. (2002).

The estimate of the annual total quantity of ***nutrients inputs*** for the soil surface nitrogen and phosphorus balance, includes the addition of :

- *inorganic or chemical nitrogen and phosphorus fertiliser*: quantity consumed by agriculture;
- *livestock manure nutrient production*: total numbers of live animals (cattle, pigs, sheep, goats, poultry, horses, and other livestock) in terms of different categories according to species (e. g. chickens, turkeys), sex, age and purpose (e. g. milk cow, beef

Table 3.1: Specific nutrient emissions for livestock.

Description	P [kg/head P]	N [kg/head N]
Calves	2.6	20.2
Male Cattle	8.3	59.7
Female Cattle	6.8	48.7
Male Cattle >2 yrs	11.5	78.6
Breeding Heifers	8.2	58.5
Dairy Cows	10	50.0
Other Cows	10	50.0
Pigs <20 kg	0.8	3.5
Pigs 20 -50 kgs	2.2	9.3
Fattening Pigs >50 kgs	3.5	15.0
Boars	4.9	20.9
Sows	4.9	20.9
Other Pigs	3.5	15.0
Sheep	1.9	9.8
Lambs	1	5.1
Goats	1.9	9.8
Broilers	0.2	0.6
Layers	0.3	0.6
Other Chicken	0.1	0.5
Ducks	0.3	1.4
Turkeys	0.6	2.3
Other Poultry Types	0.3	1.4
Horses	11.2	83.8

Table 3.2: Rates of nitrogen fixation by different crop plants.

Description	N [kg/(ha·a) N]
Pulses	80
Clover	240
Alfalfa	240
Other Legume Crops	25
Free living organisms	
Permanent Crops	5
Permanent pasture	5

cattle), multiplied by respective coefficients of the quantity of nitrogen and phosphorus contained in manure per animal and year (see Table 3.1). The NH3-volatilisation is considered in the calculation by a reduction of the gross livestock manure nitrogen production of 30%.

- *atmospheric deposition of nutrients:* total agricultural land area multiplied by a single coefficient of nutrient deposited per hectare. For the period 1985 to 1999 the results of the EMEP calculations for the individual countries were taken into account for the nitrogen deposition rates. For years before 1985, the same value as occurred in 1985 was used. For the phosphorus deposition a value of 0.5 kg/(ha·a) P was assumed;
- *biological nitrogen fixation:* area of harvested legume crops (e. g. field beans, soybeans, clover, alfalfa) multiplied by respective coefficients of nitrogen fixation/ha, plus the nitrogen fixation by free living soil organisms computed from the total agricultural land area multiplied by a single coefficient of nitrogen fixation/ha (see Table 3.2);
- *nutrients from recycled organic matter:* quantity of sewage sludge applied to agricultural land multiplied by a single coefficient of nutrient content of sewage sludge. For the sludge a nutrient content of 1.5 kg/t N and 0.5 kg/t P was assumed;
- *nutrients contained in seeds and planting materials:* quantity of seeds and planting materials (e. g. cereals, potato tubers) multiplied by respective coefficients of nutrient content of seeds/planting materials.

The estimate of the annual total quantity of ***nutrient outputs,*** or nutrient uptake, for the soil surface nutrient balance additionally includes the following :

- *harvested crops:* quantity of harvested crop production (e. g. cereals, root crops, pulses, fruit, vegetables and industrial crops) multiplied by the respective coefficients of nutrient uptake to produce a tonne of harvested crop (see Table 3.3);
- *forage crops:* quantity of forage crop production (e. g. fodder beets, hay, silage, and grass from temporary and permanent pasture) multiplied by the respective coefficients of nutrient uptake to produce a tonne of forage.

Based upon these parameters and the coefficients given in Table 3.2 and 3.3, the nutrient surplus in the agricultural area was estimated by the following equations.

Nutrient Input = Fertilisers + Net Input of Manure + Other Nutrient Inputs

Nutrient Output = Total Harvested Crops + Total Forage

Nutrient Surplus = Nutrient Outputs − Nutrient Inputs

Nutrient Surplus per Hectare Agricultural Land = Nutrient Balance (tonnes of nutrient) divided by the Total Area of Agricultural Land (hectares)

Table 3.3: Specific N and P uptake by principal crops used for the calculations.

Description	P [kg/t P]	N [kg/t N]
Spring Wheat	4.1	19.0
Winter Wheat	4.1	19.0
Barley	3.4	17.0
Maize	3.1	21.0
Millet	5	25.0
Oats	3.9	18.8
Rye	3.9	16.0
Triticale	4.1	19.0
Other Cereals Types	4.1	19.0
Soybeans		50.0
Sunflower seed	7	30.0
Rapeseed	7.6	35.0
Other Oil Crops	7.6	35.0
Total Dried Pulses and Beans	4.3	41.8
Potatoes	0.48	2.5
Other Fruit	0.42	2.6
Sugar Beet	0.7	1.6
Flax Straw	0.31	13.0
Hop	2.2	32.0
Other Industrial Crops types	2.2	13.0
Fodder Beets	0.13	1.4
Other Fodder Roots	0.61	2.7
Clover	2.6	25.0
Alfalfa	3.1	27.0
Silage Maize	0.44	3.0
Other Green Fodder	0.57	5.0
Other Harvested Fodder Crops	2.6	23.0
Permanent Grassland Production	3.1	17.0
Permanent Grassland Consumption	3.1	17.0
Straw	0.81	5.67

The nutrient balances were calculated for the long-term period 1950 to 1999 for Germany and the Czech Republic. Based on the FAO dataset a period from 1961 to 2000 could be considered for Austria, Hungary, Romania and Bulgaria. For the other countries the nutrient balance could be calculated only for the period 1992 to 2000, because FAO and national data were only available since the year of independence.

The full data set for the calculation of the nutrient balance was only available for 6 countries, at least for the years 1998, 1999 and 2000. Especially the production of fodder crops and/or permanent grassland is not taken into account in the published agricultural statistics of most countries. For these countries we derived a factor between the total N-production by forage and the gross nitrogen inputs by livestock manure for the 6 countries where all data were available. The factor was estimated as 0.557 ($n=6$; $r^2=0.915$).

For Germany, Austria, the Czech Republic, Slovakia, Hungary and Romania a calculation of the nutrient surplus was possible also for smaller administrative units, based on the data crop and livestock statistics for regions or districts collected by the consultants. The nutrient surplus for the districts was estimated with the same method than for the countries. Because consumption of mineral fertilizer was often missing for the district level, the consumption data for districts was calculated by a distribution of the mineral fertilizer according to the procedure applied for German districts (BEHRENDT et al., 2002).

Because the database is only be available for administrative units (countries, districts or municipalities) these estimations were done at first for the administrative units. Secondly the total estimated nutrient surplus for the administrative units is calculated as a specific surplus for the agricultural area of these administrative units according to the CORINE landcover or the corrected USGS landcover map. By means of these maps the specific nutrient surplus per agricultural area of CORINE is used to estimate the nutrient surplus for the different sub-catchments of the Danube.

3.1.2.2 Harmonisation Procedure of Land Use Information

For information on land use distribution within the Danube river basin two maps were considered for the aggregation of the eight classes used for the calculations (see chapter 2, Map 2.4 and Map 2.5) because in the database of higher spatial resolution of CORINE land cover (CLC, 250 m x 250 m) Croatia, Yugoslavia (Serbia and Montenegro), the Ukraine and Moldova are not included. It was therefore necessary to find a procedure for transforming the land use information from the “rougher” database of the USGS land cover map (1000 m x 1000 m) into the land use categories of CLC. As a first step the land use classes of the two databases were compared to find similar land use categories and the differences between the classes. Then the share of all classes within the investigated catchments were determined for both databases and searched for the variation of land cover changes with the altitude and precipitation. It was found that the portion of arable land in comparison with the other land use classes like pasture, forest, grassland and agricultural area with natural vegetation was related

Figure **3.2:** Variation of land use with altitude based on CLC and DEM.

to altitude based on the DEM (see Map 2.3 and Figure 3.2).

This relationship was used to transform the information of the mixed classes of land cover from the USGS database into single classes according to CLC land use based on the percentage from the analysis which shows the portion of arable land in comparison with other land use classes within the different altitudes (see Table 3.4). For each investigated catchment with only USGS land use information the portion of the mixed classes on the total catchment area were divided into single classes with the share of each calculated according to the percentages in Table 3.4.

Other land use classes which were intended to be converted one to one from the USGS land cover database show an over- or underestimation in comparison with the share of this classes according to the CLC database in the investigated catchments (see Figure 3.3 and Figure 3.4). For this reason further general conversion factors were determined (see Table 3.7) from the mean of all investigated catchments and applied to the calculation of the share of the respective land use classes at the total catchment area. Differences which occurred in the sum of all land use classes due to this procedure were eliminated by equal shares of the difference to each category.

An overview of which CORINE land cover classes were aggregated for the calculations with the MONERIS model is shown in Table 3.5. The correlation between the USGS and CLC classes that were used for the calculations is shown according to their codes in Table 3.6.

Table 3.4: Share of arable land with different altitudes based on CLC and DEM.

Altitude Class	Arable land to forest [%]	Arable land to pasture [%]	Arable land to agriculture with natural vegetation [%]	Arable land to natural grassland & moors [%]
0 - 100	93,06	93,28	91,69	93,20
100 - 200	84,41	93,28	86,48	94,46
200 - 300	63,60	93,81	74,74	89,93
300 - 400	47,87	88,64	59,57	80,47
400 - 500	40,40	75,39	54,73	80,04
500 - 600	31,41	64,49	50,32	73,84
600 - 700	14,51	40,95	35,41	54,30
700 - 800	8,15	28,93	26,11	35,74
800 - 900	2,86	14,53	15,55	14,57
900 - 1000	1,20	10,78	11,01	6,79
1000 - 1200	0,26	3,59	5,54	1,53
1200 - 1400	0,05	1,07	3,46	0,26
1400 - 1600	0,00	0,03	0,28	0,00
1600 - 1800	0,00	0,00	0,00	0,00

Table 3.5: Aggregated land use classes of CLC for the calculations with the model MONERIS.

CORINE Code	CORINE Codes (aggregated)	CORINE Description*	land use class used in calculations	Code calculations
11	111, 112	Urban fabric	Urban area	1
12	121, 122, 123, 124	Industrial, commercial and transport units	Urban area	1
13	131, 132, 133	Mine, dump and construction sites	Exploitation area	2
14	141, 142	Artificial non-agricultural vegetated areas	Urban area	1
21	211, 212, 213	Arable land	Arable land	3
22	221, 222, 223	Permanent crops	Arable land	3
23	231	Pasture	Pasture	4
24	241, 242, 243, 244	Heterogeneous agricultural area	Arable land	3
31	311, 312, 313	Forests	Forest	5
32	321, 322, 323, 324	Shrub and/or herbaceous vegetation associations	Open area	6
33	331, 332,333, 334, 335	Open spaces with little or no vegetation	Open area	6
41	411, 412	Inland wetlands	Wetlands	7
42	421, 422, 423	Coastal wetlands	Wetlands	7
51	511, 512	Inland waters	Water surface	8
52	521, 522, 523	Marine Waters	Water surface	8

*Source: http://reports.eea.eu.int/COR0-landcover/en/tab_content_RLR

Table 3.6: Correlation between USGS and CLC classes for calculations.

USGS Value	USGS Description*	USGS Code	CORINE Code	Land use description used for calculations	Code calculations
1	Urban and Built-Up Land	100	11	Urban area	1
2	Dryland Cropland and Pasture	211	21	Arable land	3
3	Irrigated Cropland and Pasture	212	21	Arable land	3
4	Mixed Dryland/ Irrigated Cropland and Pasture	213	21	Arable land	3
5	Cropland/Grassland Mosaic	280	21 resp. 23	Arable land resp. Pasture	3 resp. 4
6	Cropland/Woodland Mosaic	290	21 resp. 31	Arable land resp. Forest	4 resp. 5
7	Grassland	311	23	Pasture	4
8	Shrubland	321	33	Open area	6
9	Mixed Shrubland/Grassland	330	33	Open Area, resp. Pasture	6 resp. 4
10	Savanna	332	41, 42 resp. 33	Below 700 m Wetland, above 700 m Open area	3
11	Deciduous Broadleaf Forest	411	31	Forest	5
12	Deciduous Needleleaf Forest	412	31	Forest	5
13	Evergreen Broadleaf Forest	421	31	Forest	5
14	Evergreen Needleleaf Forest	422	31	Forest	5
15	Mixed Forest	430	31	Forest	5
16	Water Bodies	500	51	Water surface	8
17	Herbaceous Wetland	620	41, 42	Wetland	7
18	Wooded Wetland	610	41, 42	Wetland	7
19	Barren or Sparsely Vegetated	770	33	Open area	6
20	Herbaceous Tundra	820	-	-	-
21	Wooded Tundra	810	-	-	-
22	Mixed Tundra	850	-	-	-
23	Bare Ground Tundra	830	-	-	-
24	Snow or Ice	900	33	Open area	6

*Source: http://edcdaac.usgs.gov/glcc/eadoc1_2.html

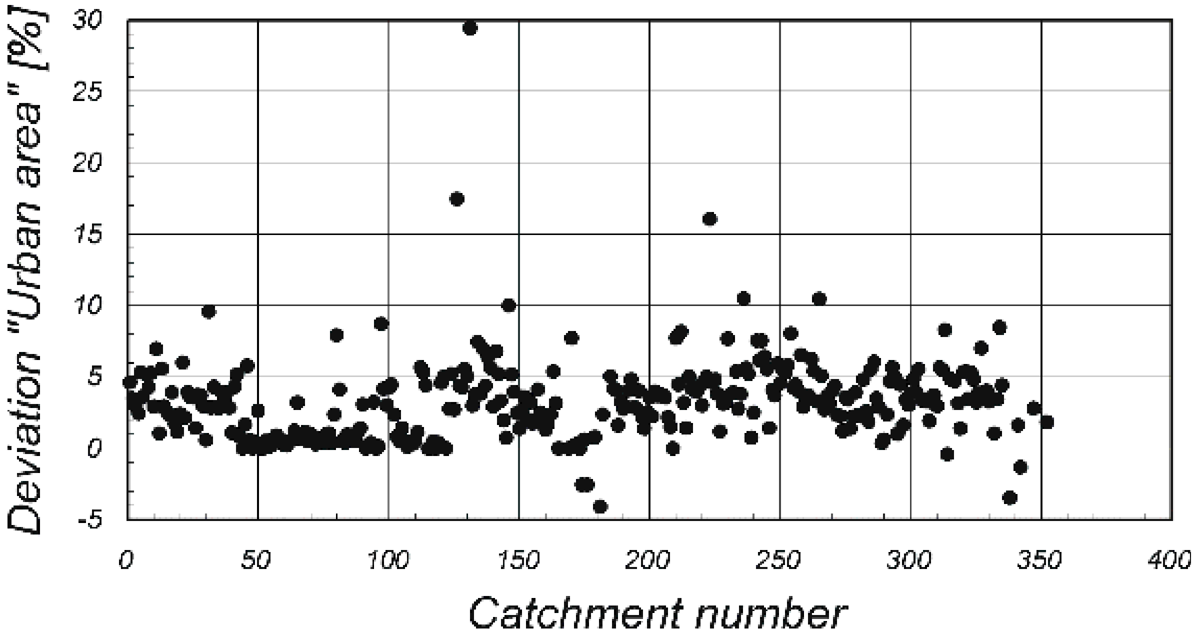


Figure **3.3:** Over- and underestimation of the land use class “Urban area”.

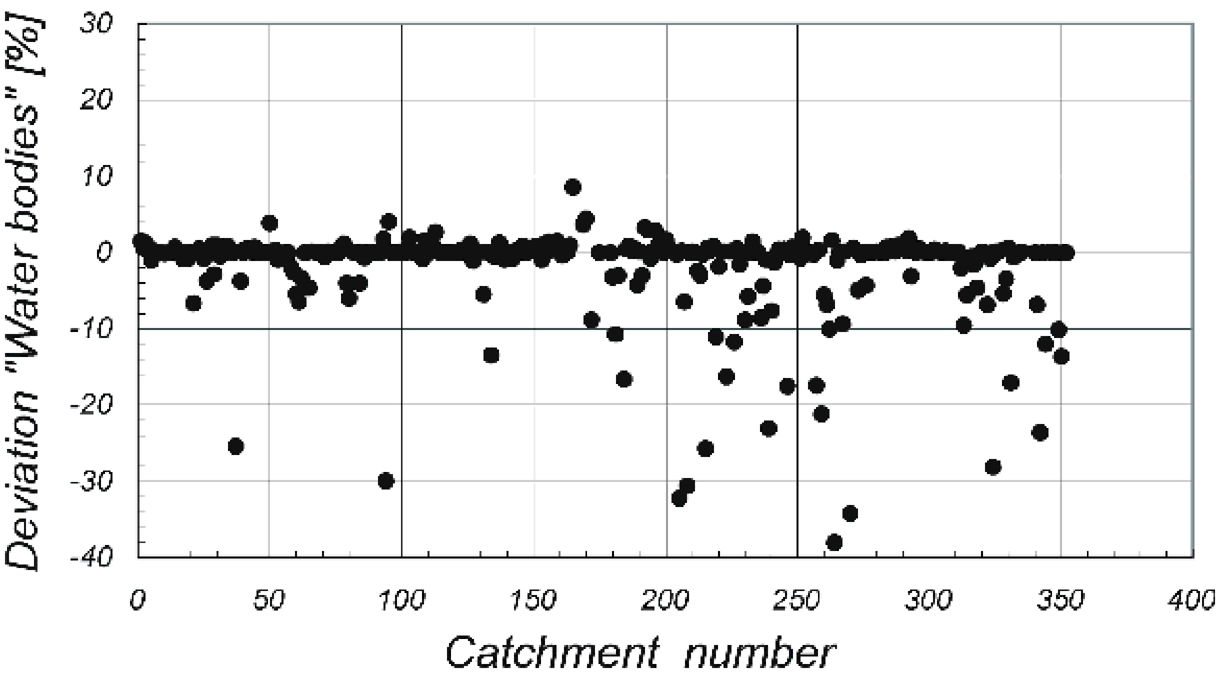


Figure **3.4:** Over- and underestimation of the land use class “Water bodies”.

Table **3.7:** Conversion factors for the harmonization procedure of land use classes

Land Use Class	Deviation USGS to CLC [%]	Conversion Factor
"Urban areas"	3.44	0.03
"Forest"	13.63	0.14
"Water bodies"	-0.46	1.0
"Sparsely vegetated"	1.56	0.02

Table 3.7 shows the conversion factors for the other land use classes within the harmonization procedure.

3.1.2.3 Nutrient Emissions via Atmospheric Deposition

The basis for estimating the direct inputs into freshwaters by atmospheric deposition was a knowledge of the area of all those surface waters within a basin which are connected to the river system. The land use map according to CORINE-landcover was used for the estimation of the area of larger lakes and rivers. Additionally, the area of the river system itself has to be taken into account. According to BEHRENDT ET AL (2000), the area of a river system is dependent on the size of the catchment. The area of surface water within a catchment is calculated according to the following formula:

$$A_W = A_{WCLC} + 0{,}001 \cdot A_{CA}^{1{,}185} \qquad (3.1)$$

with A_W = total water surface area [km²],
A_{WCLC} = water surface area from CORINE-Landcover [km²],
A_{CA} = catchment area [km²] and

This equation could not previously have been compared with independent data sets for the Danube countries and it is likely that the estimated area of surface waters is overestimated in cases of flat river catchments with low runoff such as those occur especially in Hungary and in the Danube valley in Romania and Bulgaria.

There was no information available on the wet deposition of phosphorus for any of the Danube countries. Therefore, based upon the assumptions and literature review of BEHRENDT et al. (2000), a uniform P-deposition rate was used for the whole catchment of Danube which was in the same order of magnitude as deposition rate used for the German river basins (0.37 kg/(ha·a) P).

For nitrogen the results of the EMEP-program were considered for 1999 (TSYRO, 1998a, b; BARTNICKI et al, 1998), which can be downloaded from the EMEP-internet page. The EMEP-data are available as grid maps with a cell size of 50 km for the year 1996 as NOx-N- and NH4-N-deposition in kg/(ha·a) N. The EMEP-grid maps were overlaid with the boundaries of the river basins for the estimation of the mean NO_x-N- and NH_4-N-deposition within the catchments (see map 2.11).

The nutrient inputs via atmospheric deposition were calculated as the product of the area specific deposition and the mean area of surface water in a basin.

$$EAD_{N,P} = A_W \cdot DEP_{N,P} \qquad (3.2)$$

with $EAD_{N,P}$ = nutrient emissions via atmospheric deposition [t/a] and
$DEP_{N,P}$ = area specific deposition [t/(km²·a)].

3.1.2.4 Nutrient Emissions via Surface Runoff

The inputs of dissolved nutrients by surface runoff were determined according to the scheme presented in Figure 3.5.

Because the function for the surface runoff used in MONERIS for the German river systems (4.3) fails for areas with a mean annual precipitation less than 500 mm/a, a new function was developed.

Investigations on the possibility of the separation of the total runoff into the main hydrological components were done within other studies on the nutrient emissions in the catchments of the river Spree and Main (Zweynert et al., 2003; Behrendt et al., 2003). The aim was to find

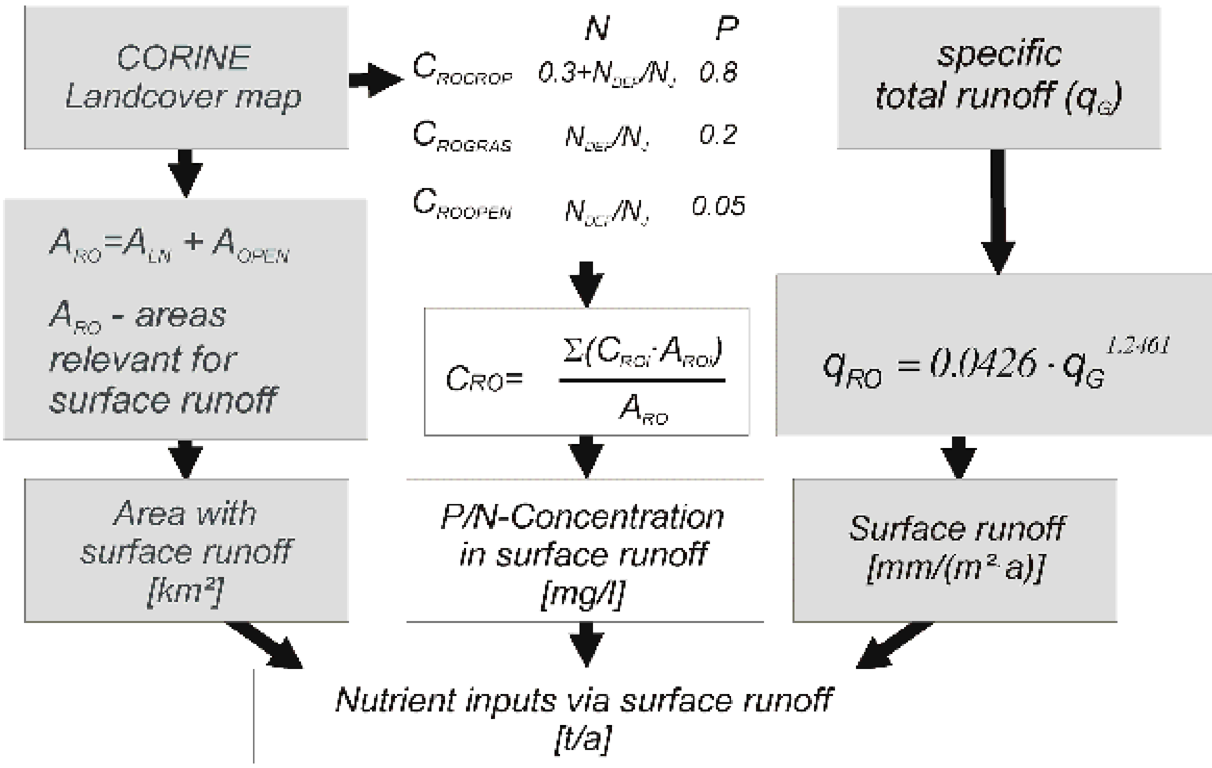


Figure 3.5: Nutrient emissions via surface runoff.

approaches for the functional disaggregation of the runoff time series, which is independent on the application of deterministic hydrological models and based on a conceptual time series model.

The input data for this model are only measured daily discharges. The model estimates the daily contribution of the baseflow, interflow and surface runoff alone by using the properties of the total runoff according to signal theory and the dynamic behaviour of the time series. A description of the model is given by Carl & Behrendt (2003).

If this approach is applied to time series of discharge for different river catchments in Germany (e.g. Main, Neckar) a clear dependency can be found between the surface runoff and the total runoff as shown in Figure 3.6. Additionally, the Figure shows the results for the application of the two hydrological models SWAT and DIFGA for the smaller river catchments of Ybbs (AT), Wulka (AT), Zala (HU), Lonyai (HU) and Neajlov (RO) within the Danube basin (see Zessner et al., 2003).

The figure demonstrates that a dependency of the annual mean of surface runoff on the annual mean of total runoff exists over a very large range of total runoff (20 to 1200 mm/(m²·a)). This dependency can be described with a simple power approach. Further the results of the conceptual time series model are comparable with the results of the hydrological models SWAT and DIFGA applied for the case study catchments within the daNUbs-project (Zessner et al., 2003).

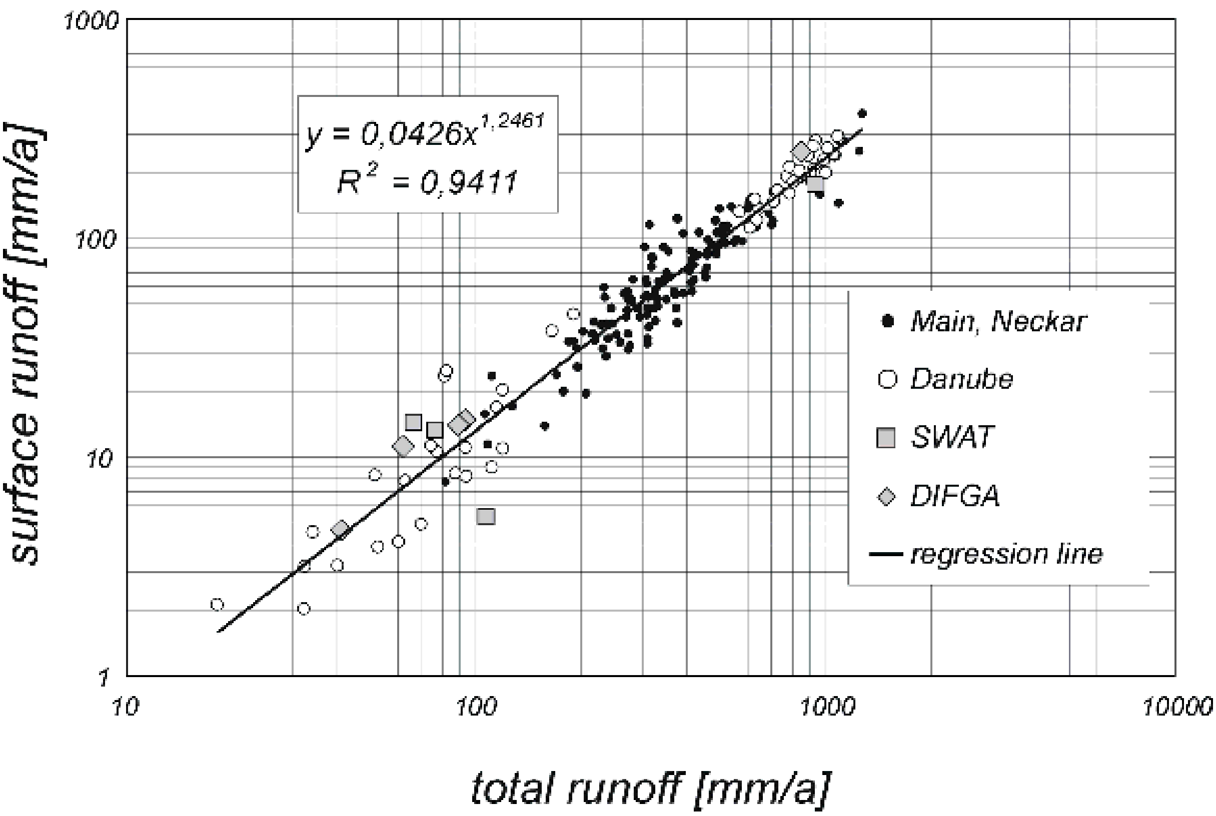


Figure 3.6: Dependency of the mean annual surface runoff on the total runoff for different river catchments in Germany and for the case study catchments of theEU-project daNUbs.

Because the correlation coefficient for this dependency is very high and the apporach is in comparison with the results of the the other models for the Danube case studies, the former approach for the calculation of surface runoff was replaced by the newer one.

The new function is given in the following equation (3.3).

$$q_{RO} = 0.0426 \cdot q_G^{1.2461} \tag{3.3}$$

with q_{RO} = specific surface runoff [l/(km²·s)],
q_G = average yearly specific runoff [l/(km²·s)],

The average yearly specific runoff q_G was calculated for each catchment as the quotient between the measured runoff (Q) and the area of the catchment. For sub catchments the surface runoff was calculated from specific long-term total runoff for the catchments by overlay of the catchment boundaries with the specific long term runoff given in Map 2.10.

The total surface runoff within a catchment can be calculated from the product of the specific surface runoff with the total area. But it is to consider that paved urban areas cause surface runoff, too. Therefore the surface runoff from natural areas within the catchment is:

$$Q_{RO} = a \cdot q_{RO} \cdot A_{EZG} - Q_{URB}) \tag{3.4}$$

with Q_{RO} = surface runoff from non-paved areas [m³/a],
a = unit conversion factor,
A_{EZG} = catchment area [km²] and
Q_{URB} = surface runoff of urban areas [km²].

It was also assumed that where surface runoff does occur then all of the surface runoff reaches the river system. The estimation of nutrient inputs via surface runoff considers only the dissolved nutrient components transported with the surface runoff into river systems. The nutrient concentration in surface runoff of every basin can be estimated as area-weighted mean of the concentrations in the surface runoff of the different land use categories and requires the division of the agricultural areas into arable land and grassland. For the area-weighted concentrations of nitrogen and phosphorus in surface runoff, the following is valid:

$$C_{RO_{N,P}} = \frac{C_{ROAR_{N,P}} \cdot A_{AR} + C_{ROGRAS_{N,P}} \cdot A_{GRAS} + C_{ROFOR_{N,P}} \cdot A_{FOR} + C_{ROOP_{N,P}} \cdot A_{OP}}{A_{AR} + A_{GRAS} + A_{FOR} + A_{OP}} \tag{3.5}$$

with $C_{RO_{N,P}}$ = nutrient concentration in surface runoff [mg/l],
A_{AR} = area of arable land [km²],
A_{GRAS} = grassland area [km²],
A_{FOR} = area of forest[km²],
A_{OP} = open area [km²],
$C_{ROAR_{N,P}}$ = nutrient concentration in surface runoff from arable land [mg/l],
$C_{ROGRAS_{N,P}}$ = nutrient concentration in surface runoff from grassland [mg/l],
$C_{ROFOR_{N,P}}$ = nutrient concentration in surface runoff from forest [mg/l],
$C_{ROOP_{N,P}}$ = nutrient concentration in surface runoff from open land [mg/l].

The nutrient input via surface runoff to the river system is therefore:

$$ERO_{N,P} = C_{RO_{N,P}} \cdot Q_{RO} \cdot a \tag{3.6}$$

with $ERO_{N,P}$ = nutrient input via surface runoff [t/a] and
a = unit conversion factor.

For the calculation of the emissions by surface runoff the nutrient concentrations given in Table 3.8 are used for all catchment areas (BEHRENDT et al., 2000).

For the open areas the same P-concentration as for Germany were assumed also for the other Danube countries.

Table 3.8: Nutrient concentrations in surface runoff for arable land, grassland and open areas.

Use	Nitrogen	Phosphorus
	[g/m³ N]	[g/m³ P]
Arable land	$0.3+N_{DEP}/N_J$	0.8
Grassland	N_{DEP}/N_J	0.2
Forest	N_{DEP}/N_J	0.05
Open land	N_{DEP}/N_J	0.03

3.1.2.5 Nutrient Emissions via Water Erosion

The data base of this project was not sufficient to develop our own harmonized data set for the soil losses within the Danube basin. However, with the support of the RIVM in the Netherlands it was possible to apply the sediment yield map for whole Europe developed by KLEPPER et al. (1995) and shown in Map 2.12. This map is based on the application of the Universal Soil Loss Equation (USLE) for grid cells of 5 km.

For the calculation of the nutrient inputs into the river system of the Danube the approach used in MONERIS (BEHRENDT et al., 2000) was applied in relation to the sediment delivery ratio (SDR) and the enrichment ratio (ER).

Figure 3.7 shows the procedure for estimating nutrient inputs by erosion based on the soil loss rate, the sediment delivery ratio and the enrichment ratio of nutrients. The mean soil loss in each subcatchment is calculated with the help of the GIS. The sediment delivery ratios for the sub catchments are determined according to Equation 3.7 (BEHRENDT et al. 2000):

$$SDR = 0.012 \cdot (SL_{CA} - 0.25)^{0.3} \cdot A_{AR}^{1.5} \tag{3.7}$$

with SDR = sediment delivery ratio [%],
SL_{CA} = mean slope from USGS-DEM [%] and
A_{AR} = area of arable land from CLC [%].

The sediment input due to erosion for the river basins is then calculated according to Eq. 3.8:

$$SED = SOL \cdot SDR \tag{3.8}$$

with SED = sediment input [t/a] and
SOL = soil loss [t/a].

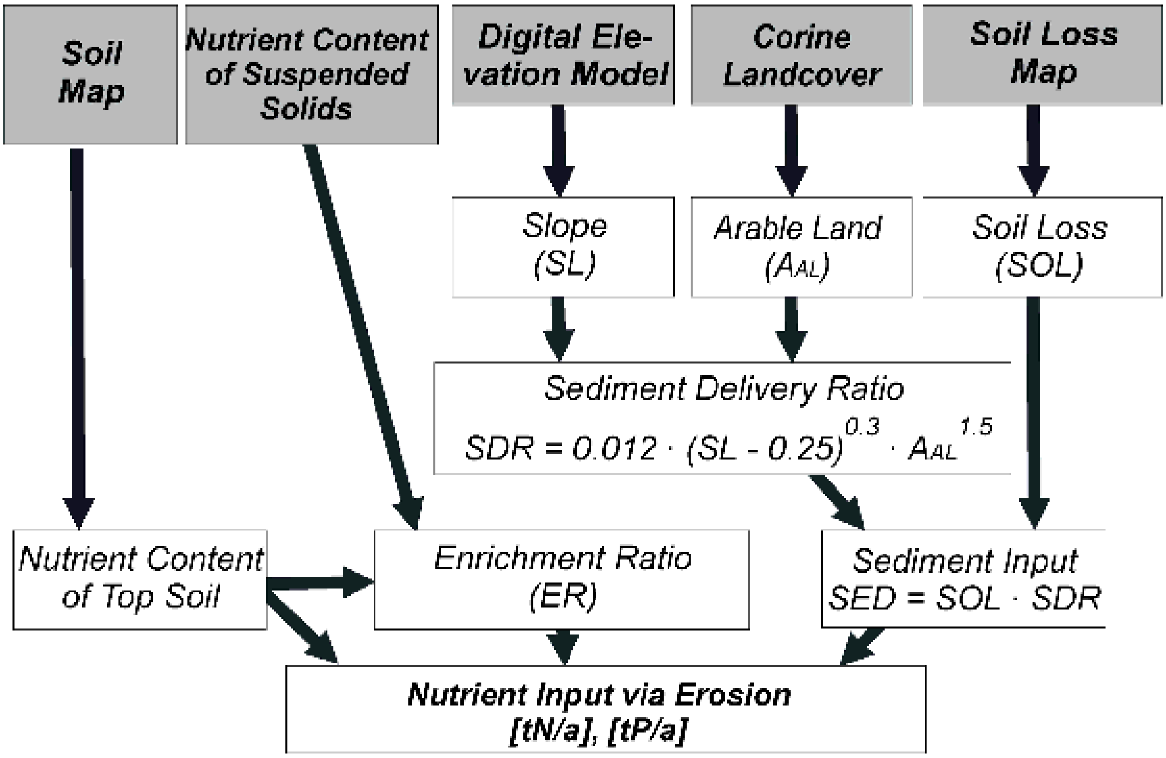


Figure 3.7: Nutrient emissions via erosion

For the TN- content of the topsoil, values were taken from the data in the FAO-soil map (see above). For the TP-content of topsoil the same method as proposed by BEHRENDT et al. (1999) was used and the P-content of topsoil was calculated on the base of the clay content of topsoil (FAO-soil map) and the long term P-accumulation within the countries.

The enrichment ratio is calculated according to the equations from BEHRENDT et al. (2000):

$$ER_P = 18 \cdot \left(\frac{SOL}{A}\right)^{-0.47} \quad (3.9)$$

$$ER_N = 7.7 \cdot \left(\frac{SOL}{A}\right)^{-0.47} \quad (3.10)$$

with $ER_{N,P}$ = enrichment ratio for nitrogen and phosphorus.

The nutrient inputs by erosion were finally calculated as the product of the nutrient content of soil, the enrichment ratio and the sediment input:

$$EER_P = a \cdot P_{SOIL} \cdot ER_P \cdot SED \quad (3.11)$$

$$EER_N = a \cdot N_{SOIL} \cdot ER_N \cdot SED \quad (3.12)$$

with $EER_{N,P}$ = nutrient input via erosion [t/a] and
a = unit conversion factor.

3.1.2.6 Nutrient Emissions via Tile Drainage

For the quantification of nitrogen and phosphorus inputs by tile drainage only the MONERIS approach was applied. This approach is based on the size of the drained area, the amount of drainage water and the average nutrient concentrations in the drainage water (Figure 3.8).

For the estimation of the size of drained areas within a basin for those countries where figures on drained areas were missing, the database on the drainage properties of the soils was used according to the FAO soil map of the world. There the different soils are characterised by 8 classes from very poorly to excessively drained soils. For each FAO-soil type a value is given for every class between 0 and 100%. The drainage classes represent the natural potential of the soil to drain water. This means a very poor drained soil has to be drained artificially for use as agricultural area and a well drained soil class represents soils where artificial drainage is not necessary.

Based on this classification we have given the different soil class a value between 0 and 40% for the portion of artificial drainage on the total agricultural area (see Table 3.9). In the next step the mean percentage of tile drained areas was calculated for each FAO-soil type and by overlaying the agricultural area with the percentage of drained agricultural areas within the sub basins.

Table 3.9: Classes of drained soils and used percentages for artificial drained areas.

Drain class	Percentage of artificial drainage **[%]**
unclassified	0
excessively drained	2
somewhat excessively drained	4
well drained	8
moderately well drained	16
imperfectly drained	24
poorly drained	32
very poorly drained	40

For the countries where the size of drained areas was known on administrative or sub basin units (see Chapter 2), the percentage of drained agricultural areas was calculated as area weighted means for the catchments.

The drainage water volume is calculated according to KRETZSCHMAR (1977) under the assumption that the drained water is the sum of 50% of winter and 10% of summer precipitation:

$$q_{DR} = 0.5 \cdot P_{WI} + 0.1 \cdot P_{SU} \qquad (3.13)$$

with q_{DR} = specific drain water flow [mm/(m²·a)],
P_{WI} = average precipitation in the winter half year [mm/(m²·a)] and
P_{SU} = average precipitation in the summer half year [mm/(m²·a)].

This approach takes into account the regional different distribution of rainfall and the volume of drainage water. On the basis of measurements, average P-concentrations in the drainage water for various soil types were determined. The results are shown in Table 3.10.

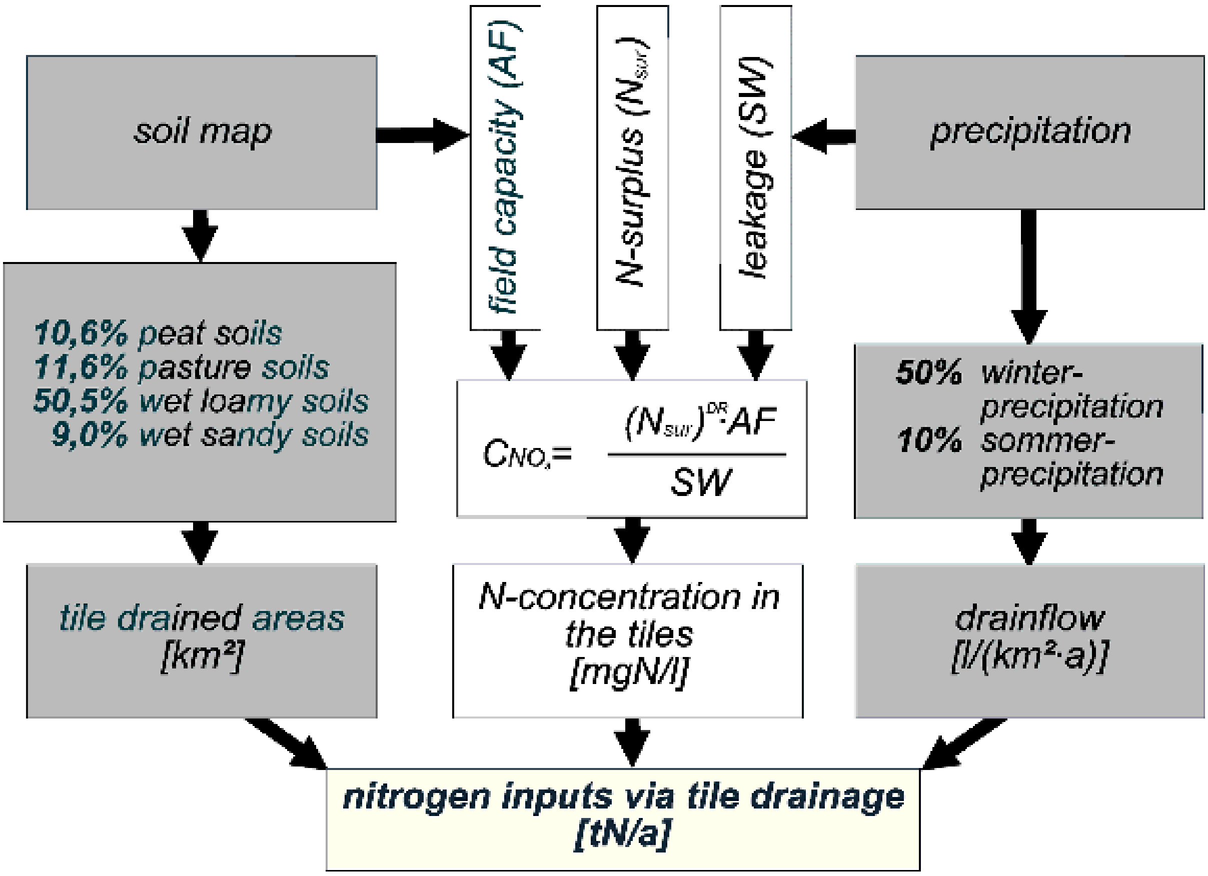


Figure 3.8: Nitrogen emissions via tile drainage

The P-concentration in the catchments was calculated as an area-weighted mean on the basis of the values in Table 3.10 and the areas of sandy soils, loams, fen and bog soils according to the soil map:

$$C_{DR_P} = \frac{C_{DRS_P} \cdot A_{DRS} + C_{DRL_P} \cdot A_{DRL} + C_{DRF_P} \cdot A_{DRF} + C_{DRB_P} \cdot A_{DRB}}{A_{DRS} + A_{DRL} + A_{DRF} + A_{DRB}} \tag{3.14}$$

with C_{DR_P} = drainage water phosphorus concentration [mg/l P],
C_{DRS_P} = drainage water phosphorus concentration for sandy soil [mg/l P],
C_{DRL_P} = drainage water phosphorus concentration for loamy soil [mg/l P],
C_{DRF_P} = drainage water phosphorus concentration for fen soil [mg/l P],
C_{DRB_P} = drainage water phosphorus concentration for bog soil [mg/l P],
A_{DRS} = area of drained sandy soil [km²],
A_{DRL} = area of drained loams [km²],
A_{DRF} = area of drained fen soil [km²] and
A_{DRB} = area of drained bog soil [km²].

The calculation of nitrogen concentrations follows the methods described in BEHRENDT et al. (2000) and is based on the regionally differentiated N-surpluses. From the N-surpluses, the seeping water quantity and the exchange factor, which is calculated from the field capacity, the potential nitrate concentration in the infiltrating water is calculated according to FREDE & DABBERT (1998).

This potential nitrate concentration in the upper soil layer is reduced by a denitrification factor (DR) which was estimated as 0.85 (BEHRENDT et al. 2000). The following equation is used for the calculation of the nitrate concentration in drainage water:

Table 3.10: P-concentrations used for drainage water for different soil types.

Soil type	C_{DR_P} [mg/l P]
Sandy soils	0.20
Loamy soils	0.06
Fen soils	0.30
Bog soils	10.00

$$C_{DR_{NO3-N}} = a \cdot \frac{(N_{SUR})^{DR} \cdot 100}{LW} \tag{3.15}$$

with $C_{DR_{NO3-N}}$ = nitrate concentration in drainage water [mg/l N],
a = unit conversion factor,
N_{SUR} = nitrogen surplus of agricultural areas [kg/(ha·a) N],
DR = exponent for denitrification (0.85) and
LW = seeping water quantity [l/(m²·a)].

The emission via tile drainage can then be calculated from the product of the drained area, the drain flow and the drain concentration:

$$EDR_{N,P} = a \cdot A_{DR} \cdot q_{DR} \cdot C_{DR_{N,P}} \tag{3.16}$$

with $EDR_{N.P}$ = nutrient emissions via tile drainage [t/a],
a = unit conversion factor and
A_{DR} = drained area [km²].

3.1.2.7 Nutrient Emissions via Groundwater

The nutrient inputs by groundwater are calculated from the product of the groundwater outflow and the groundwater nutrient concentration and include the natural interflow and the base flow. This is caused by the absence of methods to calculate the natural interflow separately. Figure 3.9 shows a scheme for the calculation of nitrogen emissions via groundwater.

The groundwater flow was calculated for each basin from the difference of the observed runoff at a monitoring station and the estimated sum of the other discharge components (drain flow, surface runoff, storm water runoff from paved urban areas and atmospheric input flow):

$$Q_{GW} = Q - Q_{DR} - Q_{RO} - Q_{URB} - Q_{AD} \tag{3.17}$$

with Q_{GW} = base flow and natural interflow [m³/s],
Q = average runoff [m³/s],
Q_{DR} = tile drainage flow [m³/s],
Q_{RO} = surface runoff from non-paved areas [m³/s],
Q_{URB} = surface runoff from urban areas [m³/s] and

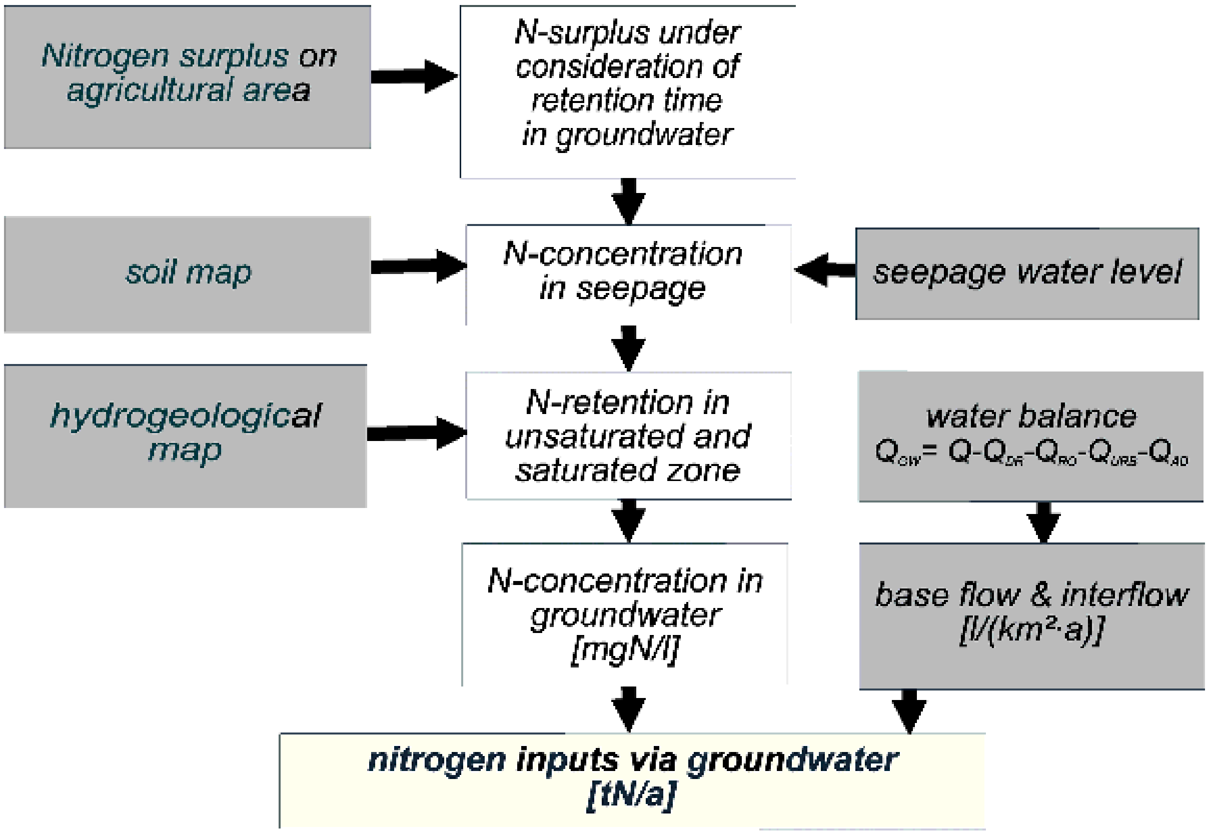


Figure 3.9: *Nitrogen emissions via groundwater.*

Q_{AD} = atmospheric input flow [m³/s].

Groundwater concentrations of soluble reactive phosphorus (SRP) for the different soil types were taken from BEHRENDT et al. (2000) (Table 3.11).

Using these values the P-concentration in the catchment areas was calculated on the basis of the concentrations and the areas of sandy soils, loamy soils, fen and bog soils as area weighted average for the agricultural land according to Equation 3.18:

$$C_{GWAG_{SRP}} = \frac{C_{GWS_{SRP}} \cdot A_S + C_{GWL_{SRP}} \cdot A_L + C_{GWF_{SRP}} \cdot A_F + C_{GWB_{SRP}} \cdot A_B}{A_S + A_L + A_F + A_B} \qquad (3.18)$$

with $C_{GWAG_{SRP}}$ = groundwater SRP concentration for agricultural land [mg/l P],
$C_{GWS_{SRP}}$ = groundwater SRP concentration for sandy soil [mg/l P],
$C_{GWL_{SRP}}$ = groundwater SRP concentration for loamy soil [mg/l P],
$C_{GWF_{SRP}}$ = groundwater SRP concentration for fen soil [mg/l P],
$C_{GWB_{SRP}}$ = groundwater SRP concentration for bog soil [mg/l P],
A_S = area of sandy soil [km²],
A_L = area of loamy soil [km²],
A_F = area of fen soil [km²] and
A_B = area of bog soil [km²].

In a second step, the average SRP concentrations in groundwater of particular catchments were calculated as an area weighted average from the SRP concentrations of agricultural and non-agricultural areas:

$$C_{GW_{SRP}} = \frac{C_{GWAG_{SRP}} \cdot A_{AG} + C_{GWWOOP_{SRP}} \cdot A_{WOOP}}{A_{AG} + A_{WOOP}} \qquad (3.19)$$

with $C_{GW_{SRP}}$ = SRP concentration in groundwater [mg/l P],
$C_{GWWOOP_{SRP}}$ = groundwater SRP conc. for woodland and open areas [mg/l P],
A_{AG} = agricultural area [km²] and
A_{WOOP} = woodland and open area [km²].

It was also taken into account that there are clear differences between the concentrations of dissolved inorganic phosphorus (SRP) and total phosphorus in anaerobic groundwater (DRIESCHER & GELBRECHT 1993). According to BEHRENDT (1996a) and DRIESCHER & GELBRECHT (1993) it can be concluded that the total phosphorus concentrations are 2 to 5 times higher than SRP concentrations determined in the normal standard monitoring programmes. Because information on areas of anaerobic groundwater was not available, those areas with a higher probability of anaerobic conditions were determined through a comparison of nitrate concentrations in groundwater and those in seeping water (see below). For the calculation of total phosphorus concentrations in groundwater it was therefore determined that in accordance with Equations 3.20 and 3.21, nitrogen concentrations in groundwater are less than 5% of those in seeping water and the TP-concentrations in groundwater are 2.5 times greater than the SRP-concentrations:

Table 3.11: P-concentrations used for groundwater below different soil types.

Soil type	C_{DRP} [mg P/l]
Sandy soils	0.10
Loamy soils	0.03
Fen soils	0.10
Bog soils	2.00

$$C_{GW_{TP}} = 2.5 \cdot C_{GW_{SRP}} \text{ if } C_{GW_N} \leq 0.15 \cdot C_{LW_N} \qquad (3.20)$$

$$C_{GW_{TP}} = C_{GW_{SRP}} \qquad \text{if } C_{GW_N} > 0.15 \cdot C_{LW_N} \qquad (3.21)$$

with C_{GW_N} = nitrogen concentration in groundwater [g/m³],
C_{SW_N} = nitrogen concentration in seeping water [g/m³],
$C_{GW_{TP}}$ = TP-concentration in groundwater [g/m³] and
$C_{GW_{SRP}}$ = SRP-concentration in groundwater [g/m³].

The N-concentrations in the groundwater were also derived from the potential nitrate concentration in the soil. The residence time of water and substances on their way from the root-zone to the groundwater, and in the groundwater itself, is much larger than for tile drainage and this residence time has to be taken into account for the groundwater pathway. The reasons are firstly that the level of losses (denitrification) can be dependent on time, and secondly that the nitrogen surplus of agricultural land is also changing over time such that the

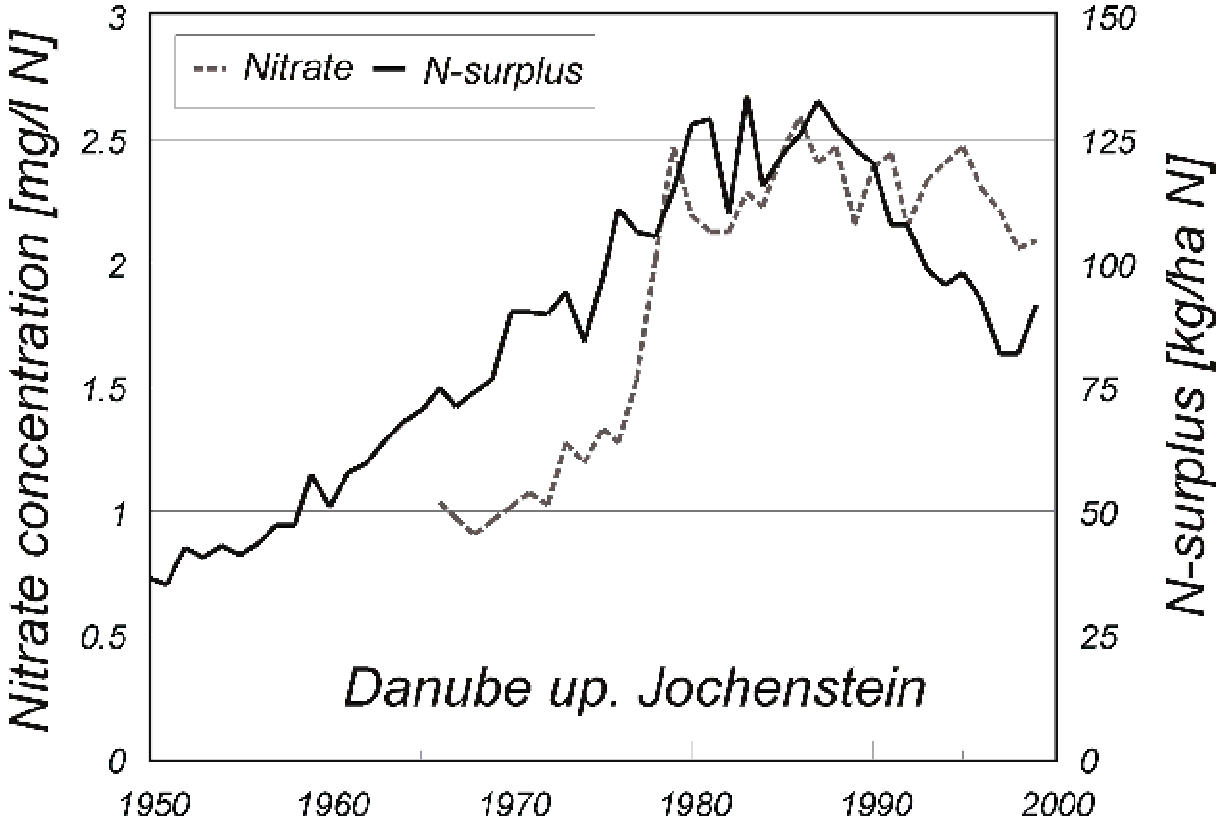


Figure 3.10: Changes of nitrogen surplus on agricultural area and nitrate concentration in the Danube upstream Jochenstein since 1950 and 1999 respectively.

nitrogen in groundwater flowing into surface waters is related to the N-surpluses in the past rather than the present.

A raw approximation of the water residence time in the unsaturated zone and in the aquifer can be made on the basis of long-term observations of nitrate concentrations in rivers and long term estimates of nitrogen surplus.

For the German part of the Danube basin a comparison of the long term change of the nitrogen surplus on the agricultural area and the nitrate concentration is shown in Figure 3.10. The time series of nitrate (see Figure 3.10) shows that the nearly constant nitrate concentrations since the late seventies are not related to the decrease of the N-surplus in the agricultural land since the late eighties. That is an indication that the residence time is in an order of magnitude between 10 and 20 years.

A comparison between the regionalized residence times estimated for the Elbe catchment and its tributaries with the WEKU model KUNKEL & WENDLAND (1999) and the long term level of precipitation in this regions indicates that the residence time in the groundwater is dependent on the level of seeping water. Therefore it was assumed that the residence time of groundwater varies in a range between 5 and 50 years and the mean residence time of each sub catchment was estimated from a relation shown in the following equation (3.22):

$$\tau_{RES} = \frac{3000}{LW} \tag{3.22}$$

with t_{RES} = mean residence time for the natural subsurface flow [a].

This residence time was used to calculate the mean nitrogen surplus on agricultural area of each sub catchment as an average of the previous years between the investigated period (t_0:1998-2000) and the period t0-t_{RES}. This calculations were made for five year periods only. It was assumed that the residence time is not longer than 50 years also for such sub catchments where the equation 3.22 gives higher values.

Based on these results the nitrogen surpluses for the different basins were corrected according to the following formula:

$$N_{TSUR} = \frac{N_{SUR} \cdot A_{AG} \cdot CLS + N_{DEP} \cdot (A_{EZG} - A_{LN} - A_W - A_{IMP} - A_M)}{A_{CA} - A_W - A_{IMP} - A_M} \tag{3.23}$$

with N_{TSUR} = total nitrogen surplus [kg/ha],
N_{SUR} = nitrogen surplus of agricultural areas [kg/ha],
CLS = correction factor for the long-term changes in surpluses,
N_{DEP} = atmospheric nitrogen deposition [kg/ha],
A_{CA} = catchment area [ha],
A_{AG} = agricultural area [ha],
A_W = total water surface area [ha],
A_{IMP} = impervious urban area [ha] and
A_M = mountain area [ha].

The N-surpluses thus estimated are used for the calculation of the overall potential nitrate concentrations in seeping waters for the areas contributing to base flow. For this, the first steps of the approach of FREDE & DABBERT (1998) are used. A condition for this is that the net-mineralisation and immobilisation are negligible. Furthermore, it is assumed that there is no denitrification in the root-zone. Then, the following applies:

$$C_{LWPOT_{NO3-N}} = \frac{N_{TSUR} \cdot 100}{LW} \tag{3.24}$$

with $C_{LWPOT_{NO3-N}}$ = potential nitrate concentration in seeping water for the total area with base flow [g/m³ N],
LW = seepingwater quantity [$l/(m^2 \cdot a)$].

The seeping water quantity (LW) is calculated from the water balance (see Equation 3.17) for each sub catchment.

The nitrogen retention (mainly denitrification) in the soil, unsaturated zone and in the groundwater is calculated from the comparison of the regionalized groundwater concentrations of nitrate and the potential nitrate concentration in seeping water. This comparison was carried out for the whole area of Germany and it was found that the nitrogen retention is dependent on the level of infiltration water and the hydrogeological conditions according to map 2.7.

The nitrate concentrations in groundwater can than be calculated from the nitrate concentrations in seeping water whilst taking account of the retention within the soil which depends on the hydrogeological rock types according to Equation 3.25 from BEHRENDT et al. (2000). The model coefficients are given in Table 3.12.

Table 3.12: Model coefficients for the determination of N-retention in areas with different hydrological conditions (Behrendt et al. 2000).

Hydrological rock type	K_1	K_2	B
Unconsolidated rock areas near groundwater	2.752	-1.54	0.627
Unconsolidated rock areas far groundwater	68.560	-1.96	0.627
Consolidated rock areas with good porosity	6.02	-0.90	0.627
Consolidated rock areas with poor porosity	0.0127	0.66	0.627

$$C_{GW_{NO3-N}} = \left(\sum_{i=1}^{4} \frac{1}{1 + k_{1i} \cdot LW^{k2i}} \cdot \frac{A_{HRT\,i}}{A_{CA}} \right) \cdot C^{b}_{LWPOT_{NO3-N}} \qquad (3.25)$$

with $C_{GW_{NO3-N}}$ = nitrate concentration in groundwater [g/m³ N],
b = model coefficient for denitrification (0.627),
k_1 and k_2 = model coefficients and
A_{HRT} = area of different hydrogeologically rock types [km²].

At the end the nutrient emissions via groundwater are estimated from the product of the regionalized nutrient concentrations and the groundwater flow of the basins:

$$EGW_{N,P} = a \cdot Q_{GW} \cdot C_{GW_{N,P}} \qquad (3.26)$$

with $EGW_{N.P}$ = nutrient emissions via groundwater [t/a] and
a = unit conversion factor.

The nutrient emissions via groundwater were calculated for each of the sub catchment in the Danube.

3.1.2.8 Nutrient Emissions via Urban Areas

Within this pathway nutrient inputs occur via four different routes:

- inputs from impermeable urban areas connected to separate sewer systems,
- inputs from impermeable urban areas by combined sewer overflows,
- inputs from households and impermeable urban areas connected to sewers without treatment and
- inputs from households and impermeable urban areas not connected to sewer systems.

The total urban area is taken from the CLC map. For the calculation of the impermeable urban area the population density is additionally taken into account according to the approach of HEANEY et al. (1976):

$$A_{IMP} = 9.6 \cdot (0.4047 \cdot POP_{DEN})^{0.573 - 0.0391 \cdot \log(0.4047 \cdot POP_{DEN})} \cdot A_{URB} \quad (3.27)$$

with A_{IMP} = impermeable urban area [km²],
A_{URB} = total urban area [km²] and
POP_{DEN} = population density [inhabitants/ha].

The total paved urban area is split into the different sewer systems according to the percentage of the different sewer systems in the river basins. Data for the estimation of the portion of paved urban area to the different sewer systems was not available with the exception of Germany and Romania. Therefore the relationship between the portion of combined sewers at the total sewer length found for different cities within the Czech and the Polish part of the Odra (see Figure 3.11) was used to calculate the areas which are connected to combined and separate sewer systems.

The sewage system ratio (ratio of the combined sewers to the sum of the length of the combined sewers and the separate sewers) of the known Polish and Czech towns in the Odra basin was related to the elevation of the towns (Figure 3.11; BEHRENDT et al. (2002b). In towns situated more than 200m a.sl. a combined sewer system is normally used. The sewage system ratio for the towns in the Danube catchment for which no data were available was calculated using the following formula:

$$SER = \frac{l_{CSO} + l_{SAS}}{l_{CSO}} = \frac{0.01534 - 0.97541}{1 + e^{(h_M - 196.66)/9}} + 0.97541 \quad (3.28)$$

with SER = sewage system ratio,
l_{CSO} = length of the combined sewer overflows [km],
l_{SAS} = length of the sanitary sewers [km] and
h_M = mean elevation of the catchment [m].

The mean elevation of the sub catchments is derived from the Digital Elevation Model (Map 2.3).

To calculate the total discharge from the different sewer systems it is necessary to calculate the surface runoff from impermeable areas as a proportion of precipitation. These values can be calculated according to HEANEY et al. (1976) for every catchment area from the level of impermeable areas with Equation 3.29:

$$a_{IMP} = 0.15 + 0.75 \cdot \frac{A_{IMP}}{A_{URB}} \quad (3.29)$$

with a_{IMP} = share of precipitation realized as surface runoff from impermeable urban areas.

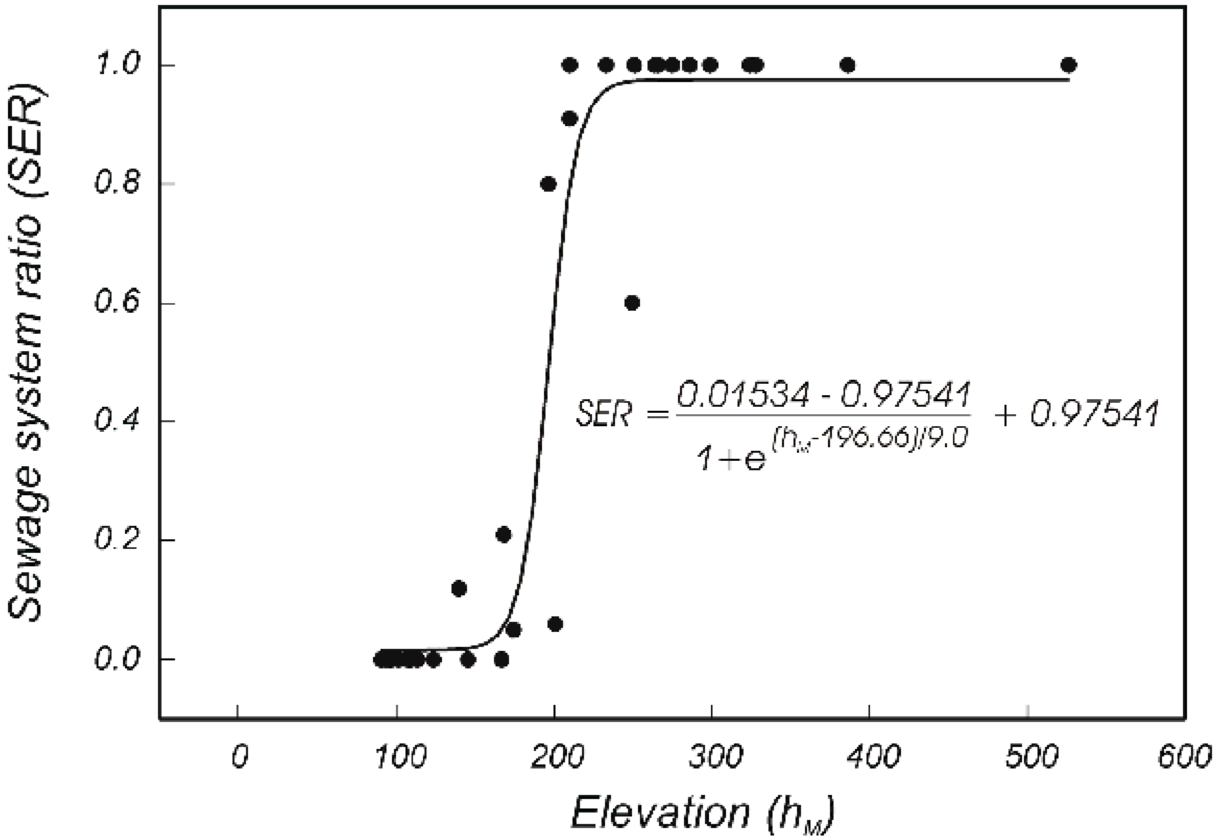


Figure 3.11: *Comparison between the calculated sewage system ratio and the known values for Polish and Czech towns within the Odra basin.*

With the share of the precipitation realized as surface runoff from impermeable urban areas and the annual rainfall, the specific surface runoff can be estimated which is discharged from impermeable urban areas during storm water events in all catchment areas:

$$q_{IMP} = a_{IMP} \cdot P_Y \tag{3.30}$$

with q_{IMP} = specific surface runoff from impermeable urban areas [l/(m²·a)].

The total surface runoff from impermeable urban areas which is discharged by combined and separated sewers can be calculated by multiplication of the specific surface runoff with the impermeable urban areas connected to the different types of sewer systems.

A schematic overview of the applied method is given Figure 3.12.

The nutrient emissions via **separate sewer systems** were estimated by means of area specific emissions. Following the approach of BROMBACH & MICHELBACH (1998) we used an area specific P-emission (of 2.5 kg/(ha·a) P. The area specific N-emissions were calculated from the sum of the atmospheric N-deposition and a value for litter fall and excreta from animals (4 kg/(ha·a) N. The N- and P-inputs are calculated by multiplying the area specific emissions with the paved urban area connected to separate sewer systems.

$$EUS_{N,P} = ES_{IMP_{N,P}} \cdot A_{IMPS} \tag{3.31}$$

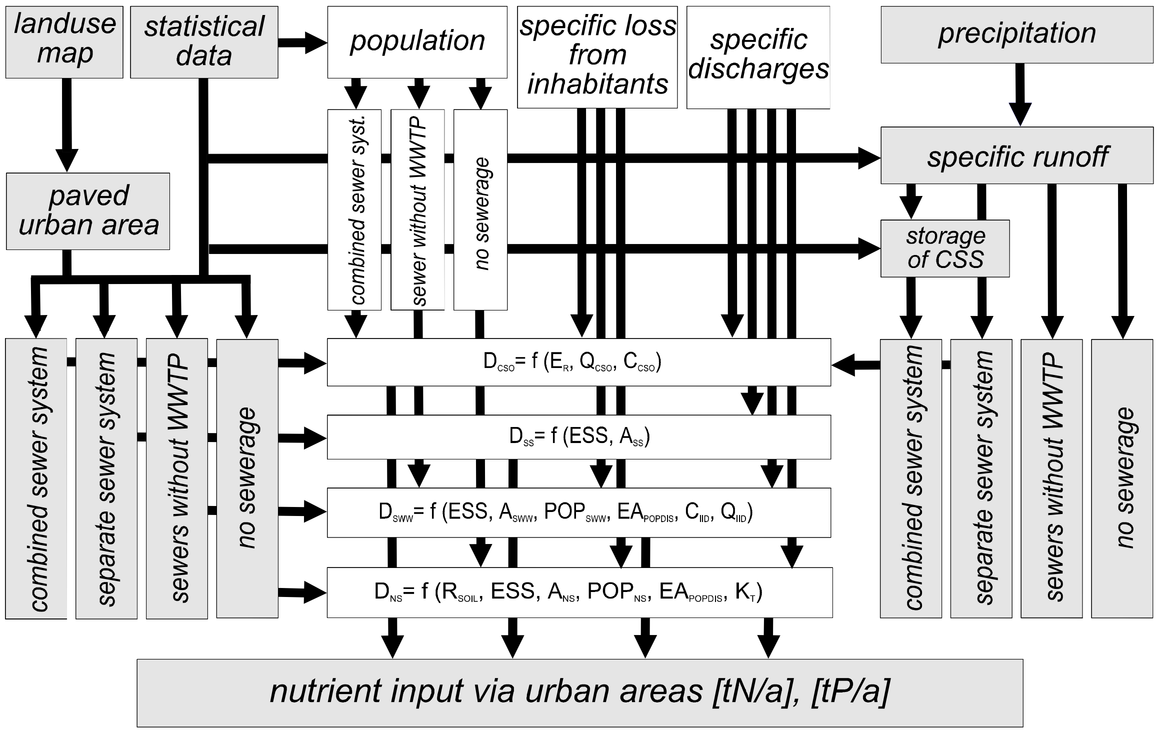


Figure 3.12: Nutrient emissions via urban areas.

with $EUS_{N,P}$ = nutrient inputs via separate sewers [t/a] and
ES_{IMP} = specific nutrient emissions from impermeable urban areas [t/(km²·a)]
A_{IMPS} = impermeable urban area connected to separated sewer system [km²].

The estimation of the nutrient emissions from **combined sewer overflows** is based on the approaches of MOHAUPT et al. (1998) and BROMBACH & MICHELBACH (1998).

The quantity of water discharged during storm water events from combined sewer overflows is dependent on the specific runoff from the paved urban areas, the number of people connected to combined sewers, the inhabitant specific water discharge (130 l/(inh.·d)), the share of industrial areas at the total impermeable urban area (0.8%), the area specific runoff from these industrial areas (432m³/(ha·d)) and the number of the days with storm water events:

$$Q_{IMPC} = q_{URBV} \cdot A_{IMPC} + Z_{NST} \cdot (IN_C \cdot q_{IN} + a_{COM} \cdot q_{COM} \cdot 100 \cdot 86.4 \cdot A_{URB}) \quad (3.32)$$

with Q_{IMPC} = storm water runoff from combined sewer system [m³/a].
A_{IMPC} = impervious urban area connected to combined sewer system [km²],
Z_{NST} = effective number of storm water days,
IN_C = number of inhabitants connected to combined sewer system,
q_{IN} = daily wastewater output per inhabitant [l/(E·d)],
a_{COM} = proportion of total urban area in commercial use and
q_{COM} = specific runoff from commercial areas [m³/(ha·d)].

It is assumed that the effective number of storm water days (Z_{NST}) is dependent on the level of precipitation. For German river systems it was found that

$$Z_{NST} = 0.0000013 \cdot P_Y^{2.55}) \tag{3.33}$$

Consequently the number of effective stormwater days varies in the Danube catchment between lower than 5 and about 50 in the cities of the mountain region.

The discharge rate of a combined sewer system was estimated according to a method developed by MEISSNER (1991) and is dependent upon the annual precipitation as well as the storage volume of the combined sewer. The storage volume holds back a fraction of the waste water during the storm water event and retards the flow to the treatment plant. Data on the storage volume of the combined sewers in the German countries was taken from the sewage water statistics. For the other Danube countries such data were not available. Therefore the storage volume was assumed to be 5.0 m³/ha which corresponds to the value in Eastern Germany at the beginning of the nineties. The discharge rate was estimated according to Equation 3.34:

$$RE = \frac{\frac{4000 + 25 \cdot q_R}{0.551 + q_R}}{V_S + \frac{36.8 + 13.5 \cdot q_R}{0.5 + q_R}} - 6 + \frac{P_Y - 800}{40} \tag{3.34}$$

with RE = discharge rate of combined sewer overflows [%],
q_R = rainfall runoff rate [l/(ha·s)] and
V_S = storage volume [m³].

The nutrient concentration in a combined sewer can be calculated from the area specific emission rate of the impermeable urban area, the inhabitant specific nutrient emissions and the concentration of nutrients in direct industrial effluents:

$$C_{C_{N,P}} = \frac{((EIN_{N,P} \cdot IN_C + C_{COM_{N,P}} \cdot Q_{COMC}) \cdot Z_{NT} + ES_{IMP_{N,P}} \cdot A_{IMPC} \cdot 100) \cdot \frac{RE}{100}}{Q_{COMC}} \tag{3.35}$$

with $C_{C_{N,P}}$ = nutrient concentration in combined sewers during overflow [g/m³],
$EIN_{N,P}$ = inhabitant specific nutrient output [g/(E·d)],
IN_C = number of inhabitants connected to combined sewer system,
$C_{COM_{N,P}}$ = nutrient concentration in commercial wastewater [g/m³] and
Q_{COMC} = runoff from commercial areas connected to combined sewers [m³/d].

For the nutrient concentration in commercial wastewater values of 1 g/m³ N and 0.1 g/m³ P were used (BEHRENDT et al. 2000).

The nutrient emissions from combined sewer systems into each river system are then calculated from the product of the quantity of water discharged by the overflow and the mean nutrient concentration during such events:

$$EUC_{N,P} = C_{C_{N,P}} \cdot RE \cdot Q_{IMPC} \tag{3.36}$$

with $EUC_{N,P}$ = nutrient emissions via combined sewer overflows [t/a].

Further the nutrient inputs from the **impermeable areas and inhabitants connected to sewers but not to a WWTP** must be considered. The population connected to sewers but not to WWTP's can be taken from the statistics. It is assumed that the proportion of urban areas which are connected to a sewer but not to a waste water treatment plant corresponds to the proportion of people only connected to a sewer system. Regarding the inputs of materials, these areas can be considered in the same way as the areas connected to separate sewer systems (see above). The same is assumed for the specific values of the nutrient inputs from these areas.

It is supposed that the particulate fraction of the human nutrient output from inhabitants only connected to sewers is transported to waste water treatment plants. For the dissolved fraction it is assumed that this proportion is fully supplied to the sewer system. The total nutrient input along this pathway will then be calculated according to Equation 3.37:

$$EUSO_{N,P} = ES_{N,P} \cdot A_{IMPSO} \cdot 100 + IN_{SO} \cdot EIN_{D_{N,P}} \cdot 0.365 + C_{COM_{N,P}} \cdot Q_{COMSO} \tag{3.37}$$

with $EUSO_{N,P}$ = nutrient input via impermeable urban areas and from inhabitants connected only to sewers [t/a],

A_{IMPSO} = urban area connected only to sewers [km²],

IN_{SO} = inhabitants connected only to sewers,

Q_{COMSO} = annual runoff from commercial areas only connected to sewers [m^3/s] and

$EIN_{D_{N,P}}$ = inhabitant specific output of dissolved nutrients [g /(inh.·d)].

The specific human dissolved nitrogen outputs was assumed to 9 g N/(inh·d) for all inhabitants in the Danube basin. For phosphorus it has to be assumed that the dissolved emissions are different for the individual countries because the use of phosphorus in detergents varies between the countries.

The analysis of the inhabitant specific P-emissions in Germany (Schmoll. 1998) has shown that about 1.62 gP/(inh.·d) will be emitted if no phosphorus is used in detergents, dish washers and so on. ICPDR has investigated the use of phosphorus within the countries of the Danube basin. Based on this data the specific P-emissions by the inhabitants of each country could be calculated. The results are shown in Table 3.13

Table 3.13: Population and P-use by detergents, dish washers and industry within the Danube countries in 2000

	Population	P used in detergents	P used in dish washers	P used in Industry	Specific P-use by chem.	Total specific P-emissions
	[Inh.]	[t/a P]	[t/a P]	[t/a P]	[g/inh.d P]	[g/inh.d P]
DE	9403880	0.2	758	402	0.34	1.96
AT	7766650	0.2	655	194	0.30	1.92
CZ	2763250	735	43	12	0.78	2.40
SK	4921490	746	27	96	0.48	2.10
HU	11757590	2570	86	225	0.67	2.29
SI	1750640	101	149	96	0.54	2.16
HR	3084940	1494	132	16	1.46	3.08
BH	3323810	1468	31	15	1.25	2.87
YU	9120920	2143			0.64	2.26
RO	20345910	1822	4	29	0.25	1.87
BG	4379630	505	4	3	0.32	1.94
MD	1023750	47		4	0.14	1.76
UA	3094380	134	0	4	0.12	1.74

According to Schmoll (1998) it can be assumed that 0.75 g/(Inh.·d) P will be emitted as particulate phosphorus. If this assumption is applied to the other Danube countries under study then dissolved emissions of between 1 g/(Inh.·d) P and 2.3 g/(Inh.·d) P are estimated.

In addition to the inputs from separate and combined sewer systems, the nutrient emission into the river systems from **impermeable urban areas and people not connected to a sewer system** also have to be considered. The following formula according to BEHRENDT et al. (2000) was therefore used:

$$EUN_{N,P} = (100 - R_{S_{N,P}}) \cdot (ES_{IMP_{N,P}} \cdot A_{IMPN} \cdot 100 + IN_N \cdot EIN_{D_{N,P}} \cdot 0.365 \cdot (100 - W_{TR})) \qquad (3.38)$$

with
- $EUN_{N,P}$ = nutrient input via inhabitants and impermeable urban areas connected neither to sewers nor to wastewater treatment plants [t/a],
- $R_{S_{N,P}}$ = nutrient retention in soil (80% for nitrogen and 90% for phosphorus),
- A_{IMPN} = impermeable urban area connected neither to a sewer nor to a wastewater treatment plant [km²],
- IN_N = inhabitants connected neither to sewers nor to wastewater treatment plants and
- W_{TR} = proportion of dissolved human nutrient output transported to wastewater treatment plants [%].

It is assumed that 40% of the dissolved human phosphorus and 20% of the dissolved human nitrogen output is transported to a wastewater treatment plant with the particulate fraction, which is generally transported to a WWTP.

3.2 River Loads

For each of the investigated sub basins where data on concentrations of nutrients and discharges were available, annual nutrient load was calculated according to the Equation 3.39. This method for the calculation of load is also favoured by OSPAR (1996) for the calculation of loads into the North Sea. In a comparison of five various methods to estimate annual nutrient load for English rivers, LITTLEWOOD (1995) showed that only this method gave reliable load estimates.

$$L_y = a \cdot \frac{Q_y}{\sum_{i=1}^{n} q_i} \sum_{i=1}^{n} q_i c_i \tag{3.39}$$

with L_y = annual load [t/a].
a = unit conversion factor,
n = number of data,
Q_y = mean annual flow [m³/s],
q_i = measured flow [m³/s] and
c_i = measured concentration [mg/l].

From the annual values, the mean load for the studied time period 1998-200 was estimated according to Equation 3.40:

$$L_P = \frac{1}{p} \cdot \sum_{i=1}^{p} L_Y \tag{3.40}$$

with L_P = average annual nutrient load in the studied period [g/s],
p = number of years with measuring data in the study period.

3.3 Retention in the Rivers

When comparing the estimated nutrient emissions and the load in the catchment areas, considerable variation was found (BEHRENDT, 1996b; BEHRENDT & OPITZ, 1999) which could not be explained by an underestimate of the load or an overestimate of the inputs (BEHRENDT & BACHOR, 1998). These differences were instead due to retention and loss processes within the river systems e.g. sedimentation, denitrification and plant uptake.

On the basis of data for nutrient emissions and loads in 100 catchment areas with a size of 100 to 200.000 km², an empirical model was therefore derived (BEHRENDT & OPITZ, 1999) for the retention of nitrogen and phosphorus in relation to the specific runoff or the hydraulic load in the catchment area. The basis for the model is the mass balance of a catchment area whereby the observed nutrient load for a time period of one or more years is the result of the balance of the sum of all inputs from point and diffuse sources and the sum of all retention and loss processes:

$$L_{N,P} = ET_{N,P} - R_{N,P} = \sum EP_{N,P} + \sum ED_{N,P} - \sum R_{N,P} \tag{3.41}$$

with $L_{N,P}$ = nutrient load [t/a],
$ET_{N,P}$ = total nutrient input [t/a],
$R_{N,P}$ = loss or retention of nutrients [t/a],
$EP_{N,P}$ = nutrient input via point sources [t/a] and
$ED_{N,P}$ = nutrient input via diffuse sources [t/a].

After adjustments of Equation 3.41 we get the following:

$$\frac{L_{N,P}}{ET_{N,P}} = \frac{1}{1 + R_{L_{N,P}}} \tag{3.42}$$

with $R_{L_{N,P}}$ = load weighted nutrient retention.

For the description of possible relationships between retention (R_L) and possible driving forces a power function is selected.

$$R_{L_{N,P}} = a \cdot x^b \tag{3.43}$$

with a, b = model coefficients.

Figures 3.13 to 3.14 show that on the basis of the available data, there are relationships between retention and specific runoff and also the hydraulic load in the catchment areas. In addition to the retention derived only for the load of inorganic dissolved nitrogen (DIN) (Figure 3.13 to 3.14) a corresponding relationship was found for total nitrogen (TN) (Figure 3.15).

T he following models are used for the calculation of retention of TN, DIN and TP:

$$\text{TN}: \quad R_{L_N} = 1.9 \cdot HL^{-0.49} \qquad n = 56,\ r^2 = 0.52 \tag{3.44}$$

with HL = hydraulic load [m/a].

$$\text{DIN}: \quad R_{L_N} = 5.9 \cdot HL^{-0.75} \qquad n = 100,\ r^2 = 0.654 \tag{3.45}$$

$$\text{TP}: \quad R_{L_P} = 26.6 \cdot q^{-1.71} \qquad n = 89,\ r^2 = 0.81 \tag{3.46}$$

with q = specific runoff [l/(s·km²)].

If these approaches are applied, the nutrient load can be calculated from the nutrient inputs for all studied catchment areas (Equation 3.50) and the results can be compared with measured loads.

$$L_{N,P} = \frac{1}{1 + R_{L_{N,P}}} \cdot ET_{N,P} \tag{3.50}$$

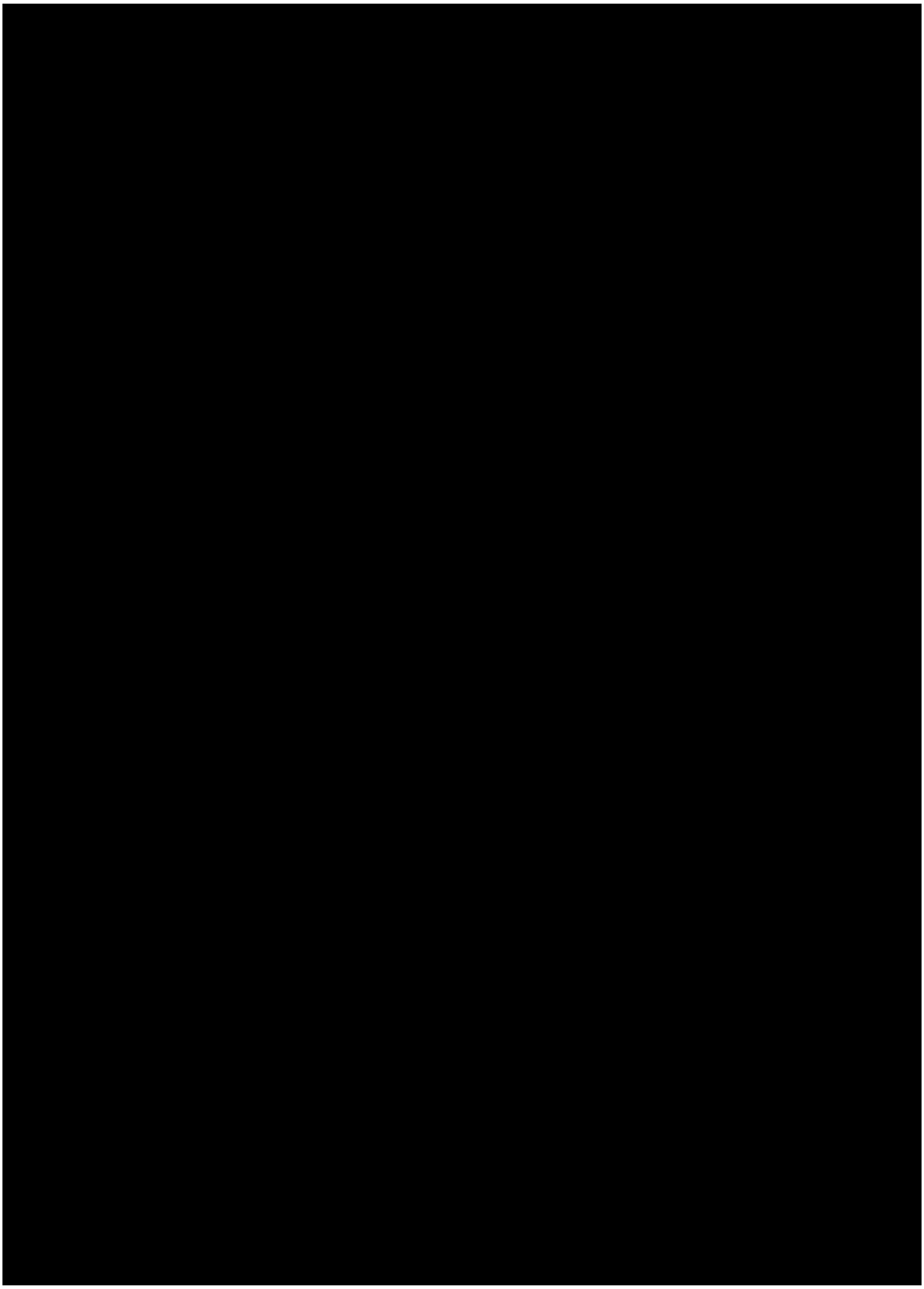


Figure 3.13: Dependence of the fractions of nutrient loadings to nutrient emissions from the specific runoff in the studied catchment areas.

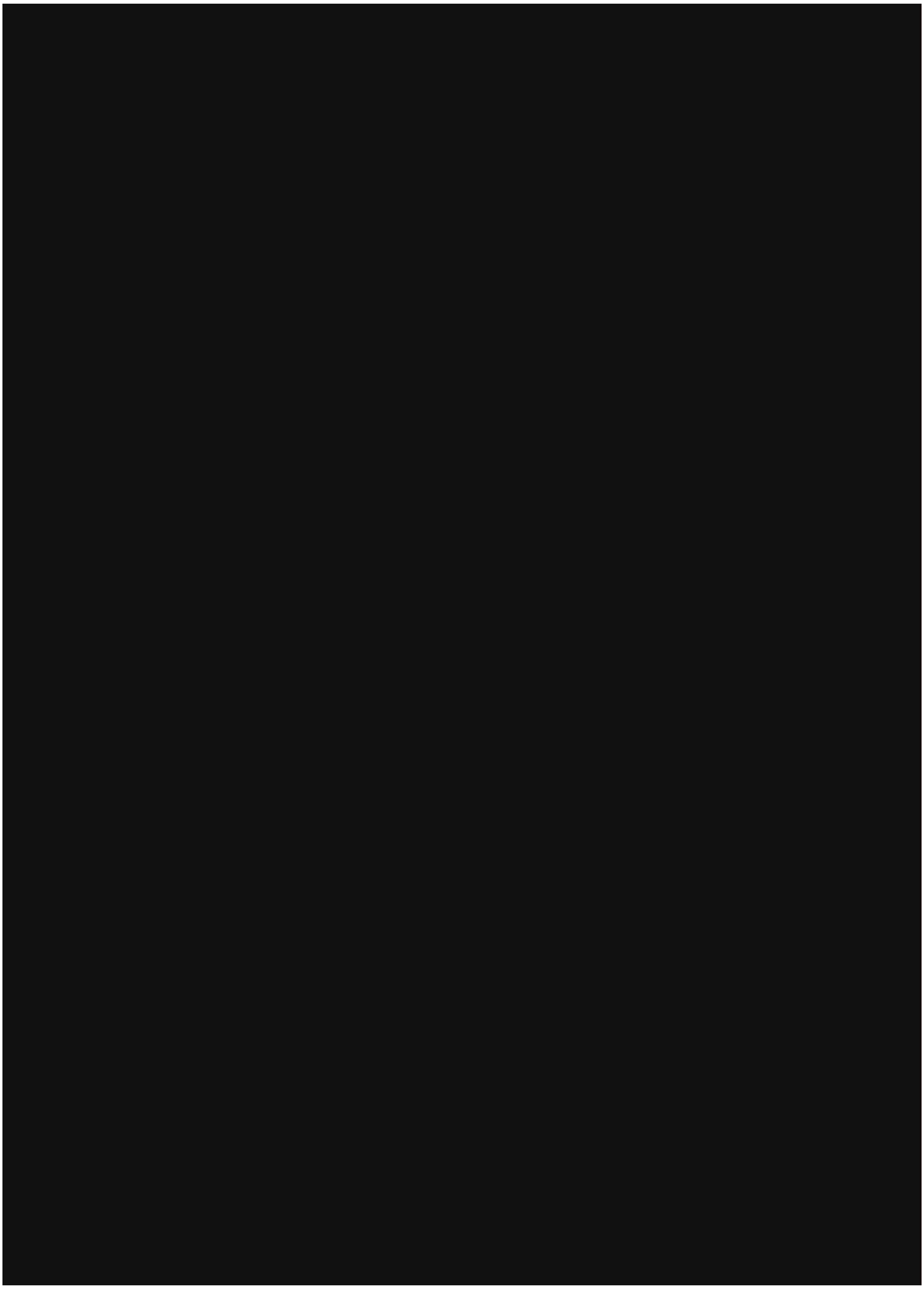


Figure 3.14: *Dependence of the fractions of nutrient loadings to nutrient emissions from the hydraulic load in the studied catchment areas.*

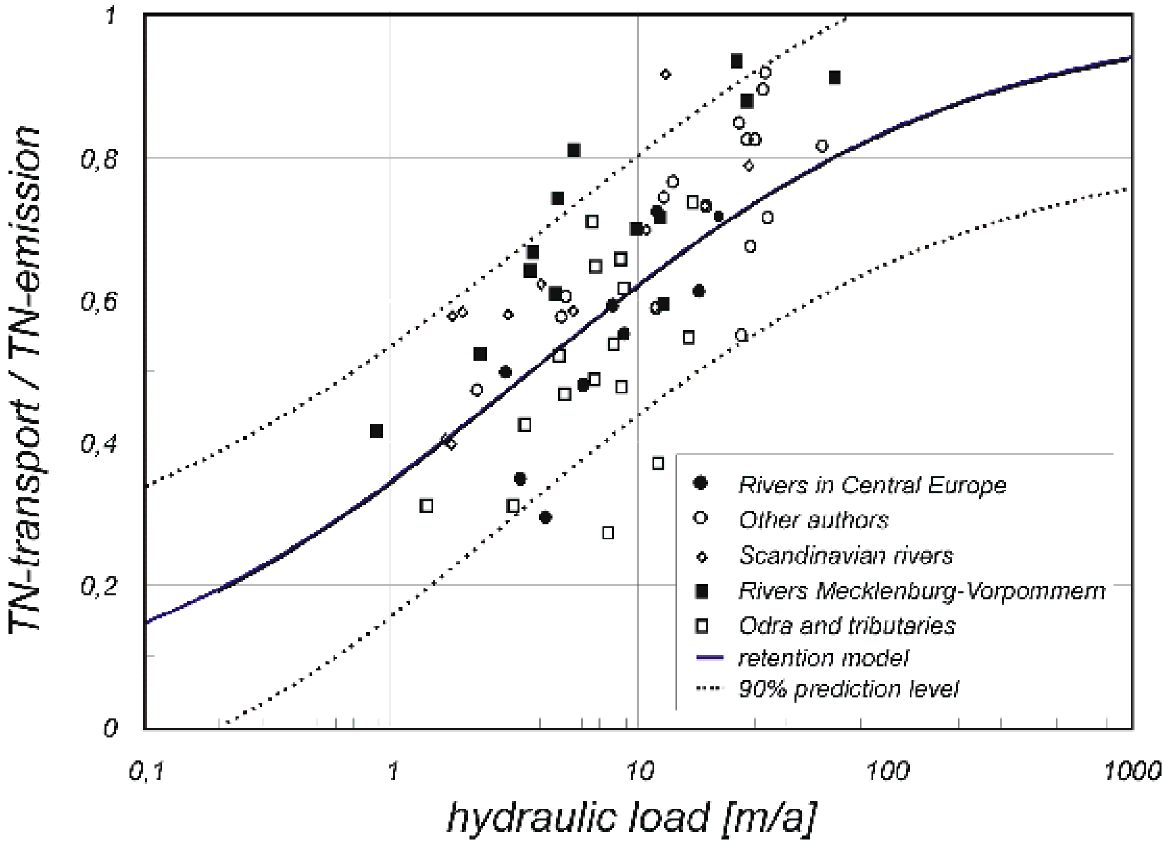


Figure 3.15: Dependence of the fractions of TN load to TN emissions from the hydraulic load in the studied catchment areas.

4 Results and Discussion

4.1 Nutrient Emissions from Diffuse Sources

4.1.1 Nutrient Balances

Figures 4.1 and 4.2 show the specific values of the mean consumption of mineral nitrogen fertilizer and the animal units in the different Danube countries. From Figure 4.1 three groups of countries can be distinguished. Germany, Slovenia and Czech Republic are the countries with a consumption of mineral nitrogen fertilizer of more than 50 kg/(ha·a) N, although there is a large difference between the three countries. In the second group of countries (Austria, Slovakia, Croatia and Hungary) the use of mineral fertilizers in agriculture is low to moderate range between 25 and 50 kg/(ha·a) N. In all other countries the level of mineral fertilizer consumption is well below 25 kg/(ha·a) N. For these countries we have to assume that these low levels will not continue in the future, but will steadily instead increase as agricultural and economic conditions improve again.

Regarding livestock density, the countries with a density of about 1 animal unit per hectare and more are Germany, Austria, Slovenia and Yugoslavia. All of the other countries have a livestock density lower than 0.5 animal units. The reason for these low densities in most countries is the strong reduction of livestock numbers within the most of the Eastern European countries during the first years after the changes of socio-economic conditions around 1990.

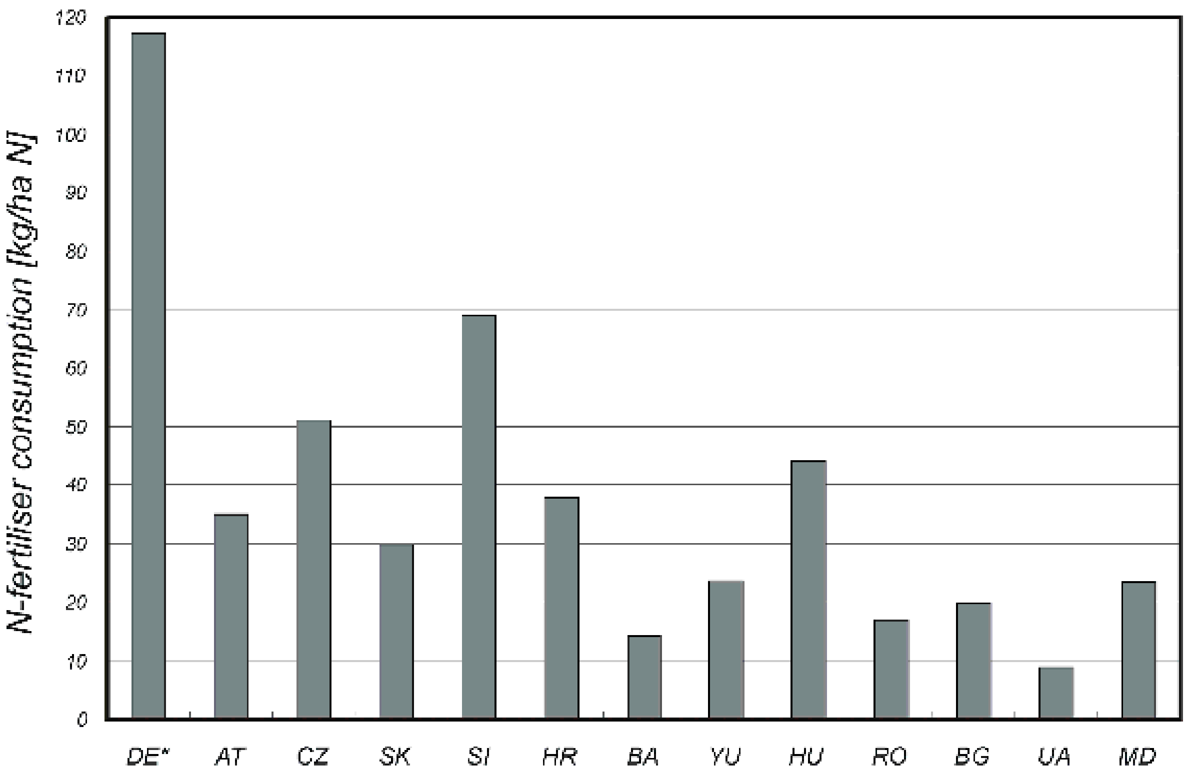


Figure 4.1: Consumption of mineral nitrogen fertiliser in the Danube countries in the period 1998-2000 (DE = only Bavaria and Baden-Wuerttemberg).*

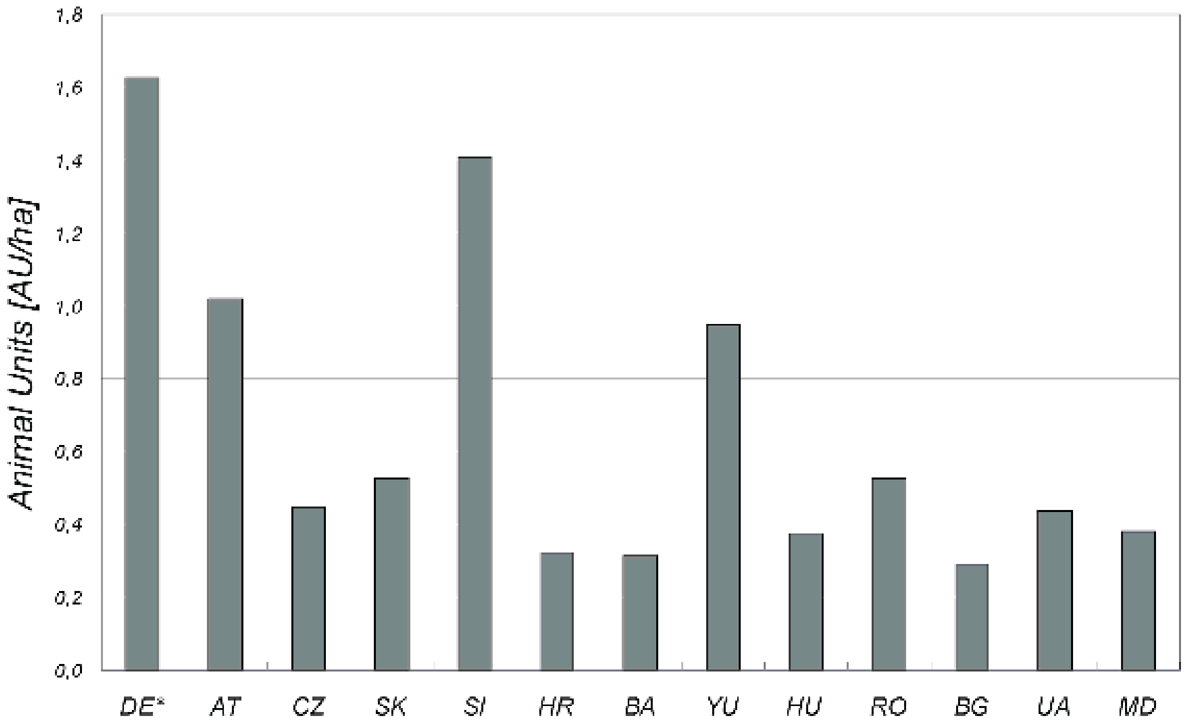


Figure 4.2: Animal units on the agricultural area of the Danube countries by livestock manure in the period 1998-2000 (DE = only Bavaria and Baden-Wuerttemberg)*

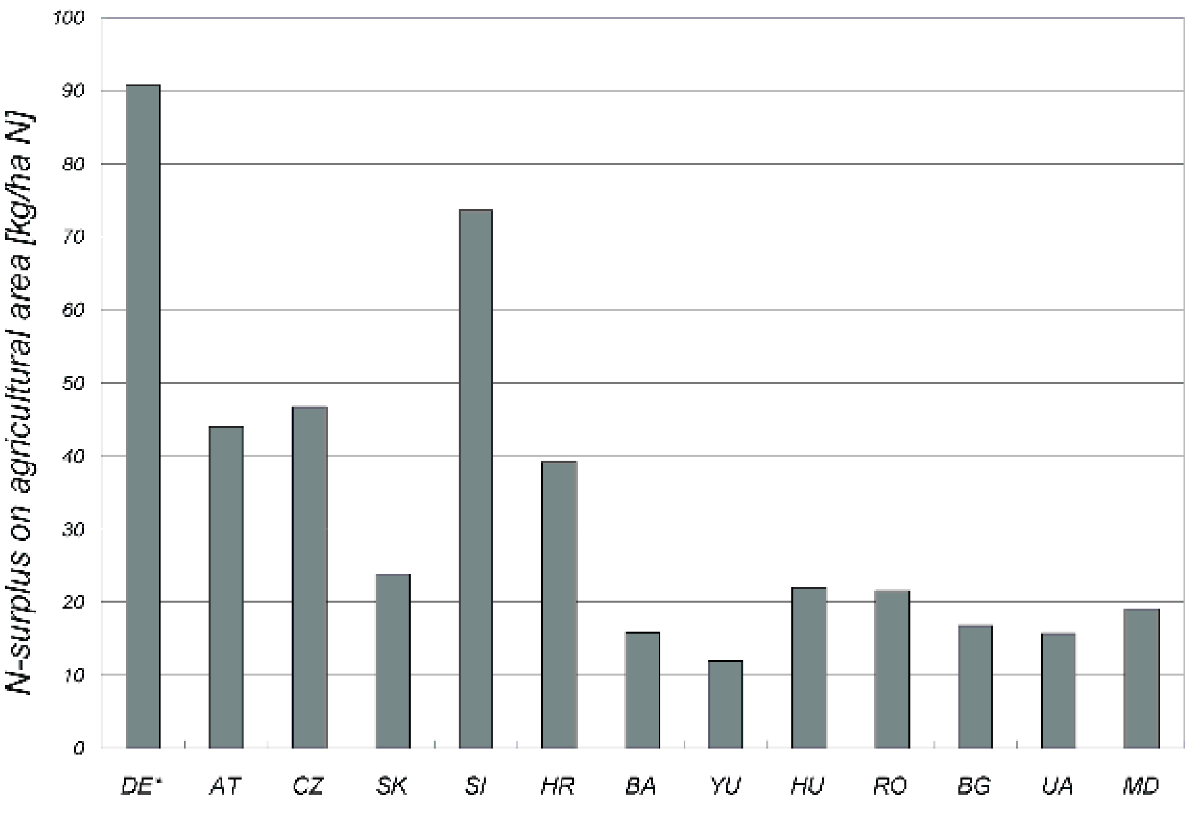


Figure 4.3: N-surplus on the agricultural area of the Danube countries in the period 1998-2000 (DE = only Bavaria and Baden-Wuerttemberg).*

The high animal density and the highest consumption of mineral nitrogen fertilizer is the reason that Germany and Slovenia are also the countries with the highest nitrogen surplus per hectare agricultural area (see Figure 4.3). The level of the N-surplus was in both countries at 91 and 74 kg/(ha·a) N for the period 1998 to 2000.

For all three Figures it is important to note that the data presented for Germany represents a mean for the federal states Baden-Wuerttemberg and Bavaria (see BEHRENDT et al., 2002b). From Figure 4.1 and 4.2 a higher difference in the N-surplus between Germany and Slovenia could be expected, but higher specific nitrogen outputs by harvested crops compensate partly for the larger fertilizer consumption and higher animal density in Germany.

For the second group of countries (Austria, Czech Republic and Croatia) the estimated N-surplus is moderate between 30 and 50 kg/(ha·a) N. The level of the N-surplus of all other countries is below 25 kg/(ha·a) N.

Figure 4.3 presents the wide variation in nitrogen surplus between country and indicates that the potential for nitrogen inputs into the surface waters of the Danube from different countries also varies widely. It cannot be expected that a further reduction of the nitrogen surplus is possible at least in the countries with a surplus lower than 25 kg/(ha·a) N.

Figure 4.4 shows the long-term changes in the nitrogen surplus of agricultural areas of those countries in the Danube basin that exist before 1992 (with exception of Czech Republic) and where relevant data was being collected. The changes in the N-surplus of agricultural land of all countries are characterized by a slow long-term increase from the 1950s to the end of the 1970s.

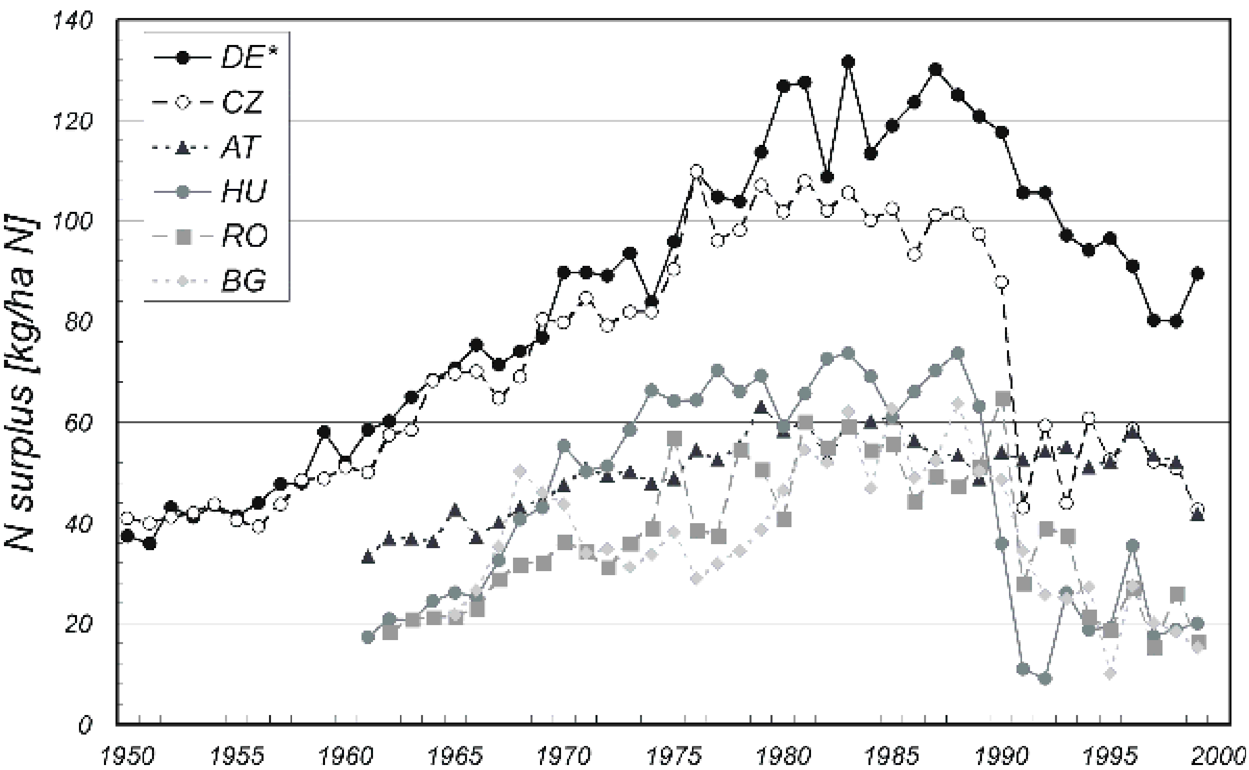


Figure 4.4: Long term changes of N-surplus on the agricultural area for different Danube countries (DE = only Bavaria and Baden-Wuerttemberg).*

Depending upon their starting level, the countries reached a high but stable range of N-surplus in the 1980s. Development in the 1990s, however, was quite different between the Western and Eastern European countries. Characteristically, N surpluses declined dramatrically in all Eastern European countries during the years after 1990. In general this reduction was in the range of 40 to 50 kg/ha N within a few years. The same could already found for other countries like Poland and the new German Federal States (Behrendt et al., 2000; Behrendt et al. 2003). Since the mid 1990s the N-surplus seems to be stabilized at the lower level. In contrast to this observation, the nitrogen surplus in the Bavaria, Baden-Wuerttemberg and in Austria has decreased much more slowly since the end of the 1990s.

According to section 3.1 the unified landcover map for the Danube was used for the transfer of the national or district results on nitrogen surplus to the river catchments. This is identical to the CORINE landcover (CLC) map for Germany, Austria, Czech Republic, Slovakia, Hungary, Slovenia, Romania and Bulgaria. It cannot however be expected that the agricultural area per country taken from the national statistics and estimated from CLC would be equal. Therefore a correction factor had to be introduced. As shown in Table 4.1 the difference between the two databases is between –7 % and +38 %. The very high difference for Germany (+22 %) and Slovenia (+38%) is due to the fact that the statistical data considers only the used agricultural area, which is much smaller than the identified landcover from satellite images. On the other hand, the total N-surplus value for the countries is constant and

Table 4.1: Balance of nitrogen on agricultural area for the Danube countries based on data of agricultural areas from national statistics and CORINE landcover (DE* = Bavaria and Baden-Wuerttemberg)

Country	NITROGEN INPUTS	NITROGEN OUTPUTS	BALANCE $AA_{STATISTIC}$	BALANCE AA_{CORINE}	Agricul-tural area Statistics	Agricul-. tural area CORINE	Devia-tion
	[kg/(ha·a) N]	[kg/(ha·a) N]	[kg/(ha·a) N]	[kg/(ha·a) N]	[km²]	[km²]	[%]
DE*	240	149	91	75	4868	5924	122
AT	109	65	44	51	3494	3040	87
CZ	119	72	47	43	4280	4668	109
SK	80	56	24	24	2443	2471	101
SI	160	87	74	53	500	691	138
HR	74	35	39	39	2743		
BH	47	31	16	16	1850	1883	102
YU	71	59	12	12	6175		
HU	85	63	22	20	6186	6656	108
RO	67	45	22	26	14727	12238	83
BG	52	35	17	18	6197	5970	96
UA	48	32	16	16	41585		
MD	61	42	19	19	2550		

the transfer of the results from national statistics to the CLC database can be done by the consideration of the ratio between both datasets for agricultural area. The correction can be understood as the distribution of the N-surplus on the used agricultural area to the total agricultural area identified with the CORINE landcover method.

As shown in Figure 4.5, the consequence of using such normalised data is that nitrogen surpluses calculated using the CLC are (especially for Germany and Slovenia) much lower than calculated previously used data from national statistics (see Figure 4.4). On the other hand the N-surplus increases for Austria, Romania and Bulgaria because the agricultural area estimated from CLC is smaller than the data published in the national statistics for these countries.

Compared to Figure 4.4 the big difference between Germany and Slovenia and all the other countries is reduced, especially for Slovenia, where the N-surplus based on CLC is similar to the value of Austria and only 10 kg/(ha·a) N higher than for the Czech Republic. The case of Slovenia shows that it seems to be very difficult to compare the results for N-surplus derived from national statistics if the difference in the basic data is not taken into account. Further it is extremely necessary to harmonise the published statistics for the landuse and landcover between the different countries of Europe. If in the countries where CLC is not available the landuse map is adjusted to the published statistics and these N-surpluses were not corrected (see Table 4.1).

At a country level this reflects the relative values of N-surplus between countries (Figure 4.5), but it is important to note that a high variance also exists within those countries for which the calculation of N-surplus at district level was possible. Map 4.1 shows the regional distribution of the N-surplus within the Danube basin based on the CLC-corrected dataset.

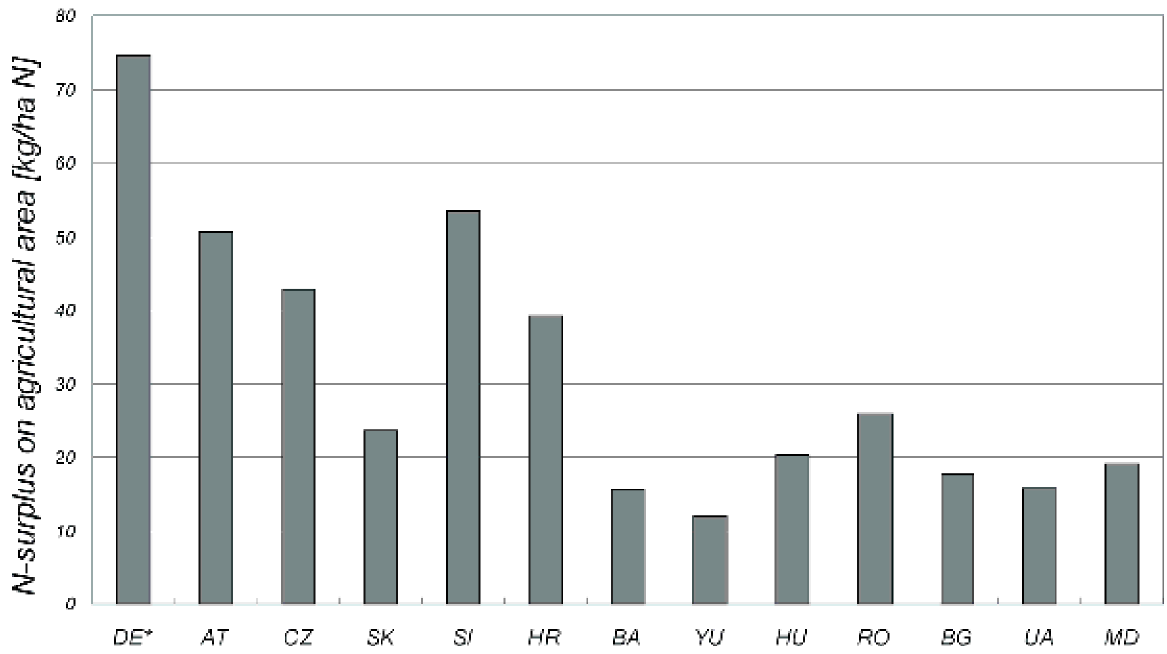
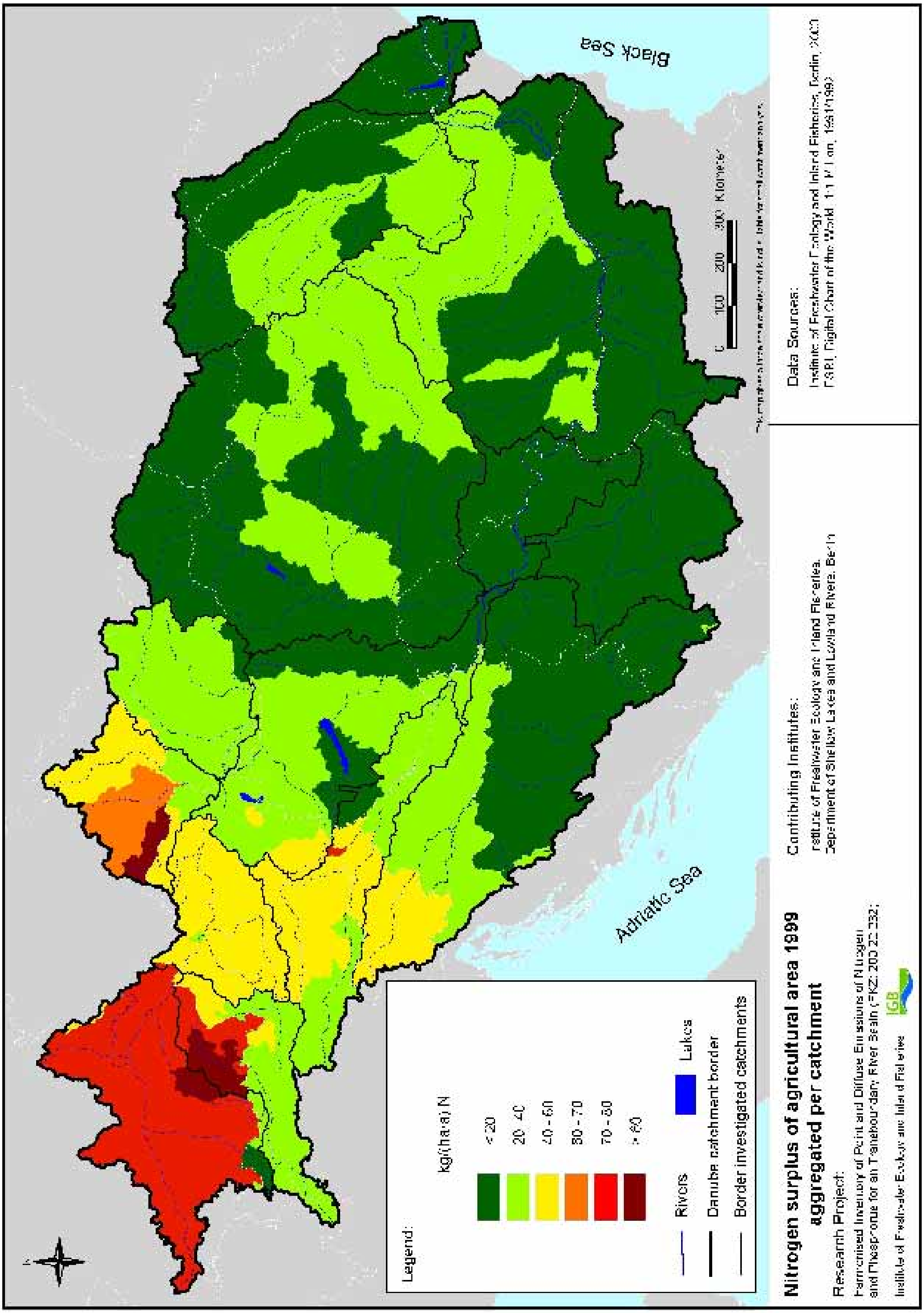


Figure 4.5: N-surplus normalised to agricultural area of the Danube countries according to CORINE Landcover in the period 1998-2000 (DE = only Bavaria and Baden-Wuerttemberg).*



Map 4.1: Distribution of nitrogen surplus within the Danube river basin in the period 1998-2000.

The unexpectedly high values of N-surplus in some parts of the Dye in Czech Republic and the Mure in Austria are caused by a very high surplus for one of the administrative districts within these catchments. Because data on the parts of the nutrient balance was not available for the district level for all countries we had to distribute equally the mean national N-surplus to all catchments within this area. This can be an important source of errors because the differences existing between the agricultural practice of different regions of a country as shown in Map 4.1 for Germany, Austria, Czech Republic, Hungary and Romania are neglected.

All of the N-surplus was calculated within this study using the OECD method (OECD, 2001) with the same coefficients for the nitrogen content of harvested crops and livestock excreta for all countries (see chapter 3). The coefficients for the calculation were taken from the published OECD database for Czech Republic (OECD Nitrogen balance database: http://www.oecd.org/agr/env/indicators.htm). To evaluate these results, comparison is necessary with one or more other methods. For the German federal states of Baden-Wuerttemberg and Bavaria this is possible because for this area the N-surplus was also calculated with the method of Bach et al. (1998). The results for the long-term changes of the N-surplus of both of these German federal states are published by Behrendt et al. (2001). Table 4.2 shows the results for the different parts of the nitrogen balance. It is obviously that the difference for the estimated N-surplus is relatively small and in a range lower than 10 %. But on the other hand the difference for some parts of the balance, especially net input by livestock manure and the output by harvested crops is larger than 30 % and 20 % respectively. Because these differences are both in the same direction the effect on the total

Table 4.2: Comparison of the balance of nitrogen on agricultural area calculated with OECD method and according to BACH (1998) for Bavaria (BAV) and Baden-Wuerttemberg (B-W)

Parameter	B-W OECD	B-W Bach	Devia-tion	BAV OECD	BAV Bach	Devia-tion
	[kg/ha N]	[kg/ha N]	[%]	[kg/ha N]	[kg/ha N]	[%]
NITROGEN INPUTS	220	197	111.6	248	224	110.8
Nitrogenous Inorganic Fertilisers	109	109	100.0	121	121	100.0
Organic Fertilisers (without manure)	4			4		
Net Input of Livestock Manure	73	53	136.9	83	64	130.3
Atmospheric Deposition	21	21	100.0	25	25	100.0
Biological Nitrogen Fixation	11	14	75.4	13	15	89.1
Seeds and Planting Material	3			3		
NITROGEN OUTPUTS	141	121	117.4	152	135	113.0
Total Harvested Crops	73	58	126.3	68	56	121.3
Total Harvested Forage	68	62	109.2	84	79	107.2
BALANCE (Inputs minus Outputs)	78	76	102.4	96	90	107.5

balance is relatively small. But this can only be expected for areas with a livestock density and crop production similar to that for these German states. Consequently, for areas with any other distribution between livestock and crop production the deviation in the estimated surplus can be expected to be much higher than 10% depending upon the method used, and especially the coefficients used for the nutrient contents of harvested crops and livestock excreta.

In relation to later scenario calculations, the analysis shows that potential for a further reduction of nitrogen surplus exists especially in the German part of the Danube basin and in Slovenia, because the livestock density as well as the used amount of mineral fertilizer are high compared to the nitrogen outputs by harvested crops and forages. In contrast to this, it seems reasonable to expect that the N-surplus in Slovakia, Hungary, Bosnia Herzegowina, Serbia and Montenegro, Romania, Bulgaria, Ukraine and Moldova will increase in the coming years because the present level seems to be too low. Although the nitrogen output from agriculture (especially to groundwater) has reduced dramatically during the last decade in most of the Danube countries, this has not been reflected so-far in a reduction of nitrogen emissions to surface waters. This is because in most catchments of the Danube the residence time of water in the unsaturated zone and in groundwater is large (see 4.1.6 and chapter 3).

4.1.2 Nutrient Emissions via Atmospheric Deposition

Direct P and N inputs to surface waters via atmospheric deposition for the period 1998-2000 are shown in Table 4.3 and 4.4, and summarized for the main river catchments and for the countries within the Danube basin in Figure 4.6. During the period under investigation, there was an overall phosphorus emission through atmospheric deposition of 604 t/a P and 18680 t/a N. The mean area related P- and N-emissions amount only 7.5 g/(ha·a) P and 0.23 kg/(ha·a) N.

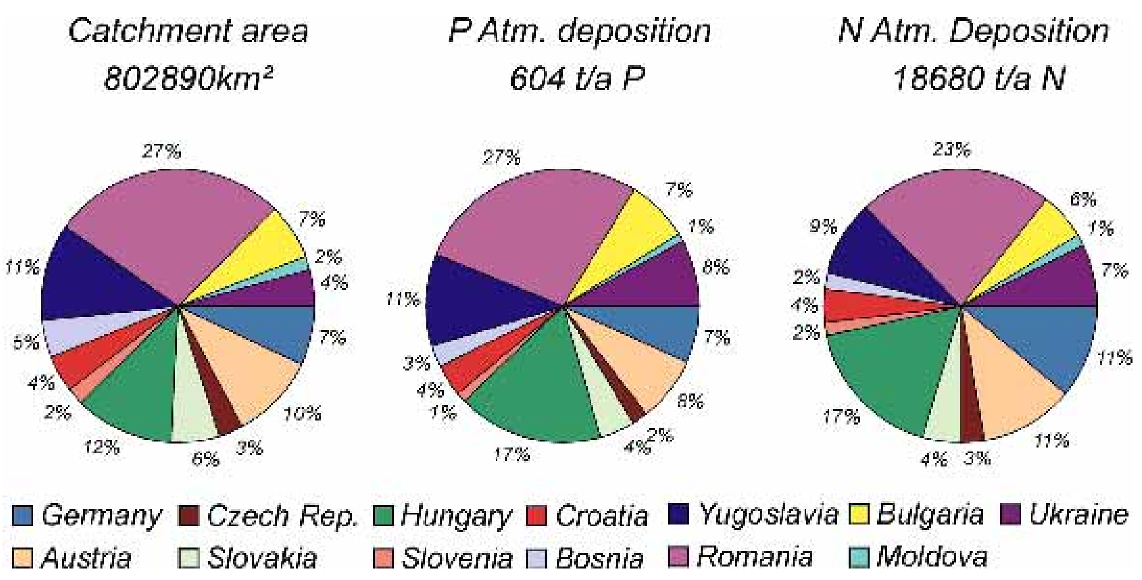
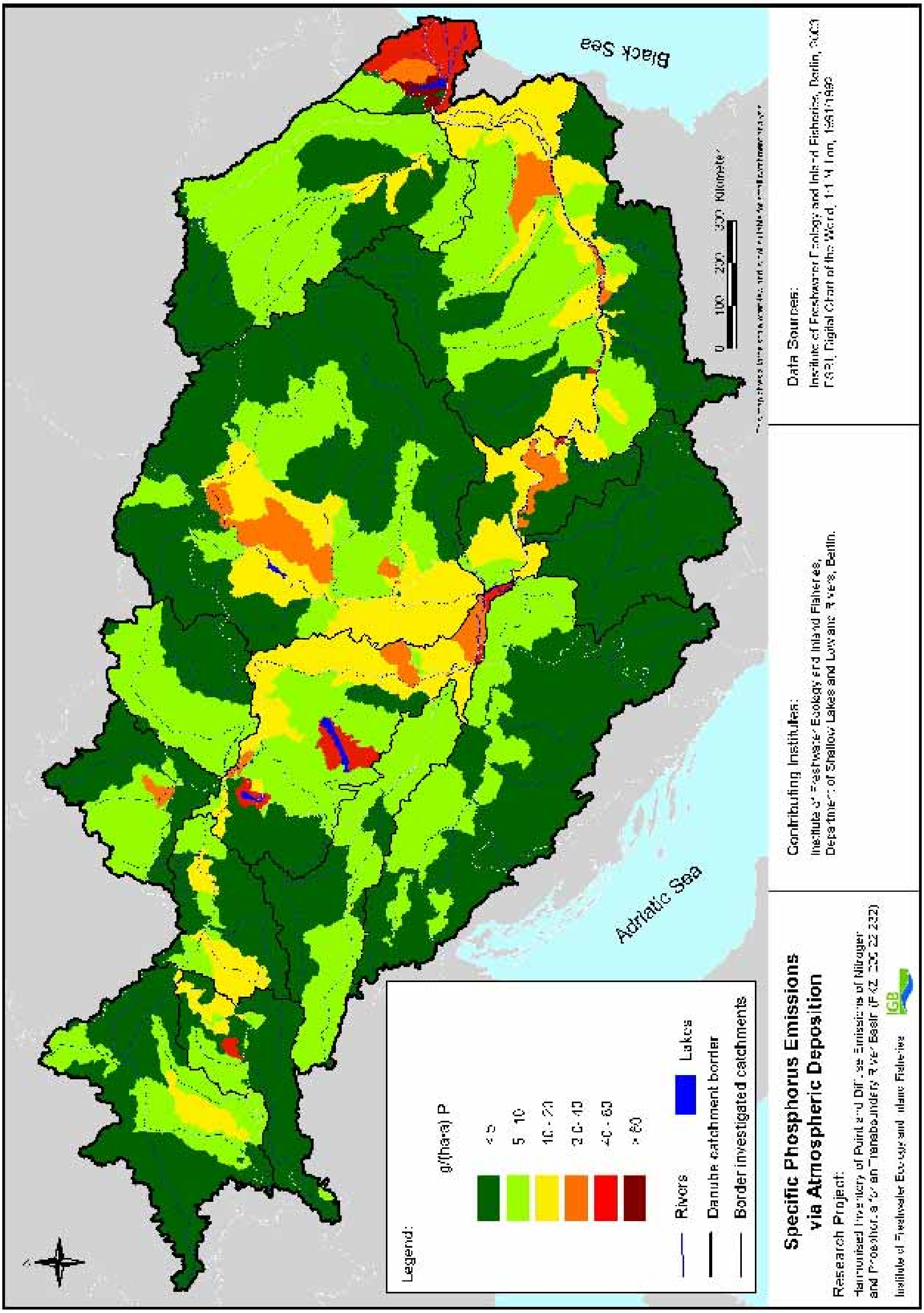


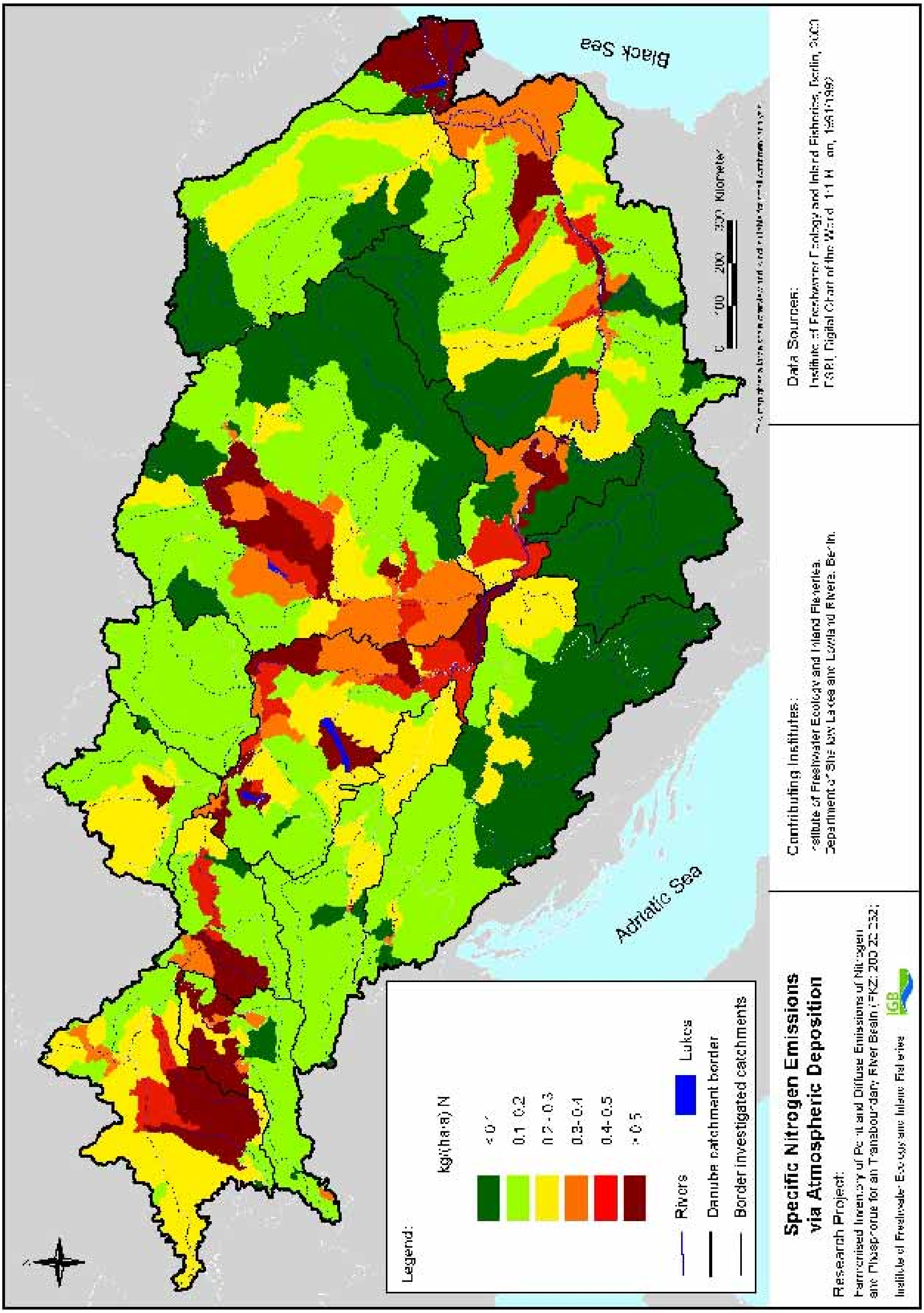
Figure 4.6: Contribution of Danube countries to the total catchment area of the Danube and the total phosphorus and nitrogen discharges by atmospheric deposition.

Table 4.3: Nutrient inputs by atmospheric deposition into the Danube and its tributaries in the Period 1998-2000

Basin	Station	Area	EAD_P	EAD_{Pspec}	EAD_N	$EAD_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	30	6.0	1810	0.36
Inn	up.Passau-Ingling	26070	15	5.8	850	0.33
Austrian Danube	Passau to Nussdorf	26240	16	6.1	760	0.29
Morava	Marchdorf	26650	14	5.3	590	0.22
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	14	4.7	500	0.17
Pannonian Danube	Nussdorf to up.Tisza	60370	87	14.4	2720	0.45
Drava	up. Ossijek	40310	22	5.5	720	0.18
Drava	up. Mura	15330	8	5.2	280	0.18
Mura	Mouth	14060	5	3.6	180	0.13
Sava	up. Belgrade	95890	45	4.7	1260	0.13
Sava	up.Crna Bara	62520	26	4.2	780	0.12
Drina	up.Crna Bara	19610	8	4.1	180	0.09
Tisa	up.Tisza	151780	112	7.4	3200	0.21
Somes/Szamos	up. Oar	15370	7	4.6	190	0.12
Crisuri/Koeroes	up. Magyartes	25410	26	10.2	760	0.30
Mures/ Maros	up. Mako	28650	13	4.5	330	0.12
Banat-East.Serbia	up. Tisza to Prahovo	28940	30	10.4	770	0.27
Velika Morava	up. Mouth	37630	13	3.5	300	0.08
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	40	7.4	1060	0.20
Iskar	up. Orechovitza	8260	4	4.8	90	0.11
Muntenia	Prahovo-Giurgiul. RO	82250	63	7.7	1620	0.20
Jiu	up. Zaval	9960	4	4.0	90	0.09
Olt	up. Izbiceni	24250	14	5.8	320	0.13
Arges	up. Clatesti	12580	10	7.9	280	0.22
Ialomita	Tandarei	10290	6	5.8	180	0.17
Prut-Siret	Giurgiul. & Sendreni	73470	41	5.6	1080	0.15
Prut	Giurgiulesti	28580	18	6.3	480	0.17
Siret	Sendreni	44890	24	5.3	600	0.13
Delta-Liman	Giurgiul. - Mouth	19450	63	32.4	1420	0.73
Danube	**Total**	802890	604	7.5	18680	0.23



Map 4.2: Specific phosphorus emissions via atmospheric deposition in the period 1998 – 2000.



Map 4.3: Specific nitrogen emissions via atmospheric deposition in the period 1998 – 2000.

Table 4.4: Nutrient inputs by atmospheric deposition into country parts of the Danube river basin in the period 1998-2000

Basin	Area	EAD_P	EAD_{Pspec}	EAD_N	$EAD_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	38	6.7	2310	0.41
Austria	80850	43	5.3	1830	0.23
Czech Republic	21690	12	5.5	500	0.23
Slovakia	47210	23	4.9	820	0.17
Hungary	92770	121	13.0	3630	0.39
Slovenia	16410	7	4.3	280	0.17
Bosnia-Herzegovina	34630	22	6.4	660	0.19
Croatia	37600	15	4.0	370	0.10
Yugoslavia	88490	69	7.8	1790	0.20
Romania	222330	163	7.3	4070	0.18
Bulgaria	55190	41	7.4	1070	0.19
Moldova	12330	7	5.7	190	0.15
Ukraine	33930	42	12.4	1130	0.33
other Countries	2820	1	3.5	50	0.18
Total	802890	604	7.5	18680	0.23

The specific P- and N-emissions by atmospheric deposition vary between 3.5 and 32.4 g/(ha·a) P and 0.08 and 0.73 kg/(ha·a) N respectively. The main reason for the high variance is the difference in the area of surface waters, especially lakes, within the subcatchments. This is also shown in Map 4.2 and 4.3 where the area related P- and N-emissions by atmospheric deposition are presented for all 391 investigated subcatchments of the Danube basin. If the total nutrient emission by atmospheric deposition is divided between the countries, the contribution is similar to the proportion of the total area of the Danube basin occupied by each country. The countries with more than 10 % P- and N-emissions are Romania, Hungary, Austria (only N), Germany (only N) and Yugoslavia (only P).

Since the EMEP deposition rates in recent years were calculated on a yearly basis and are also available over the internet, they can, with an eventual improvement in resolution, provide a very good data base for a harmonised quantification of nitrogen inputs via deposition. Unfortunately, for phosphorus, such data do not exist. Although the calculated P-inputs through deposition are relatively small, they can have an important role, particularly for individual lakes.

4.1.3 Nutrient Emissions via Surface Runoff

The calculation results of nutrient emissions via surface runoff within the different catchments and countries of the Danube river basin are shown in Tables 4.5 and 4.6, Maps 4.3 and 4.4 as well as in Figure 4.7.

The total emissions of phosphorus and nitrogen via surface runoff are 4190 t/a P and 42480 t/a N. The area related P- and N-emissions are estimated at about 52 g/(ha·a) P and 0.53 kg/(ha·a) N.

When interpreting these results it should be taken into account that, in addition to emissions of dissolved nutrient compounds by surface runoff, this pathway also includes the emissions into the Danube river system caused by snow smelt over the most parts of the year, especially in the higher altitudes of the Alps. This is the reason that the highest P- and N-emissions via surface runoff were estimated for the Inn and the Drava river. From the country view the most of the P- and N-emissons by surface runoff and snow smelt are caused by Austria (P: 20 %; N: 50 %). That can also be seen from the specific P- and N-emissions, which are for Austria and the summarized rest of area – dominated by the Swiss and Italian part of the Danube basin – more than 4 times higher than the Danube average. On the other hand the estimated emissions via surface runoff are very low for the catchments of Morava, Panonian Central, Ialomita and Delta-Liman as well as for the countries for Czech Republic, Hungary and Moldova. This is due to the method used to calculate the mean annual surface runoff as a function of the mean annual total runoff within this catchment. Because the model is derived for Central European conditions it is unclear up to now whether the results are also correct for the more southern catchments within the Danube basin. It will be a task for further studies to improve this approach.

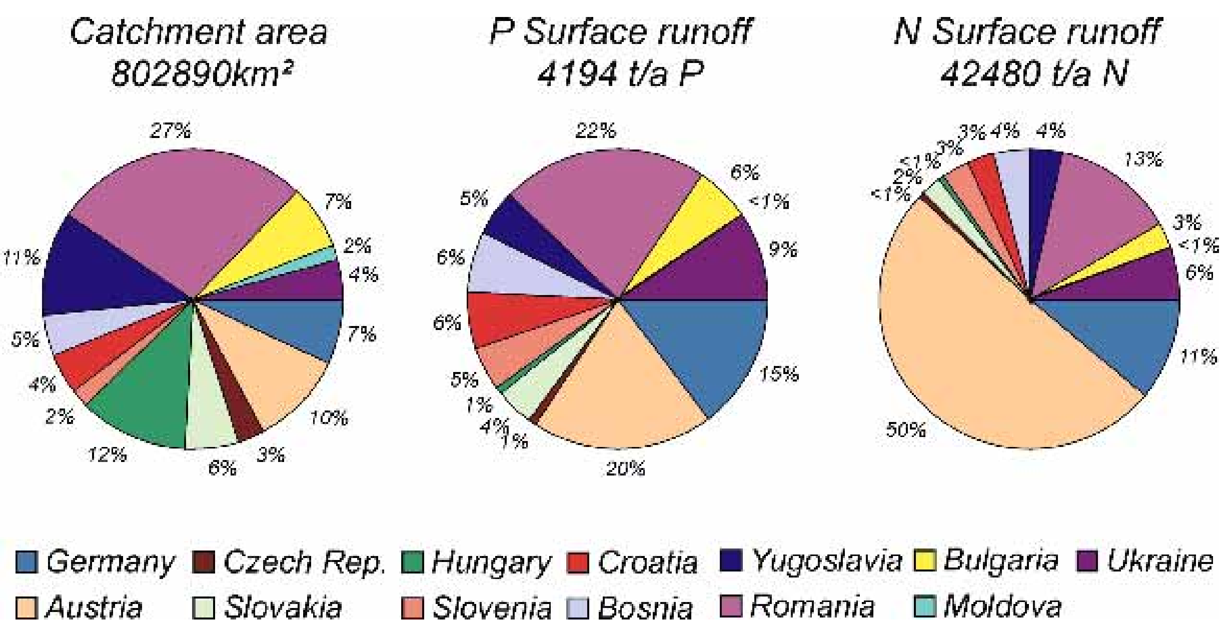
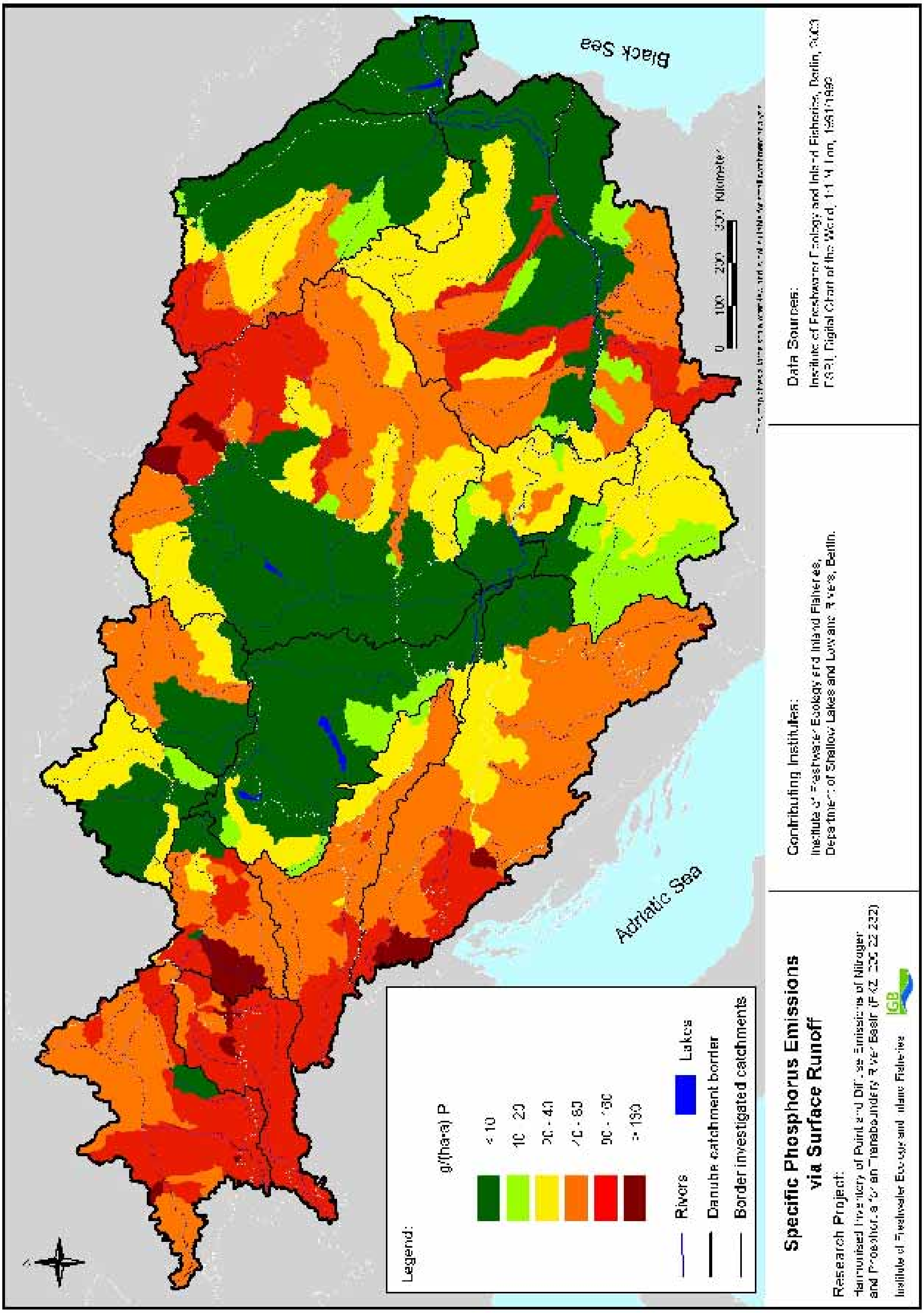


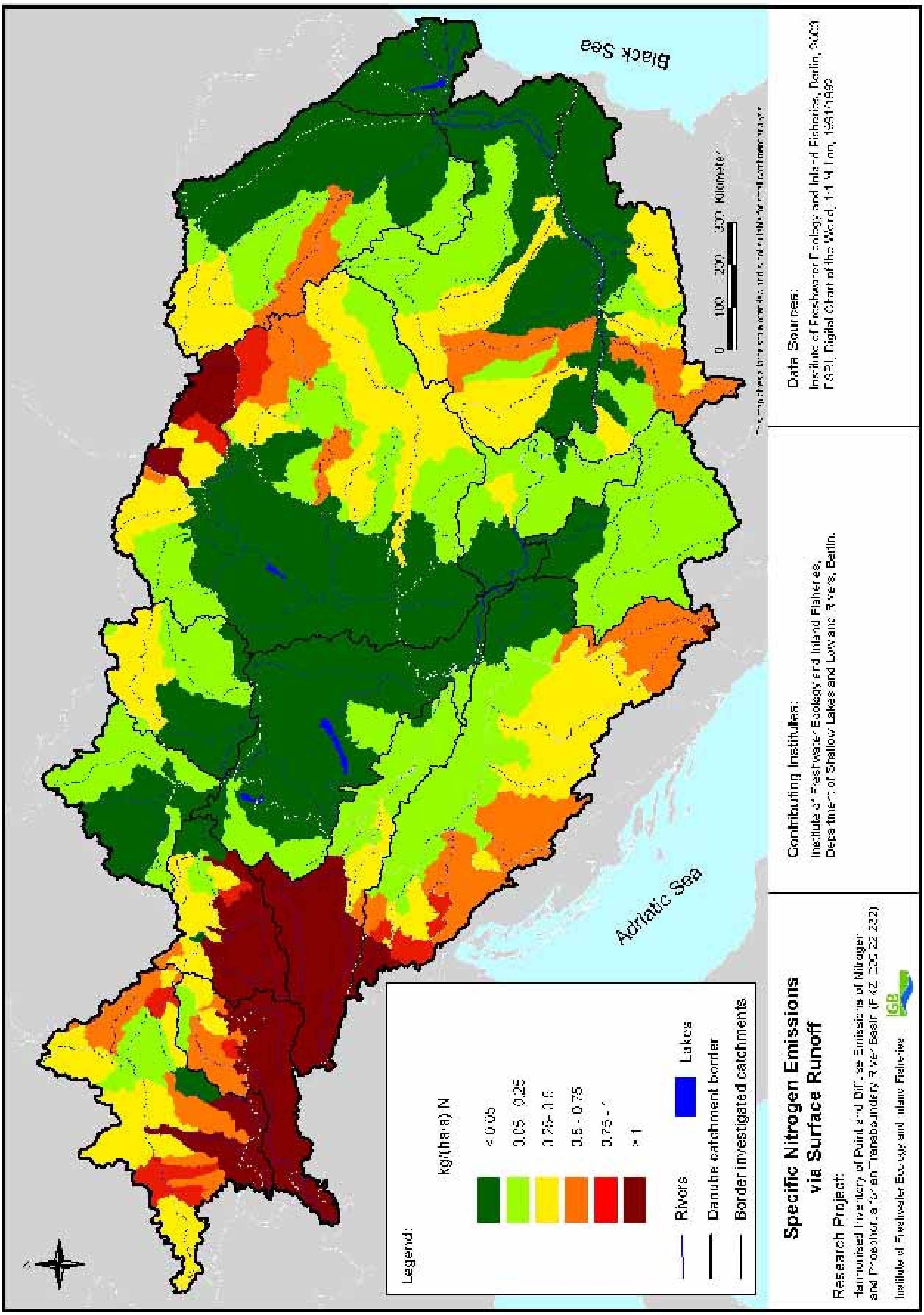
Figure 4.7: Portion of the countries to the total catchment area of the Danube and the total phosphorus and nitrogen discharges by surface runoff .

Table 4.5: Nutrient emissions by surface runoff into the Danube and its tributaries in the Period 1998-2000

Basin	Station	Area	ESR_P	ESR_{Pspec}	ESR_N	$ESR_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	530	106.1	5600	1.12
Inn	up.Passau-Ingling	26070	387	148.4	10870	4.17
Austrian Danube	Passau to Nussdorf	26240	287	109.4	3750	1.43
Morava	Marchdorf	26650	46	17.3	220	0.08
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	94	31.5	630	0.21
Pannonian Danube	Nussdorf to up.Tisza	60370	46	7.6	200	0.03
Drava	up. Ossijek	40310	354	87.8	6780	1.68
Drava	up. Mura	15330	188	122.6	4620	3.01
Mura	mouth	14060	109	77.5	1970	1.40
Sava	up. Belgrade	95890	697	72.7	4460	0.47
Sava	up.Crna Bara	62520	536	85.7	3130	0.50
Drina	up.Crna Bara	19610	134	68.3	1250	0.64
Tisa	up.Tisza	151780	727	47.9	4300	0.28
Somes/Szamos	up. Oar	15370	136	88.5	730	0.47
Crisuri/Koeroes	up. Magyartes	25410	88	34.6	490	0.19
Mures/ Maros	up. Mako	28650	151	52.7	920	0.32
Banat-East.Serbia	up. Tisza to Prahovo	28940	89	30.8	420	0.15
Velika Morava	up. Mouth	37630	82	21.8	580	0.15
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	242	44.8	1130	0.21
Iskar	up. Orechovitza	8260	103	124.7	530	0.64
Muntenia	Prahovo-Giurgiul. RO	82250	378	46.0	2080	0.25
Jiu	up. Zaval	9960	67	67.3	370	0.37
Olt	up. Izbiceni	24250	185	76.3	1030	0.42
Arges	up. Clatesti	12580	65	51.7	410	0.33
Ialomita	Tandarei	10290	32	31.1	160	0.16
Prut-Siret	Giurgiul & Sendreni	73470	233	31.7	1450	0.20
Prut	Giurgiulesti	28580	100	35.0	460	0.16
Siret	Sendreni	44890	133	29.6	990	0.22
Delta-Liman	Giurgiul. - Mouth	19450	<1	<1	<1	<0.01
Danube	**Total**	802890	4194	52.2	42480	0.53



Map 4.4: Specific phosphorus emissions via surface runoff in the period 1998 – 2000.



Map 4.5: Specific nitrogen emissions via surface runoff in the period 1998 – 2000.

Table 4.6: Nutrient emissons by surface runoff into country parts of the Danube river basin in the period 1998-2000

Basin	Area	ESR_P	ESR_{Pspec}	ESR_N	$ESR_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	610	107.7	4620	0.82
Austria	80850	832	102.9	20750	2.57
Czech Republic	21690	41	18.9	220	0.10
Slovakia	47210	173	36.6	1030	0.22
Hungary	92770	46	5.0	150	0.02
Slovenia	16410	192	117.0	1350	0.82
Bosnia-Herzegovina	34630	254	73.3	1090	0.31
Croatia	37600	263	69.9	1560	0.41
Yugoslavia	88490	206	23.3	1540	0.17
Romania	222330	921	41.4	5420	0.24
Bulgaria	55190	246	44.6	1150	0.21
Moldova	12330	<1	<1	<1	<0.01
Ukraine	33930	375	110.5	2230	0.66
other Countries	2820	35	124.1	1360	4.82
Total	802890	4194	52.2	42480	0.53

Further it has to be considered that this pathway includes only the emissions of dissolved fractions of both nutrients. The emissions of the particulate fractions of P and N are calculated within the pathway erosion.

4.1.4 Nutrient Emissions via Erosion

As shown in Tables 4.5 and 4.6 as well as in Figure 4.7, the total P- and N-inputs by erosion calculated with MONERIS within the Danube river basin were about 25.6 kt/a P and 28.5 kt/a N respectively for the period 1998 - 2000. The relative contribution of each country to the P- and N-inputs by erosion does not differ very much from their relative share of the total area of the Danube basin. The proportion of P-inputs from the Austrian and Czech part of the Danube Basin is slightly higher than these countries relative share of the total catchment area, while the proportion of N- inputs is higher for Slovakian catchment area.

Maps 4.6 and 4.7 give an overview of the spatial distribution of the nutrient inputs by erosion within the Danube river basin. The highest specific inputs can be observed in the subcatchments with high slope and high portion of arable land.

Table 4.7: Nutrient inputs by erosion into the Danube and its tributaries in the Period 1998-2000

Basin	Station	Area	EER_P	EER_{Pspec}	EER_N	$EER_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	1765	353.4	1670	0.33
Inn	up.Passau-Ingling	26070	1143	438.4	900	0.35
Austrian Danube	Passau to Nussdorf	26240	1075	409.7	1110	0.42
Morava	Marchdorf	26650	1409	528.7	1800	0.68
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	1298	435.0	1440	0.48
Pannonian Danube	Nussdorf to up.Tisza	60370	1529	253.3	1570	0.26
Drava	up. Ossijek	40310	1373	340.6	1330	0.33
Drava	up. Mura	15330	558	364.0	460	0.30
Mura	mouth	14060	475	337.8	360	0.26
Sava	up. Belgrade	95890	2882	300.6	3660	0.38
Sava	up.Crna Bara	62520	1955	312.7	2540	0.41
Drina	up.Crna Bara	19610	305	155.5	330	0.17
Tisa	up.Tisza	151780	3939	259.5	4010	0.26
Somes/Szamos	up. Oar	15370	671	436.6	650	0.42
Crisuri/Koeroes	up. Magyartes	25410	466	183.4	410	0.16
Mures/ Maros	up. Mako	28650	1038	362.3	990	0.35
Banat-East.Serbia	up. Tisza to Prahovo	28940	1161	401.2	1400	0.48
Velika Morava	up. Mouth	37630	794	211.0	1210	0.32
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	1877	347.2	2020	0.37
Iskar	up. Orechovitza	8260	214	259.1	240	0.29
Muntenia	Prahovo-Giurgiul. RO	82250	2006	243.9	2130	0.26
Jiu	up. Zaval	9960	299	300.2	320	0.32
Olt	up. Izbiceni	24250	692	285.4	760	0.31
Arges	up. Clatesti	12580	227	180.4	210	0.17
Ialomita	Tandarei	10290	420	408.2	470	0.46
Prut-Siret	Giurgiul. & Sendreni	73470	3110	423.3	3640	0.50
Prut	Giurgiulesti	28580	1492	522.0	1740	0.61
Siret	Sendreni	44890	1618	360.4	1900	0.42
Delta-Liman	Giurgiul. - Mouth	19450	237	121.9	630	0.32
Danube	**Total**	802890	25597	318.8	28520	0.36

Consequently the nutrient inputs by erosion are the highest in the upper part of the Danube river basin in the Inn, Austrian Danube, Morava, and upper Drava subcatchments as well as for catchments in the upper Prut. High P-inputs by erosion also occur in the tributaries of the Pannonian Danube in the Raba, Rabca and Zala catchments, as well as for the Sajo, tributary of the Tisza, caused by high P-contents in the topsoil and the high proportion of arable land at the total catchment area.

Exceptions are the catchments in the middle part of the Sava sub-basin and catchments in the lower Prut sub-basin. Here the high P-inputs by erosion are mainly due to the high proportion of arable land (62.4 % and 87.6 % respectively). However, these estimations must be handled carefully due to the fact that land use information is missing from the CORINE landcover (CLC) for these subcatchments in Croatia, Yugoslavia (Serbia and Montenegro), Ukraine and Moldova. The only available spatial information on land use distribution was from the USGS which is of a lower resolution and therefore “rougher” than CLC and was transformed into CLC land use categories as described in chapter 3. High N-inputs by erosion in the Sava subcatchments, the lower Velika Morava and lower Prut sub-basin are also due to the high N-contents in topsoil and high proportion of arable land.

The estimated emissions of nutrients into surface waters by erosion is strongly dependent on the quality of the soil loss map used as the starting point for the calculation. Such a map was not available up to now for the whole catchment of the Danube. Therefore the sediment yield map for Europe from the RIVM (Klepper et al., 1995) was used. It should be possible during further studies to derive a soil loss map, but for that the existing digital soil map of Europe in a scale of 1:1 Million prepared by the Soil Bureau of the JRC in Ispra and more detailed information on the grown crops (C-factor of the USLE) on the district of municipal level are necessary.

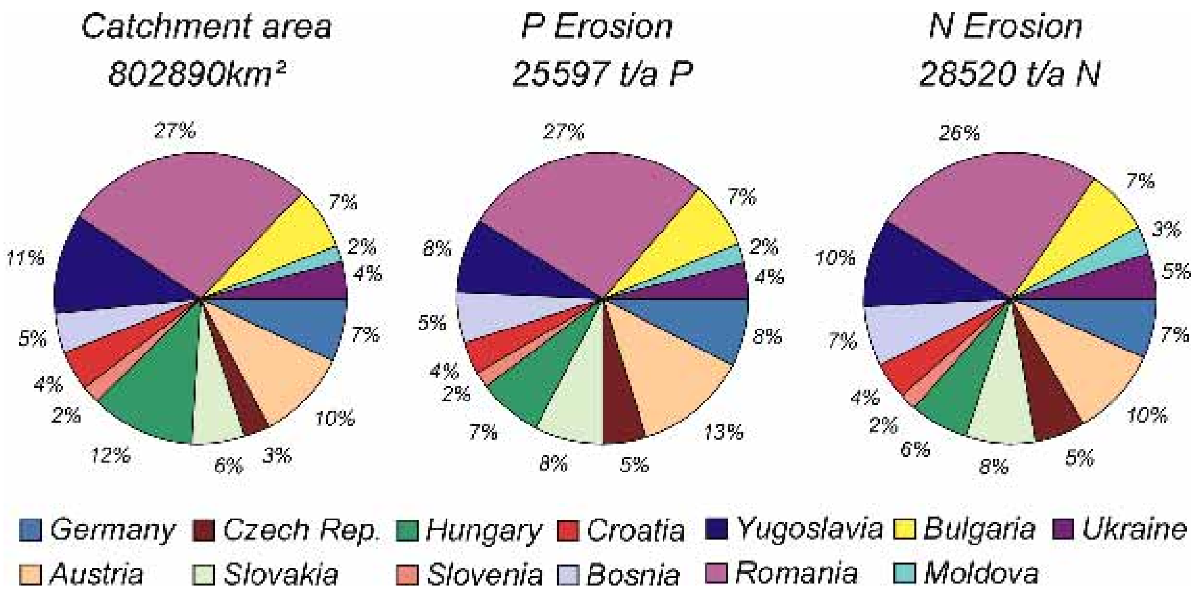
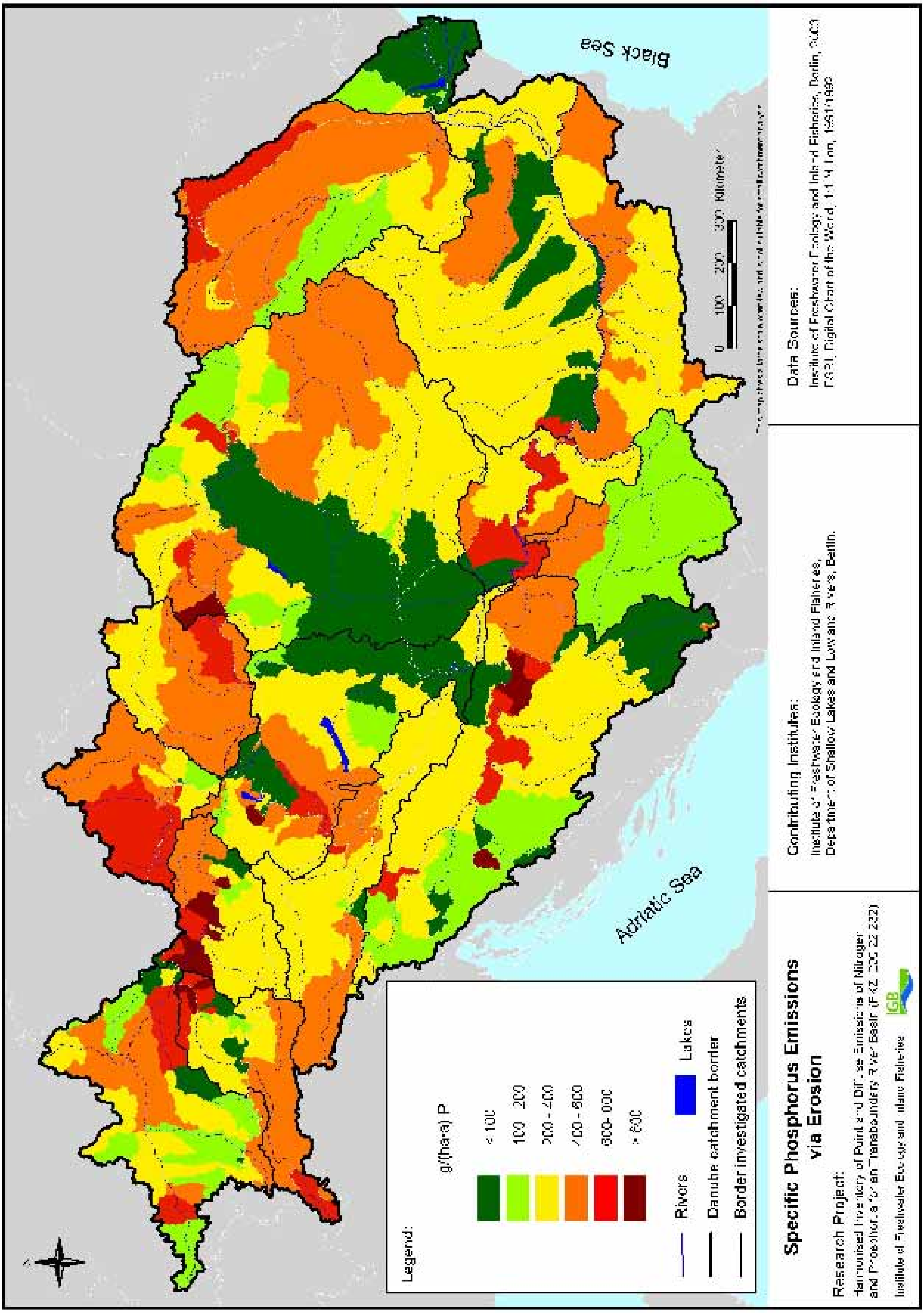
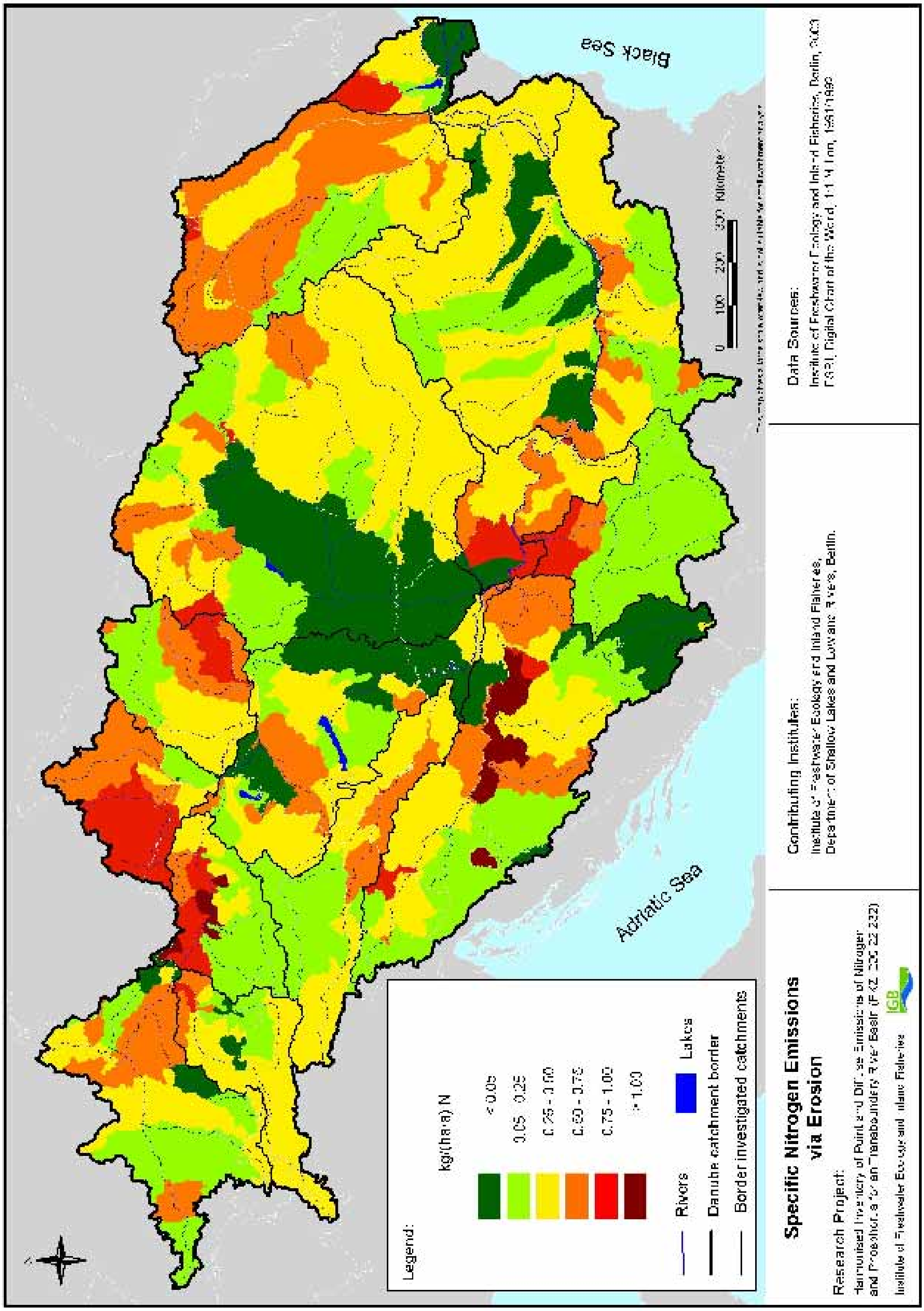


Figure 4.8: Portion of the countries to the total catchment area of the Danube and the total phosphorus and nitrogen discharges by erosion .



Map 4.6: Specific phosphorus emissions via erosion in the period 1998 – 2000.



Map 4.7: Specific nitrogen emissions via erosion in the period 1998 – 2000.

Table 4.8: Nutrient inputs by erosion into country parts of the Danube in the period 1998-2000

Basin	Area	EER_P	EER_{Pspec}	EER_N	$EER_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	1935	342	1870	0.33
Austria	80850	3256	403	2880	0.36
Czech Republic	21690	1177	543	1540	0.71
Slovakia	47210	1925	408	2200	0.47
Hungary	92770	1776	191	1840	0.20
Slovenia	16410	475	290	540	0.33
Bosnia-Herzegovina	34630	905	261	1180	0.34
Croatia	37600	1375	366	1870	0.50
Yugoslavia	88490	2138	242	2830	0.32
Romania	222330	7016	316	7340	0.33
Bulgaria	55190	1899	344	2040	0.37
Moldova	12330	551	447	820	0.67
Ukraine	33930	1005	296	1440	0.42
other Countries	2820	164	582	130	0.46
Total	802890	25597	319	28520	0.36

Another possibility would be the use and harmonization of the existing soil loss maps of the different countries. It is known that at least for Germany, Czech Republic and Romania such maps exist and it can be expected that also other countries possesses such soil loss maps.

4.1.5 Nutrient Emissions via Tile Drainage

Based on nitrogen surplus in the catchments of the Danube river basin (see Map 4.1) the inputs by tile drainage were calculated according to the method given in Chapter 3.1.2.5. The estimated tile drained area in the Danube river basin is about 43050 km². This corresponds to 5 % of the total area or 10 % of the agricultural area. Map 4.8 gives an overview of the regional differences of the tile drained areas within the Danube basin.

The P-inputs by tile drainage in the period 1998 – 2000 are 407 t/a P, whereas the N-inputs are about 66965 t/a N (see Table 4.9 and Table 4.10). Maps 4.9 and 4.10 give an overview of the spatial distribution of the specific nutrient inputs from tile drained areas.

The calculated nitrogen concentrations within the subcatchments range between 28.5 mgN/l (Dyje) and 2.9 mgN/l (Drina). For the subcatchments within the Czech part of the Danube river basin the nitrogen concentration of tile drained area is within 11.9 mgN/l (Grosse Muehl upstream Neufelden) and 28.5 mgN/l (Dyje upstream confluence Svratka). Measurements of nitrate concentrations in different drained areas of Czech Republic show that the concentrations vary from 4 to 40 mgN/l (SVOBODOVÁ & KLÍMOVÁ, 1981 KVÍTEK 1996; IVANEK, SOUKUP & KRÁLOVCOVÁ 1998; SOUKUP et al., 1997). The calculated drainage concentrations for the Czech part of the Danube river basin are within this range.

The present approach for calculating nutrient emissions from tile drained areas probably leads to an underestimation. This is caused on the one hand by the low percentage of total agricultural area estimated as tile drained for those countries were information on the amount of drained areas is missing (see chapter 3). On the other hand there is also a need for more data, especially on the drainage runoff necessary to implement a better approach to the model.

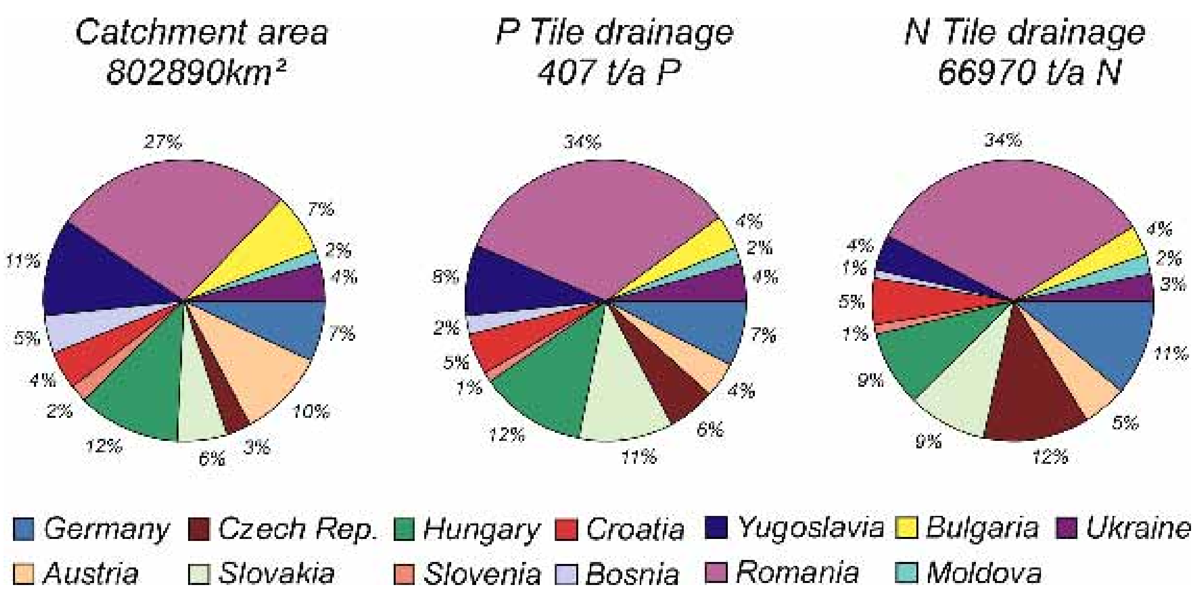
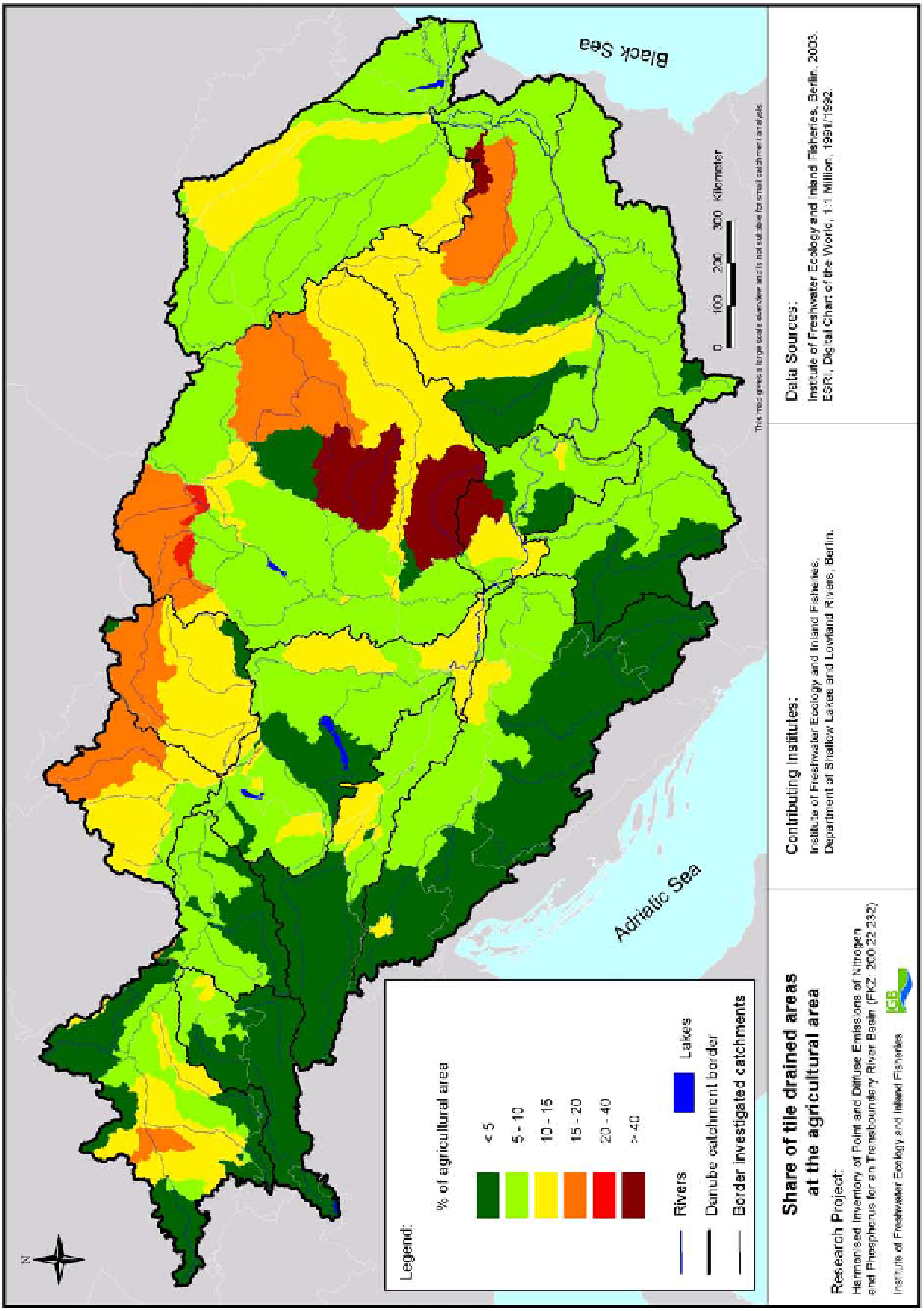


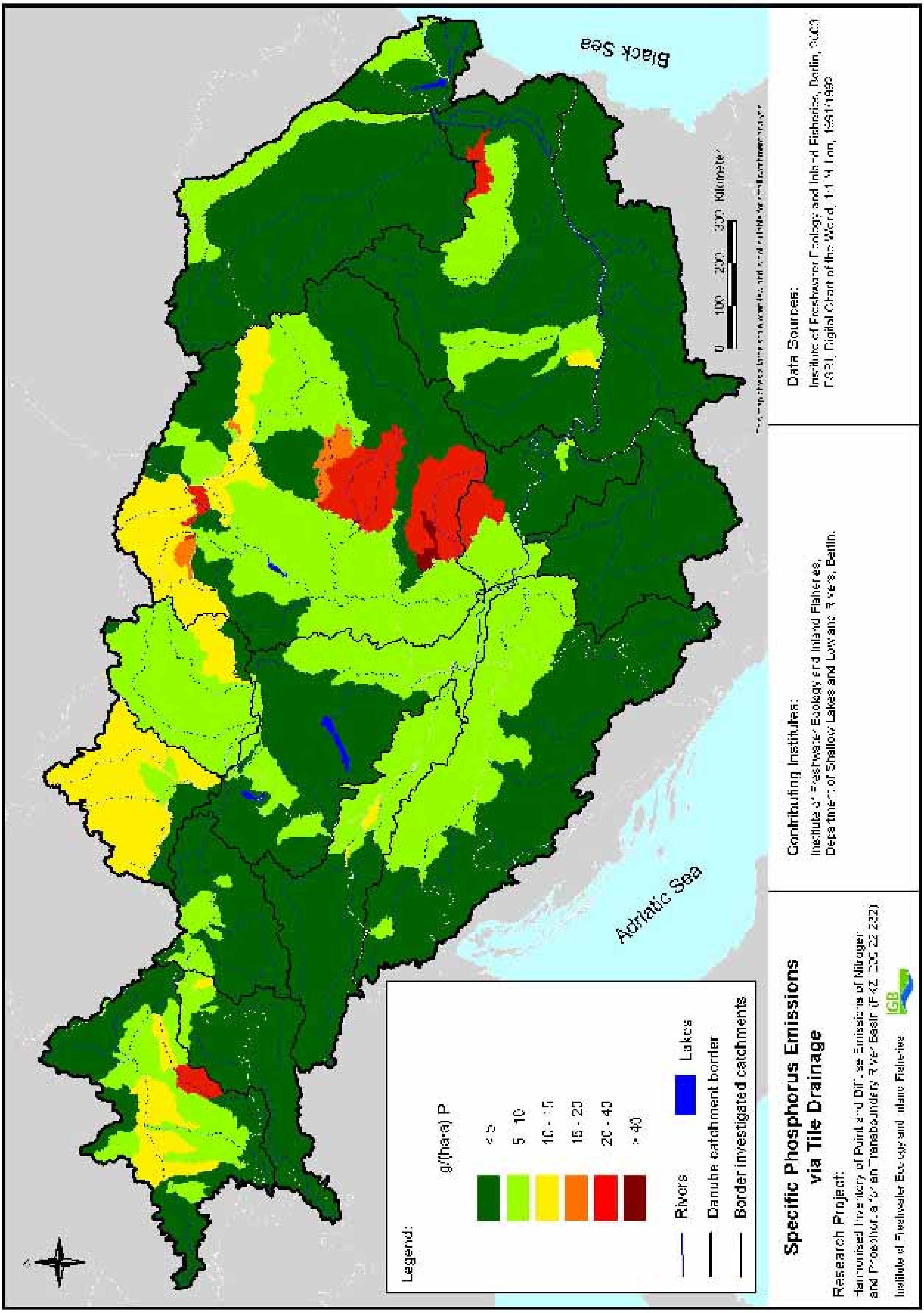
Figure 4.9: Portion of the countries to the total catchment area of the Danube and the total phosphorus and nitrogen emissions by tile drainage.

Table 4.9: Nutrient inputs by tile drainage into the Danube and its tributaries in the period 1998-2000

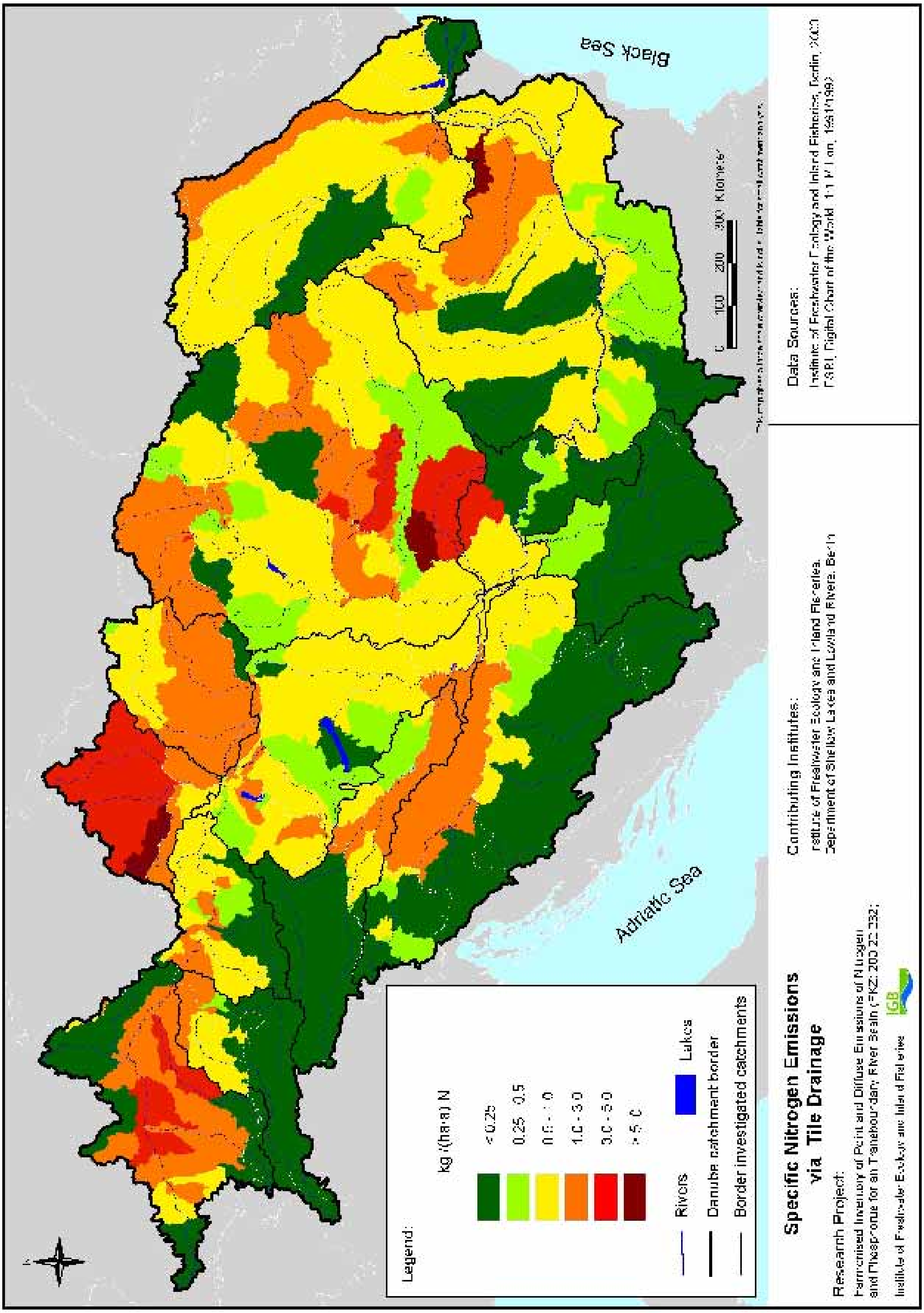
Basin	Station	Area	EDR_P	EDR_{Pspec}	EDR_N	$EDR_{Nspec.}$
		[km²]	[gP/a]	[tP/ha·a]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	28	5.6	6970	1.40
Inn	up.Passau-Ingling	26070	4	1.5	870	0.33
Austrian Danube	Passau to Nussdorf	26240	7	2.7	1450	0.55
Morava	Marchdorf	26650	26	9.8	8570	3.22
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	22	7.4	3530	1.18
Pannonian Danube	Nussdorf to up.Tisza	60370	28	4.6	4190	0.69
Drava	up. Ossijek	40310	13	3.2	2150	0.53
Drava	up. Mura	15330	2	1.3	300	0.20
Mura	mouth	14060	4	2.8	770	0.55
Sava	up. Belgrade	95890	31	3.2	3610	0.38
Sava	up.Crna Bara	62520	18	2.9	2350	0.38
Drina	up.Crna Bara	19610	2	1.0	160	0.08
Tisa	up.Tisza	151780	121	8.0	15190	1.00
Somes/Szamos	up. Oar	15370	12	7.8	1820	1.18
Crisuri/Koeroes	up. Magyartes	25410	31	12.2	4240	1.67
Mures/ Maros	up. Mako	28650	9	3.1	1710	0.60
Banat-East.Serbia	up. Tisza to Prahovo	28940	34	11.7	4180	1.44
Velika Morava	up. Mouth	37630	6	1.6	480	0.13
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	16	3.0	2440	0.45
Iskar	up. Orechovitza	8260	2	2.4	190	0.23
Muntenia	Prahovo-Giurgiul. RO	82250	35	4.3	7050	0.86
Jiu	up. Zaval	9960	1	1.0	160	0.16
Olt	up. Izbiceni	24250	11	4.5	2250	0.93
Arges	up. Clatesti	12580	4	3.2	640	0.51
Ialomita	Tandarei	10290	8	7.8	1700	1.65
Prut-Siret	Giurgiul. & Sendreni	73470	29	3.9	4900	0.67
Prut	Giurgiulesti	28580	16	5.6	2620	0.92
Siret	Sendreni	44890	13	2.9	2270	0.51
Delta-Liman	Giurgiul. - Mouth	19450	7	3.6	1370	0.70
Danube	**Total**	802890	407	5.1	66970	0.83



Map 4.8: Portion of tile drained areas at the agricultural area of the subcatchments.



Map 4.9: Specific phosphorus emissions via tile drainage in the period 1998 – 2000.



Map 4.10: Specific nitrogen emissions via tile drainage in the period 1998 – 2000.

Table 4.10: Nutrient inputs by tile drainage into country parts of the Danube river basin in the period 1998-2000

Basin	Area	EDR_P	EDR_{Pspec}	EDR_N	$EDR_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	30	5.3	7510	1.33
Austria	80850	17	2.1	3370	0.42
Czech Republic	21690	23	10.6	8060	3.72
Slovakia	47210	44	9.3	6090	1.29
Hungary	92770	50	5.4	5820	0.63
Slovenia	16410	4	2.4	810	0.49
Bosnia-Herzegovina	34630	20	5.8	3500	1.01
Croatia	37600	9	2.4	690	0.18
Yugoslavia	88490	32	3.6	2710	0.31
Romania	222330	137	6.2	22390	1.01
Bulgaria	55190	16	2.9	2450	0.44
Moldova	12330	8	6.5	1490	1.21
Ukraine	33930	17	5.0	2070	0.61
other countries	2820	0	0.0	10	0.04
Total	802890	407	5.1	66970	0.83

4.1.6 Nutrient Emissions via Groundwater

Tables 4.11 and 4.12 show the calculated P- and N-emissions via groundwater for the main subcatchments and countries within the Danube basin. For the period 1998-2000, total phosphorus emissions via this pathway were estimated to be about 4455 t/a P. Map 4.11 shows that P-emissions via groundwater are highest in catchments with large leakage rates and a high proportion of agricultural area. The mean specific P-emission was estimated as 55 g/(ha·a) P and ranges between 12 and 112 g/(ha·a) P.

Nitrogen emissions via groundwater and natural interflow were estimated as about 324800 t/a N for the period 1998-2000. The mean specific N-emission by groundwater was estimated as 4.1 kg/(ha·a) N, and varies between 0.1 and 13.1 kg/(ha·a) N. Map 4.12 shows regional differences in calculated percolating groundwater emissions. The catchment-differentiated picture remains valid and reflects the fact that very high nitrogen retention in the unsaturated zone and in groundwater can be expected, especially in areas with low rates of percolating water. In these areas (Pannonian Central, Delta-Liman ant other), retention is more than 95 % of the total N-pool. In contrast, in the upper Danube, as well upper Drava and Sava the nitrogen retention of groundwater is less than 50 %.

Table 4.11: Nutrient inputs by groundwater into the Danube and its tributaries in the period 1998-2000

Basin	Station	Area	EGW_P	EGW_{Pspec}	EGW_N	$EGW_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	496	99	65600	13.14
Inn	up.Passau-Ingling	26070	200	77	18780	7.20
Austrian Danube	Passau to Nussdorf	26240	275	105	19250	7.34
Morava	Marchdorf	26650	69	26	10400	3.90
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	119	40	10390	3.48
Pannonian Danube	Nussdorf to up.Tisza	60370	209	35	8030	1.33
Drava	up. Ossijek	40310	170	42	12920	3.21
Drava	up. Mura	15330	56	37	4240	2.77
Mura	mouth	14060	60	43	5220	3.71
Sava	up. Belgrade	95890	839	87	46920	4.89
Sava	up.Crna Bara	62520	570	91	35140	5.62
Drina	up.Crna Bara	19610	220	112	10430	5.32
Tisa	up.Tisza	151780	830	55	46960	3.09
Somes/Szamos	up. Oar	15370	125	81	8200	5.34
Crisuri/Koeroes	up. Magyartes	25410	114	45	4840	1.90
Mures/ Maros	up. Mako	28650	168	59	13800	4.82
Banat-East.Serbia	up. Tisza to Prahovo	28940	87	30	6060	2.09
Velika Morava	up. Mouth	37630	128	34	8010	2.13
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	218	40	22600	4.18
Iskar	up. Orechovitza	8260	84	102	8500	10.29
Muntenia	Prahovo-Giurgiul. RO	82250	449	55	30620	3.72
Jiu	up. Zaval	9960	70	70	5200	5.22
Olt	up. Izbiceni	24250	183	75	15660	6.46
Arges	up. Clatesti	12580	82	65	4750	3.78
Ialomita	Tandarei	10290	34	33	2320	2.25
Prut-Siret	Giurgiul. & Sendreni	73470	345	47	17960	2.44
Prut	Giurgiulesti	28580	134	47	6150	2.15
Siret	Sendreni	44890	211	47	11810	2.63
Delta-Liman	Giurgiul. - Mouth	19450	24	12	260	0.13
Danube	**Total**	802890	4455	55	324780	4.05

Table 4.12: Nutrient inputs by groundwater into country parts of the Danube river basin in the period 1998-2000

Basin	Area	EGW_P	EGW_{Pspec}	EGW_N	$EGW_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	611	108	80540	14.22
Austria	80850	458	57	31870	3.94
Czech Republic	21690	56	26	10050	4.63
Slovakia	47210	202	43	16650	3.53
Hungary	92770	315	34	5580	0.60
Slovenia	16410	193	118	14280	8.70
Bosnia-Herzegovina	34630	243	70	17010	4.91
Croatia	37600	304	81	14740	3.92
Yugoslavia	88490	375	42	18720	2.12
Romania	222330	1119	50	73250	3.29
Bulgaria	55190	222	40	22910	4.15
Moldova	12330	19	15	300	0.24
Ukraine	33930	331	98	18580	5.48
other countries	2820	6	21	310	1.10
Total	802890	4455	55	324780	4.05

Figure 4.10 shows that Germany has the highest proportion of nitrogen emissions via groundwater, which is more than 3 times higher than the size of Germany in proportion to the total area of the Danube basin. This is due to the high N-surplus on German agricultural areas (see 4.1.1) and the low nitrogen retention. On the other hand Hungary contributes only 2% to the total N-emissions via groundwater whilst accounting for 12% of the total area of the Danube basin. This is caused by the very large residence time in groundwater and that therefore more than 95% of the losses of agricultural areas are retained mostly by denitrification.

Since these results are especially important for the implementation of further measures to reduce the nitrogen concentrations in the Danube River and the load of Danube into the Black Sea, an evaluation is necessary using independent data that reflects the situation for groundwater N-emissions into the Danube. This can be done as proposed by Behrendt et al. (2000) who suggested that if a large number of observed concentrations of nitrate in groundwater wells was available this data could then be regionalised. Because such data could not be collected within this study a comparison between the measured and the calculated nitrogen concentrations was carried out based on an indicator derived directly from the data of water quality monitoring of the different rivers in the Danube. As shown by Behrendt et al. (2003) such an indicator can be the mean concentration of nitrate in the rivers at low flow conditions and at low temperatures.

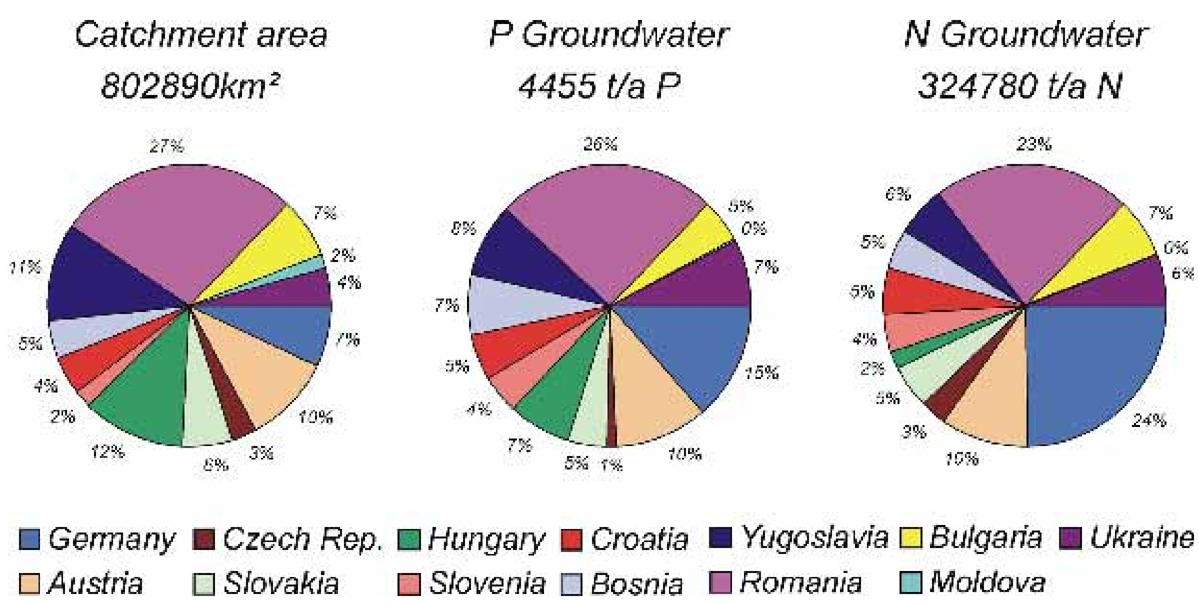


Figure 4.10: Portion of the countries to the total catchment area of the Danube and the total phosphorus and nitrogen emissions by groundwater.

A further precondition is that the proportion of point sources to the total N-emissions in the river should be low. During theses conditions the flow in the river is dominated by the groundwater inputs and the denitrification within the water is assumed to be low. Because the nitrogen input by groundwater is mostly nitrate this mean concentration levels can be used as a comparison for the calculated N-concentration of the groundwater emissions into surface waters. For this procedure monitoring data over a longer period (3 to 5 years) have to be used to establish a mean concentration, as the analysis of only a small amount of data per country can be distorted by the large number of countries involved.

Figure 4.11 shows the comparison between the observed nitrate concentration at low flow conditions and low temperature for the different water quality monitoring stations in the smaller rivers of the Danube, and the nitrogen concentration of the groundwater emissions calculated with MONERIS for the river catchments upstream of these monitoring stations. The comparison was carried out for all catchments with a proportion of point discharges to the total nitrogen emissions lower than 50 % and 20 %. Additionally to the procedure derived for the Odra, all rivers strongly influenced by snow melt in the high altitudes of the Alps were removed from the analysis.

In total, data from 100 different monitoring stations and their related sub-catchments could be used for the comparison. The mean deviation between observed and calculated concentrations for this dataset is 36%. For 16 stations the deviation is larger than 50%. Importantly, the large underestimation of the calculated N-concentration for some of the stations indicates that at least for these stations the observed data are influenced by point source discharges.

The similarity between the observed and calculated concentration is increasing for catchments with a share point source discharge lower than 20%. The mean deviation is reduced to 24 %, and only for 4 of the remaining 51 catchments was the deviation larger than

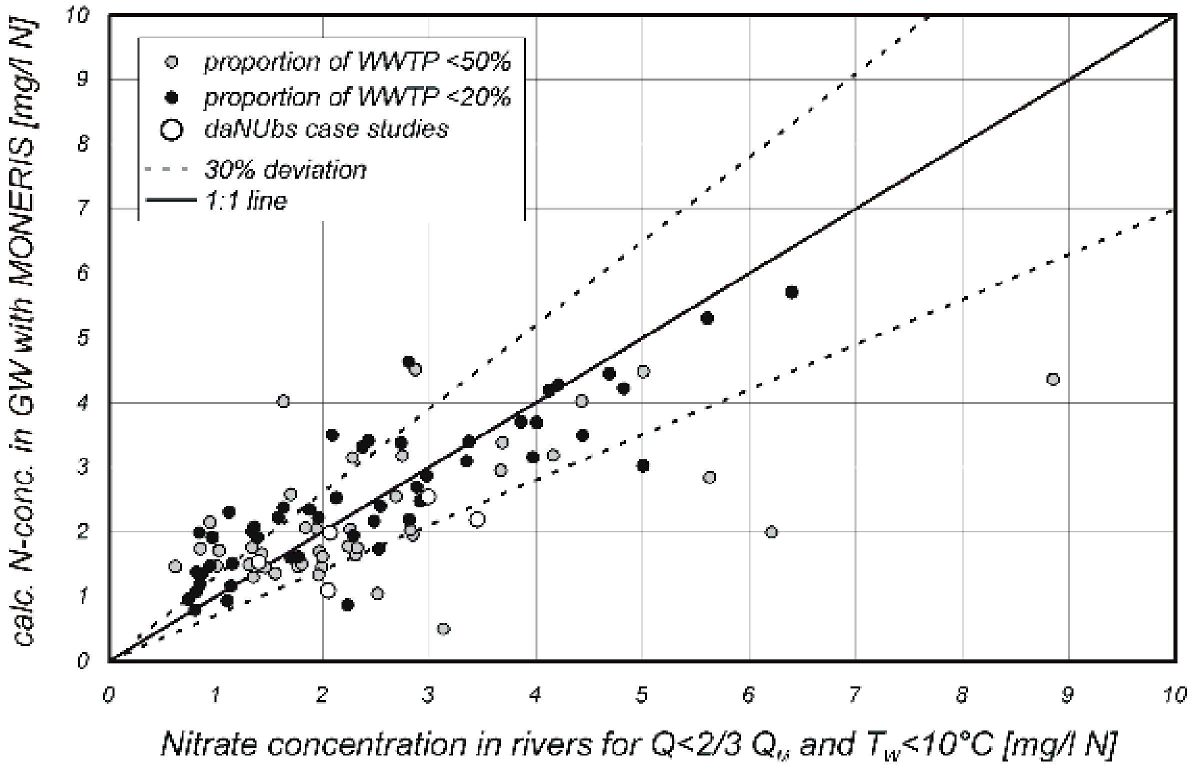
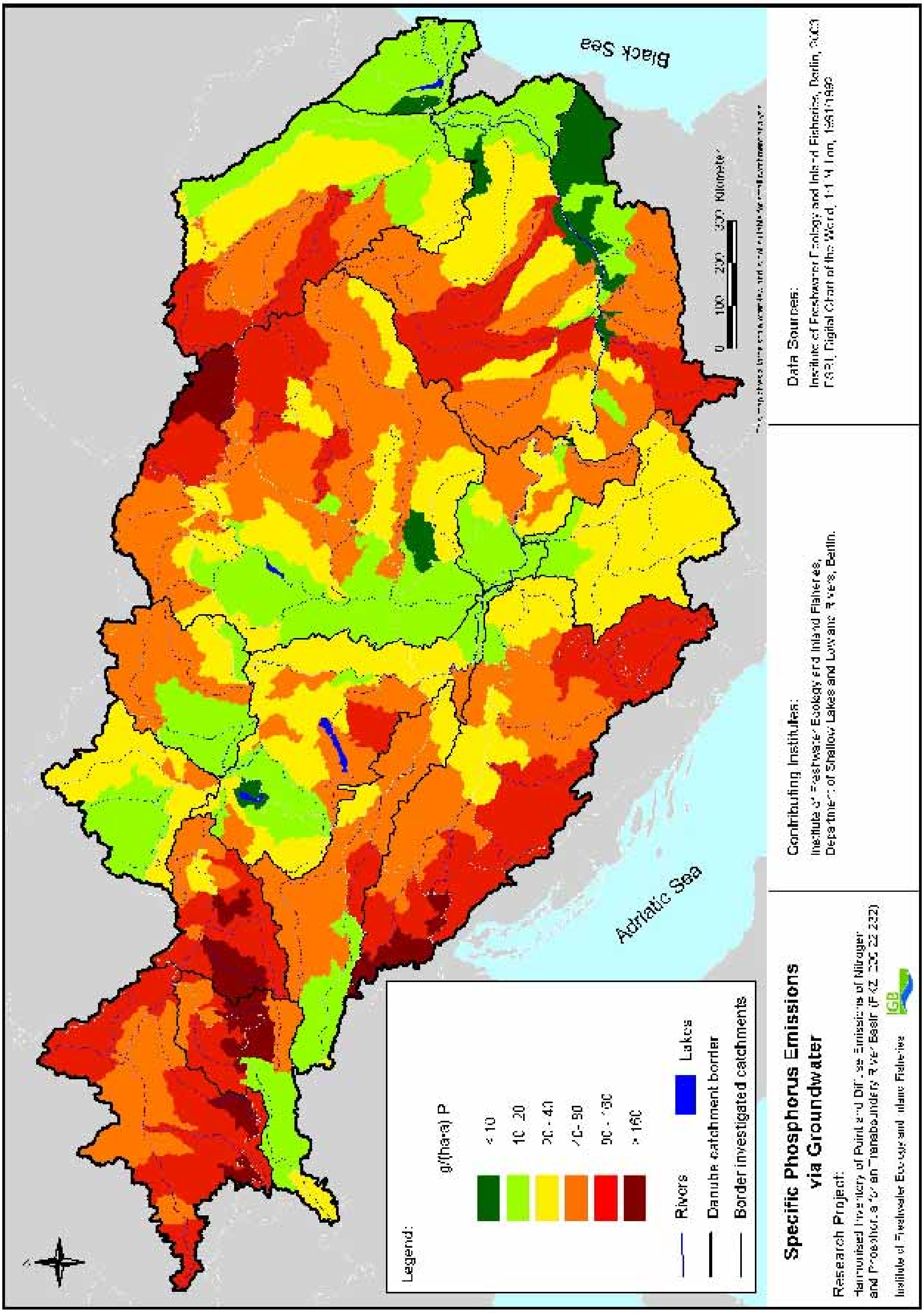


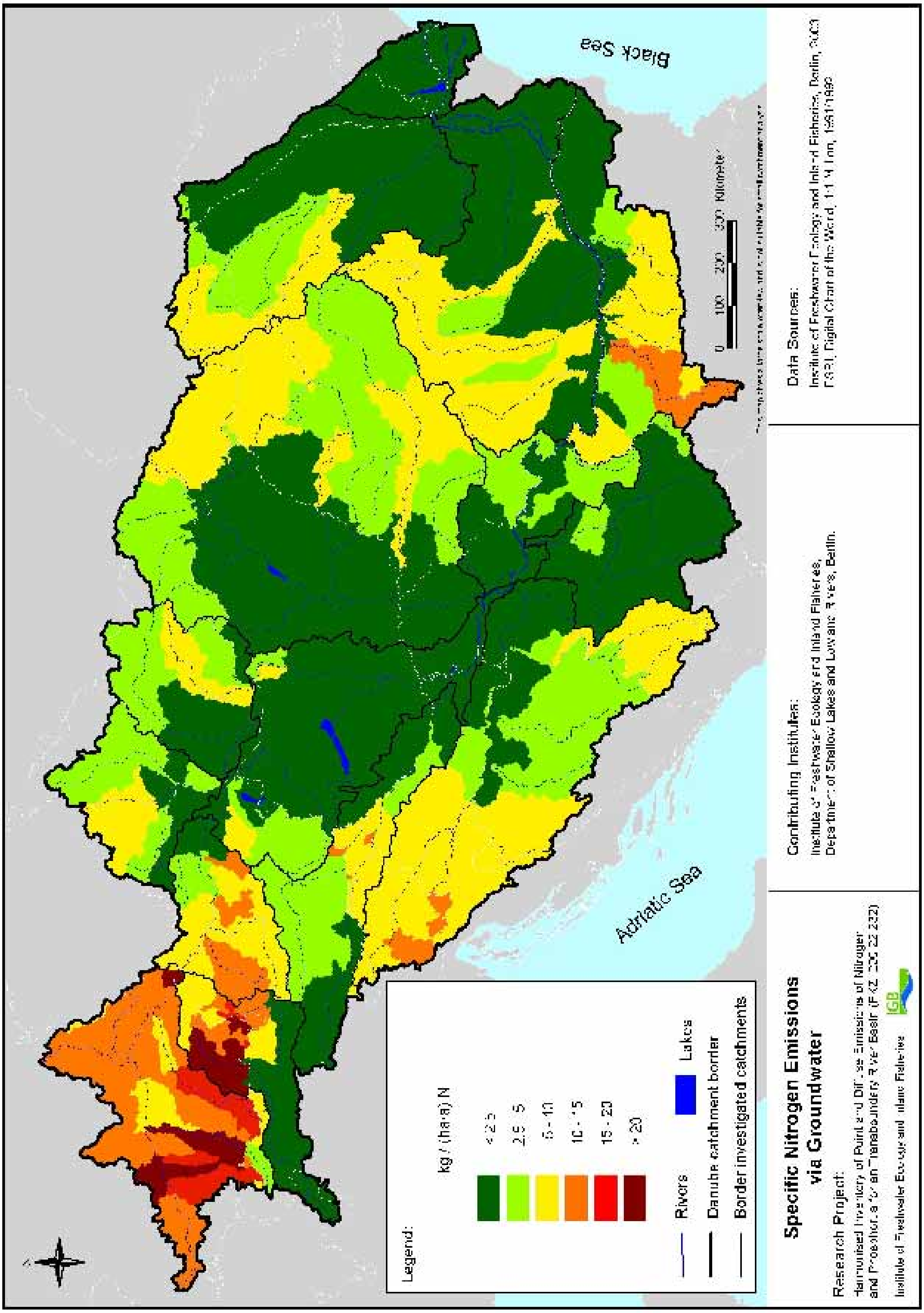
Figure 4.11: Comparison of nitrate concentrations at low flow conditions and low temperature for different monitoring stations and the calculated nitrogen concentrations in groundwater with the model MONERIS.

50%. The quality of the calculated N-concentrations in the groundwater is strongly dependent on the accuracy of the input data, especially nitrogen surplus, within the catchment. Consequently the mean deviation between the observed and the calculated N-concentrations of groundwaters is smaller for the parts of the Danube for which regionalised data of N-surplus were available (23 % for Danube upstream of Hungarian-Yugoslavian border). This illustrates the need for a better resolution of the statistical data, especially for agriculture. Data for the national level are not sufficient to explain the differences of the nitrogen concentrations in groundwater, because this data does not reflect the differences of the intensity of agriculture within the country.

In general, one can conclude from the comparison that the groundwater submodel of MONERIS seems to be applicable to the Danube basin. For further development of this submodel it seems to be necessary that statistical data for agriculture are available for, at least, the district level of the countries. If this data is available for the whole Danube basin the model can be changed or calibrated to reduce the deviation between observed and calculated concentrations. Further, it would be very useful if more of the results of measurements in the smaller rivers of the Danube basin were available and collected by the ICPDR. This is also important because the nitrate concentrations in rivers at low flow and in winter time can be helpful in indicating possible long term changes of the N-inputs via groundwater.



Map 4.11: Specific phosphorus emissions via groundwater in the period 1998 – 2000.



Map 4.12: Specific nitrogen emissions via groundwater in the period 1998 – 2000.

4.1.7 Nutrient Emissions via Urban Areas

Tables 4.13 and 4.14 show the estimated P-emissions from urban areas. This pathway includes emissions from the sewer system in the form of combined sewer overflow and separate sewers from urban areas, and from the population not connected to the sewer system. In the period 1998-2000, the P-emission into the Danube basin from this pathway was estimated as 8522 t/a P. The mean area specific P-emission from urban areas is 110 g/(ha·a) P and varies between 46 g/(ha·a) P and 280 g/(ha·a) P.

As shown in Map 4.13, the present hot-spots for urban P-emissions are in the catchments of the Iskar, Arges, Pannonian Central, upper Sava and Ialomita. For the Inn, Austrian Danube, Drina and Delta-Liman the specific P-emissions from urban areas are below average. This is mostly caused by the low proportion of paved urban areas within these catchments, but is also dependent on the proportion of Phosphorus used in detergents for all urban areas with combined sewer systems.

The N-emissions from urban areas are also shown in Tables 4.13 and 4.14 as well as Map 4.14. Overall these emissions were estimated as 69320 t/a N for 1998-2000. The mean N-emission from urban areas is 0.86 kg/(ha·a) N with a variance between 0.43 kg/(ha·a) N and 2.4 kg/(ha·a) N. The regional hot-spots were the same as for phosphorus.

The proportion contributed by each country to the total nutrient emissions in urban areas is similar to the proportion contributed in the basins area with exception of Germany and Austria, which contribute a lower proportion of this emission.

The results for the estimation of nutrient emissions from paved urban areas are only raw, because up to now data on the used sewer systems was not available with exception of the German part of the Danube. It seems to be necessary that the point source inventory of the ICPDR should be enlarged with information on the kind of sewer systems used in the different cities.

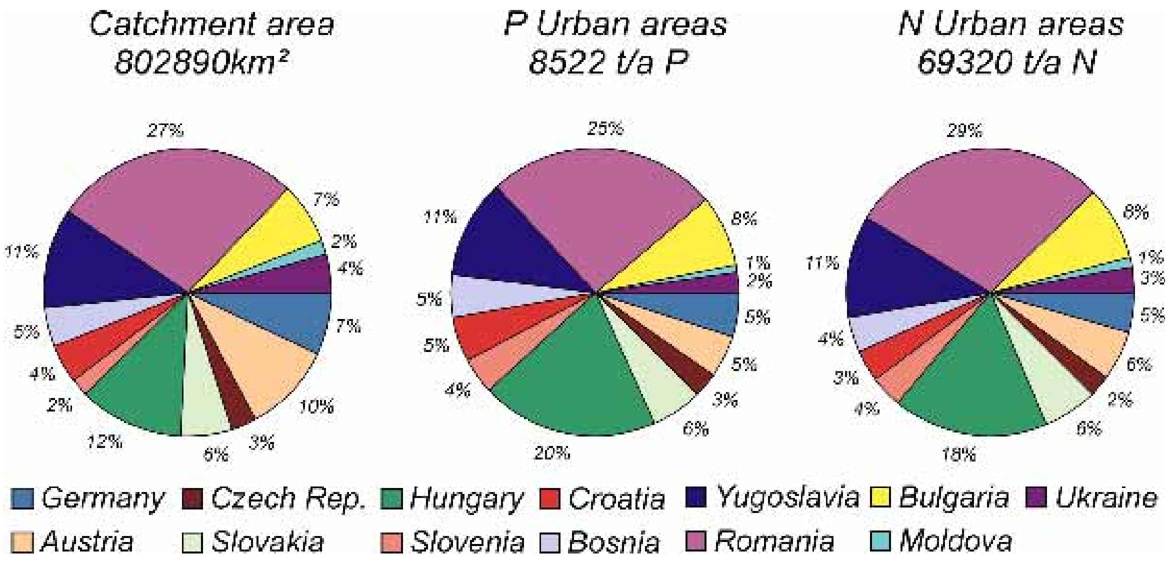
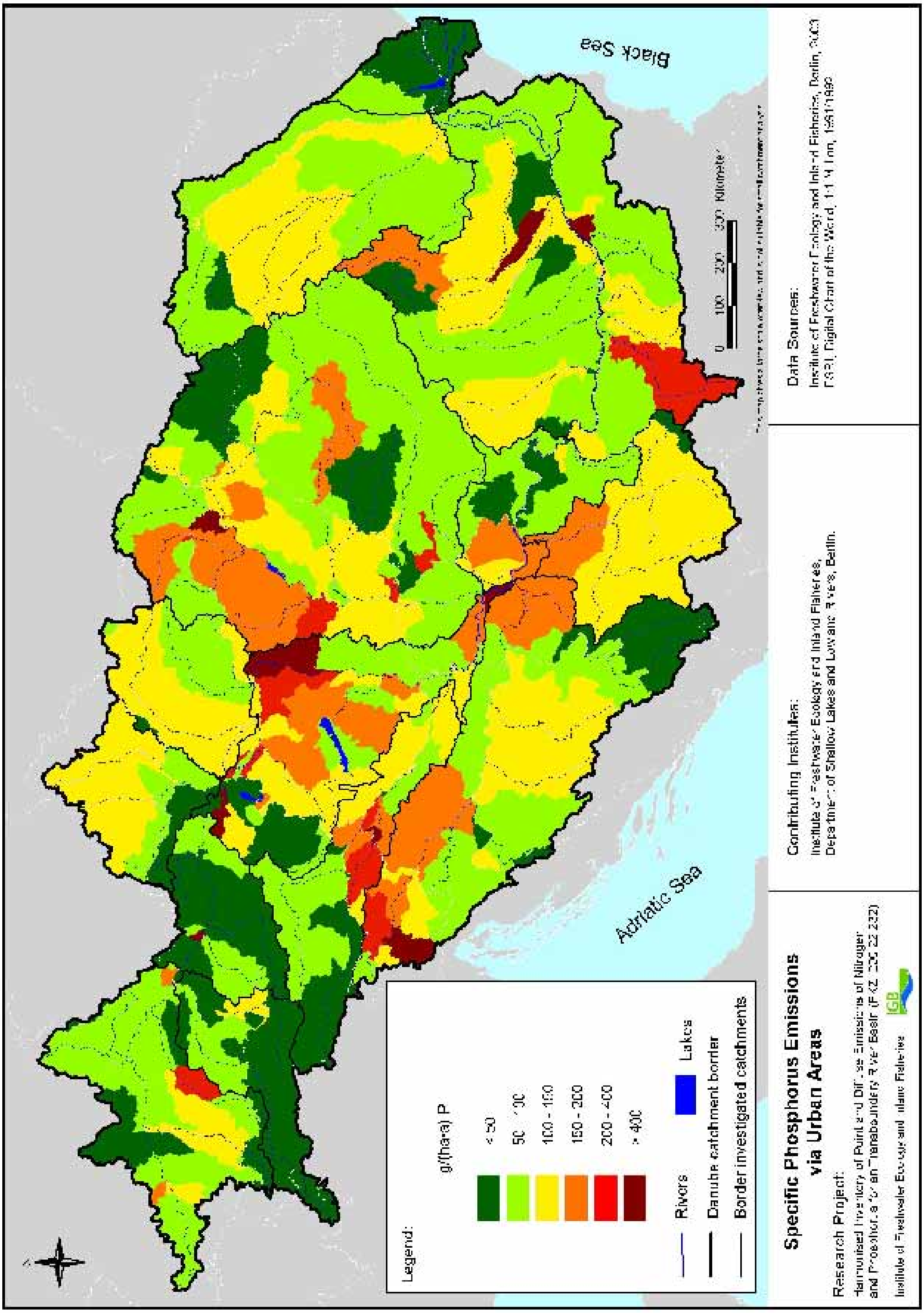


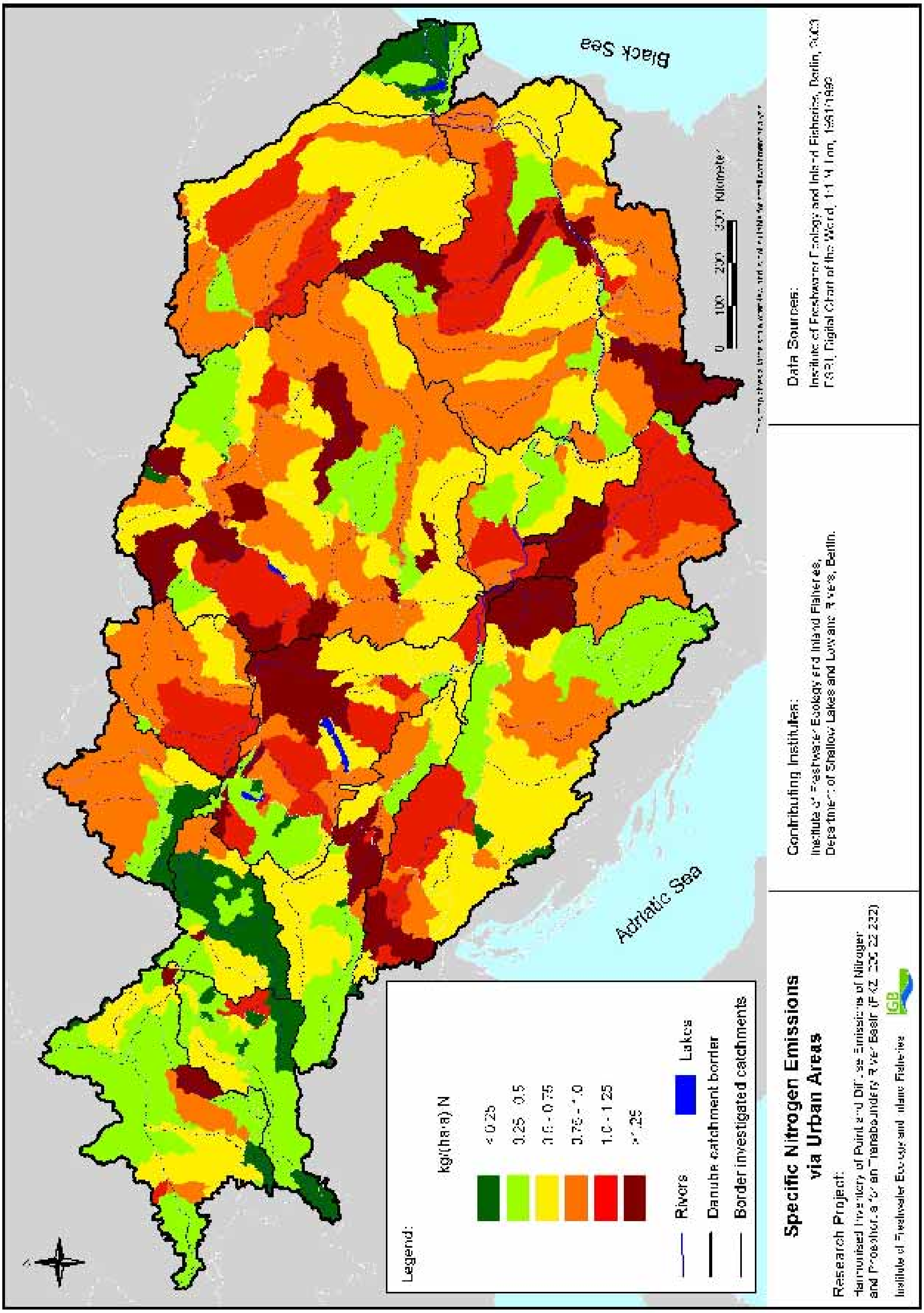
Figure 4.12: Portion of the countries to the total catchment area of the Danube and the total phosphorus and nitrogen discharges by urban areas.

Table 4.13: Nutrient inputs from urban areas into the Danube and its tributaries in the period 1998-2000

Basin	Station	Area	$EURB_P$	$EURB_{Pspec}$	$EURB_N$	$EURB_{Nspe.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	371	74.3	2740	0.55
Inn	up.Passau-Ingling	26070	125	47.9	1110	0.43
Austrian Danube	Passau to Nussdorf	26240	121	46.1	1160	0.44
Morava	Marchdorf	26650	244	91.6	1830	0.69
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	324	108.6	2650	0.89
Pannonian Central	Nussdorf to up.Tisza	60370	1094	181.2	8270	1.37
Drava	up. Ossijek	40310	368	91.3	2760	0.68
Drava	up. Mura	15330	129	84.1	920	0.60
Mura	mouth	14060	119	84.6	1010	0.72
Sava	up. Belgrade	95890	1144	119.3	7730	0.81
Sava	up.Crna Bara	62520	845	135.2	5570	0.89
Drina	up.Crna Bara	19610	99	50.5	730	0.37
Tisa	up.Tisza	151780	1618	106.6	13430	0.88
Somes/Szamos	up. Oar	15370	164	106.7	1580	1.03
Crisuri/Koeroes	up. Magyartes	25410	237	93.3	1900	0.75
Mures/ Maros	up. Mako	28650	246	85.9	2360	0.82
Banat-East.Serbia	up. Tisza to Prahovo	28940	259	89.5	2190	0.76
Velika Morava	up. Mouth	37630	448	119.1	3830	1.02
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	687	127.1	5730	1.06
Iskar	up. Orechovitza	8260	231	279.7	1960	2.37
Muntenia	Prahovo-Giurgiul. RO	82250	962	117.0	8820	1.07
Jiu	up. Zaval	9960	106	106.4	990	0.99
Olt	up. Izbcieni	24250	234	96.5	2220	0.92
Arges	up. Clatesti	12580	293	232.9	2690	2.14
Ialomita	Tandarei	10290	137	133.1	1230	1.20
Prut-Siret	Giurgiul & Sendreni	73470	654	89.0	6120	0.83
Prut	Giurgiulesti	28580	262	91.7	2520	0.88
Siret	Sendreni	44890	391	87.1	3600	0.80
Delta-Liman	Giurgiul. - Mouth	19450	102	52.4	940	0.48
Danube	**Total**	802890	8522	106.1	69320	0.86



Map 4.13: Specific phosphorus emissions via urban areas in the period 1998 – 2000.



Map 4.14: Specific nitrogen emissions via urban areas in the period 1998 – 2000.

Table 4.14: Nutrient inputs from urban areas into country parts of the Danube river basin in the period 1998-2000

Basin	Area	$EURB_P$	$EURB_{Pspec}$	$EURB_N$	$EURB_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	422	74.5	3170	0.56
Austria	80850	412	51.0	3850	0.48
Czech Republic	21690	223	102.8	1660	0.77
Slovakia	47210	505	107.0	4170	0.88
Hungary	92770	1689	182.1	12260	1.32
Slovenia	16410	339	206.6	2460	1.50
Bosnia-Herzegovina	34630	421	121.6	2390	0.69
Croatia	37600	402	106.9	2750	0.73
Yugoslavia	88490	968	109.4	7860	0.89
Romania	222330	2189	98.5	20280	0.91
Bulgaria	55190	691	125.2	5760	1.04
Moldova	12330	77	62.4	740	0.60
Ukraine	33930	179	52.8	1940	0.57
other countries	2820	5	17.7	40	0.14
Total	802890	8522	106.1	69320	0.86

4.1.8 Total Diffuse Nutrient Emissions

In Chapters 4.1.2 to 4.1.7 the results of estimations of nutrient emissions via the various diffuse emission pathways were shown.

The overall results for estimates of diffuse nutrient emissions are shown in Tables 4.15 and 4.16 as well as Figure 4.13 and Maps 4.15 and 4.16. For the 1998-2000 period, a value of 43.8 kt/a P was estimated for diffuse phosphorus emissions. The area specific diffuse P-emission is 545 g/(ha·a) P and vary between 223 g/(ha·a) P (Delta-Liman) and 772 g/(ha·a) P (Inn). As shown in Map 4.15, the specific diffuse P-emissions were the highest for the catchments with large cities inside. This illustrates that the P-emisions from urban areas are one important source for diffuse P-emissions. Comparatively low specific diffuse P-emissions can be seen for some rivers in the sub basins of Pannonian Danube, Delta Liman.

Figure 4.14 also shows the proportion of diffuse pathways through the total diffuse P-emissions for the different sub catchments of the Danube basin. Overall, erosion is the most important P-emission pathway with about 59% of total diffuse emissions. The proportion of erosion to the total diffuse P-emissions varies between 33 % (Arges) and 78 % (Morava). The second dominant diffuse pathway is P-emissions from urban areas with about 20% for the whole Danube basin, a minimum of 7% for the Inn and a maximum of 43% for the Arges. The high proportion of P-emissions from urban areas to the total diffuse P-emissions is mainly caused by the low proportion of population connected to sewer systems, and waste water treatment plants, within the more downstream countries of the Danube.

Table 4.17 shows a comparison of the diffuse P-emissions estimated with the model MONERIS for different large European river basins. From this comparison it can be concluded that the diffuse P-emissions in the Danube basin are similar to Odra and Vistuals and lower than some areas, especially in relation to the Rhine and Po.

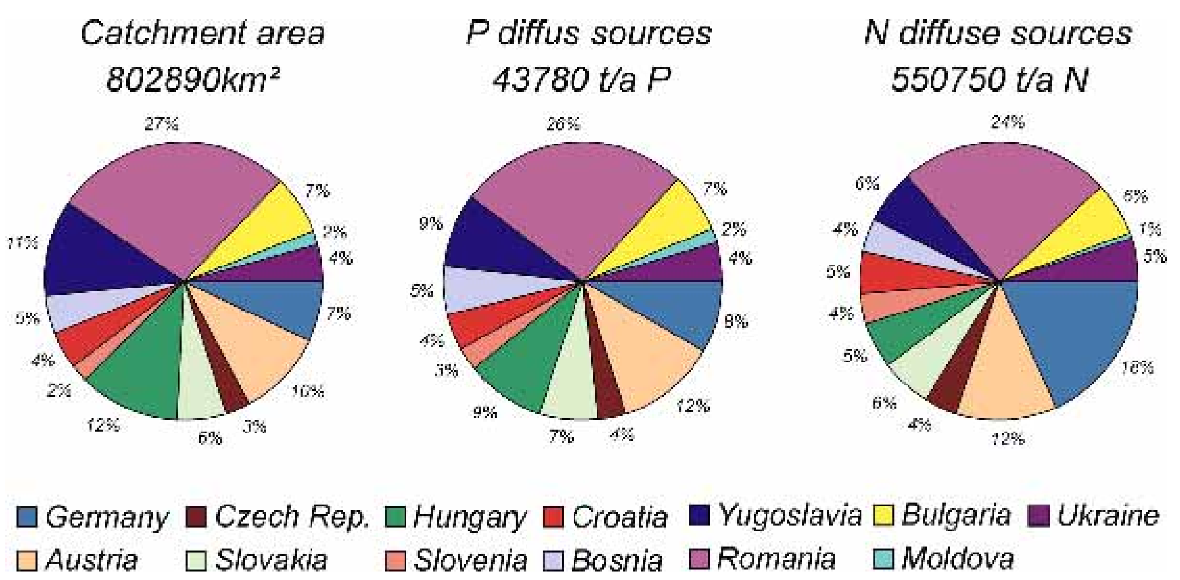


Figure 4.13: Portion of the countries at the total catchment area of the Danube and the total phosphorus and nitrogen discharges by diffuse pathways.

Estimated diffuse nitrogen emissions are also shown in Tables 4.15 and 4.16, Figures 4.13 and 4.14 and Map 4.16. The total diffuse N-emission was estimated as 550.8 kt/a N for the period 1998-2000. Most of the diffuse N-emission was through groundwater (mean: 59 %; Minimum: 6 % Maximum: 80 %) followed by emissions by paved urban areas (mean: 13%; minimum: 3 %; maximum: 33 %) and tile drained areas (mean: 12 %; minimum: 1 %; maximum: 37 %). The contribution of the other diffuse pathways to the total diffuse N-emissions is only important for some individual catchments like atmospheric deposition for Delta-Liman and N-emissions by surface runoff for the Inn and the Drava.

Compared to the other river basins (Table 4.17) the diffuse N-emissions in the Danube are comparable only with those of the Odra. For all of the other basins the diffuse N-emissions are larger and amount especially for Rhine and Po more than the double.

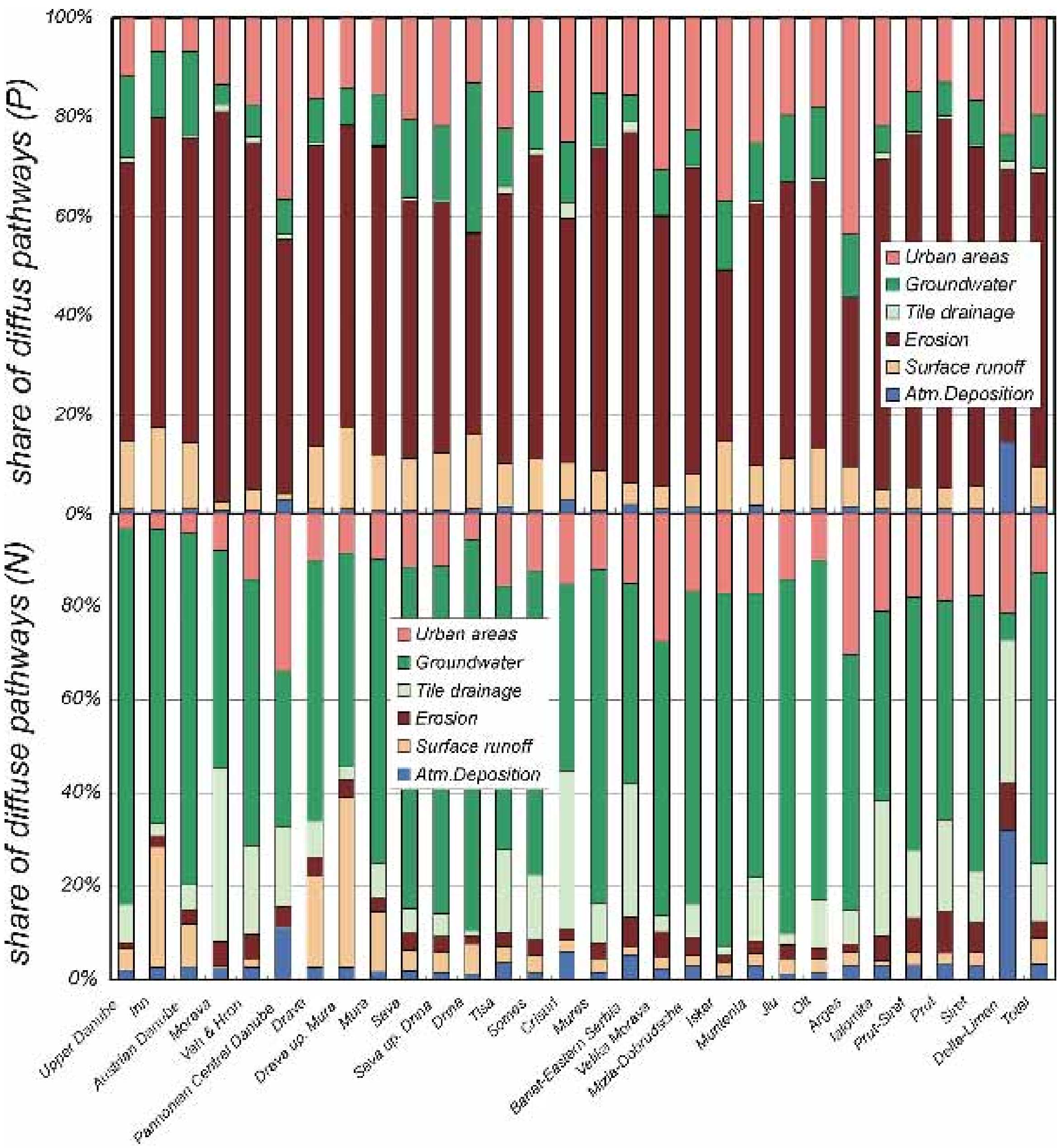


Figure 4.14: Portion of the pathways to the total diffuse P- and N-emissions within the subcatchments of the Danube in the period 1998-2000.

Table 4.15: Diffuse nutrient inputs into the Danube subbasins in the period 1998-2000

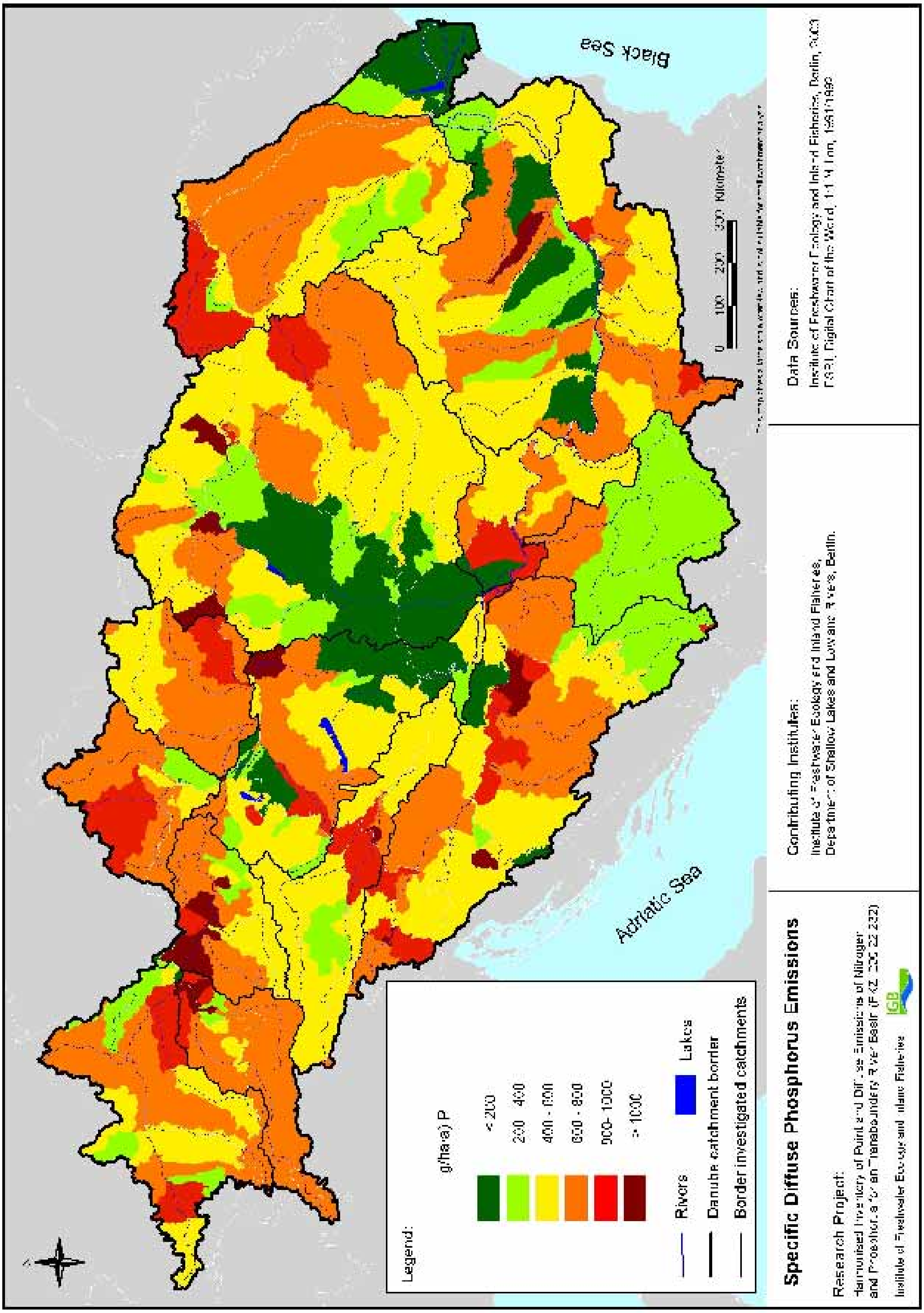
Basin	Station	Area	$EDIF_P$	$EDIF_{Pspec}$	AD_P	$EDIF_N$	$EDIF_{Nspec.}$	AD_N
		[km²]	[t/a P]	[g/ha·aP]	[%]	[t/a N]	[kg/ha·a N]	[%]
Upper Danube	up.Passau	49940	3220	645	78.8	84390	16.90	87.9
Inn	up.Passau-Ingling	26070	1874	719	57.8	33380	12.80	94.6
Austrian Danube	Passau to Nussdorf	26240	1781	679	87.1	27480	10.47	86.6
Morava	Marchdorf	26650	1808	678	74.5	23410	8.78	79.9
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	1871	627	78.9	19140	6.41	79.8
Pannonian Central	Nussdorf to up.Tisza	60370	2993	496	47.8	24980	4.14	52.5
Drava	up. Ossijek	40310	2300	571	73.3	26660	6.61	83.9
Drava	up. Mura	15330	941	614	74.0	10820	7.06	86.3
Mura	mouth	14060	772	549	72.6	9510	6.76	80.9
Sava	up. Belgrade	95890	5638	588	59.2	67640	7.05	81.4
Sava	up.Crna Bara	62520	3950	632	58.8	49510	7.92	80.7
Drina	up.Crna Bara	19610	768	392	69.2	13080	6.67	92.4
Tisa	up.Tisza	151780	7347	484	73.9	87090	5.74	83.4
Somes/Szamos	up. Oar	15370	1115	725	84.2	13170	8.57	86.4
Crisuri/Koeroes	up. Magyartes	25410	962	379	75.7	12640	4.97	87.4
Mures/ Maros	up. Mako	28650	1625	567	85.7	20110	7.02	86.2
Banat-East.Serbia	up. Tisza to Prahovo	28940	1660	574	44.4	15020	5.19	62.4
Velika Morava	up. Mouth	37630	1471	391	48.6	14410	3.83	74.9
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	3080	570	59.5	34980	6.47	78.8
Iskar	up. Orechovitza	8260	638	772	42.9	11510	13.93	80.9
Muntenia	Prahovo-Giurgiul. RO	82250	3893	473	55.6	52320	6.36	76.0
Jiu	up. Zaval	9960	547	549	70.9	7130	7.16	80.4
Olt	up. Izbiceni	24250	1319	544	84.0	22240	9.17	91.0
Arges	up. Clatesti	12580	681	541	25.7	8980	7.14	50.0
Ialomita	Tandarei	10290	637	619	61.5	6060	5.89	80.5
Prut-Siret	Giurgiul. & Sendreni	73470	4412	601	86.2	35150	4.78	85.0
Prut	Giurgelesti	28580	2022	707	87.5	13970	4.89	87.8
Siret	Sendreni	44890	2390	532	85.1	21170	4.72	83.3
Delta-Liman	Giurgiul. - Mouth	19450	433	223	63.4	4620	2.38	74.4
Danube	**Total**	802890	43779	545	64.6	550750	6.86	80.1

Table 4.16: Diffuse nutrient inputs into the country parts of the Danube in the period 1998-2000

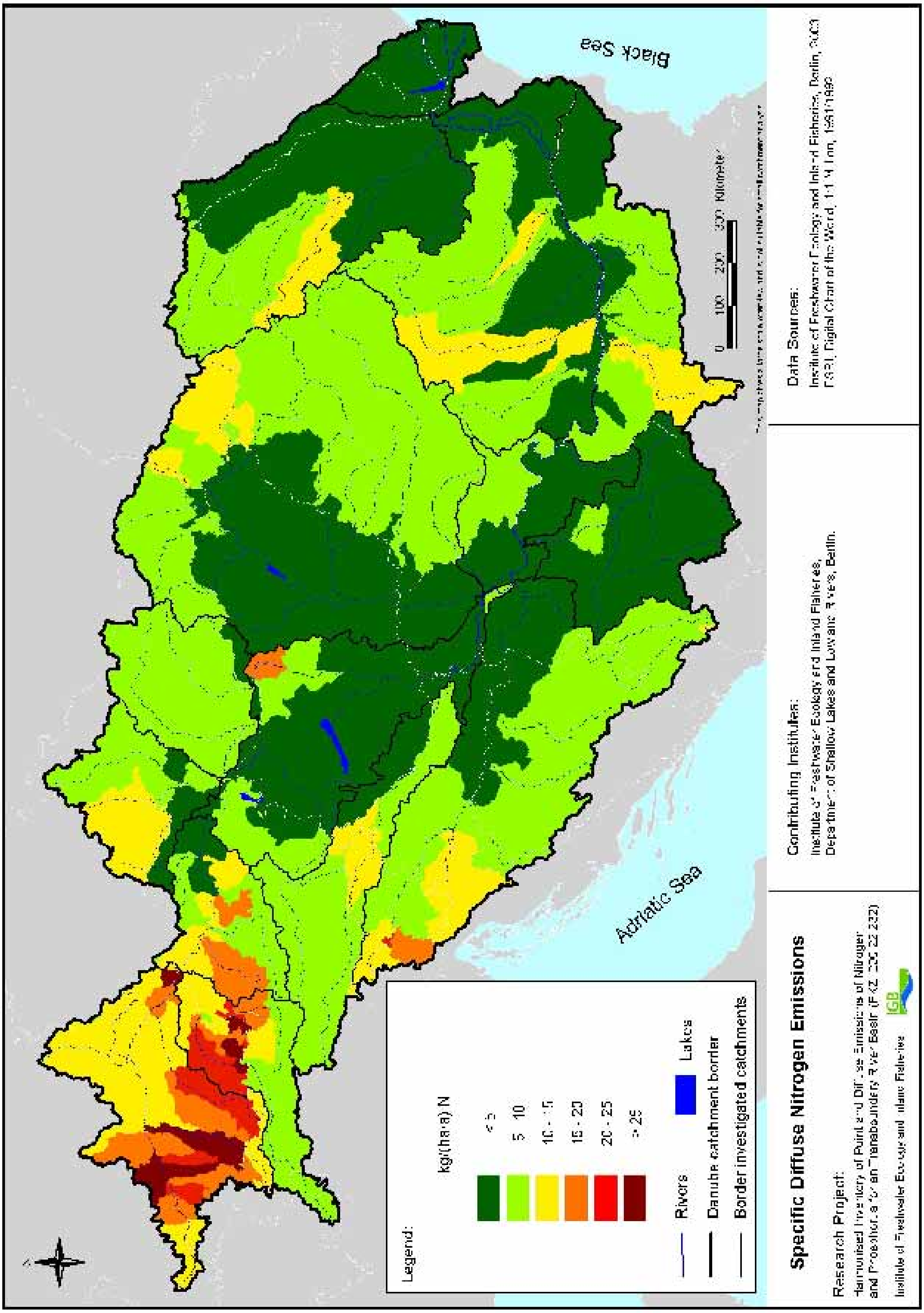
Basin	Area	$EDIF_P$	$EDIF_{Pspec}$	AD_P	$EDIF_N$	$EDIF_{Nspec.}$	AND
	[km²]	[t/a P]	[g/ha·a P]	[%]	[t/a N]	[kg/ha·a N]	[%]
Germany	56630	3646	644	76.6	100020	17.66	88.7
Austria	80850	5018	621	70.4	64550	7.98	80.1
Czech Republic	21690	1532	706	72.5	22030	10.16	80.0
Slovakia	47210	2872	608	71.6	30960	6.56	77.1
Hungary	92770	3997	431	57.2	29280	3.16	64.8
Slovenia	16410	1210	737	59.6	19720	12.02	82.6
Bosnia-Herzegovina	34630	1865	539	56.6	25830	7.46	80.2
Croatia	37600	2368	630	68.6	21980	5.85	85.9
Yugoslavia	88490	3788	428	40.7	35450	4.01	63.7
Romania	222330	11545	519	72.1	132750	5.97	81.2
Bulgaria	55190	3115	564	59.7	35380	6.41	79.0
Moldova	12330	662	537	80.0	3540	2.87	81.8
Ukraine	33930	1949	574	80.2	27390	8.07	93.7
other countries	2820	211	748	99.1	1900	6.74	99.0
Total	802890	43779	545	64.6	550750	6.86	80.1

Table 4.17: Comparison of the diffuse nutrient emissions for different large river basins in Europe and different time periods.

River	Period	Area	Discharge	Diffuse N-emissions	specific diffuse N-emissions	Diffuse P-emissions	specific diffuse P-emissions
		[km²]	[l/(km²·s)]	[t/a N]	[kg/(ha·a)N]	[t/a P]	[g/(ha·a)P]
Rhine*	83/87	159715	15.6	290014	18.2	11844	742
Rhine*	93/97	159715	14.5	220038	13.8	9830	616
Rhine*	98/00	159715	16.8	247575	15.5	10514	658
Po	91/95	73761	20.5	144997	19.7	5087	690
Elbe	83/87	134855	5.4	207499	15.4	9428	699
Elbe	93/97	134855	5.4	139531	10.3	7492	556
Elbe	98/00	134855	5.0	137192	10.2	7042	522
Vistula	91/95	190309	5.2	160790	8.4	8525	448
Odra	93/97	118581	4.7	78976	6.7	4872	411
Danube	98/00	802888	8.6	550750	6.9	43779	545



Map 4.15: Specific diffuse phosphorus emissions in the period 1998 – 2000.



Map 4.16: Specific diffuse nitrogen emissions in the period 1998 – 2000.

4.2 Nutrient Emissions from Point Sources

Tables 4.18 and 4.19 present an overview on the point source inputs into the river system of the Danube and its main tributaries. According to these tables the total amount of point source inputs into the Danube river system are about 240 kt/a P and 137 kt/a N for the investigation period 1998 to 2000. As shown in Figure 4.15 most of the point source emissions into the river system of the Danube are caused by Yugoslavia (Serbia Montenegro) (22 % and 14 % for P and N, respectively) and Romania (19 % and 22 % for P and N, respectively). Proportionally for Yugoslavia these are 11 % (P) and 3 % (N) higher than the percentage of the Yugoslavian population as a proportion of the total population living in the Danube river basin (11%). For Romania however these figures are by 7 % (P) and 4 % (N) lower than the proportion of the population as a whole (26 %). A higher P-input, more than 1 % of the proportion of population living in the Danube river basin resulted for Bosnia-Herzegovina (2 %) and for Bulgaria (4 %), whereas higher N-inputs resulted for Austria (3 %) and Bulgaria (2 %). This is not only an indication of the present state regarding nutrient elimination in the WWTP`s in the countries but also for the different phosphorus emissions per inhabitant (Austria 1.92 g/(Inh.·d) P; Bosnia-Herzegovina 2.94 g/(Inh.·d) P; Yugoslavia 2.26 g/(Inh.·d) P; Bulgaria 1.95 g/(Inh.·d) P) mainly caused by the different use of phosphorus in detergents. For nitrogen different levels, direct industrial discharges can also influence the point source inputs in the sub catchment.

Maps 4.17 and 4.18 show the regional distribution of the inhabitant specific point source emissions within the investigated sub catchments of the Danube. For both nutrients these specific discharges vary in a large range.

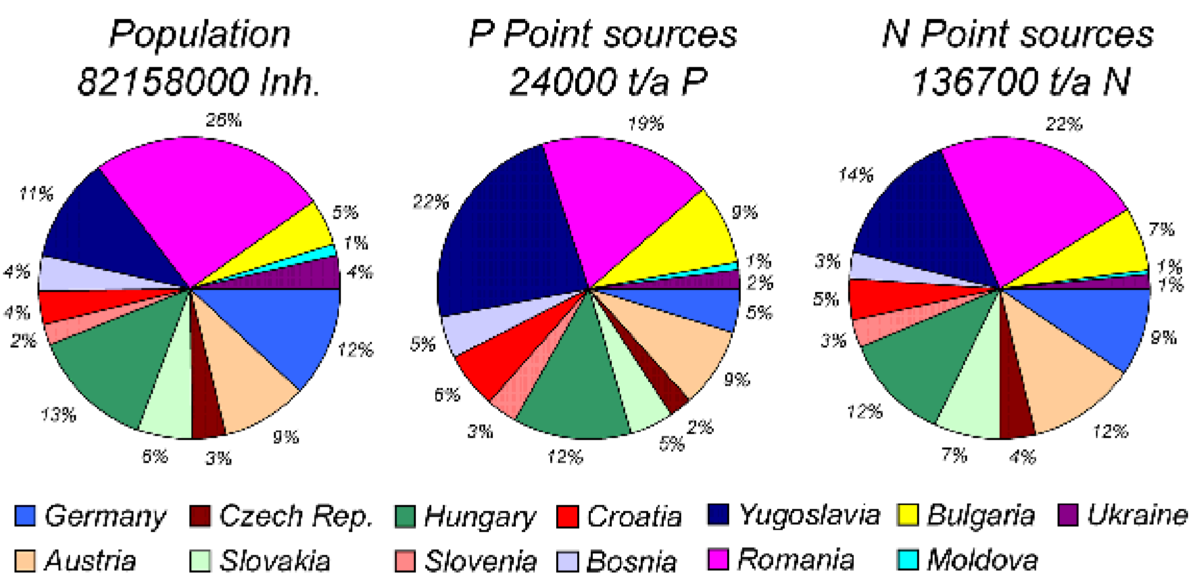


Figure 4.15: Portion of the countries at the total population and the total phosphorus and nitrogen discharges by point sources.

Table 4.18: Nutrient inputs by point sources into the Danube subbasins in the period 1998-2000

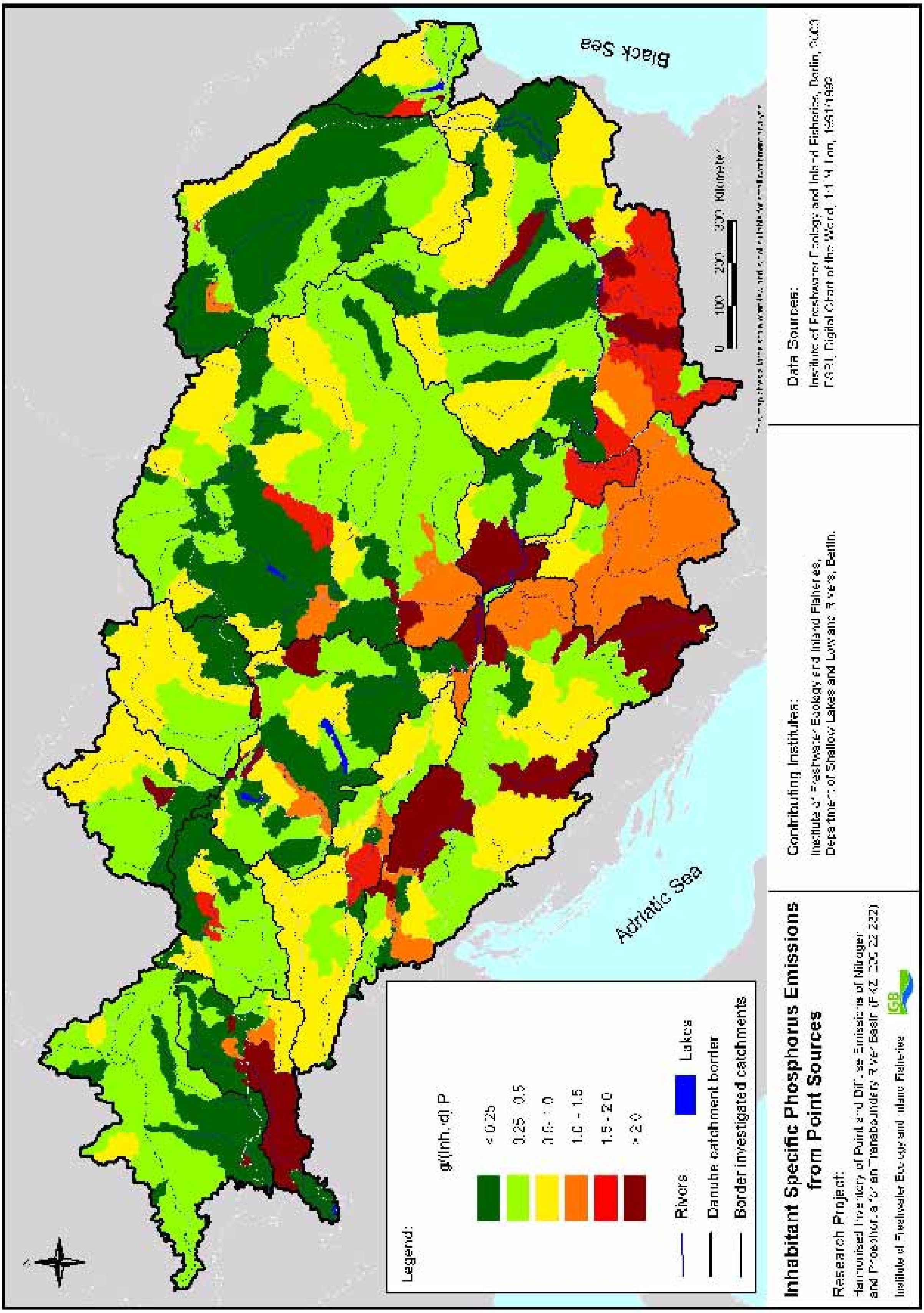
Basin	Station	Pop.	EP_P	EP_{Pspec}	AP_P	EP_N	$EP_{Nspec.}$	AP_N
		[1000]	[t/a P]	[g/(inh·d) P]	[%]	[t/a N]	[g/(inh·d) N]	[%]
Upper Danube	up.Passau	8498	867	0.28	26.9	11660	3.76	12.0
Inn	up.Passau-Ingling	2344	1370	1.60	47.1	1920	2.24	6.0
Austrian Danube	Passau to Nussdorf	2539	263	0.28	16.5	4260	4.60	12.8
Morava	Marchdorf	3116	620	0.55	31.8	5900	5.19	20.4
Vah & Hron & Ipel	Kom. & Kam. & Salka	3204	499	0.43	26.8	4850	4.15	20.5
Pannonian Central	Nussdorf to up.Tisza	8916	3271	1.01	55.9	22640	6.96	48.0
Drava	up. Ossijek	3237	837	0.71	29.8	5120	4.33	14.7
Drava	up. Mura	991	330	0.91	28.4	1720	4.76	15.2
Mura	mouth	1297	292	0.62	29.9	2240	4.73	13.9
Sava	up. Belgrade	8605	3882	1.24	48.3	15500	4.93	18.7
Sava	up.Crna Bara	5706	2771	1.33	49.0	11810	5.67	19.3
Drina	up.Crna Bara	852	341	1.10	36.3	1070	3.44	7.5
Tisa	up.Tisza	13457	2595	0.53	33.4	17290	3.52	16.8
Somes/Szamos	up. Oar	1399	209	0.41	22.8	2070	4.05	13.8
Crisuri/Koeroes	up. Magyartes	1759	309	0.48	30.8	1820	2.84	12.8
Mures/ Maros	up. Mako	2016	271	0.37	20.5	3220	4.38	13.8
Banat-East.Serbia	up. Tisza to Prahovo	2392	2075	2.38	64.4	9060	10.38	38.3
Velika Morava	up. Mouth	3954	1557	1.08	57.2	4820	3.34	25.7
Mizia-Dobrudscha	Prahovo-Giurgiul. B	3760	2099	1.53	47.6	9410	6.86	21.2
Iskar	up. Orechovitza	1471	850	1.58	63.3	2720	5.06	18.7
Muntenia	Prahovo-Giurgiul. RO	9947	3110	0.86	50.9	16480	4.54	23.8
Jiu	up. Zaval	1003	225	0.61	36.1	1740	4.75	19.6
Olt	up. Izbiceni	2122	251	0.32	20.9	2210	2.85	8.9
Arges	up. Clatesti	3259	1970	1.66	77.4	8980	7.55	49.8
Ialomita	Tandarei	1361	399	0.80	45.0	1470	2.96	20.0
Prut-Siret	Giurgiul & Sendreni	6976	707	0.28	18.2	6190	2.43	15.4
Prut	Giurgiulesti	3138	289	0.25	16.9	1950	1.70	12.7
Siret	Sendreni	3839	417	0.30	19.2	4240	3.03	17.1
Delta-Liman	Giurgiul. - Mouth	1213	250	0.56	31.6	1590	3.59	26.0
Danube	**Total**	82158	24002	0.80	42.0	136690	4.56	19.9

Table 4.19: Nutrient inputs by point sources into the country parts of the Danube river basin in the period 1998-2000

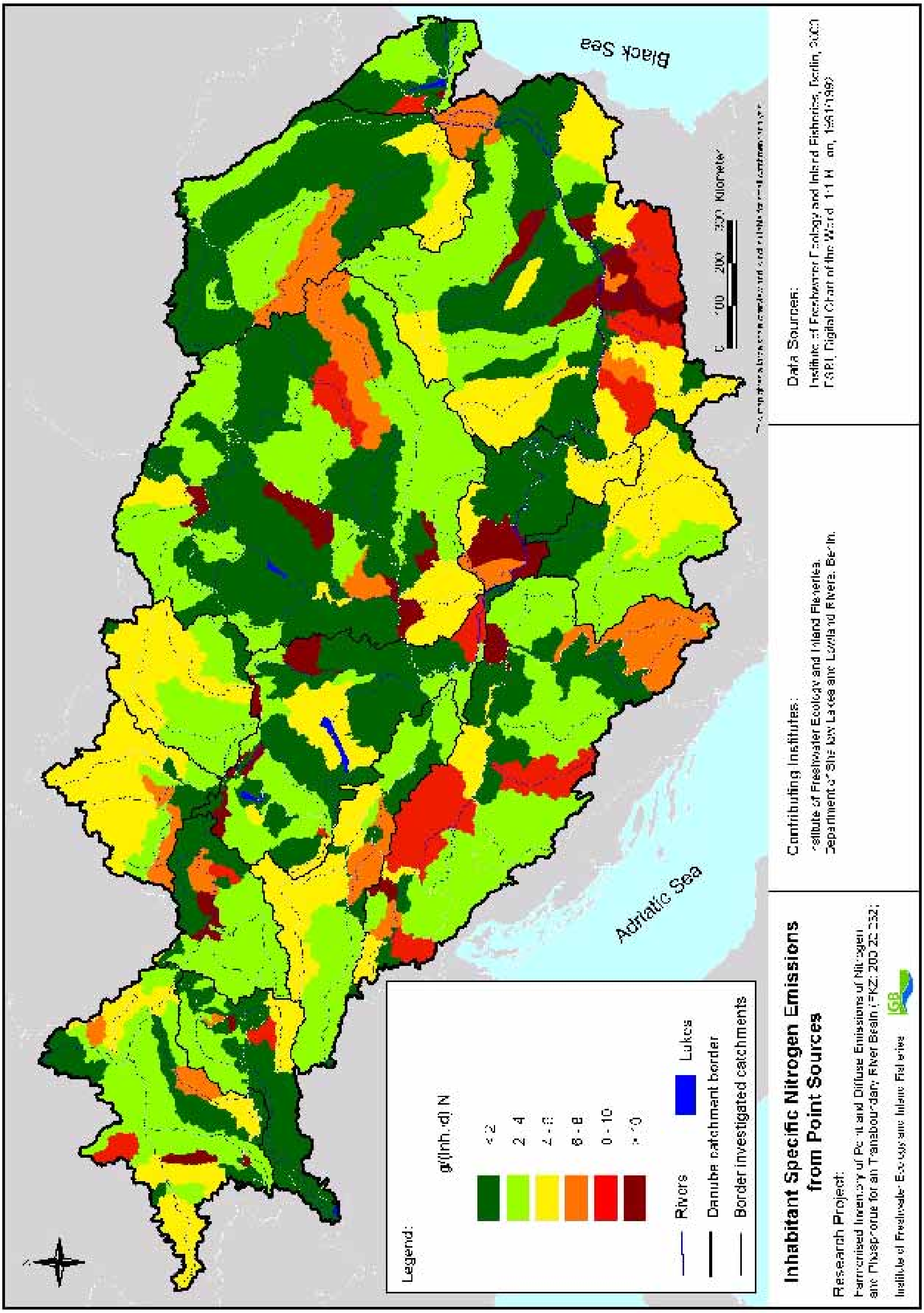
Basin	Pop.	EP_P	EP_{Pspec}	AP_P	EP_N	$EP_{Nspec.}$	AP_N
	[1000]	[t/a P]	[g/(inh·d) P]	[%]	[t/a N]	[g/(inh·d) N]	[%]
Germany	9717	1113	0.31	29.8	12782	3.60	11.1
Austria	7702	2108	0.75	33.5	16054	5.71	19.8
Czech Republic	2767	580	0.57	33.9	5502	5.45	20.2
Slovakia	5009	1140	0.62	35.5	9206	5.03	23.3
Hungary	10944	2994	0.75	45.4	15932	3.99	35.7
Slovenia	1738	819	1.29	46.9	4157	6.55	17.1
Bosnia-Herzegovina	3010	1432	1.30	52.1	6372	5.80	19.9
Croatia	3144	1086	0.95	38.6	3613	3.15	14.3
Yugoslavia	9144	5518	1.66	65.3	20216	6.07	37.0
Romania	20844	4462	0.59	35.0	30780	4.05	18.9
Bulgaria	4231	2101	1.35	47.4	9417	6.07	21.0
Moldova	892	165	0.51	21.7	794	2.44	19.4
Ukraine	2951	480	0.45	27.5	1828	1.70	6.4
other countries	66	2	0.09	1.1	17	0.70	1.7
Total	82158	24002	0.80	41.9	136670	4.56	20.0

It has to be taken into account that these specific discharges are calculated based on the total population living within the catchments and reflect two effects: the level of nutrient elimination in the municipal and industrial WWTP`s and the level of population connected to WWTP`s.

For phosphorus the maps show that especially the sub catchments including the large cities show substantial high inhabitant specific point source discharges.



Map 4.17: Inhabitant specific phosphorus emissions in the period 1998 – 2000.



Map 4.18: Inhabitant specific nitrogen emissions in the period 1998 – 2000.

4.3 Total Nutrient Emissions

An overview on the total nutrient emissions (point and diffuse sources) into the river system of the Danube is given in Tables 4.20 and 4.21, while Figure 4.16 shows the contribution of the countries to these total nutrient emissions.

For phosphorus a total emission by point and non-point sources of 67780 t/a P was estimated for the time period 1998-2000. A total of 35 % of the P-emissions originated as discharges from municipal waste water treatment plants and industrial waste water; 37 % of the total P-emissions were caused by erosion and 13 % by discharges from urban areas and people which are not connected to WWTP`s and sewer systems. P-emissions into the surface water by groundwater and natural interflow as well as surface runoff contributed 7 % and 6 % respectively to the total P-emissions. Other sources are of minor importance for the P-emissions into the river system of the Danube. As shown in Map 4.19 and Figure 4.17, the proportion of the different pathways to the total P-emissions varies widely between the subcatchments of the Danube. Point source P-discharges with more than 50 % were estimated for Pannonian Danube, Banat-Eastern Serbia, Velika Morava, Iskar and Arges. These are mainly catchments in which the large cities of Budapest, Beograd, Sofia and Bucharest are located.

As shown in the Map 4.19, Table 4.20 and Figure 4.19, the highest total P-emissions occur with more than 1200 g/(ha·a) P in the subcatchments of the Inn, Banat-Eastern Serbia, Iskar and Arges. In the last both river catchments the specific P-emissions are more than the double the mean for the whole Danube (844 g/(ha·a) P).

If the analysis is done for the countries within the Danube basin, the highest specific P-emissions with more than 1000 g/(ha·a) P are caused by Slovenia and Yugoslavia (Serbia and Montenegro) (Table 4.21; Figure 4.22). A point source contribution to the total P-emissions of more than 50 % was only estimated for Yugoslavia. For Hungary, Croatia, Slovenia and Bulgaria the point source contribution is also above 40 %.

Compared with other transboundary river systems in Europe to which the MONERIS model has been applied (Rhine, Elbe, Odra; see Behrendt et al. 2000; 2003a; 2003b), the total phosphorus emissions into the Danube river system are of the same order of magnitude as found for the Elbe (765 g/(ha·a) P) basin, but much lower than in the Odra (1088 g/(ha·a) P) and in the Rhine (1101 g/(ha·a) P).

The analysis of P-emissions into the Danube river system shows the need to reduce P-emissions, especially from point sources. However, this can only be achieved if the necessary increase in the connected population to waste water treatment plants (present state is 56 %) is combined with an improvement of the existing waste water treatment. Otherwise the P-discharges by point sources and the total P-emissions into the Danube river system will increase.

Preliminary calculations have also shown that the replacement of phosphorus in detergents can contribute to the reduction of the P-discharges by point sources and also from urban areas. The effect of P-replacement in detergents is for point sources a 24 % reduction and for the total P-emissions a reduction of 12 % and a decrease below 60000 t/a P. The proportion of the point discharges to the total P-emissions would decrease to 30 %. But a contribution of point sources of more than 50 % would remain for Yugoslavia (Serbia and Montenegro).

For nitrogen the total emission into the Danube river system by point and diffuse sources amounts about 687.4 kt/a N in the period 1998-2000 (see Table 4.20 and 4.21). In contrast to phosphorus the contribution of point source discharges to the total nitrogen emissions into the Danube surface waters is only 20 % and varies between 6 % for the catchment of Inn and 50% for the Arges catchment. The predominant source of the N-emissions into the Danube river system is groundwater. About 47 % of N-emissions are caused by this pathway, which includes also the N-emissions from natural interflow since this pathway could not to-date be separated within the hydrological module of MONERIS. The N-emissions from paved urban areas and tile drained agricultural areas contribute to 10 % of the total N-emissions. Other sources (erosion, surface runoff and atmospheric deposition) only contribute 3 to 6 % of the total N-emissions and are of minor importance overall, although it should be noted that the contribution by these pathways can be important for individual catchments as shown in Figure 4.23.

Figure 4.16 presents the contribution of the German parts of the Danube basin to the total N-emissions which is more than 2.3 times higher compared to the contribution to the catchment area. This is due to the high N-emissions via groundwater and the highest N-surplus for agricultural areas in the German part of the Danube basin. For Slovenia the ratio between the contribution to the N-emissions and to the area is 1.7 and for Czech Republic 1.5. The reason for this high ratio for the Czech Republic is not the high nitrogen surplus, but the high proportion of tile drained agricultural areas (see chapter 4.1.5).

The mean specific N-emission into the Danube river system is about 8.6 kg/(ha·a) N. Specific N-emissions of 10 kg/(ha·a) N or more were estimated for the subcatchments of Upper Danube, Inn, Austrian Danube, Morava, Iskar, Olt and Arges as well as for the countries Germany (20.0 kg/(ha·a) N), Slovenia (14.6 kg/(ha·a) N), Czech Republic (12.7 kg/(ha·a) N) and Austria (10.0 kg/(ha·a) N) (see Figures 4.23 and 4.27). For Hungary and Moldova the specific N-emissions are lower than 5 kg/(ha·a) N due to the very low percolation rate of water and high N-retention in the unsaturated zone and in groundwater.

In comparison to other large transboundary rivers the total specific N-emissions into the Danube are the lowest. Behrendt et al. (2003a) estimated for the Rhine and the Elbe a specific N-emission of about 21.9 kg/(ha·a) N and 13.7 kg/(ha·a) N, respectively, for the same time period. For the Odra a specific N-emission of 10.6 kg/(ha·a) N was calculated for the period 1993-1997 (Behrendt et al. 2003b). This can be explained by the lower N-surplus in agriculture for most of the Danube countries as well as the lower population density and population connected to sewers and WWTP`s in the Danube catchment.

Table 4.20: Sum of all nutrient emissions into the Danube and its tributaries in the period 1998-2000

Basin	Station	Area	$ESUM_P$	$ESUM_{Pspec}$	$ESUM_N$	$ESUM_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	4087	818	96050	19.23
Inn	up.Passau-Ingling	26070	3244	1244	35300	13.54
Austrian Danube	Passau to Nussdorf	26240	2044	779	31740	12.10
Morava	Marchdorf	26650	2428	911	29310	11.00
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	2370	794	23990	8.04
Pannonian Central	Nussdorf to up.Tisza	60370	6264	1038	47620	7.89
Drava	up. Ossijek	40310	3137	778	31780	7.88
Drava	up. Mura	15330	1271	829	12540	8.18
Mura	mouth	14060	1064	757	11750	8.36
Sava	up. Belgrade	95890	9521	993	83140	8.67
Sava	up.Crna Bara	62520	6721	1075	61320	9.81
Drina	up.Crna Bara	19610	1110	566	14150	7.22
Tisa	up.Tisza	151780	9943	655	104380	6.88
Somes/Szamos	up. Oar	15370	1324	861	15240	9.92
Crisuri/Koeroes	up. Magyartes	25410	1271	500	14460	5.69
Mures/ Maros	up. Mako	28650	1896	662	23330	8.14
Banat-East.Serbia	up. Tisza to Prahovo	28940	3737	1291	24080	8.32
Velika Morava	up. Mouth	37630	3029	805	19230	5.11
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	5177	958	44390	8.21
Iskar	up. Orechovitza	8260	1487	1800	14230	17.23
Muntenia	Prahovo-Giurgiul. RO	82250	7003	851	68800	8.36
Jiu	up. Zaval	9960	772	775	8870	8.91
Olt	up. Izbiceni	24250	1570	647	24450	10.08
Arges	up. Clatesti	12580	2651	2107	17960	14.28
Ialomita	Tandarei	10290	1036	1007	7530	7.32
Prut-Siret	Giurgiul & Sendreni	73470	5119	697	41340	5.63
Prut	Giurgiulesti	28580	2311	809	15920	5.57
Siret	Sendreni	44890	2807	625	25410	5.66
Delta-Liman	Giurgiul. - Mouth	19450	683	351	6210	3.19
Danube	**Total**	802890	67783	844	687420	8.56

Table 4.21: Sum of all nutrient emissions into country parts of the Danube river basin in the period 1998-2000

Basin	Area	$ESUM_P$	$ESUM_{Pspec}$	$ESUM_N$	$ESUM_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	4759	840	112800	19.92
Austria	80850	7126	881	80600	9.97
Czech Republic	21690	2112	974	27530	12.69
Slovakia	47210	4012	850	40170	8.51
Hungary	92770	6991	754	45210	4.87
Slovenia	16410	2029	1236	23880	14.55
Bosnia-Herzegovina	34630	3297	952	32200	9.30
Croatia	37600	3454	919	25590	6.81
Yugoslavia	88490	9311	1052	55670	6.29
Romania	222330	16007	720	163530	7.36
Bulgaria	55190	5214	945	44800	8.12
Moldova	12330	827	671	4330	3.51
Ukraine	33930	2429	716	29220	8.61
other countries	2820	213	755	1920	6.81
Total	802890	67783	844	687420	8.56

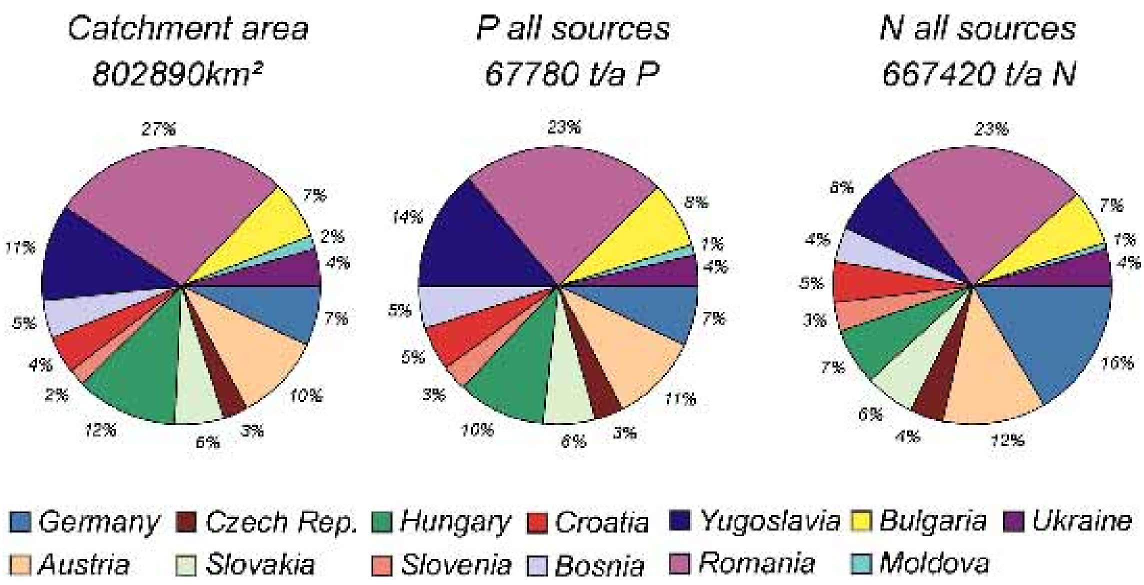
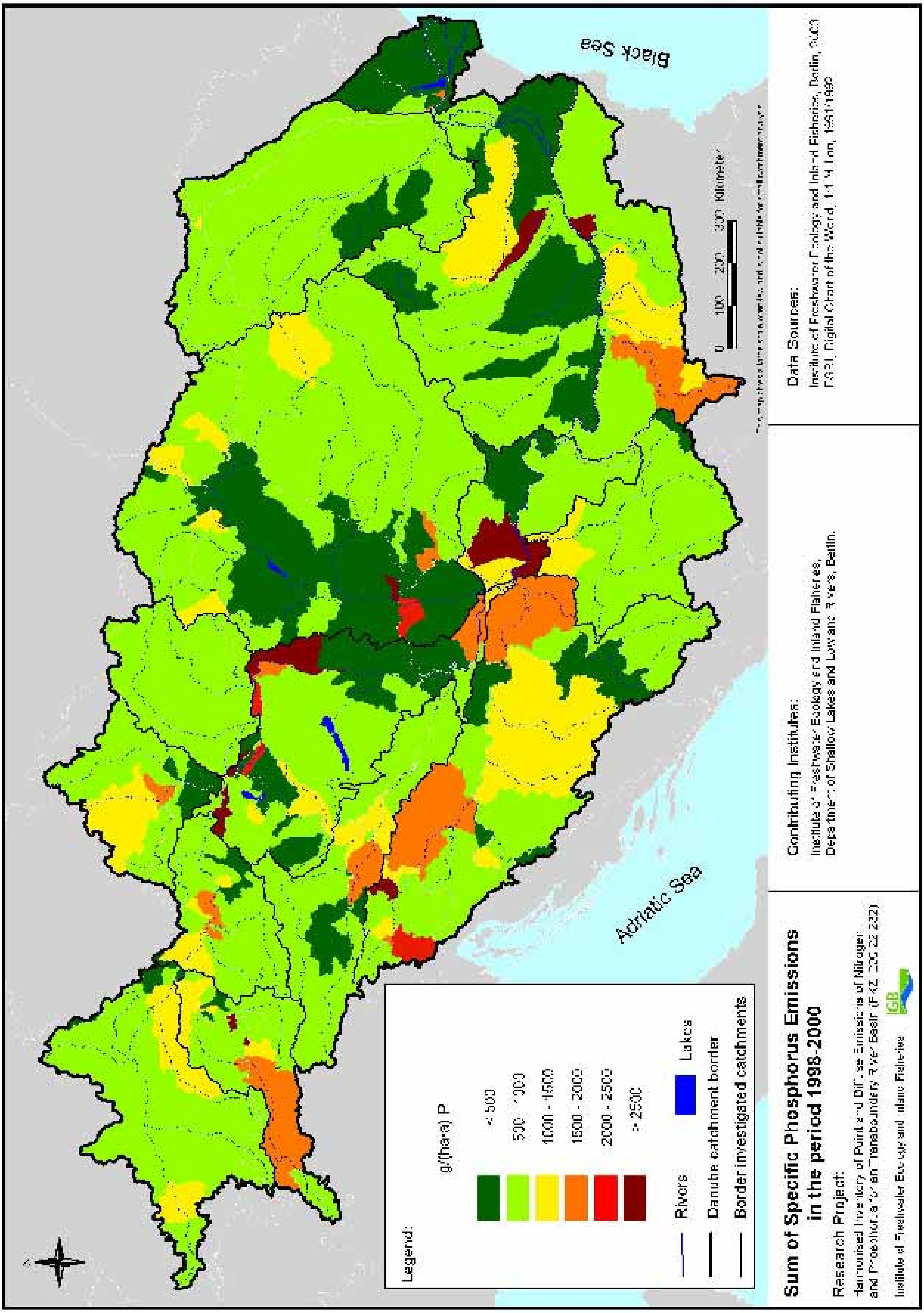
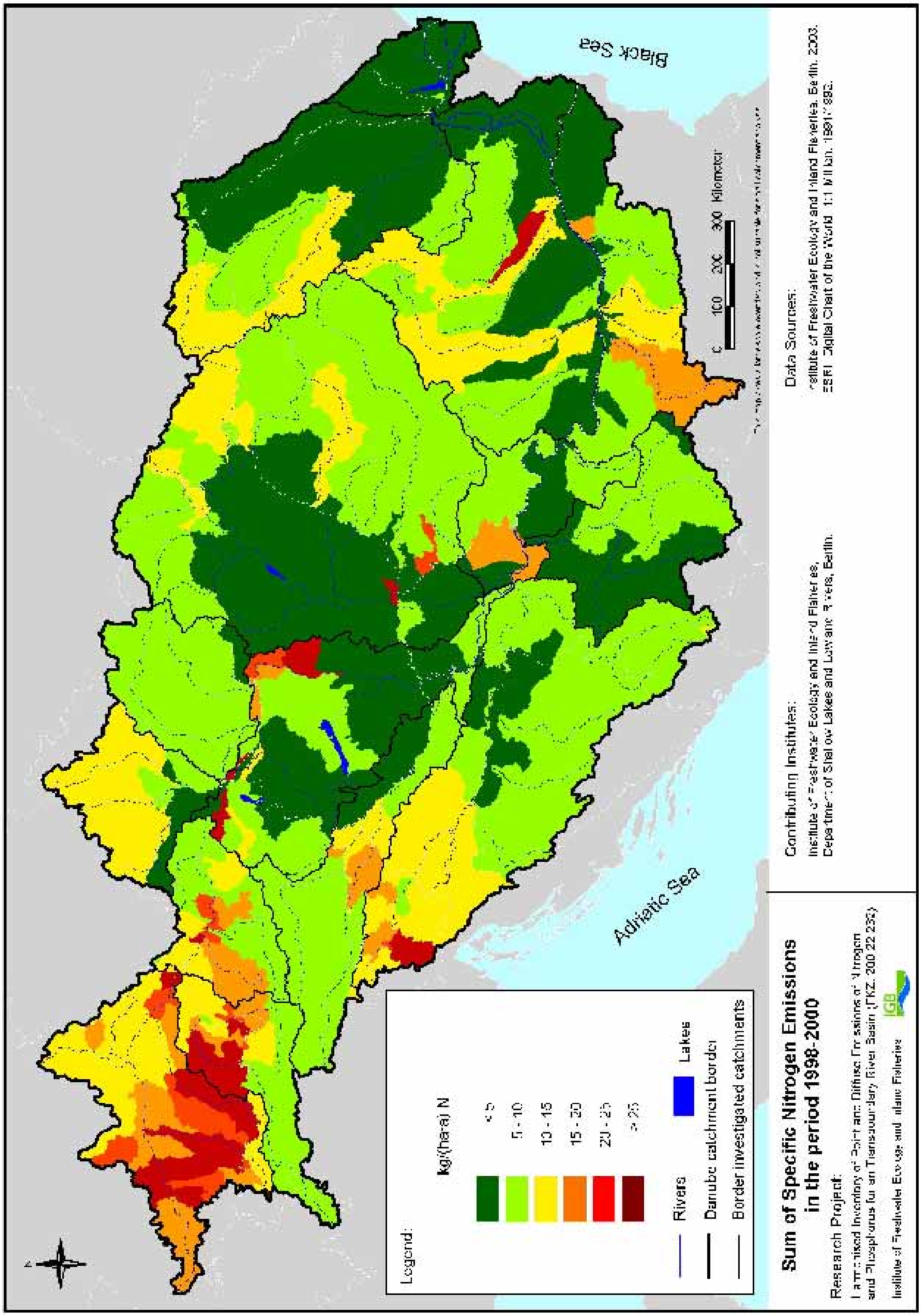


Figure 4.16: Proportion of the countries at the total catchment area of the Danube and the phosphorus and nitrogen discharges by point and diffuse pathways.



Map 4.19: Total specific phosphorus emissions in the period 1998 – 2000.



Map 4.20: Total specific nitrogen emissions in the period 1998 – 2000.

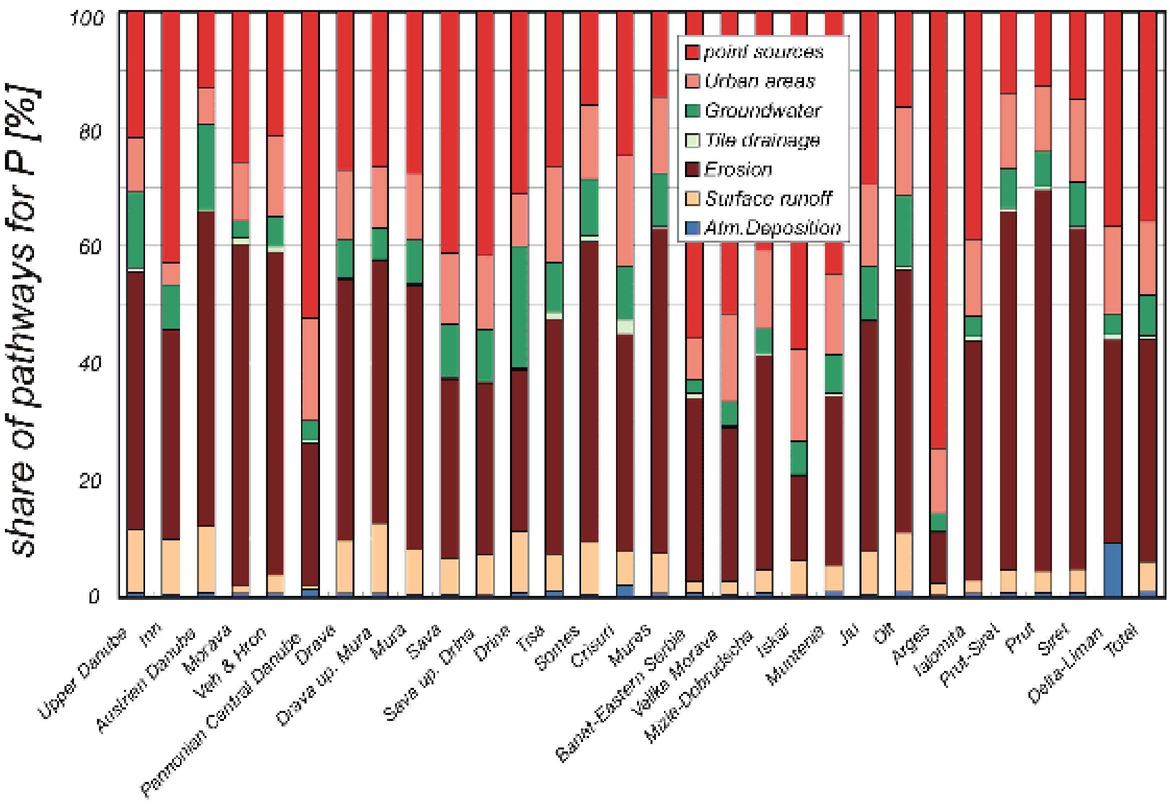


Figure 4.17: Share of the pathways of the total phosphorus emissions into the Danube subcatchments.

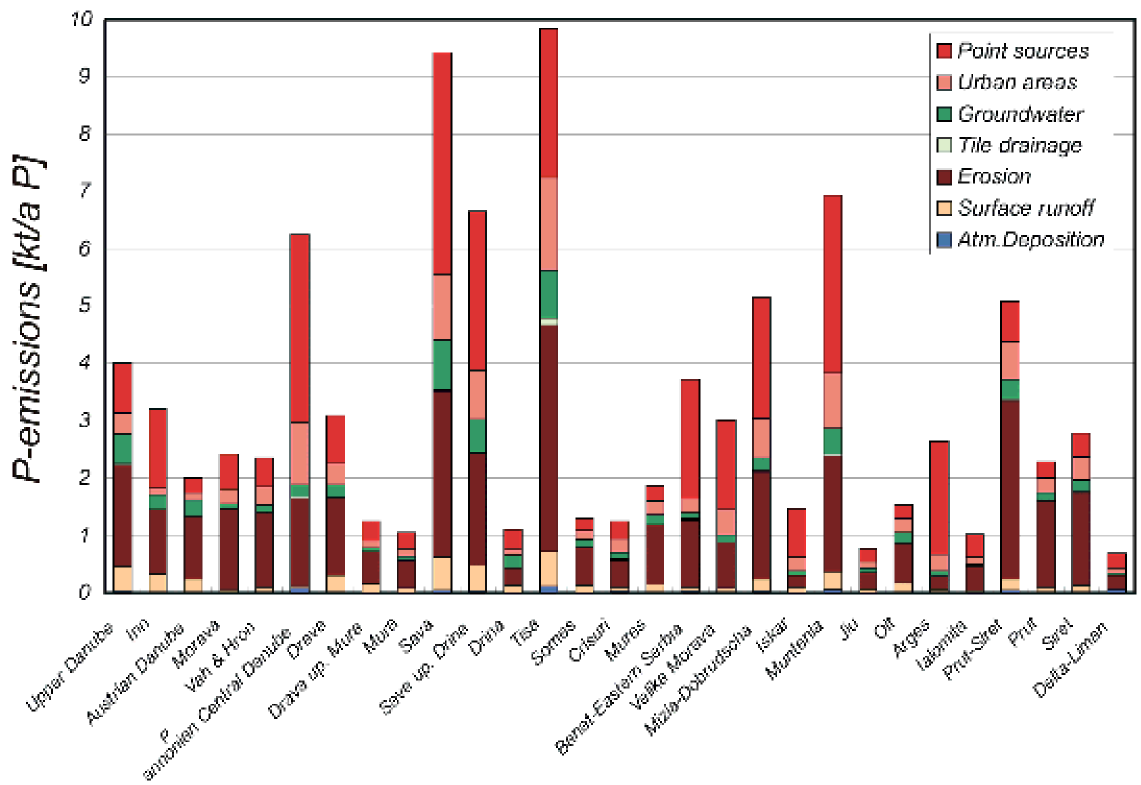


Figure 4.18: Total phosphorus emissions into the Danube subcatchments.

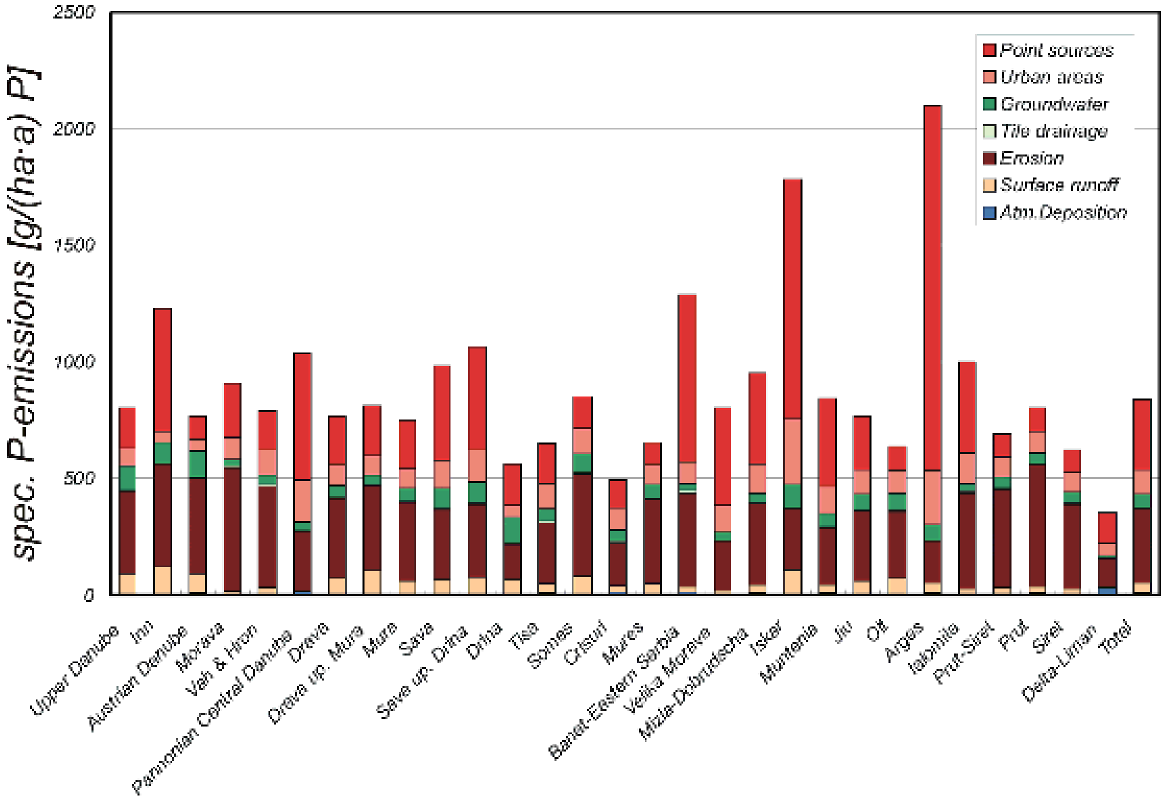


Figure 4.19: Specific total phosphorus emissions by pathways into the subcatchments of the Danube.

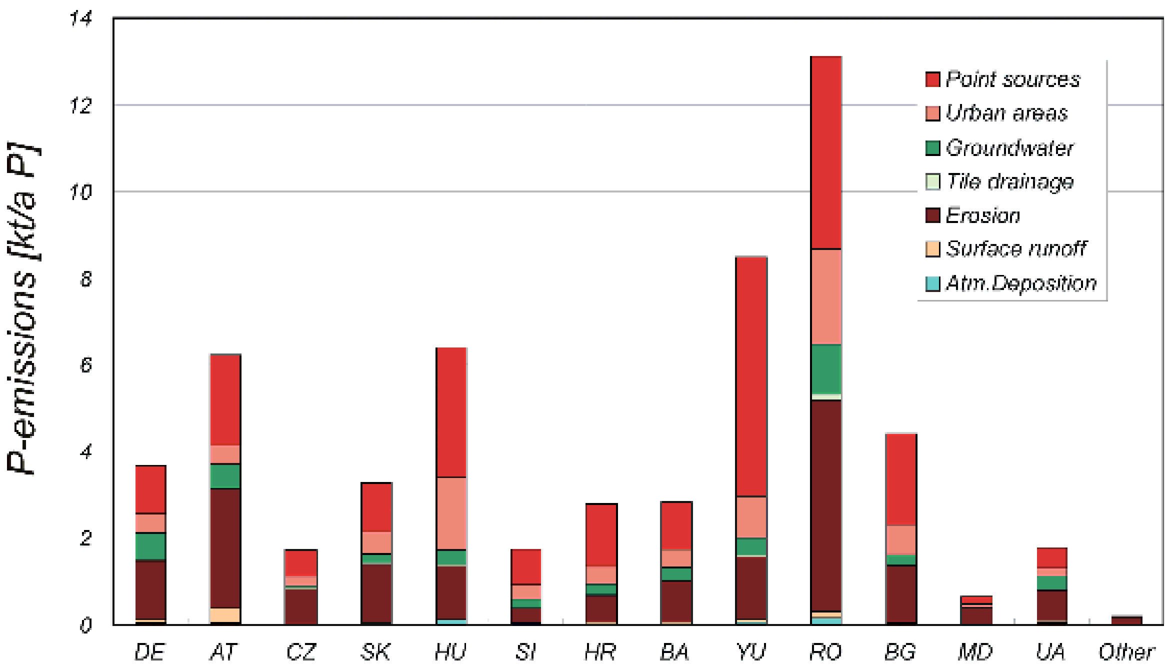


Figure 4.20: Total phosphorus emissions in the Danube river basin by countries.

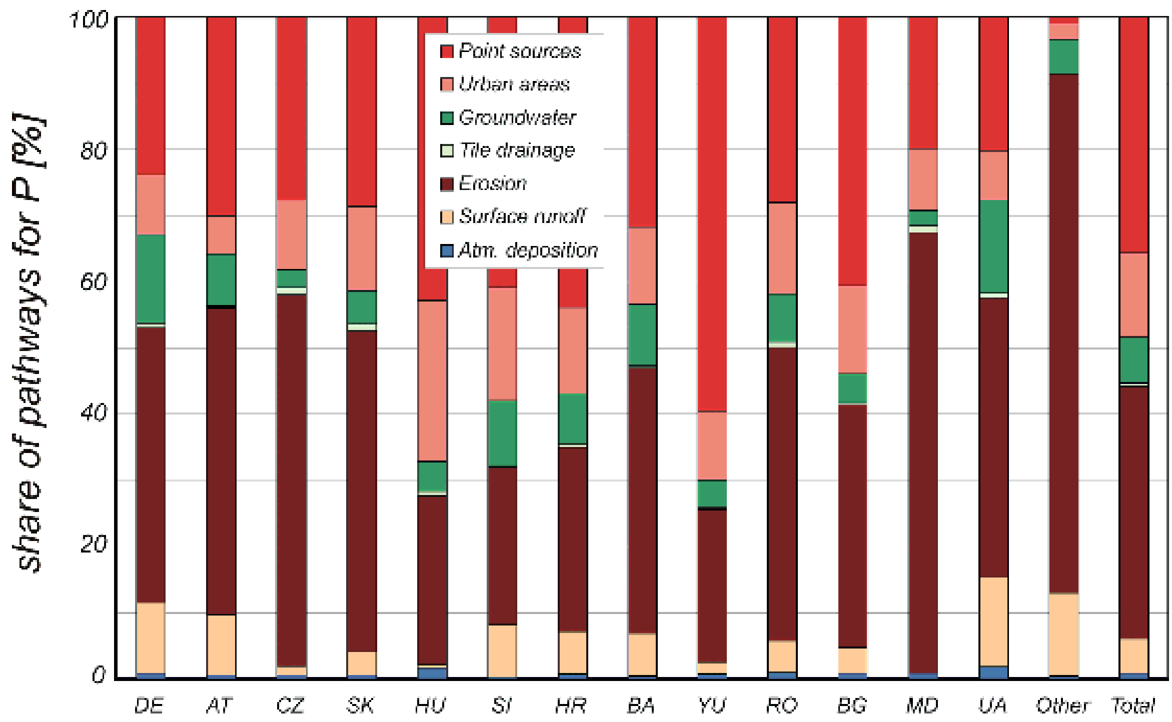


Figure 4.21: Share of pathways of the total phosphorus emissions by countries.

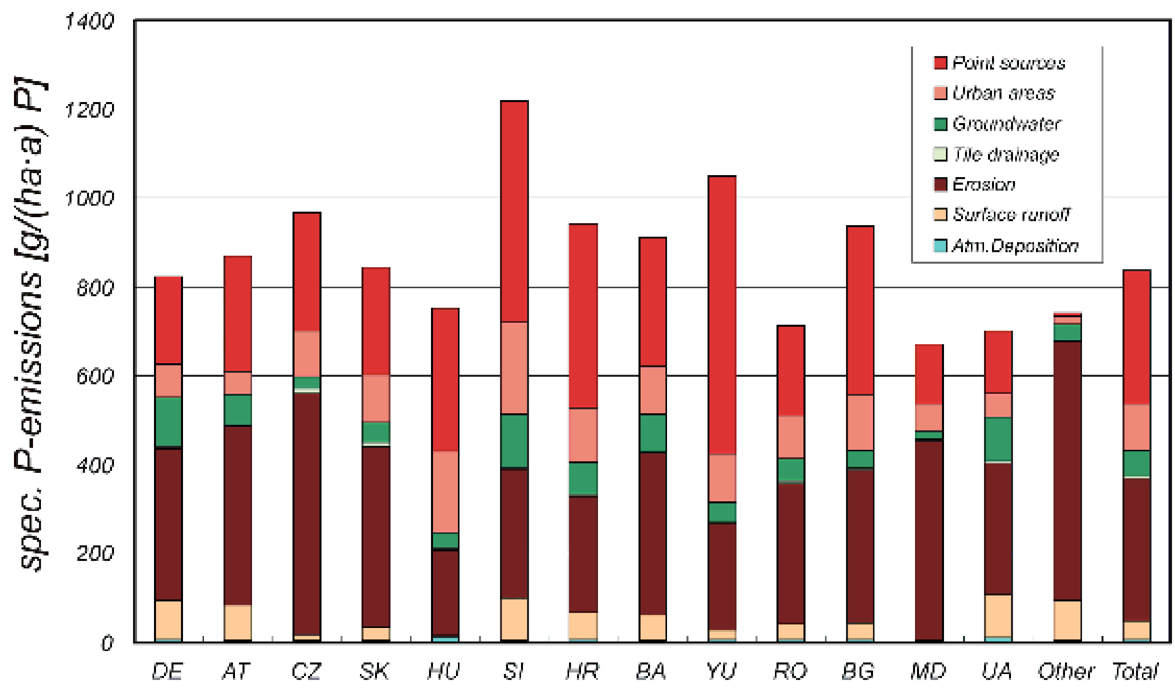


Figure 4.22: Specific total phosphorus emissions in the Danube river basin by countries.

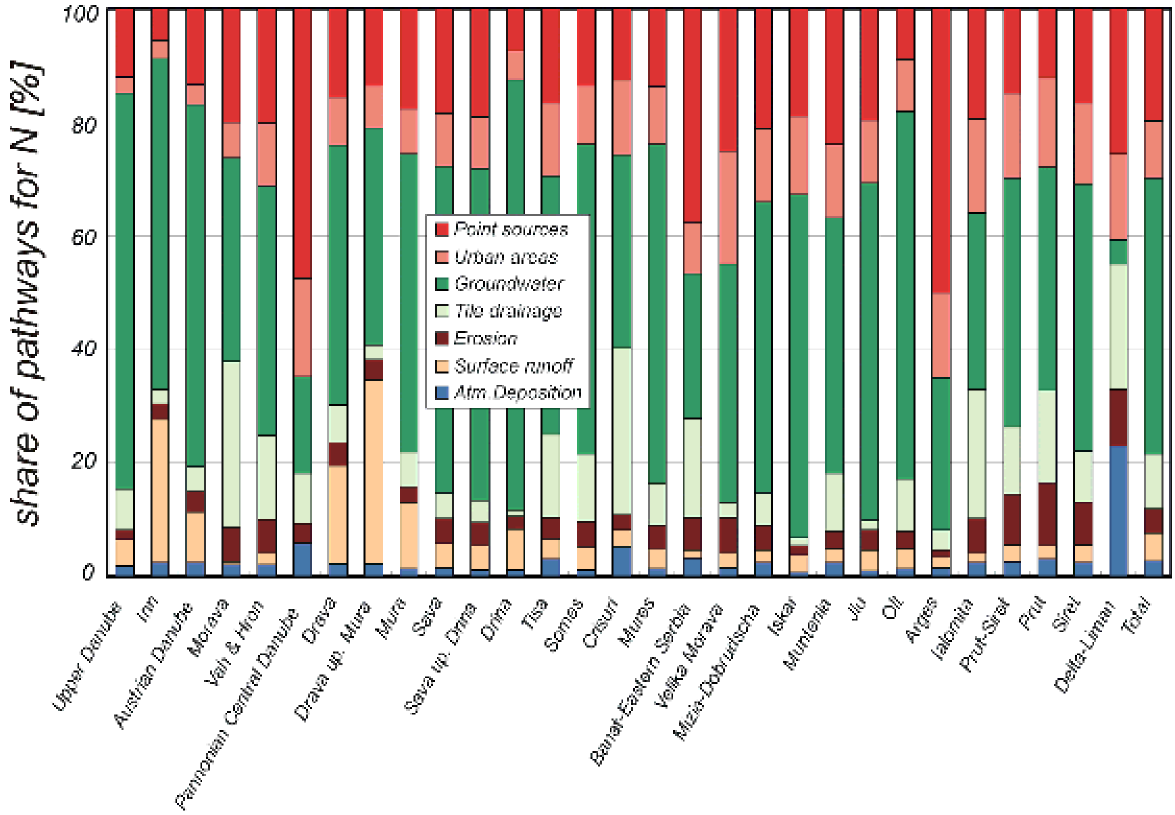


Figure 4.23: Share of the pathways of the total nitrogen emissions into the Danube

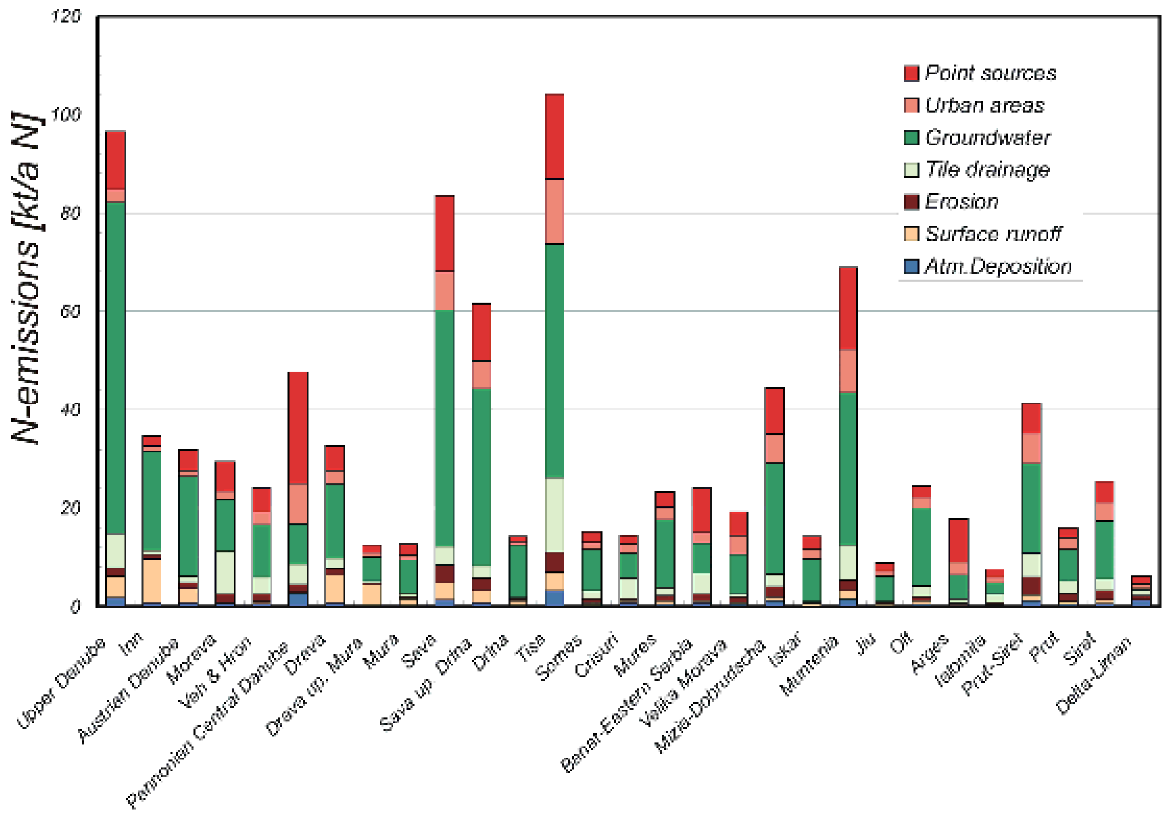


Figure 4.24: Total nitrogen emissions into the Danube subcatchments.

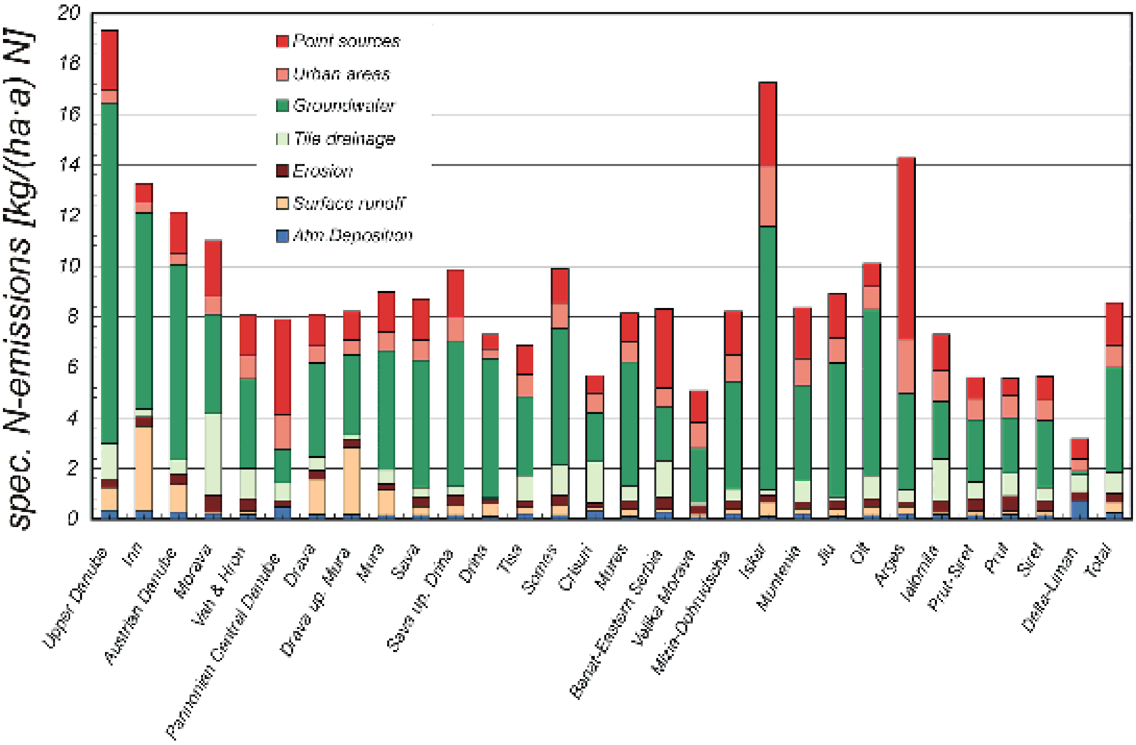


Figure 4.25: Specific total nitrogen emissions by pathways into the subcatchments of the Danube.

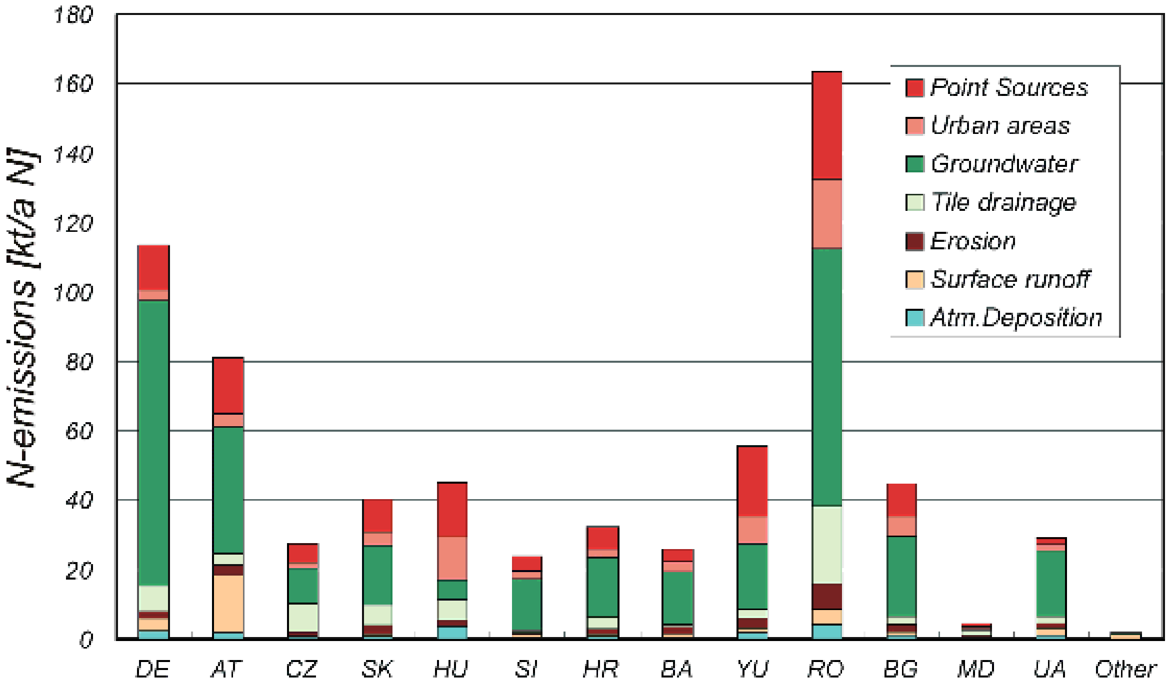


Figure 4.26: Total nitrogen emissions in the Danube river basin by countries.

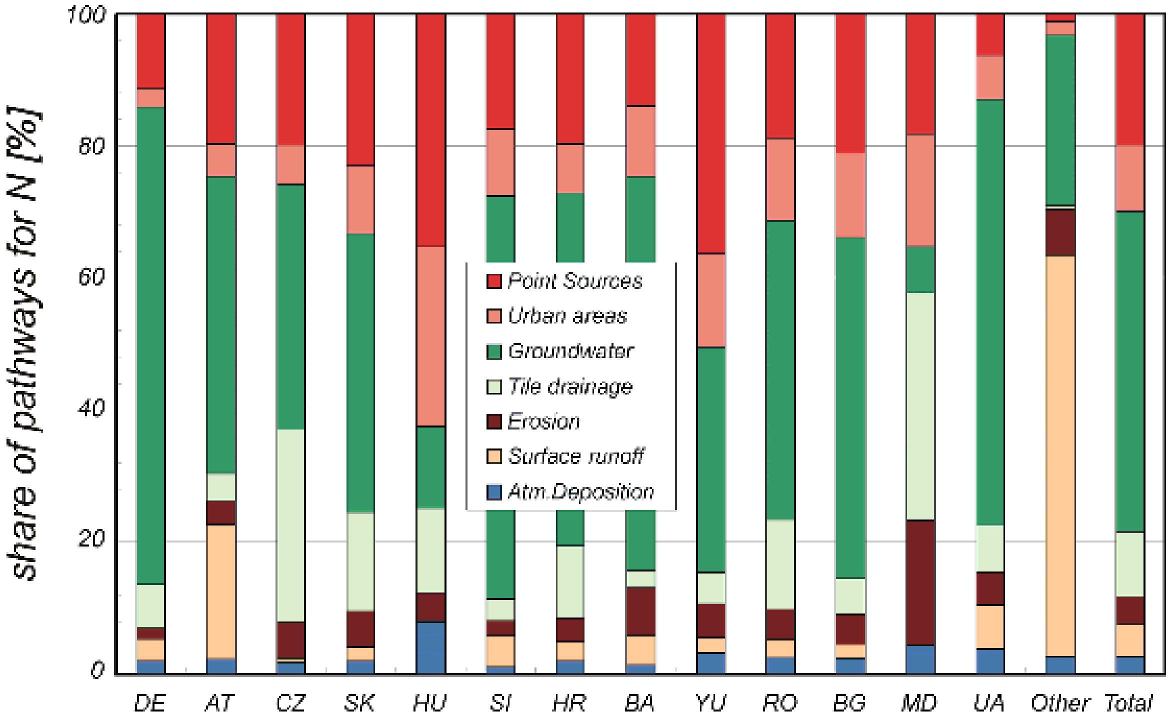


Figure 4.27: Share of pathways of the total nitrogen emissions by countries.

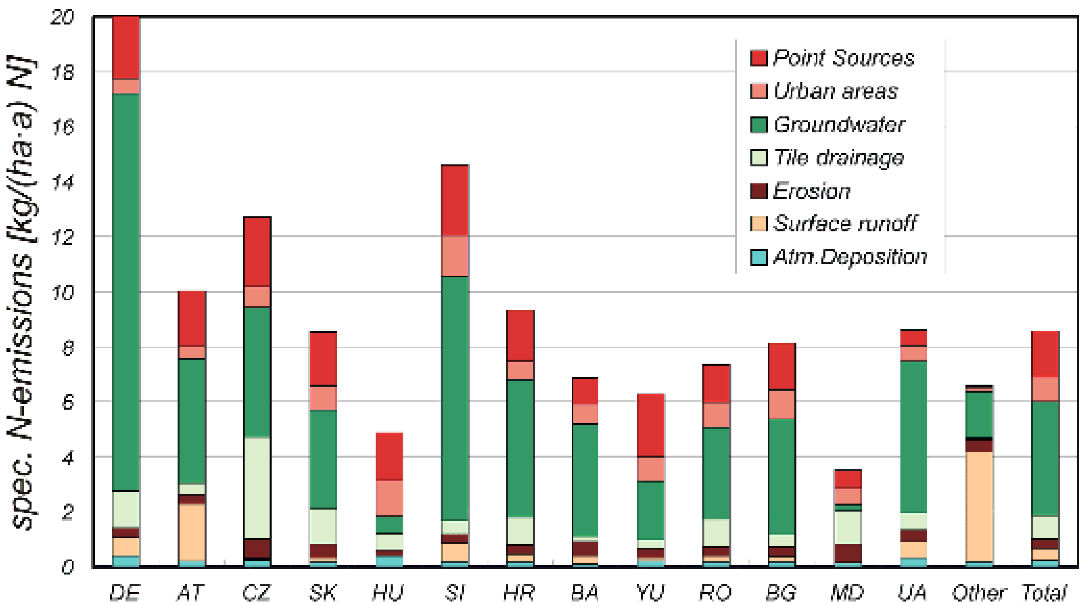


Figure 4.28: Specific total nitrogen emissions in the Danuberiver basin by countries.

If the N-surplus of agriculture in the Danube countries remains at the present level for the next 20 years (see 4.1.1) a further reduction of N-emissions of 4% to an amount of 650000 t/a N could be expected within this time period.

On the other hand, if it is assumed that the N balance of all countries within the Danube basin will tend towards the present moderate level of Austria, Slovenia and partly Czech Republic, and that a constant N-surplus for agriculture of 50 kg/(ha·a) N is maintained then an increase of the total N-emissions of about 100000 t/a N or 14 % can be expected in the next decades. This is because although there would be a substantial decrease in the agricultural N-surplus and N-emissions by groundwater and tile drained areas for Germany and Slovenia, there would be a significant increase in N-emissions by groundwater and tile drained areas for Slovakia, Hungary, Bosnia-Herzegovina, Yugoslavia (Serbia and Montenegro), Romania, Bulgaria, Ukraine and Moldova.

With regard to possible scenario calculations concerning the influence of agricultural activities on the nutrient emissions and loads in the Danube basin, it seems to be important that the levels of the nitrogen surplus should differ for the countries, because the population densities differ too.

4.4 Nutrient emissions for background conditions

For evaluation of the present state of the nutrient emissions in the Danube river system it is necessary to separate those emissions into the river system which are caused by natural conditions and those caused by human acitivities.

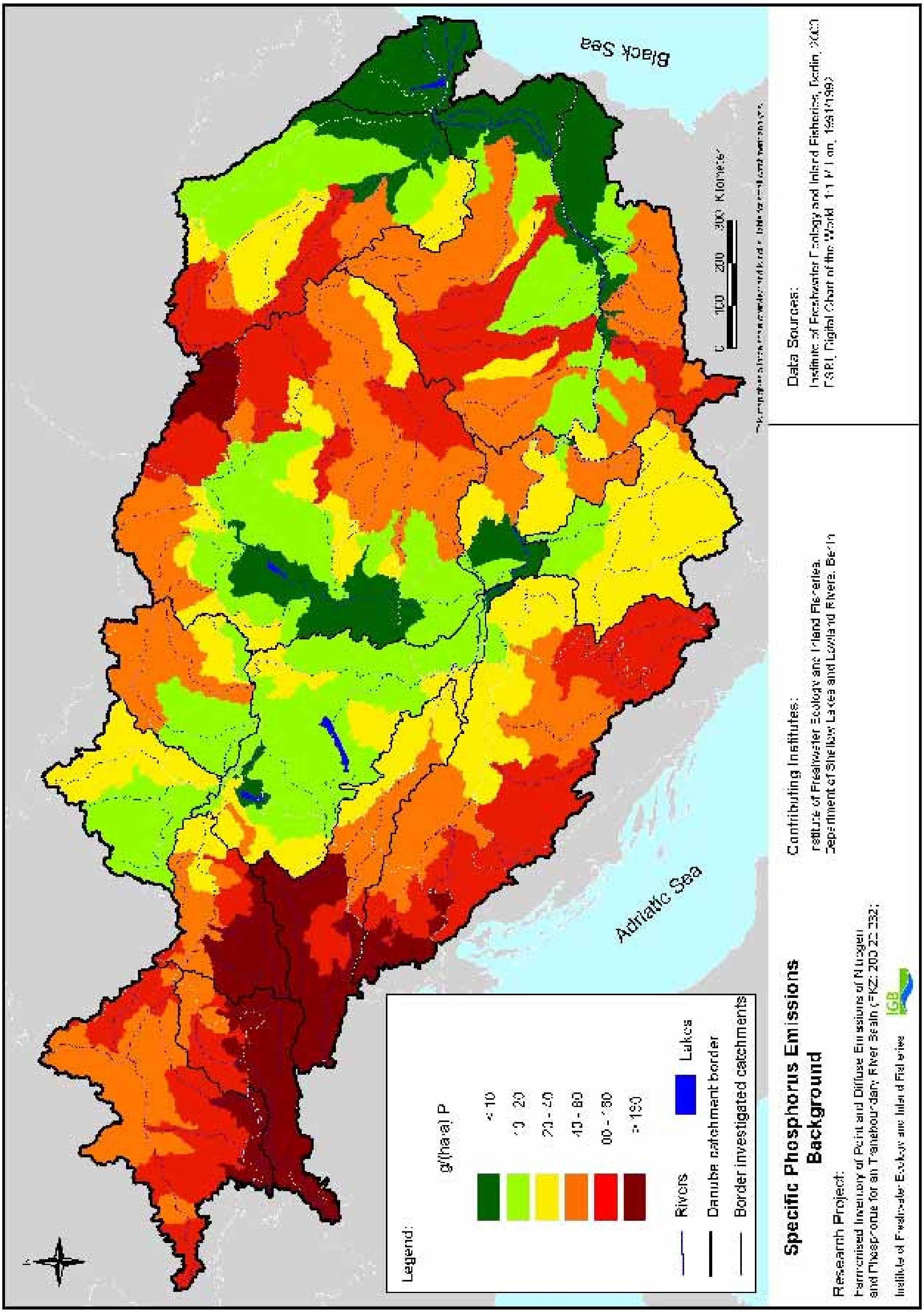
This is only possible, if the emissions for natural background conditions (i.e. the quantity of emissions independent of human influence) are estimated. Knowledge on natural background is also necessary in relation to the definition of water quality targets of the European Water Framework Directive. For this reason the MONERIS model was used to estimate the nutrient emissions for a scenario which is assumed to be near to the natural background conditions.

An attempt was made to determine realistic background emissions for the Danube basin based on the mean annual discharge conditions for 1998-2000 and the following defined conditions:

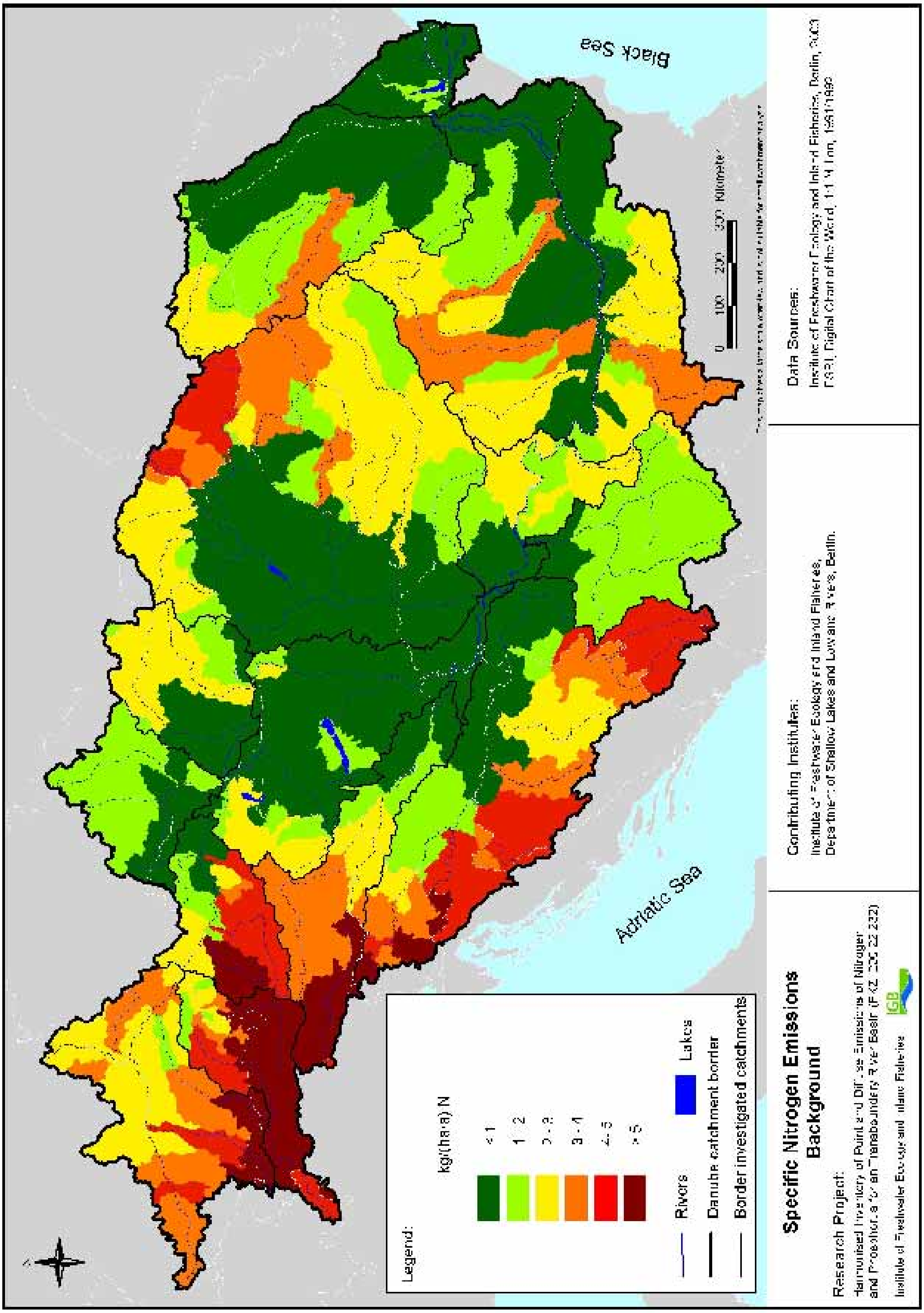
- Nutrient inputs from point sources and urban areas are non-existent. The same applies to inputs from drainage.
- Areas which are agricultural or urban today are considered as woodland.
- With the exception of areas subject to natural erosion (alpine and foothills) soil input through erosion is ignored.
- A nitrogen deposition under background conditions of around 5 kg /(ha·a) N is assumed which is constant for all regions.
- The P-concentrations in groundwater of all wetlands is the same.
- The ratio of total to dissolved phosphorus concentrations under anaerobic ground-water conditions is 1.5 instead of 2.5.

Table 4.22: Nutrient emissions for background conditions into the Danube and its tributaries.

Basin	Station	Area	$EBACK_P$	$EBACK_{Pspec}$	$EBACK_N$	$EBACK_{Nspec.}$
		[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Upper Danube	up.Passau	49940	580	116	17600	3.5
Inn	up.Passau-Ingling	26070	940	361	13310	5.1
Austrian Danube	Passau to Nussdorf	26240	370	141	8500	3.2
Morava	Marchdorf	26650	60	23	3320	1.2
Vah & Hron & Ipel	Kom. & Kam. & Salka	29840	140	47	5020	1.7
Pannonian Central	Nussdorf to up.Tisza	60370	110	18	5020	0.8
Drava	up. Ossijek	40310	650	161	12040	3.0
Drava	up. Mura	15330	400	261	6410	4.2
Mura	Mouth	14060	200	142	4330	3.1
Sava	up. Belgrade	95890	940	98	28310	3.0
Sava	up.Crna Bara	62520	640	102	19710	3.2
Drina	up.Crna Bara	19610	260	133	7840	4.0
Tisa	up.Tisza	151780	800	53	25880	1.7
Somes/Szamos	up. Oar	15370	130	85	4270	2.8
Crisuri/Koeroes	up. Magyartes	25410	100	39	3370	1.3
Mures/ Maros	up. Mako	28650	210	73	6540	2.3
Banat-East.Serbia	up. Tisza to Prahovo	28940	100	35	4480	1.5
Velika Morava	up. Mouth	37630	130	35	5860	1.6
Mizia-Dobrudscha	Prahovo-Giurgiul. B	54060	230	43	9590	1.8
Iskar	up. Orechovitza	8260	100	121	3190	3.9
Muntenia	Prahovo-Giurgiul. RO	82250	480	58	15030	1.8
Jiu	up. Zaval	9960	80	80	2740	2.8
Olt	up. Izbiceni	24250	220	91	6630	2.7
Arges	up. Clatesti	12580	100	79	2510	2.0
Ialomita	Tandarei	10290	40	39	1160	1.1
Prut-Siret	Giurgiul & Sendreni	73470	300	41	8530	1.2
Prut	Giurgiulesti	28580	90	31	2880	1.0
Siret	Sendreni	44890	200	45	5650	1.3
Delta-Liman	Giurgiul. - Mouth	19450	10	5	940	0.5
Danube	**Total**	802890	5848	73	163430	2.0



Map 4.21: Specific phosphorus emissions in the subcatchments of the Danube for background conditions



Map 4.22: Specific nitrogen emissions in the subcatchments of the Danube for background conditions

Based on these preconditions, it was possible to calculate the nutrient emissions for background conditions for the individual catchments of the Danube. The results are presented in Tables 4.22 and 4.23, as well as in Figure 4.29.

It was found that the nutrient emissions for background conditions into the Danube river sytem would be about 5850 t/a P and 163630 t/a N. This corresponds to specific background emissions of about 73 g/(ha·a) P for phosphorus and 2 kg/(ha·a) N for nitrogen.

The specific P-emissions for background conditions varies between 5 g/(ha·a) P (Delta Liman) and around 361 g/(ha·a) P (Inn). The same subcatchments represent the minimum and the maximum of the nitrogen emissions for background conditions (0.5 and 5.1 kg/(ha·a) N).

Table 4.20 shows the estimated nutrient emissions for the country parts within the Danube basin. It is obvious, that the countries with a high portion of area in the Alps and other high mountainous regions have the highest background emissions due to the assumed occurrence of natural erosion and high precipitation as well as discharges.

Table 4.23: Nutrient emissions for background conditions into country parts of the Danube river basin.

Basin	Area	$EBACK_P$	$EBACK_{Pspec}$	$EBACK_N$	$EBACK_{Nspec.}$
	[km²]	[t/a P]	[g/ha·a P]	[t/a N]	[kg/ha·a N]
Germany	56630	580	102	19430	3.4
Austria	80850	1738	215	30110	3.7
Czech Republic	21690	57	26	3190	1.5
Slovakia	47210	215	46	8660	1.8
Hungary	92770	151	16	4080	0.4
Slovenia	16410	226	138	6340	3.9
Bosnia-Herzegovina	34630	236	68	7620	2.2
Croatia	37600	351	93	10960	2.9
Yugoslavia	88490	387	44	14330	1.6
Romania	222330	1190	54	37480	1.7
Bulgaria	55190	233	42	9840	1.8
Moldova	12330	11	9	250	0.2
Ukraine	33930	308	91	9750	2.9
other countries	2820	165	585	1380	4.9
Total	802890	5848	73	163430	2.0

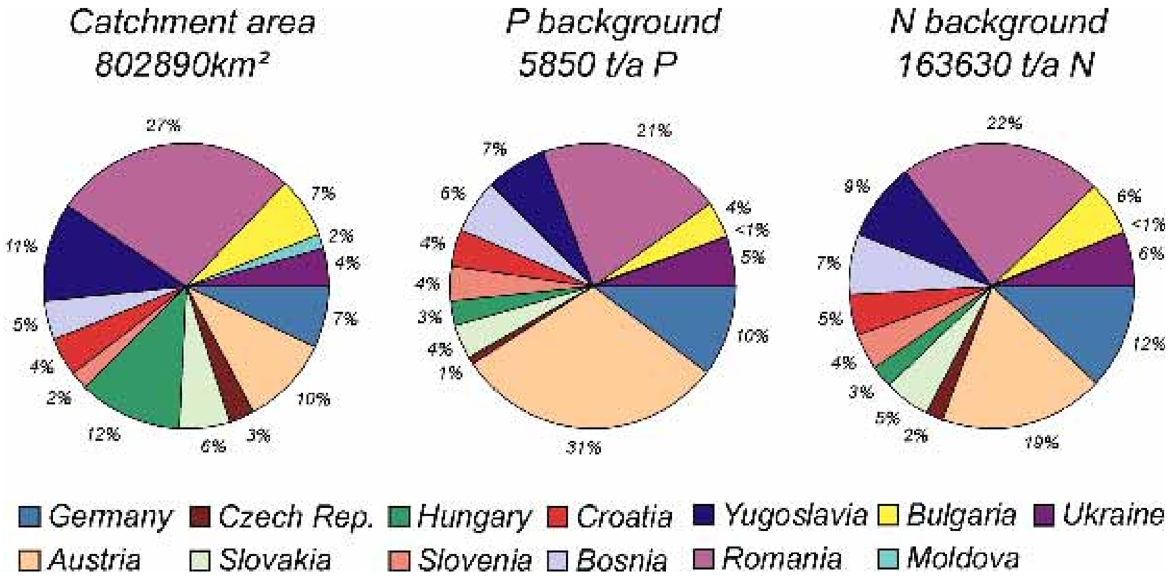


Figure 4.29: Portion of the countries at the total catchment area of the Danube and the phosphorus and nitrogen emisions for background conditions.

4.5 Nutrient emissions by agricultural activities

Based on the calculation of the nutrient emissions for the diffuse pathways and for background conditions it is possible to calculate the proportion of emissions that are related to agricultural activities. For this purpose it was assumed that the emissions caused by agricultural activities are the difference between the sum of emissions from surface runoff, erosion, groundwater and tile drained areas on the one hand and the total emissions for background conditions on the other hand. For nitrogen it was additionally assumed that the atmospheric deposition of ammonium is due to agricultural activities.

The results of the estimation of the nutrient emissions by agricultural activities into the river system of the Danube is a mean value of 28.8 kt/a P and 310 kt/a N emitted into the the river system of the catchment (see Table 4.24 and 4.25). The specific emissions are 359 g/(ha·a) P and 3.9 kg/(ha·a) N for the whole Danube basin. The highest specific agricultural nutrient emissions were found for the Morava and the Prut (559 and 578 g/(ha·a) P) and the Upper Danube (12.7 kg/(ha·a) N). For the Delta-Liman the lowest amount of agricultural emissions was estimated for phosphorus as well as for nitrogen (133 g/(ha·a) P; 1.1 kg/(ha·a) N).

If these values are compared with the background emissions (Table 4.22 and 4.23) the agricultural impact can be calculated. The agricultural impact is defined as the ratio between the nutrient emissions by agricultural activities and the background emissions expressed in percent. For the whole catchment it was found that the agricultural impact is about 490 % for phosphorus and about 190 % for nitrogen (Table 4.24 and 4.25). That means the nutrient emissions due to agricultural activities are about 5 or 2 times higher than the background level. As shown in Maps 4.23 and 4.24, the degree of the agricultural impacts varies widely -

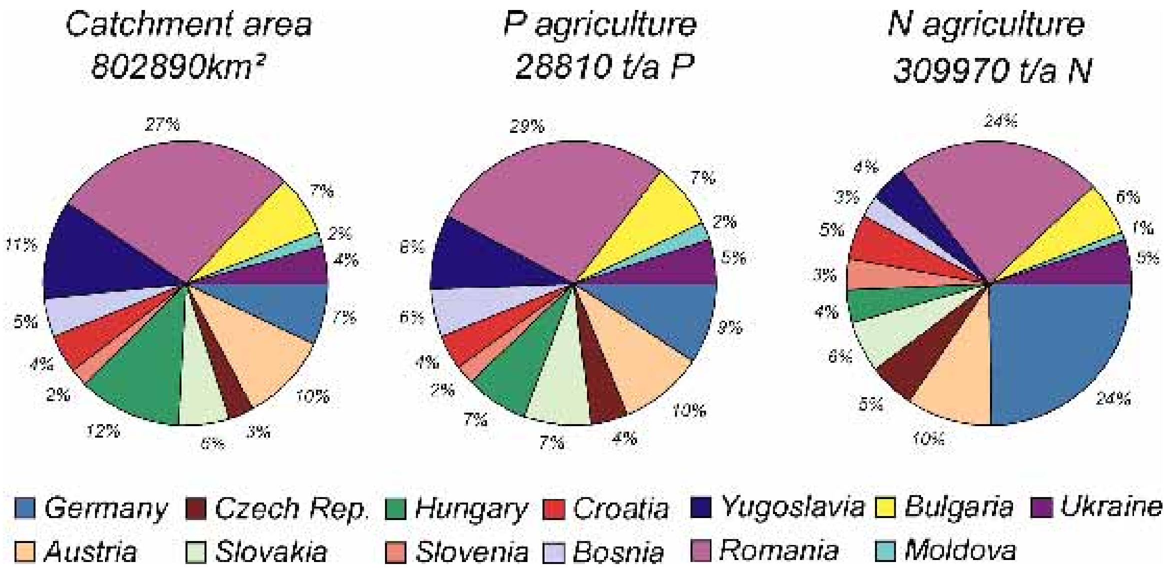


Figure 4.30: Portion of the countries at the total catchment area of the Danube and the phosphorus and nitrogen emissions caused by agricultural activities.

for phosphorus 80 - 2600 % and for nitrogen 50 - 540 %. A relationship does not exist between the degree of agricultural impacts and the absolute amount of nutrient inputs caused by agricultural activities. For example, Delta-Liman is the subcatchment with the lowest phophorus emissions from agriculture, but also with the highest agricultural impact. This behaviour is caused by the different hydrological conditions. For nitrogen the subcatchment with the highest agricultural impact is the Morava, which is mainly due to the highest proportion of tile drained agricultural area within the whole basin of the Danube.

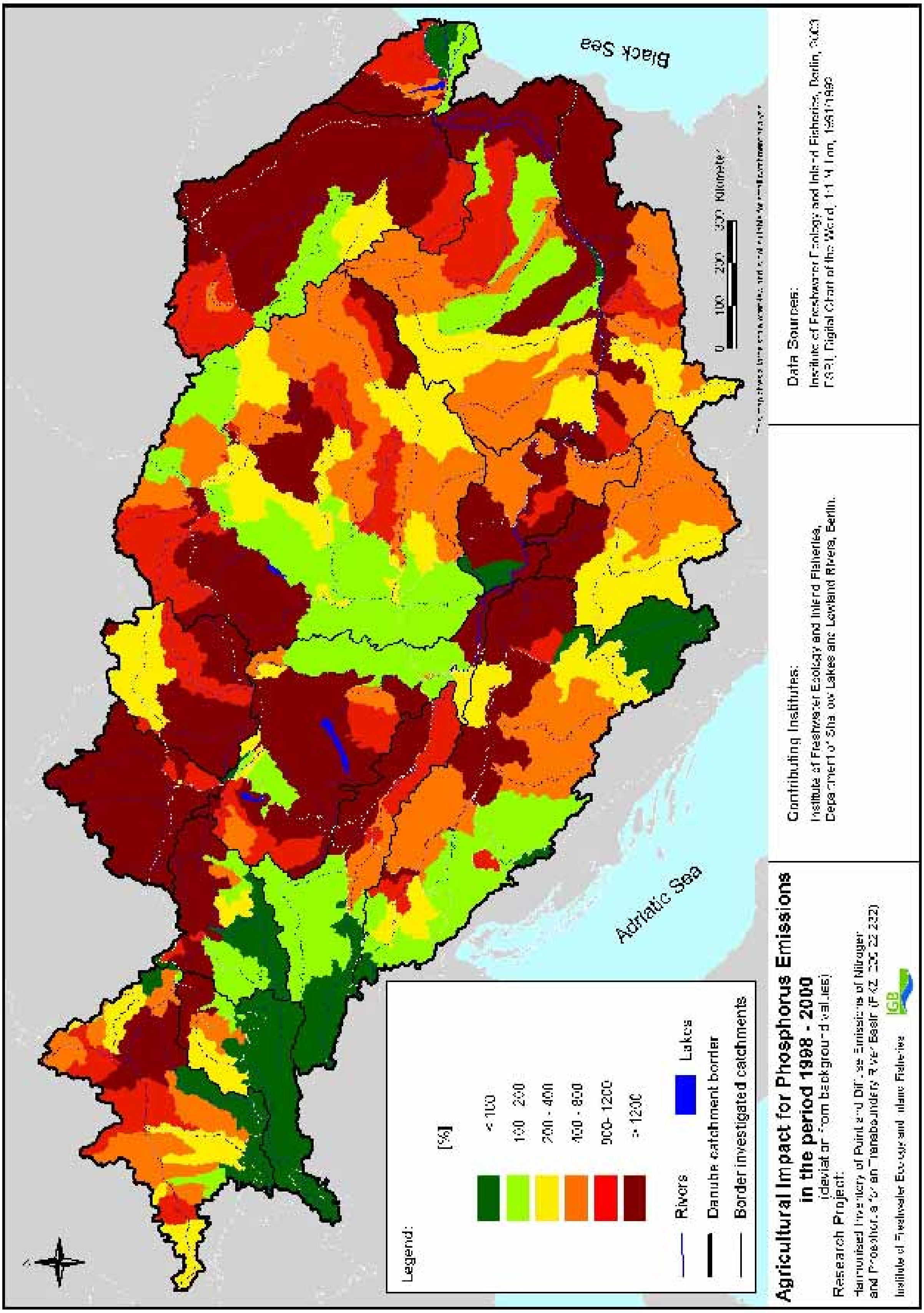
For the Danube countries it was found that the highest agricultural impacts occur for both nutrients in Moldova followed by the Czech Republic and Slovakia for phosphorus and the Czech Republic and Germany for nitrogen. The high agricultural impact of nitrogen for Moldova and Hungary is due to the very low background levels, where relative low additional emissions causes a high deviation from these background conditions.

For the Czech Republic the reason is the combination of moderate nutrient surplus with high portion of tile drained areas and for Germany (only N) alone the high nitrogen surplus. The analysis of the situation regarding the agricultural impact shows clearly that the intensity of the agricultural land use, indicated by the nutrient surplus is important, but only one factor. Other factors are the water management in agriculture and the background situation itself. Further, it can be concluded that measures for reduction of agricultural emissions of nutrients have not only to be implemented in countries with high rates, but also in such countries where the agricultural impact is high.

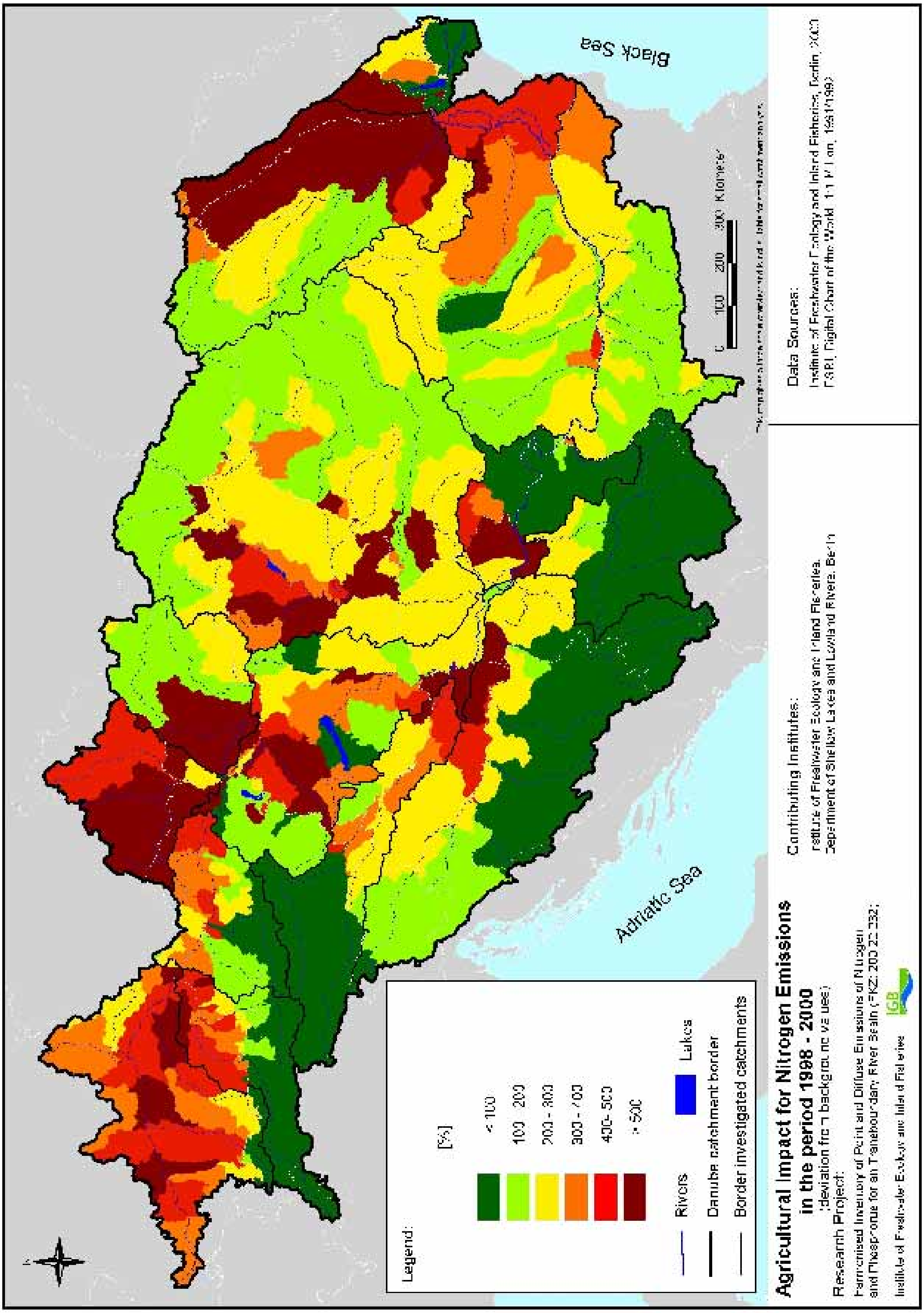
The existing uncertainties especially in relation to the estimation of the background emissions have to be taken into account too. For this reason the results for the agricultural impacts should be used only as a raw estimate.

Table 4.24: Nutrient emissions caused by agricultural activities into the Danube and its tributaries in the period 1998-2000

Basin	Area	EAG_P	EAG_{PSPEZ}	EAG_{PIMP}	EAG_N	EAG_{NSPEZ}	EAG_{NIMP}
	[km²]	[t/a P]	[g/(ha·a) P]	[%]	[t/a N]	[kg/(ha·a) N]	[%]
Upper Danube	49940	2239	448	386	63270	12.7	359
Inn	26070	794	305	84	18600	7.1	140
Austrian Danube	26240	1274	486	344	17490	6.7	206
Morava	26650	1490	559	2483	18010	6.8	542
Vah & Hron & Ipel	29840	1393	467	995	11260	3.8	224
Pannonian Danube	60370	1702	282	1547	10520	1.7	210
Drava	40310	1260	313	194	11550	2.9	96
Drava	15330	404	264	101	3370	2.2	53
Mura	14060	448	319	224	4090	2.9	94
Sava	95890	3509	366	373	31060	3.2	110
Sava	62520	2439	390	381	23890	3.8	121
Drina	19610	401	204	154	4430	2.3	57
Tisa	151780	4817	317	602	46410	3.1	179
Somes/Szamos	15370	814	530	626	7240	4.7	170
Crisuri/Koeroes	25410	599	236	599	7040	2.8	209
Mures/ Maros	28650	1156	403	550	11070	3.9	169
Banat-East.Serbia	28940	1271	439	1271	8020	2.8	179
Velika Morava	37630	880	234	677	4590	1.2	78
Mizia-Dobrudscha	54060	2123	393	923	19040	3.5	199
Iskar	8260	303	367	303	6320	7.7	198
Muntenia	82250	2388	290	498	27940	3.4	186
Jiu	9960	357	358	446	3360	3.4	123
Olt	24250	851	351	387	13250	5.5	200
Arges	12580	278	221	278	3660	2.9	146
Ialomita	10290	454	441	1135	3590	3.5	309
Prut-Siret	73470	3417	465	1139	20040	2.7	235
Prut	28580	1652	578	1836	8360	2.9	290
Siret	44890	1775	395	888	11660	2.6	206
Delta-Liman	19450	258	133	2580	2130	1.1	227
Danube	802890	28805	359	493	309970	3.9	190



Map 4.23: Agricultural impacts for the phosphorus emissions in the subcatchments of the Danube



Map 4.24: Agricultural impacts for the nitrogen emissions in the subcatchments of the Danube

Table 4.25: Nutrient emissions caused by agricultural activities into country parts of the Danube river basin in the period 1998-2000

Basin	Area	EAG_P	EAG_{PSPEZ}	EAG_{PIMP}	EAG_N	EAG_{NSPEZ}	EAG_{NIMP}
	[km²]	[t/a P]	[g/(ha·a) P]	[%]	[t/a N]	[kg/(ha·a) N]	[%]
Germany	56630	2606	460	449	76430	13.5	393
Austria	80850	2825	349	163	29810	3.7	99
Czech Republic	21690	1240	572	2175	16960	7.8	532
Slovakia	47210	2129	451	990	17780	3.8	205
Hungary	92770	2036	219	1348	11380	1.2	279
Slovenia	16410	638	389	282	10800	6.6	170
Bosnia-Herzegovina	34630	1186	342	503	15540	4.5	204
Croatia	37600	1600	426	456	8110	2.2	74
Yugoslavia	88490	2364	267	611	12490	1.4	87
Romania	222330	8003	360	673	73240	3.3	195
Bulgaria	55190	2150	390	923	19320	3.5	196
Moldova	12330	567	460	5155	2470	2.0	988
Ukraine	33930	1420	419	461	15210	4.5	156
other countries	2820	40	142	24	460	1.6	33
Total	802890	28805	359	493	309970	3.9	190

4.6 Comparison with other results

A comparison of the results of this study with other analysis for the whole Danube and for the same time period is not possible. Estimations of the nutrient emissions into the Danube were published within the PHARE-study (EU/AR102A91, 1997) and the HASKONING-study (Haskoning, 1994). Based on more recent results, Zessner & van Gils (2002) revised the emission situation estimated by EU/AR102A91 (1997) for 1992 and enlarged the time period for the nutrient emissions in the Danube for the situation around 1988 and 1996/1997. For the purpose of comparison, it has to be taken into account that all earlier studies were done for a different time period (1992) and do not cover the whole area of the Danube basin. The HASKONING study does not include Bosnia-Herzegovina and Yugoslavia (Serbia and Montenegro) and the PHARE-study additional does not consider the nutrient emissions from Croatia. Zessner & van Gils (2002) tried to compensate this by considering a correction factor of 1.25 for the calculation of the total nutrient emissions for the the years 1988 and 1992. For the period 1996-1997 these authors also made the first attempt to calculate the emissions for these three countries. According to the results within the present study (see chapter 4.3) the contribution of these countries to the total nutrient emissions into the river system of the Danube is 12 % for nitrogen and 20 % for phosphorus (Bosnia-Herzegovina and Yugoslavia (Serbia and Montenegro) and 4 % (N) and 5 % (P), respectively, for Croatia. If the contributing area and the population are taken into account the portion of these three countries to the whole catchment and population of Danube is 20 % and 18.6 %. Consequentely the correction factor of 1.25 used by Zessner & van Gils (2002) to estimate the total nutrient emissions for the Danube basin would be too large especially for nitrogen.

The methods used for the estimation of the nutrient emissions are also different. All earlier studies were done only on a country level and without results for the different hydrological pathways. The analysis of the diffuse nutrient emissions was focused on the emissions from different land uses and to a great extent based upon generalised loss rates from observations and literature data. One of the most significant differences is that the earlier studies take into account nutrient emissions from agricultural point sources. This source of emissions was not considered in the present study because the estimation of point source losses is too dependent upon assumptions that cannot be validated with real measurements. For the following comparison the agricultural point sources were added to the other diffuse emissions for a better comparability.

Figure 4.31 shows the total nutrient emissions and the contribution of diffuse and point sources estimated within the three studies.

For the total nitrogen emissions the difference between the present results and the former studies is low. If the possible contributions of the neglected countries are taken into account for the PHARE and the HASKONING-study the total N-emissions are 41 % (PHARE) and 11 % (HASKONING), respectively, higher. Both studies quantified a higher contribution of point sources for the year 1992 compared with the results for the time period 1998-2000. The

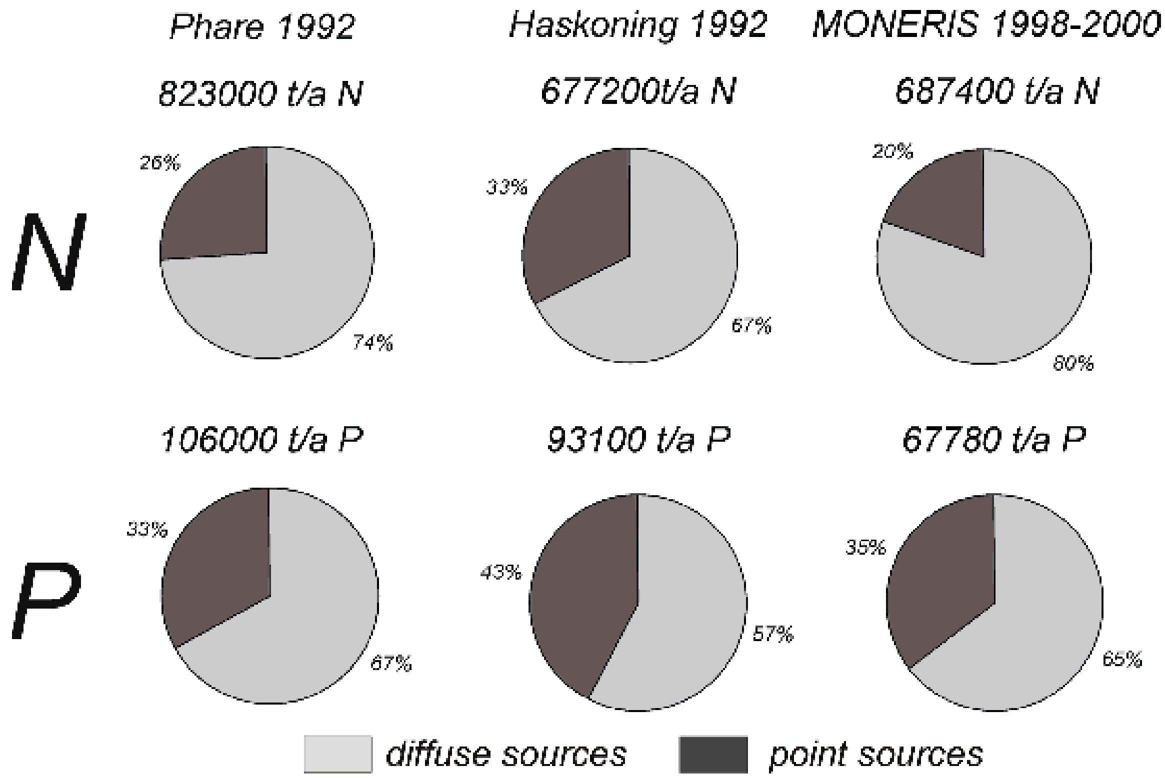


Figure 4.31: Comparison of the portion of point and diffuse nutrient emissions in the Danube.

amount of the point source emissions of nitrogen is for both studies about 220 kt/a N. This is approximately 60 % above the point source emissions for 1998-2000 (137 kt/a N). In contrast to this the diffuse N-emissions estimated for the time period 1998-2000 were 554 kt/a N and within the range of the findings of the earlier studies (PHARE: 605 kt/a N; HASKONING: 455 kt/a N). Beside the fact that an interpretation of the estimated differences for the time periods at the begin and at the end of the last century is not allowed due to the different methods, some general conclusions seem to be possible. Firstly, it can be concluded that the change in diffuse nitrogen emissions in the last decade was probably low. Secondly, the possible larger reduction of the point source emissions of nitrogen could be explained by lower discharges from direct and indirect industrial sources for the transition countries within the Danube basin. In particular, the reduced discharges from indirect industrial sources (discharges from smaller industry into the sewer systems) would also lead to lower emissions from urban areas and municipal waste water treatment plants.

A similar development was found for the Eastgerman river basins, where the point source N-emissions were reduced from 1985 to 1995 by 40 to 60 % mainly due to the decrease of direct and indirect industrial nitrogen discharges (Behrendt et al., 2000).

For the Danube upstream Jochenstein (77100 km²) this assumption is supported by the long-term measurements of dissolved inorganic nitrogen (DIN = NO_3-N + NH_4-N + NO_2-N) These measurements indicate clearly that at least for this part of the Danube the decrease of the DIN load is lower than 10% within the time period from 1983-1987 to 1998-2000 (Behrendt et al., 2003a).

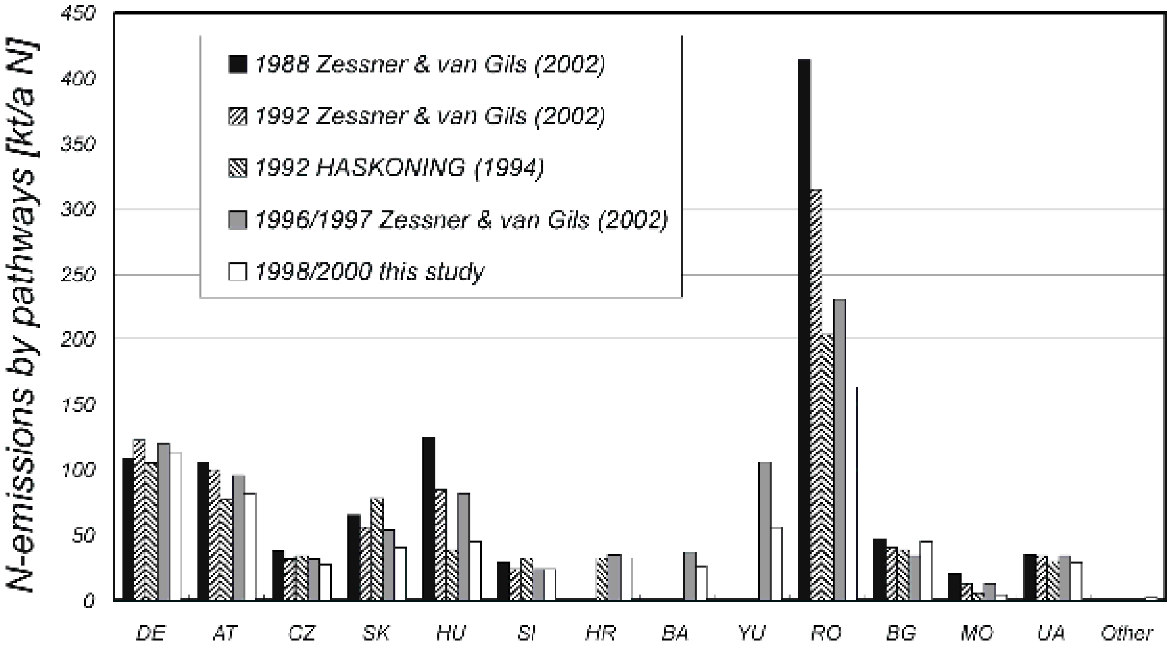


Figure 4.32: Comparison of the N-emissions for theDanube countries.

If the results of all studies are compared for the German part of the Danube basin, a very low increase of the total N-emissions is shown (Figure 4.32). There is a small difference in the estimated N-emissions, which indicates a low increase instead of a low decrease. This is probably due to the methodological differences between the three studies and cannot be interpreted as a change over time. Regarding other Danube countries (Slovenia, Czech Republic, Croatia, Bulgaria and Ukraine) the differences between the study results are also low, supporting the conclusion that the N-emissions in the Danube did not changed very much in the last decade. The exceptions are Austria, Slovakia, Hungary and Romania, where the estimated N-emissions of the earlier studies are more than 30 % higher than the results of this study. In general the differences between the PHARE and the HASKONING-study are larger than the differences between the mean of these results compared with the MONERIS results. Therefore it can also be concluded that most of the differences between the estimated N-emissions are caused by different methods and the possible decrease of point source discharges.

Because the contribution of point sources to the total N-emissions is relatively low in the Danube basin, it can be further concluded that the larger reduction of the point sources discharges influences the total N-emissions to a lower extent and a decrease of the N-emissions and loads of more than 10 to 30% seems to be improbable. According to Zessner & van Gils (2002), the decrease of the nitrogen emissions into the surface waters of the Danube river system would be 27 % from 1988 to 1996/1997. Because the assumed correction factor of Zessner & van Gils (2002) for the consideration of the N-emissions of Croatia, Bosnia Herzegovina and Yugoslavia (Serbia and Montenegro) seems to be too high and for the discussed methodological differences the calculation of a decrease of N-emissions based on the results of Zessner & van Gils (2002) and this study would lead to an overestimation of the possible reduction of N-emissions.

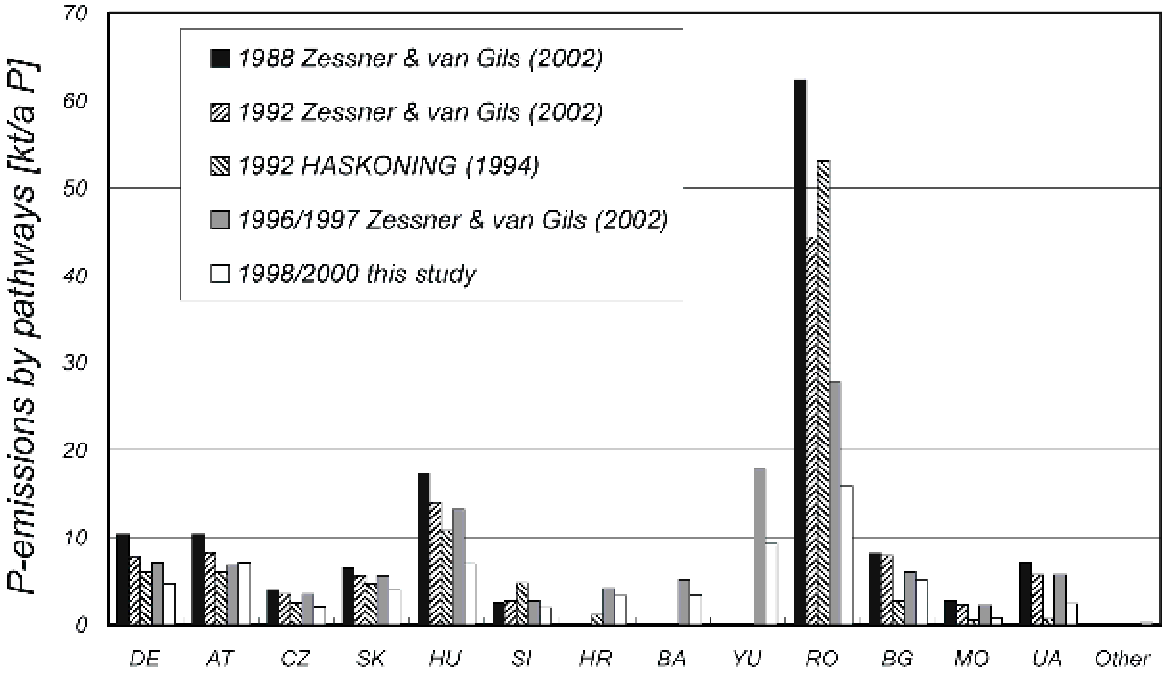


Figure 4.33: Comparison of the P-Emissions for the countries.

For phosphorus the former studies estimated significantly higher emissions for the time period around 1992. In contrast to nitrogen, these large differences concern the diffuse as well as the point source emissions.

For the German part of the Danube, Behrendt et al. (2003a) found that the load of total phosphorus as well as the sum of the P-emissions is decreased to 50 % and 60 %, respectively within the last 15 years.

This is mainly due to the reduction of point sources by 85 % as the result of a complete exchange of phosphorus in detergents and the establishment of extra treatment for P-elimination in all larger WWTP`s. From this study, it can also be concluded that the diffuse P-emissions are decreased only in a range of 5 %. According to these results the difference between the diffuse P-emissions within the German part of the Danube is estimated as 7 kt/a P by EU/AR102A91 (1997) and 4 kt/a P by Haskoning (1994) respectively. The 3.6 kt/a P quantified in the present study is the consequence of the application of different methodologies and is not an indication for the change of this sources within the last decade. If the change of the P-emissions in the German part of the Danube from the comparison of the existing studies (see Figure 4.33) is compared with results of Behrendt et al. (2003a), the development is similar, but the reasons for the reduction are different.

Regarding the other countries, large reductions of point source P-discharges and P-emissions from urban areas can also be expected for the Eastern European countries, but the reason is mainly the introduction of P-free detergents. This is illustrated by the following scenario calculation with MONERIS. If we assume that the efficiency of the P-elimination of WWTP`s is the same as for the period 1998-2000 and the inhabitant specific P-emission is changed to 4.2 g/(inh.·d) P for all Danube countries with exception of Germany and Austria, the sum of point source P-discharges for Czech Republic, Slovakia, Hungary, Slovenia, Romania, Bulgaria, Moldova and Ukraine estimated with MONERIS is about 26.4 kt/a P. This is 20 % below the results of the former studies (PHARE: 32.7 kt/a P; HASKONING: 32.9 kt/a P). This means that about two third of the difference between the point source emissions of MONERIS results for these countries for the period 1998-2000 (12.7 kt/a P) and the estimates of the mentioned studies could be explained by the reduction of the inhabitant specific P-emissions caused by changing the P-content of the detergents or increasing use of P-free detergents. The remaining one third of the reduction are probably due to the improvement of the P-elimination of the WWTP`s in these countries.

The same scenario calculation shows that the change of the inhabitant specific P-emissions would explain a reduction of the diffuse P-emissions for these countries of about 20 % due to the decrease of the P-concentrations of combined sewer overflows and of sewer systems which are not connected to WWTP`s. But the difference between the results of the former studies and the present estimations for the diffuse P-emissions is more than a factor 1.6 for the PHARE-study and 1.2 for the HASKONING-study. According to Figure 4.33 the main part of this difference of the total and the diffuse P-emissions concerns Romania only and is due to the assumption of very high agricultural point source emissions caused by some pig farms with more than one million animals. At the beginning of the last decade the number of pigs in Romania was between 10 and 12 million. If an animal specific P-emission of 3.5 kg/(pig·a) is assumed the total P-emission of all Romanian pigs was between 35 and 42 kt/a P. The difference between the diffuse P-emissions estimated by the PHARE and the HASKONING study and the MONERIS results is 16 and 27 kt/a P. Corresponding to this about the half of the Romanian pigs would discharge all of the P-emissions directly to the Romanian surface waters. If this was really true the difference of the diffuse P-emissions is explained and it can be concluded over all that the difference of 40 to 50 % between the study results can be assumed to be a reduction of the total P-emissions within the last decade. This reduction could only be found for the lower part of the Danube. For the Danube upstream of Hercegszanto the reduction of the P-emissions and loads was probably much lower.

4.7 River Nutrient Loads

The estimation of the nutrient loads for the whole Danube river system, including the sub-catchments, was done for the measured nutrient concentrations and discharges for monitoring stations based on Equation 3.42. The calculation of the nutrient load was possible for the catchments upstream of 91 monitoring stations for dissolved inorganic nitrogen (DIN), of 63 monitoring stations for total phosphorus (TP) and 16 monitoring stations for total nitrogen (TN). Data of TN-concentrations were only available for the Hungarian monitoring stations, which explain the low number for these load estimations. Most of the data that can be used for the calculation of the nutrient loads are included in the TNMN-monitoring program of the ICPDR. For additional stations measured concentrations of the DIN and TP were available, but the time period was not in agreement with the studied period of 1998-2000. Therefore this data could not be considered for the further analysis. For all stations where the measurements were done for different locations at the same cross section of the Danube the load was calcu-

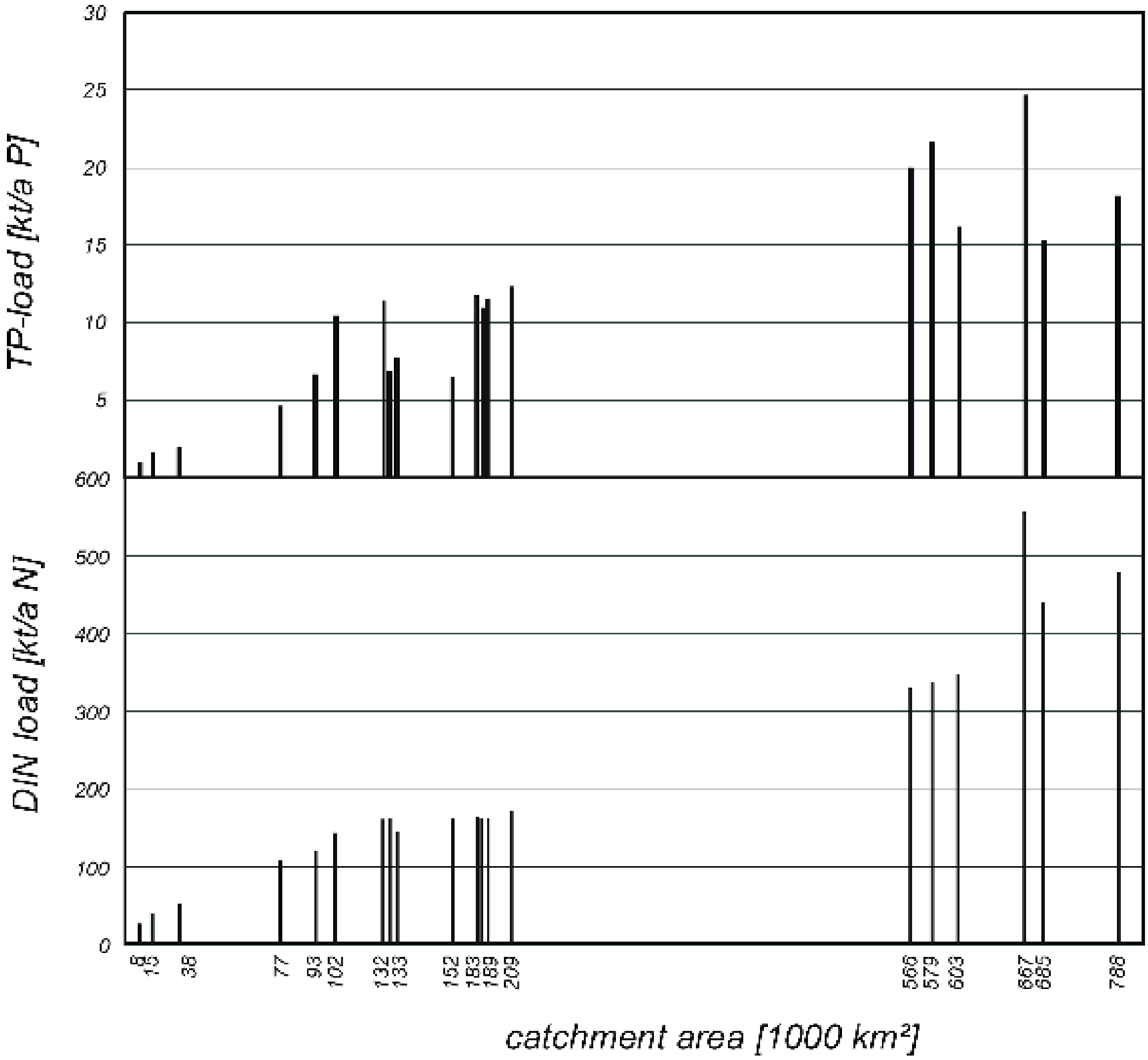


Figure 4.34: TP- and DIN-loads calculated from measured concentration and discharges along the main stream of the Danube.

lated as the mean of the individual loads for all of these locations. If stations of two countries are at the same location the mean of these loads were calculated.

Figure 4.34 shows the change of the mean annual load of total phosphorus (TP) and dissolved inorganic nitrogen (DIN) for the period 1998-2000 along the main stream of the Danube. If reservoirs or lakes are not part of the main stream it is expected that the loads are increasing with a different amount from the upstream to the downstream area. According to this, the estimated loads of DIN can be assumed as consistent with the exception of the DIN load for the station upstream of the Arges (catchment area: 667 tkm²) where the DIN load should be overestimated in comparison to the upstream and downstream stations. The estimated DIN-load of the Danube at the station Reni, the last station upstream of the Danube delta, was about 477 kt/a N.

The change of the TP-load along the main stream of the Danube shows two ranges where the load is decreasing or varies between the neighbouring stations. The first range is downstream of the Austrian station Wolfsthal (132 tkm²) where the next three stations (at Bratislava, Medvedov/Medve, and Komarno/Komarom) show a significantly lower TP-load than upstream and downstream. The given load for all three stations is a mean value for the and downstream. The given load for all three stations is a mean value for the Slovakian and Austrian or Hungarian measurements. A more detailed analysis shows that the difference is mainly caused by lower loads of the Slovakian stations. A limited decrease within this Danube stretch could be explained by retention in the Gabcikovo Reservoir, which is located in this range, but this does not explain the large decrease because there is no reason for the substantial increase of the TP-load between Komarom and the next Hungarian station at Szob. It seems to be more likely that the estimated TP-concentration for the Slovakian Danube stations are systematically underestimated.

Within the downstream part of the Danube, the estimated TP-loads vary from station to station in a very wide range which can not be explained by a consistent set of data. In correspondence to nitrogen an improbably high TP-load is found for the station upstream of the mouth of the Arges river. But on the other hand the TP-loads at the stations Pristol/Novo Selo and Silistra/Chichiu are too low in comparison to the load estimated for the station at Reni. These differences can not be explained by retention processes on the one hand and large inputs of phosphorus on the other hand and are probably caused by special problems at the sample locations, the sampling procedure, the transport of samples and the analytical procedures for the measurements itself.

Without an addititional support by other analysis it is impossible to give a harmonised value for the TP-load for the whole Danube upstream of the delta.

4.8 Comparison of observed and calculated nutrient loads

As shown by Alexander et al. (1999), Billen & Garnier (1999) and Behrendt & Opitz (1999) the nutrient emissions into a river system can not be directly compared with the observed load because retention processes within the system of surface waters have to be taken into account. The MONERIS model includes the possibility to calculate this retention for phosphorus and nitrogen based on river parameters as specific runoff and hydraulic load (see Chapter 3.3).

If these retention formulas are applied to the Danube and its subcatchments the phosphorus and nitrogen load can be estimated for the investigated time period 1998-2000 and compared with the observed loads given above. The result of this comparison is presented in Figures 5.35, 5.36 and 5.37 for dissolved inorganic nitrogen (DIN), total nitrogen (TN) and total phosphorus (TP), respectively.

Especially for the both nitrogen components the calculated loads agree well with the results of the measurements. The deviation between the measured and calculated loads exceeds a deviation of 50 % for 9 (DIN) and 2 (TN) subcatchments (see Table 5.26).

The mean deviation is below 21 or 22 % for DIN and TN load, respectively. If the possible error of the observed load is taken into account (see Chapter 4.7), the real deviation can be assumed to be less than 20%.

The highest deviation in observed nitrogen loads were found for the subcatchments within the Hungarian part of the Danube and some Romanian catchments. Because the sampling frequency for the Romanian catchments is only monthly, it can be assumed that the reason for the deviation is also a wrong estimation of the mean annual DIN-load. For the Hungarian subcatchments the sampling density is bi-weekly and therefore the observed DIN-loads should have a much lower bias. Furthermore the comparison shows that the calculated loads are systematically lower than the observed loads of DIN. It is assumed that the reason for these large deviations is an overestimation of the surface water area by the application of Equation 3.1, which was derived for German rivers, where the plains are often wet and artificially drained by ditches. For the dry areas of the Pannonian plains the surface water area could probably be overestimated with this formula. In this case the retention will also be overestimated. For the catchments around the Balaton (Kapos and Sio) it can be further assumed that the emissions are underestimated, because most of the WWTP`s in the catchment of the Balaton are discharging the treated waste water to the Kapos and Sio catchments and not in the Balaton.

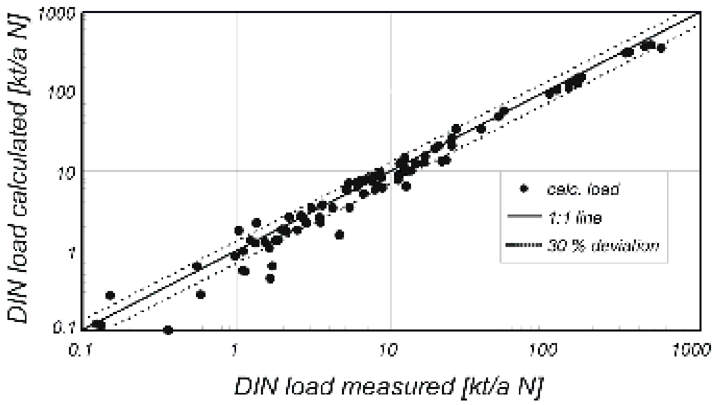


Figure 4.35: Comparison of observed and calculated loads of dissolved inorganic nitrogen (DIN).

For total nitrogen the number of 16 stations with measured loads is too low for a general discussion of the comparison with the calculated loads.

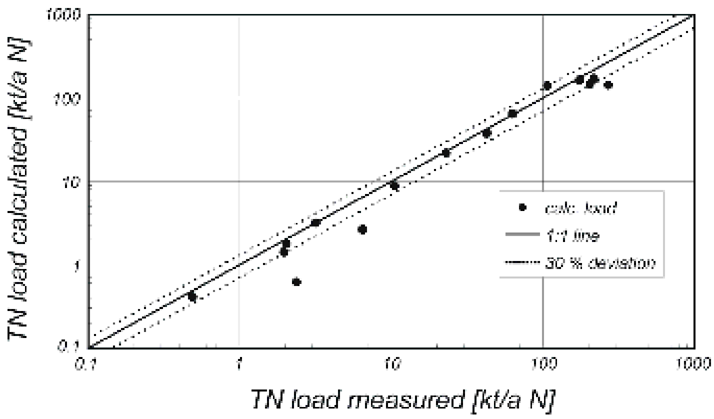


Figure 4.36: Comparison of observed and calculated loads of total nitrogen (TN).

The calculated load for the Danube upstream of Reni is 391 kt/a N for DIN and 451 kt/a N for TN. For this station only data for the dissolved inorganic nitrogen were available. Therefore a comparison with the observed TN load is not possible. The observed DIN load at the station Reni was 478 kt/a N, which is 18 % higher than the

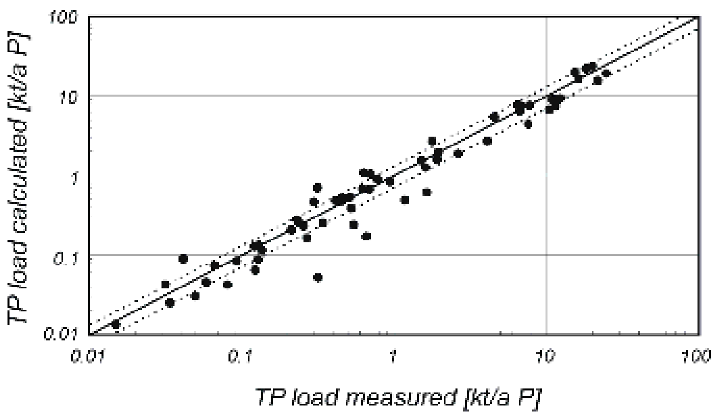


Figure 4.37: Comparison of observed and calculated loads of total phosphorus (TP).

Table 4.26: Results of the comparison between observed and calculated nutrient loads for the Danube river system and its tributaries in the period 1998-2000.

	TP	TN	DIN
Number of values with deviations >50%	12	2	8
Number of values with deviations >30%	21	4	19
Number of stations with load measurements	64	16	92
Mean deviation [%]	29.7	22.1	21.4

calculated load but very close to the calculated load of TN. The reason for the difference between the calculated and observed DIN-load could be the preparation and the transport of the water samples. According to Popescu (pers. comm.) the taken water samples were not filtered at the sampling station and were transported as unfiltered sample to the laboratory. Depending on transport time and temperature a part of the dissolved nitrogen can be uptaken by phytoplankton. The consequence could be an underestimation of the concentrations and the load of dissolved inorganic nitrogen especially during summer time.

For phosphorus, Figure 4.37 shows that the deviation between calculated and observed loads is higher than for nitrogen. The mean deviation between calculated and observed loads was estimated to be 29.7 % which is about 10% higher than for nitrogen. In contrast to nitrogen the deviation is larger than 50% for 12 catchments and for about one third of the catchments larger than 30% (see Table 4.26). Additionally a clear tendency exists that the calculated P-loads are below the observed loads.

Because the possible error of the measurements of total phosphorus is higher than for nitrogen (see Table 4.26) this may be one reason for the higher deviation between calculated and observed TP-loads, although this would not explain the systematical underestimation of calculated TP-loads for a sub set of catchments.

A more detailed analysis of the catchments with the high underestimation of the phosphorus load shows that most of these catchments are also located in the Hungarian part of the Danube. In general it can be assumed that the deviation results due to the same reasons, overestimation of the retention by overestimation of the surface water area and underestimation of the total P-emissions especially for Kapos, Sio and Lonyai. Because the measurements for these catchments are showing mostly strong dilution functions for the concentration due to high point source discharges, it can be assumed that especially the point source discharges are underestimated for these catchments within the model.

Based on the results of this analysis it is an important task for the future to adapt the approach for the estimation of the surface water area to the conditions within the dry plain areas of the Danube basin and to consider some specific conditions in the Hungarian catchments surrounding the Lake Balaton. Also a revision of the point source discharges especially for Hungary will be necessary.

For the stations of the Danube downstream of the Iron Gate an overestimation of the calculated TP-loads occurs in comparison to the observed TP-loads (see Figure 4.38). This indi-

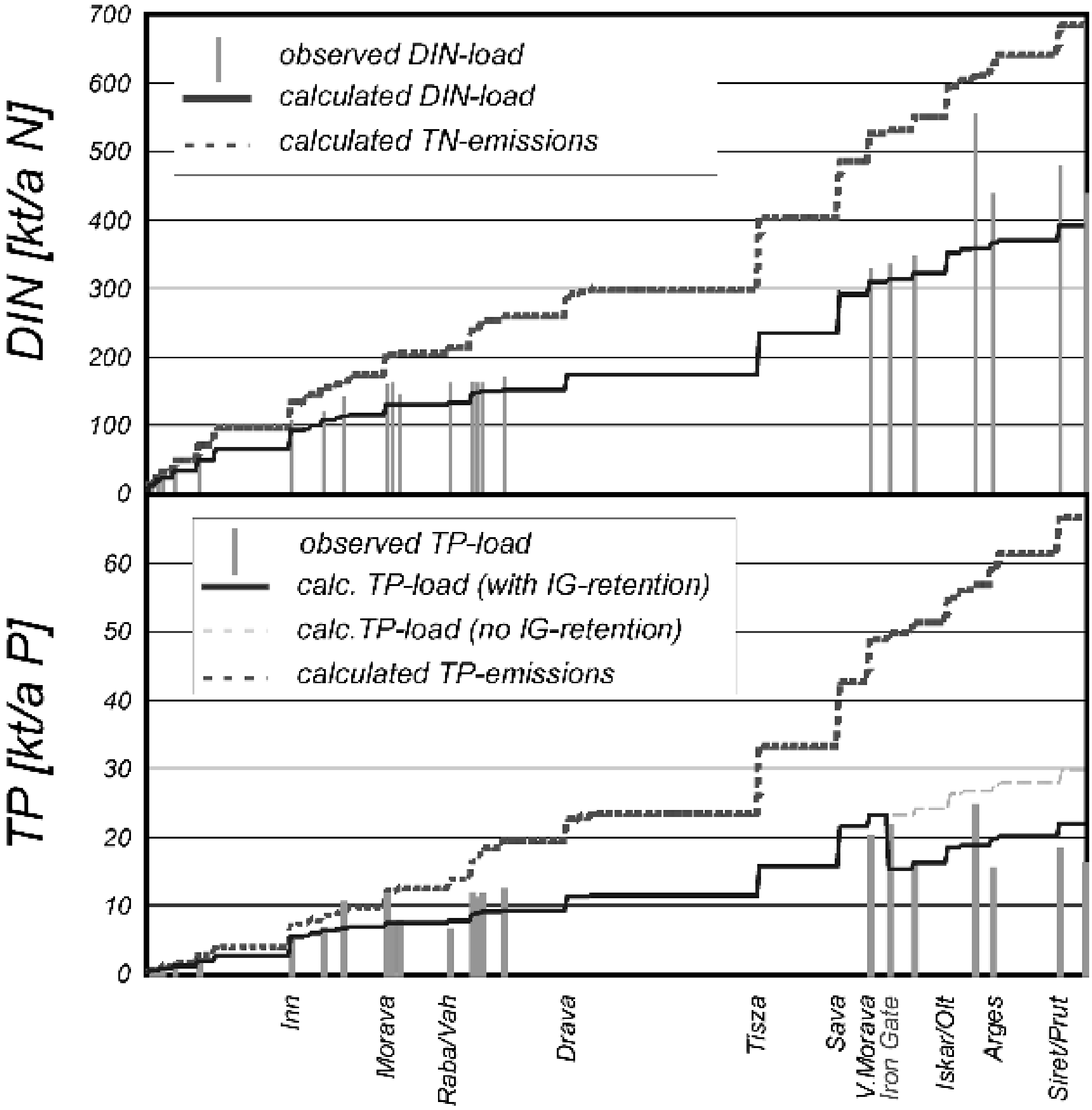


Figure 4.38: Change of the observed and calculated loads of DIN and TP as well as N- and P-emissions along the Danube for period 1998-2000.

cates that the Iron Gate reservoir is an additional sink for phosphorus. If such an additional P-retention in the catchment including the Iron Gate reservoir is taken into account and the amount of this retention is estimated by minimizing the deviation of the observed and calculated TP-loads for the Danube stations downstream of the Iron Gate, the P-retention of this reservoir is found to be about 8.5 kt/a P or 36 % of the TP-inputs into the reservoir. If the P-retention in the Iron Gate reservoir is taken into account the calculated TP-load of the Danube to the Delta was 22 kt/a P for the period 1998-2000, which is 21% above the TP-load observed for the station Reni the last Danube station upstream of the Delta.

The main processes of the phosphorus retention are sedimentation and sorption. From the model results it can be concluded that about 46 kt/a P or 68 % of the P-emissions into the surface waters will be retained. About 20% of this total retention would be realized within the reservoir at the Iron Gate.

In general, the comparison of the calculated and observed nutrient loads shows that for nitrogen a sufficient level of agreement was already reached. Before the approaches used by the model for the different pathways are specified for specific conditions in the Danube river basin, it is necessary to improve the spatial resolution of the model so that nitrogen surpluses can also be calculated on a regional basis rather than simply on a national basis. This requires the collection of more agricultural data at a regional level. For phosphorus the deviations between calculated and observed loads are about 30 %, which is too high. Therefore the database (especially for point source discharges) as well as some of the model approaches especially for erosion and surface runoff have to be improved within the next phase of the model development.

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