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Nutrient Emissions into River Basins of Germany

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16. Kurzfassung Für 300 deutsche Flußgebiete wurden mit Hilfe des Modellsystems MONERIS die Nährstoffemissionen von punktuellen und diffusen Eintragsquellen für die Zeiträume 1983-1987 und 1993-1997 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 1993-1997 Einträge von insgesamt ca. 819 kt N/a für Deutschland ermittelt werden. Diese Einträge haben sich im letzten Jahrzehnt um 266 kt N/a vermindert. Für Phosphor beträgt die Reduzierung 56 kt P/a. Z. Zt liegen die gesamten P-Einträge in die deutschen Flußgebiete bei 37 kt P/a. Ein Vergleich der abgeschätzten mit gemessenen Nährstofffrachten zeigt für 80% der untersuchten Flußgebiete mittlere Abweichungen von weniger als 30%. Die regionale Auflösung des Modells erlaubt die Identifikation von Schwerpunkten der Nährstoffbelastung und die Ableitung gebietsspezifischer Maßnahmen.		
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16. Abstract

The nutrient emissions from point and diffuse sources into about 300 German river basins were estimated for the periods 1983-1987 and 1993-1997 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 input into the German river systems amounts about 819 kt N/a in the period 1993 to 1997. These emissions were decreased since the mid of eighties by about 266 kt N/a, mainly caused by the reduction of point discharges. For phosphorus the emissions were reduced by 56 kt P/a and amount 37 kt P/a in the period 1993-1997. The comparison of the calculated loads (nutrient emissions minus retention) with the observed loads shows for 80 percent of the river basins a deviation lower as 30% for nitrogen and phosphorus, respectively. The regional resolution of the model allows the identification of hot spots for the different pathways for phosphorus and nitrogen.

17. Keywords
nitrogen and phosphorus inputs, emission method, MONERIS, source apportionment, point sources, diffuse sources, river basins, 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

AbwV	German wastewater regulation
Addr.	address
AL	area of agricultural land
atm.	atmospheric
ATMP	Aminotrismethylenphosphonat
ATV	German Association for Water, Wastewater and Waste (Abwassertechnische Vereinigung)
B	biological wastewater treatment plant
B(D)	biological wastewater treatment plant with denitrification
B(N)	biological wastewater treatment plant with nitrification
B(P)	biological wastewater treatment plant with phosphorus elimination
BB	Brandenburg
BE (W)	Berlin (West)
BE	Berlin
BfG	Federal Agency for Hydrology (Bundesanstalt für Gewässerkunde)
BGR	Federal Institute for Geosciences and Natural Ressources (Bundesanstalt für Geowissenschaften und Rohstoffe)
BÜK	general soil map of Germany
BV	Bavaria
BW	Baden-Württemberg
CLC	CORINE-Landcover
DEM	digital elevation model
DIN	dissolved inorganic nitrogen
DKSR	German Commission for the Protection of the Rhine (Deutsche Kommission zum Schutze des Rheins)
DNMI	Det Norske Meteorologiske Institutt
DOC	dissolved organic carbon
DTPMP	Diethylentriaminpentamethylenphosphonat
DVWK	German Association for Water Resources and Land Improvement (Deutscher Verband für Wasserwirtschaft und Kulturbau)
DWD	German Weather Service (Deutscher Wetterdienst)
E	inhabitant
EDTMP	Ethylendiamintetramethylenphosphonat
EGW	population equivalent caused by indirect industrial discharges
Elim.	elimination
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
ESRI	Environmental Research Systems Institute
EW	population equivalent
FEA	Federal Environmental Agency
GDR	German Democratic Republic
GER	Germany
GIS	Geographic Information System
HB	Bremen

HE	Hesse
HEDP	1-Hydroxyethan-1,1-diphosphonat
HH	Hamburg
ICPD	International Commission for the Protection of the Danube
ICPE	International Commission for the Protection of the Elbe
ICPLC	International Commission for the Protection of Lake Constance
ICPR	International Commission for the Protection of the Rhine
IFEIF	Institute of Freshwater Ecology and Inland Fisheries
LAWA	State Water Working Group (Länderarbeitsgemeinschaft Wasser)
LS	Lower Saxony
M	mechanical wastewater treatment plant
MMK	medium-scale agricultural site mapping in Germany
MONERIS	MOdelling Nutrient Emissions in RIver Systems
MW	Mecklenburg-Western Pomerania
N	nitrogen
NGS	new German states
NH_4	ammonia
NLL	nutrient loading level
NO_3	nitrate
NO_x	nitric oxides
NW	North Rhine-Westphalia
OGS	old German states
P	phosphorus
PARCOM	Paris Commission
PO_4	phosphate
RIVM	National Institute of Public Health and the Environment
RP	Rhineland-Palatinale
SH	Schleswig-Holstein
SL	Saarland
SN	Saxony
SRP	soluble reactive phosphorus
SS	suspended solids
ST	Saxony-Anhalt
TH	Thuringia
TK25AS	topographic map 1:25000
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
U.S.	United States
USGS	United States Geological Survey
USLE	uniformed soil loss equation
WWTP	wastewater treatment plant

Abbreviations used in Formulas

A_{ACKER}	area of arable land
A_{AU}	area of flood plain soils
A_{DR}	drained area
A_{DRHM}	area of drained bog soil
A_{DRL}	area of drained loams
A_{DRNM}	area of drained fen soil
A_{DRS}	area of drained sandy soil
A_{EZG}	catchment area
AF	exchange factor
A_{GEB}	mountain area
$AG_{EGW_{N,P}}$	EGW specific nutrient output
$AG_{E_{N,P}}$	inhabitant specific nutrient output
$AG_{ES_{N,P}}$	inhabitant specific output of dissolved nutrients
a_{GEW}	proportion of total urban area in commercial use
$AG_{EW_{N,P}}$	inhabitant equivalent specific nutrient output
$A_{GRÜN}$	grassland area
A_{GWS}	area of wet sandy soil
AH	exchange frequency
A_{HG}	area of different hydrogeologically rock types
A_{HM}	area of bog soil
A_{L}	area of loamy soil
A_{LN}	agricultural area
A_{MO}	area of peat soil
A_{NM}	area of fen soil
A_{OF}	open area
A_{S}	area of sandy soil
A_{SOURCE}	source areas which are sensitive for soil input in the river system
A_{STL}	area of wet loamy soil
$AS_{URB_{N}}$	specific N-input from impervious urban areas
AU	rate of utilisation of wastewater treatment plants
A_{URB}	total urban area
A_{URBK}	urban area connected only to sewers
A_{URBN}	impervious urban area connected neither to a sewer nor to a wastewater treatment plant
a_{URBV}	share of precipitation realized as surface runoff from impervious urban areas
A_{URBV}	impervious urban area
A_{URBVM}	impervious urban area connected to combined sewer system
A_{URBVT}	impervious urban area connected to separated sewer system
A_{W}	total water surface area
A_{WAOF}	woodland and open area
A_{WCLC}	water surface area from CORINE-Landcover
A_{WFGW}	surface area of flowing waters
A_{WSEE}	water surface area from land use map

BA	soil loss
$C_{DRHM_{N,P}}$	drainage water nutrient concentration for bog soil
$C_{DRL_{N,P}}$	drainage water nutrient concentration for loamy soil
$C_{DR_{N,P}}$	drainage water nutrient concentration
$C_{DRNM_{N,P}}$	drainage water nutrient concentration for fen soil
$C_{DRS_{N,P}}$	drainage water nutrient concentration for sandy soil
$C_{GEW_{N,P}}$	nutrient concentration in commercial wastewater
$C_{GWHM_{N,P}}$	groundwater nutrient concentration for bog soil
$C_{GWL_{N,P}}$	groundwater nutrient concentration for loamy soil
$C_{GWLN_{N,P}}$	groundwater nutrient concentration for agricultural land
$C_{GW_{N,P}}$	nutrient concentration in groundwater
$C_{GWNM_{N,P}}$	groundwater nutrient concentration for fen soil
$C_{GWS_{N,P}}$	groundwater nutrient concentration for sandy soil
$C_{GW_{SRP}}$	SRP-concentration in groundwater
$C_{GWWAOF_{N,P}}$	groundwater nutrient concentration for woodland and open areas
$C_{KA_{DIN}}$	outflow concentration of inorganic nitrogen from municipal WWTP
$C_{KA_{ON}}$	outflow concentration of organic nitrogen from municipal WWTP
$C_{KA_{TP}}$	outflow concentration of total phosphorus from municipal WWTP
$C_{MISCH_{N,P}}$	mixed sample nutrient concentration
$C_{M_{N,P}}$	nutrient concentration in combined sewers during overflow
$C_{ROACKER_{N,P}}$	nutrient concentration in surface runoff from arable land
$C_{ROGRÜN_{N,P}}$	nutrient concentration in surface runoff from grassland
$C_{RO_{N,P}}$	nutrient concentration in surface runoff
$C_{ROOF_{N,P}}$	nutrient concentration in surface runoff from open land
$C_{SW_{N,P}}$	nutrient concentration in leakage water
$C_{SWPOT_{NO3-N}}$	potential nitrate concentration in leakage water
$C_{T_{N,P}}$	nutrient outflow concentration in separate sewer systems
$C_{t_{N,P}}$	nutrient concentration at sampling time
DNR	denitrification rate
DR	exponent for denitrification
$EAD_{N,P}$	nutrient input via atmospheric deposition
E_{DICHTE}	population density
$ED_{N,P}$	nutrient input via diffuse sources
$EDR_{N,P}$	nutrient inputs via tile drainage
$EDR_{SP_{N,P}}$	specific nutrient emissions via tile drainage
$EER_{N,P}$	nutrient input via erosion
$EG_{N,P}$	total nutrient input
EGW	population equivalents by indirect industrial discharges
$EGW_{N,P}$	nutrient input via groundwater and natural interflow
$EID_{N,P}$	nutrient input via direct industrial discharges
E_{KA}	inhabitants connected to municipal WWTP
$EKK_{N,P}$	nutrient inputs via municipal wastewater treatment plants
$EP_{N,P}$	nutrient input via point sources
$ER_{N,P}$	nutrient enrichment ratio
$ERO_{N,P}$	nutrient input via surface runoff

$EUK_{N,P}$	nutrient input via impervious urban areas and inhabitants connected only to sewers
$EUM_{N,P}$	nutrient input via combined sewer overflows
$EUN_{N,P}$	nutrient input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants
$EUR_{N,P}$	nutrient input via urban areas
E_{URBK}	inhabitants connected only to sewers
E_{URBN}	inhabitants connected neither to sewers nor to wastewater treatment plants
$EUT_{N,P}$	nutrient inputs via separate sewers
EW_{AB}	wastewater treatment plant capacity (in population equivalents)
EW_{AU}	population equivalent treated in wastewater treatment plants
FK_{WE}	field capacity in the root zone of soil
HL	hydraulic load
K_{ABF}	proportion of dissolved human nutrient output transported to wastewater treatment plants
l_{AFS}	specific load of suspended solids
$L_{BASIS_{AFS}}$	suspended solids from autochthonous material and point sources
$L_{J_{AFS}}$	annual load of suspended solids
$L_{J_{N,P}}$	annual nutrient load
LKF	correction factor for the long-term changes in surpluses
$L_{KRIT_{AFS}}$	critical load of suspended solids
$L_{N,P}$	nutrient load
$L_{U_{N,P}}$	average annual nutrient load during the studied period
MQ	average discharge
N_{BODEN}	nitrogen content in the topsoil
N_{DEP}	atmospheric nitrogen deposition
N_E	inhabitant specific nitrogen emission via wastewater treatment plants
N_{GEB}	nitrogen content of mountainous area soil
$NH_{4_{DEP}}$	atmospheric ammonia deposition
N_J	annual precipitation
$NO_{X_{DEP}}$	atmospheric nitrogen oxide deposition
N_{SO}	average precipitation in the summer half year
$N_{ÜGES}$	total nitrogen surplus
$N_{ÜLN}$	nitrogen surplus of agricultural areas
N_{WI}	average precipitation in the winter half year
P_{ACKER}	phosphorus content of arable top-soil
P_{AFS}	phosphorus content of suspended solids
P_{BODEN}	phosphorus content in the top-soil
P_{DEP}	atmospheric phosphorus deposition
P_E	inhabitant specific phosphorus emission via wastewater treatment plants
P_{GEB}	phosphorus content of mountainous area top-soil
Q	average runoff
q	specific runoff
Q_{AD}	atmospheric input flow
Q_{DR}	tile drainage flow
q_{DR}	specific drain water flow

q_E	daily wastewater output per inhabitant
Q_F	external water
q_G	specific runoff
Q_{GES}	total wastewater
Q_{GEW}	industrial and commercial wastewater
q_{GEW}	specific runoff from commercial areas
Q_{GEWK}	runoff from commercial areas only connected to sewers
Q_{GEWM}	runoff from commercial areas connected to combined sewers
Q_{GW}	base flow and natural interflow
Q_H	domestic wastewater
Q_{KRIT}	critical runoff
$Q_{MEß}$	average annual runoff based on daily runoff for the concentration measurements
Q_{MISCH}	runoff during measuring period
Q_N	storm wastewater
q_R	rainfall runoff rate
Q_{RO}	surface runoff from non-paved areas
q_{RO}	specific surface runoff
q_{SG}	snow- or glacier-derived specific outflow
Q_t	runoff at sampling time
Q_T	urban wastewater
Q_{TGL}	average annual runoff based on daily measurements
Q_{URB}	surface runoff from urban areas
Q_{URBM}	storm water runoff from combined sewer system
q_{URBV}	specific surface runoff from impervious urban areas
$R_{B_{N,P}}$	nutrient retention in soil
RE	discharge rate of combined sewer overflows
$R_{GW_{NO3-N}}$	retention or denitrification of nitrate in the unsaturated zone and in groundwater
$R_{L_{N,P}}$	load weighted nutrient retention
$R_{N,P}$	loss or retention of nutrients
SAR_{GIS}	area-related sediment delivery ratio
SAR_{MOD}	sediment area ratio
SDR	sediment delivery ratio
SED	sediment input
SED_{POT}	potential sediment input
SL	mean slope from USGS-DHM
SW	leakage water quantity
TG_{ACKER}	clay content of arable soil
U_f	factor for the correction of runoff data according to the size of the catchment area upstream the monitoring station
V	evapotranspiration
V_S	storage volume
WF	weighting factor
Z_{NE}	number of storm water events
Z_{NT}	effective number of storm water days

Summary

The model **MONERIS** (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) was developed and applied to estimate the nutrient inputs into river basins of Germany 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
- atmospheric deposition
- erosion
- surface runoff
- groundwater
- tile drainage
- paved urban areas

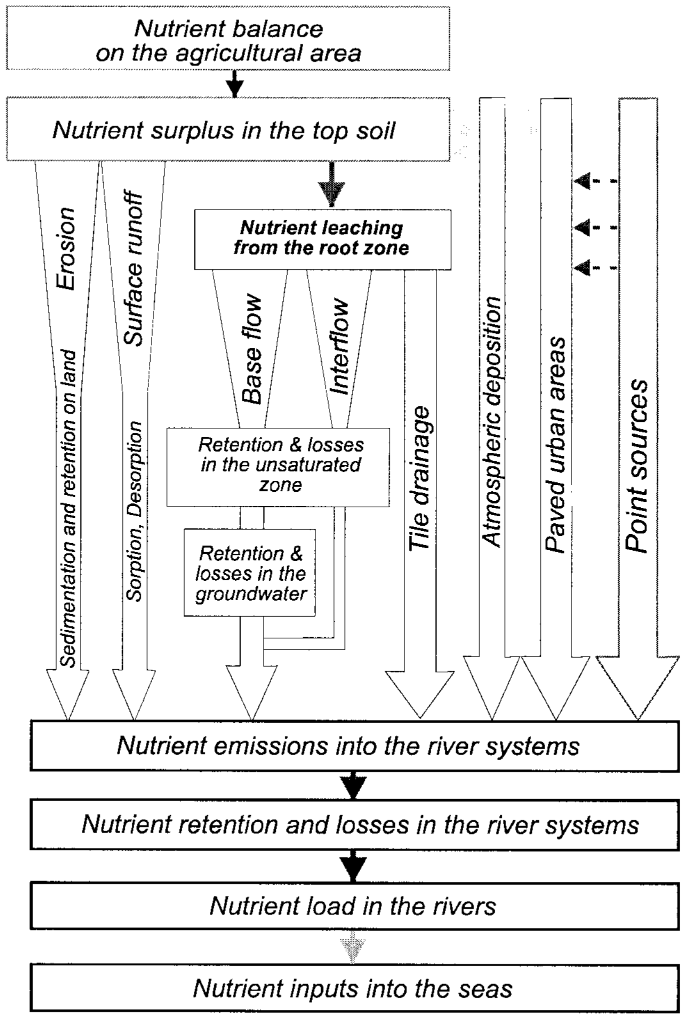


Figure 1: Pathways and processes within MONERIS.

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.

Since current knowledge of the processes and the up to now limited database especially for river basins of medium and large size, the description of the processes can not be done by detailed dynamic models.

Therefore, MONERIS estimates the different pathways with already existing and new conceptual approaches, which are developed especially for the modelling in the medium and large spatial scale. Topics of the model development were:

- to develop a GIS-supported method for regional differentiated estimation of diffuse and point emissions for river basins of a size of more than 500 km²,
- to establish a submodel for regionally differentiated estimation of nutrient discharges from waste water treatment plants by a countrywide detailed inventory of these waste water treatment plants,
- to establish a submodel for inputs of nutrients and suspended solids caused by erosion, which can be applied to all investigated river basins. This model is based on the modified uniform soil loss equation but considers only those areas, which are relevant for a input into the river system. The submodel was validated with observed loads of suspended solids and particulate phosphorus for river basins,
- to develop a submodel which allows the estimation of groundwater concentrations of nitrogen from the nitrogen surplus in agricultural areas by means of a retention function. This retention function is dependent on the hydrogeological conditions, the rate of groundwater recharge and the nitrogen surplus itself. The retention model includes first raw estimates of the residence time of water within the unsaturated zone and aquifer of the river basins,
- to develop a GIS-supported submodel for regionally differentiated estimation of the agricultural areas modified by tile drainage. The submodel is based on soil types and a classification of soil water conditions and is validated by overlaying digitised maps of tile drained areas with a soil map,
- to establish a submodel for different pathways of nutrient emissions within urban areas considering the regional differences in the sewer systems and the development of storage volume especially for combined sewer systems and
- to establish a submodel for nutrient retention and losses in surface waters, which can be applied for all river basins. This model is based on the dependency of the nutrient retention on the hydraulic load or the specific runoff in the river system. The model allows the estimation of the nutrient loads from the nutrient inputs in a river basins. Therefore, a direct comparison of calculated and observed nutrient loads is possible for river basins upstream of a monitoring station.

One special topic of the model development was that the different submodels were be validated by using independent data sets, for example the groundwater model was developed with the observed nitrogen concentrations in the groundwater and not on the base of the observed nutrient loads in the rivers.

The use of a GIS allows a regional differentiated quantification of nutrient emissions into river systems. Therefore, estimates were not only carried out for large river basins. Altogether the MONERIS model was applied to 300 different river basins for the two time periods 1983-1987 and 1993-1997. The temporal changes of nutrient emissions were calculated for the different hydrological conditions in both periods as well as under the assumption of identical hydrological conditions in order to estimate the changes caused by human factors.

The results of the calculations of the nutrient emissions into the German parts of the largest river basins Danube, Elbe, Rhine and Weser as well as for the German parts of the catchments of North Sea, Baltic Sea and Black Sea and all of Germany are presented in Tables 1 to 4 and Figures 2 to 5.

Nitrogen emissions into the river basins of Germany were about 819 kt N/a in the period 1993-1997 and thus 266 kt N/a, or 25% lower than in the period 1983-1987. This means that the target of the 50% reduction of nitrogen loads from Germany into the North Sea and the Baltic Sea could not be achieved. The main cause for the decrease of the nitrogen emissions into the river systems was the large reduction of nitrogen discharges from point sources by 46%. On the other hand the estimated decrease of diffuse emissions was only about 10%. The input via groundwater is with 48% the dominant pathway in the period 1993-1997. The share of point sources in nitrogen emissions amounts to about 28%. The contributions of erosion, surface runoff and atmospheric deposition to the total nitrogen input are low and amount to about 2% only for each of these pathways.

The total phosphorus emissions into the German river basins were about 37 kt P/a in the period 1993-1997. Compared with the period 1983-1987, the phosphorus emissions were reduced by about 57 kt P/a or 60%. The target of a 50% reduction of the phosphorus loads into the seas was reached. Again the decrease of phosphorus emissions is mainly caused by a 80% reduction of point sources. The decrease of diffuse phosphorus emissions was larger than for nitrogen, which is caused by a 56% reduction of the emissions from urban areas. In spite of the enormous reduction of phosphorus discharges from point sources these sources remain the dominant pathway of phosphorus emissions with 34% in the period 1993-1997. Among the diffuse pathways, emissions by erosion dominate and represent 22% of the total input.

Amongst the individual river catchments and also the basins of North Sea, Baltic Sea and Black Sea the nutrient inputs as well as the shares in the various nutrient input pathways vary to a relatively large extent as shown in Tables 1 to 4 and Figures 2 to 5.

In spite of the substantial decrease of the nitrogen surplus in agricultural areas a slight reduction of the nitrogen emissions to the groundwater based upon identical hydrological conditions can only be estimated for the Rhine basin. For the other river basins, one has to assume that nitrogen inputs via this pathway will still increase during the nineties due to the long residence times of water in the unsaturated zone and in the aquifer. Only after the year 2000 the reduced nitrogen surplus will be followed by a slow reduction of the nitrogen concentrations in the groundwater and thus of total nitrogen inputs via this pathway.

Inputs to those parts of the Danube, Elbe and Rhine basins outside of Germany amounted to a total of 231 kt N/a and 16 kt P/a in the period 1993-1997. This corresponds to shares of 15% (nitrogen) and 29% (phosphorus) for the Danube basin upstream of Jochenstein. For the Elbe basin upstream Zollenspieker the shares in nutrient emissions originating outside of Germany were 37% for nitrogen and 43% for phosphorus. In the Rhine basin upstream of Lobith 30% of the nitrogen emissions and 41% of the phosphorus emissions originated from those parts of the basin that are outside of Germany.

The nutrient loads, which were calculated from the measured flow and nutrient concentrations, show similar changes as the nutrient emissions for the periods 1983-1987 and 1993-1997 for the investigated river basins.

The nutrient inputs 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 30%.

The nutrient loads of the individual river catchments were calculated from the nutrient emissions accounting the retention and loss processes within the river systems of the catchments for the two periods. These calculated loads were compared with the load estimates based on the measured flow and nutrient concentrations in both time periods. The comparison shows that for nitrogen the deviation between the calculated and observed loads is for 148 of 168 river basins lower than 30%. Only for 13 basins, usually smaller basins with low loads of dissolved inorganic nitrogen, the deviation is larger than 40%.

For phosphorus, in general, the deviation between the calculated and observed load is slightly larger than for nitrogen. But the tendency is the same that the deviation is increasing with the decrease of the size of the basins and the phosphorus load. This phenomenon can be caused by larger errors in the estimates of nutrient emissions and in the "measured" loads for smaller basins.

The calculation of different scenarios shows that the target of a 50% reduction of the nitrogen load into the seas can not be reached by measures focused on the decrease of the nitrogen emissions from point and diffuse sources alone. Additional measures aimed at an increased retention and losses of nitrogen near by or within the surface waters of a river system (e. g. buffer strips, establishing renaturalization of wetlands, small reservoirs) are necessary.

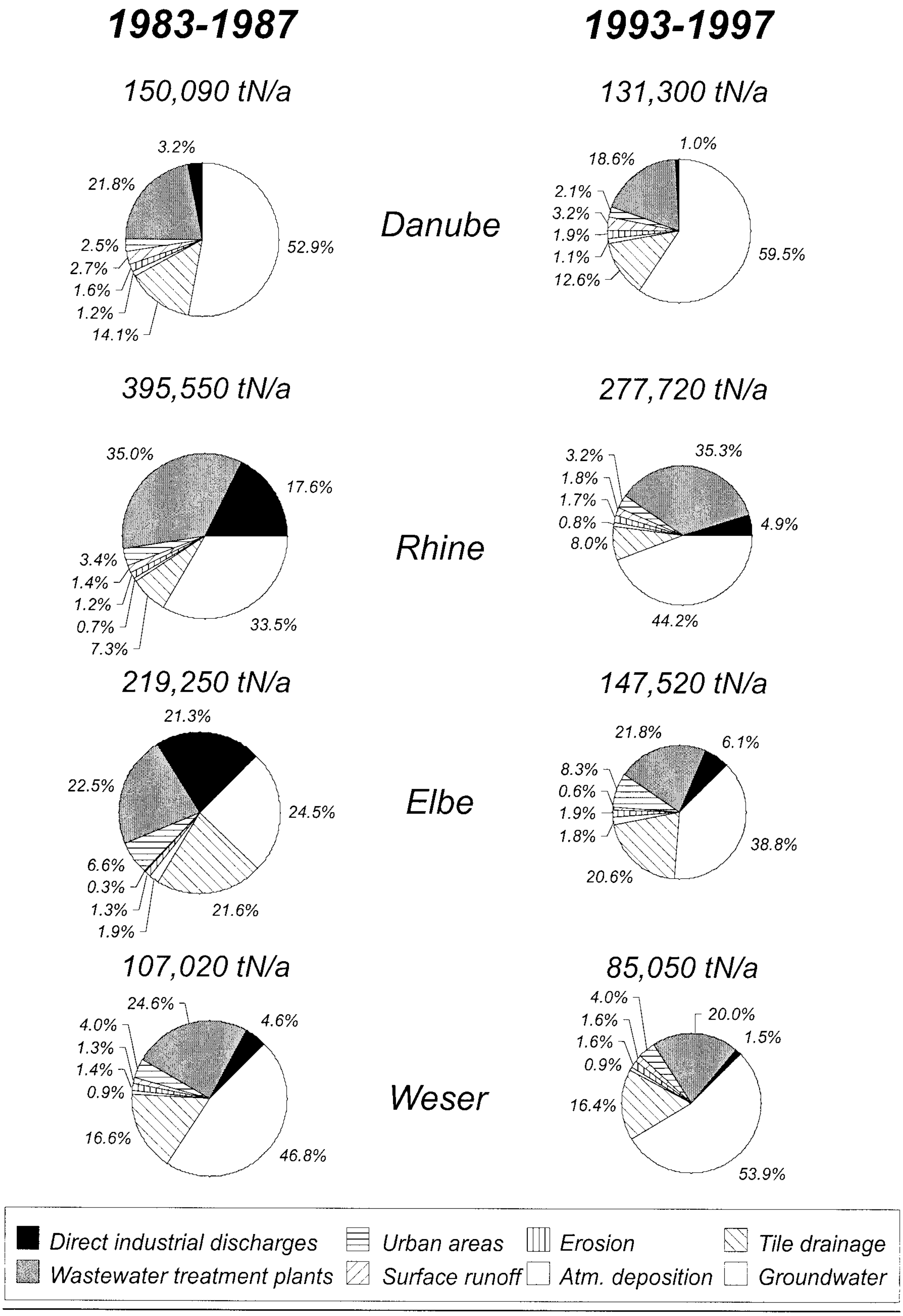


Figure 2: Nitrogen inputs via the various pathways into German river basins in the time periods 1983-1987 and 1993-1997.

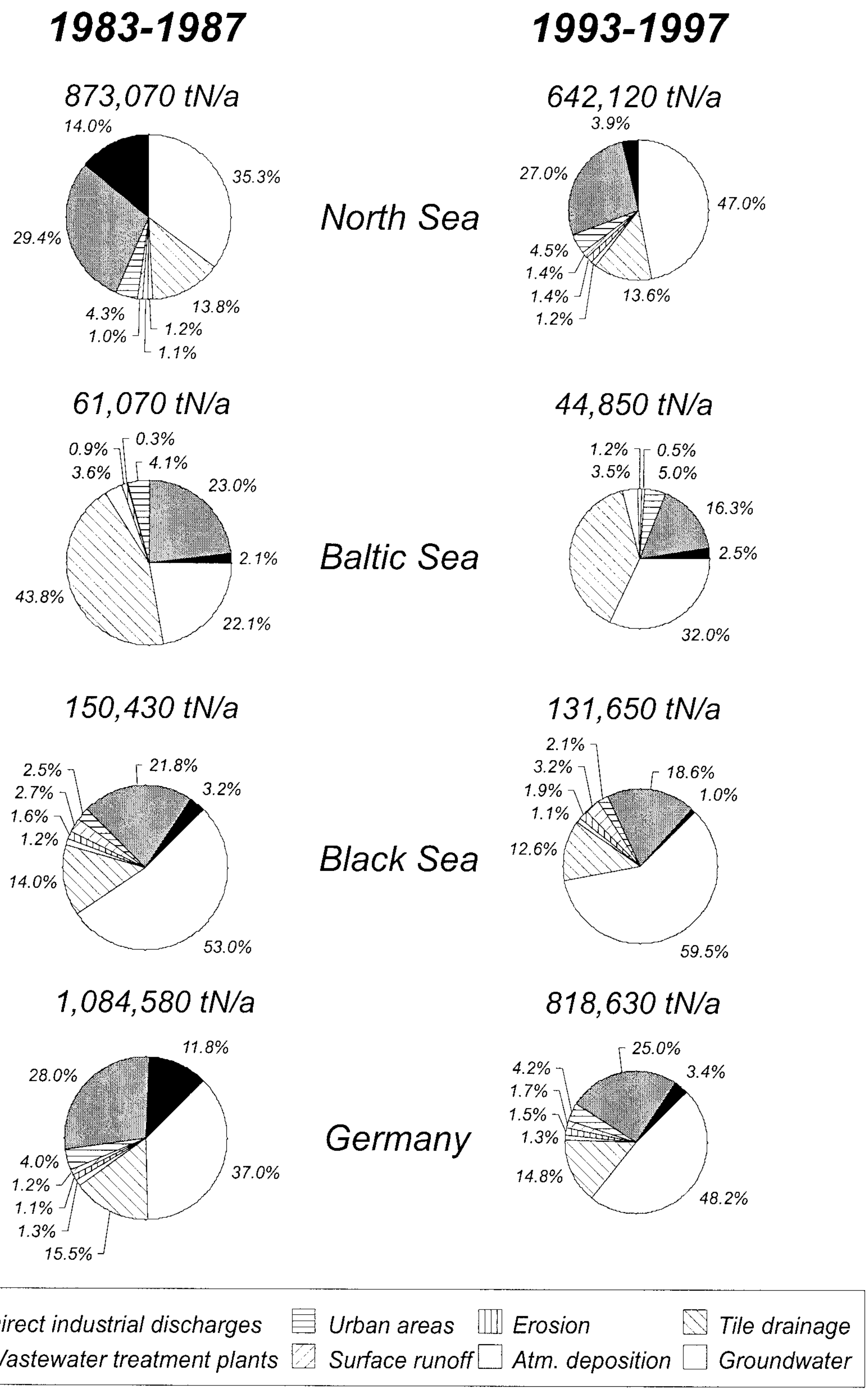


Figure 3: Nitrogen inputs via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987 and 1993-1997.

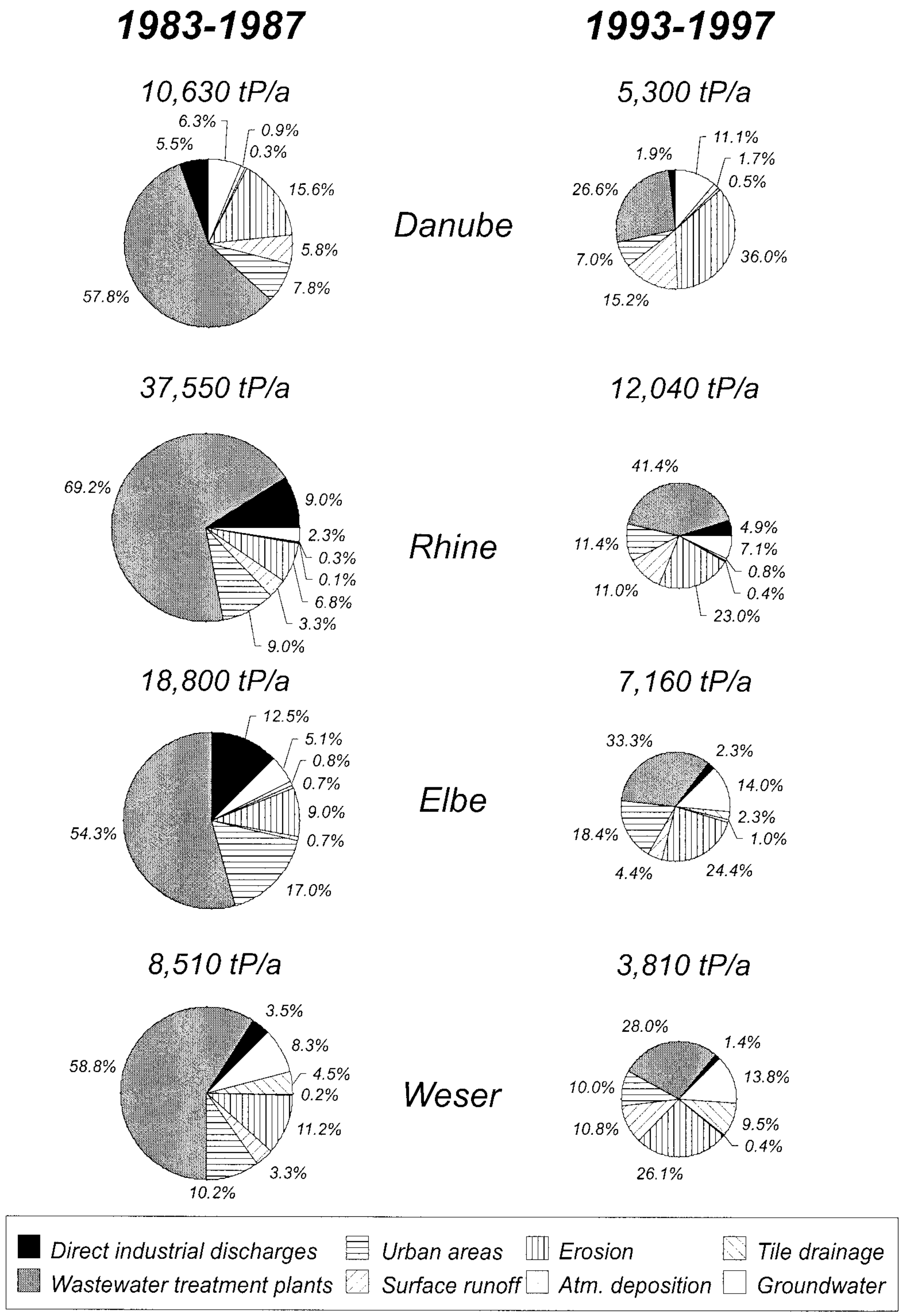


Figure 4: Phosphorus inputs via the various pathways into German river basins in the time periods 1983-1987 and 1993-1997.

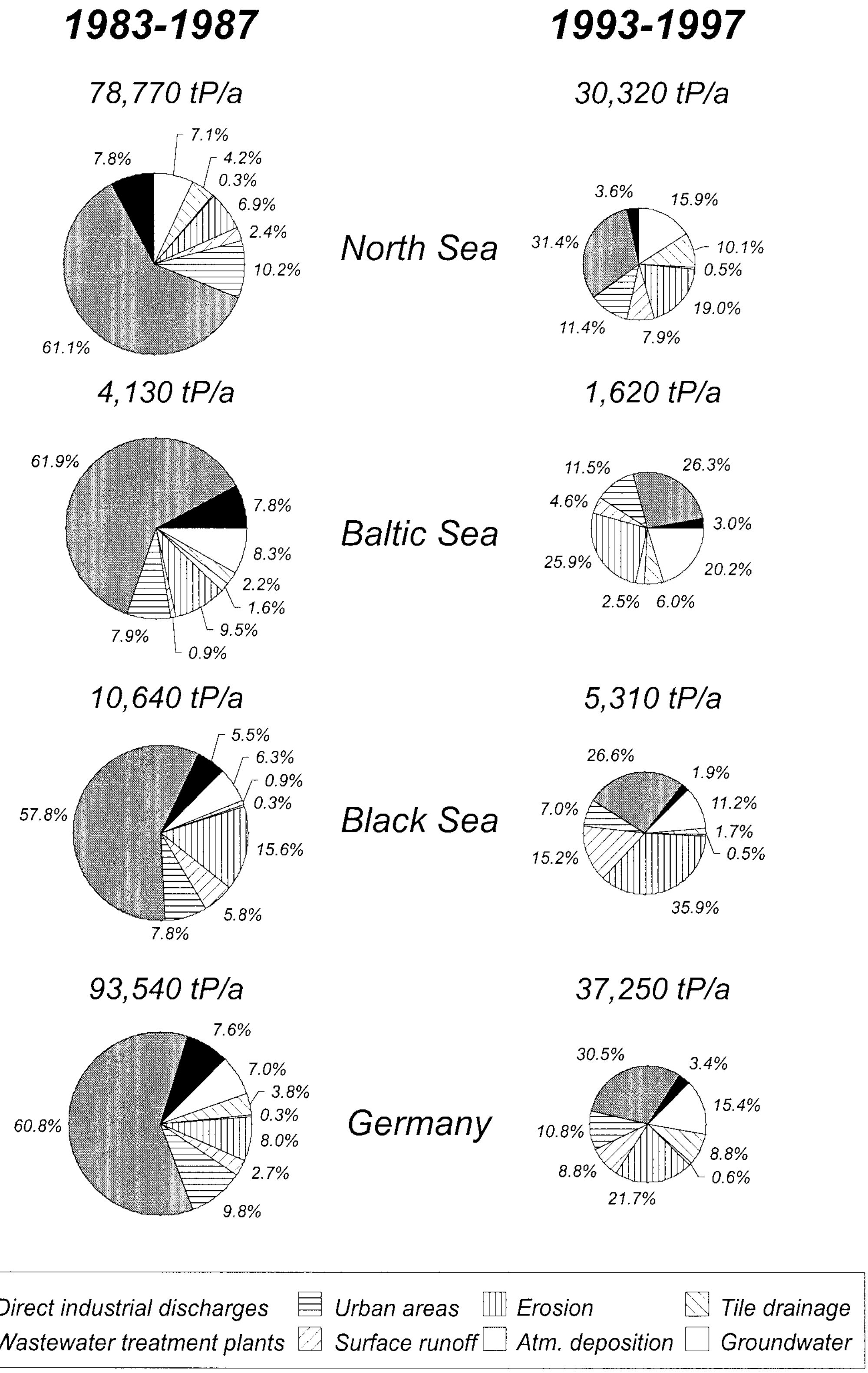


Figure 5: Phosphorus inputs via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987 and 1993-1997.

Table 1: Nitrogen inputs via various pathways, their contributions to the total input and their changes for the German parts of the Elbe, Rhine and Danube basins and the Weser for the periods 1983-1987 and 1993-1997.

Pathway		**Elbe**			**Weser**			**Rhine**			**Danube**		
		1983-87	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**
Groundwater	[t N/a]	53,760	57,270	*+6.5%*	50,060	45,820	*-8.5%*	132,580	122,750	*-7.4%*	79,400	78,090	*-1.6%*
	[%]	24.5	38.8		46.8	53.9		33.5	44.2		52.9	59.5	
Tile drainage	[t N/a]	47,460	30,340	*-36.1%*	17,740	13,910	*-21.6%*	28,690	22,340	*-22.1%*	21,110	16,600	*-21.4%*
	[%]	21.6	20.6		16.6	16.4		7.3	8.0		14.1	12.6	
Erosion	[t N/a]	2,880	2,830	*-1.6%*	1,460	1,400	*-4.3%*	4,570	4,610	*+1.0%*	2,340	2,490	*+6.2%*
	[%]	1.3	1.9		1.4	1.6		1.2	1.7		1.6	1.9	
Surface runoff	[t N/a]	570	890	*+56.9%*	1,340	1,380	*+3.1%*	5,660	5,110	*-9.7%*	4,090	4,190	*+2.3%*
	[%]	0.3	0.6		1.3	1.6		1.4	1.8		2.7	3.2	
Atmospheric deposition	[t N/a]	4,060	2,700	*-33.3%*	960	740	*-22.5%*	2,760	2,300	*-16.8%*	1,790	1,440	*-19.8%*
	[%]	1.9	1.8		0.9	0.9		0.7	0.8		1.2	1.1	
Urban areas	[t N/a]	14,430	12,250	*-15.1%*	4,270	3,440	*-19.4%*	13,580	8,850	*-34.8%*	3,830	2,800	*-26.7%*
	[%]	6.6	8.3		4.0	4.0		3.4	3.2		2.5	2.1	
Sum diffuse sources	**[t N/a]**	**123,160**	**106,290**	***-13.7%***	**75,820**	**66,690**	***-12.0%***	**187,840**	**165,970**	***-11.6%***	**112,560**	**105,610**	***-6.2%***
	[%]	**56.2**	**72.0**		**70.8**	**78.4**		**47.5**	**59.8**		**75.0**	**80.4**	
Municipal WWTP`s	[t N/a]	49,330	32,230	*-34.7%*	26,310	17,050	*-35.2%*	138,250	98,010	*-29.1%*	32,750	24,420	*-25.4%*
	[%]	22.5	21.8		24.6	20.0		35.0	35.3		21.8	18.6	
Direct industrial discharges	[t N/a]	46,760	9,000	*-80.7%*	4,890	1,320	*-73.1%*	69,450	13,740	*-80.2%*	4,780	1,270	*-73.4%*
	[%]	21.3	6.1		4.6	1.5		17.6	4.9		3.2	1.0	
Sum point sources	**[t N/a]**	**96,090**	**41,230**	***-57.1%***	**31,200**	**18,360**	***-41.1%***	**207,700**	**111,750**	***-46.2%***	**37,530**	**25,690**	***-31.5%***
	[%]	**43.8**	**28.0**		**29.2**	**21.6**		**52.5**	**40.2**		**25.0**	**19.6**	
Sum all sources	**[t N/a]**	**219,250**	**147,520**	***-32.7%***	**107,020**	**85,050**	***-20.5%***	**395,550**	**277,720**	***-29.8%***	**150,090**	**131,300**	***-12.5%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 2: Nitrogen inputs via various pathways, their contributions to the total input and their changes for the German parts of the North Sea, Baltic Sea and Black Sea basins and all of Germany for the periods 1983-1987 and 1993-1997.

Pathway		North Sea			Baltic Sea			Black Sea			Germany		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t N/a]	308,240	301,690	*-2.1%*	13,510	14,340	*+6.1%*	79,680	78,390	*-1.6%*	401,430	394,430	*-1.7%*
	[%]	35.3	47.0		22.1	32.0		53.0	59.5		37.0	48.2	
Tile drainage	[t N/a]	120,400	87,280	*-27.5%*	26,780	17,510	*-34.6%*	21,110	16,600	*-21.4%*	168,290	121,390	*-27.9%*
	[%]	13.8	13.6		43.8	39.0		14.0	12.6		15.5	14.8	
Erosion	[t N/a]	9,330	9,270	*-0.6%*	530	530	*+0.5%*	2,340	2,490	*+6.4%*	12,200	12,290	*+0.8%*
	[%]	1.1	1.4		0.9	1.2		1.6	1.9		1.1	1.5	
Surface runoff	[t N/a]	9,080	9,140	*+0.6%*	160	220	*+43.0%*	4,110	4,200	*+2.2%*	13,350	13,560	*+1.6%*
	[%]	1.0	1.4		0.3	0.5		2.7	3.2		1.2	1.7	
Atmospheric deposition	[t N/a]	10,040	7,510	*-25.2%*	2,210	1,560	*-29.4%*	1,790	1,440	*-19.9%*	14,050	10,510	*-25.2%*
	[%]	1.2	1.2		3.6	3.5		1.2	1.1		1.3	1.3	
Urban areas	[t N/a]	37,290	29,060	*-22.1%*	2,520	2,230	*-11.6%*	3,830	2,810	*-26.6%*	43,650	34,100	*-21.9%*
	[%]	4.3	4.5		4.1	5.0		2.5	2.1		4.0	4.2	
Sum diffuse sources	**[t N/a]**	**494,380**	**443,940**	***-10.2%***	**45,700**	**36,390**	***-20.4%***	**112,880**	**105,940**	***-6.1%***	**652,970**	**586,280**	***-10.2%***
	[%]	**56.6**	**69.1**		**74.8**	**81.1**		**75.0**	**80.5**		**60.2**	**71.6**	
Municipal WWTP's	[t N/a]	256,460	173,110	*-32.5%*	14,070	7,320	*-48.0%*	32,770	24,440	*-25.4%*	303,300	204,860	*-32.5%*
	[%]	29.4	27.0		23.0	16.3		21.8	18.6		28.0	25.0	
Direct industrial discharges	[t N/a]	122,230	25,080	*-79.5%*	1,300	1,140	*-12.4%*	4,780	1,270	*-73.4%*	128,310	27,490	*-78.6%*
	[%]	14.0	3.9		2.1	2.5		3.2	1.0		11.8	3.4	
Sum point sources	**[t N/a]**	**378,690**	**198,180**	***-47.7%***	**15,370**	**8,460**	***-45.0%***	**37,550**	**25,710**	***-31.5%***	**431,610**	**232,350**	***-46.2%***
	[%]	**43.4**	**30.9**		**25.2**	**18.9**		**25.0**	**19.5**		**39.8**	**28.4**	
Sum all sources	**[t N/a]**	**873,070**	**642,120**	***-26.5%***	**61,070**	**44,850**	***-26.6%***	**150,430**	**131,650**	***-12.5%***	**1,084,580**	**818,630**	***-24.5%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 3: Phosphorus inputs via various pathways, their contributions to the total input and their changes for the German parts of the Elbe, Rhine and Danube basins and the Weser for the periods 1983-1987 and 1993-1997.

Pathway		**Elbe**			**Weser**			**Rhine**			**Danube**		
		1983-87	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**	**1983-87**	**1993-97**	**Change**
Groundwater	[t P/a]	950	1,000	*+5.3%*	710	530	*-25.6%*	880	850	*-2.7%*	670	590	*-12.1%*
	[%]	5.1	14.0		8.3	13.8		2.3	7.1		6.3	11.1	
Tile drainage	[t P/a]	140	160	*+13.3%*	380	360	*-4.9%*	100	100	*+0.9%*	100	90	*-9.2%*
	[%]	0.8	2.3		4.5	9.5		0.3	0.8		0.9	1.7	
Erosion	[t P/a]	1,680	1,740	*+3.6%*	960	1,000	*+4.0%*	2,560	2,770	*+7.8%*	1,660	1,910	*+14.8%*
	[%]	9.0	24.4		11.2	26.1		6.8	23.0		15.6	36.0	
Surface runoff	[t P/a]	120	320	*+159.5%*	280	410	*+46.5%*	1,230	1,320	*+6.9%*	620	810	*+30.8%*
	[%]	0.7	4.4		3.3	10.8		3.3	11.0		5.8	15.2	
Atmospheric deposition	[t P/a]	130	70	*-45.9%*	16	14	*-9.7%*	48	46	*-5.4%*	30	29	*-5.7%*
	[%]	0.7	1.0		0.2	0.4		0.1	0.4		0.3	0.5	
Urban areas	[t P/a]	3,200	1,320	*-58.8%*	860	380	*-55.9%*	3,390	1,380	*-59.4%*	820	370	*-55.0%*
	[%]	17.0	18.4		10.2	10.0		9.0	11.4		7.8	7.0	
Sum diffuse sources	**[t P/a]**	**6,230**	**4,620**	***-25.9%***	**3,210**	**2,690**	***-16.1%***	**8,210**	**6,460**	***-21.3%***	**3,900**	**3,790**	***-2.8%***
	[%]	**33.2**	**64.5**		**37.7**	**70.6**		**21.9**	**53.7**		**36.7**	**71.5**	
Municipal WWTP`s	[t P/a]	10,210	2,380	*-76.7%*	5,010	1,070	*-78.7%*	25,970	4,990	*-80.8%*	6,140	1,410	*-77.1%*
	[%]	54.3	33.3		58.8	28.0		69.2	41.4		57.8	26.6	
Direct industrial discharges	[t P/a]	2,350	160	*-93.1%*	300	50	*-81.6%*	3,370	590	*-82.4%*	580	100	*-82.7%*
	[%]	12.5	2.3		3.5	1.4		9.0	4.9		5.5	1.9	
Sum point sources	**[t P/a]**	**12,560**	**2,540**	***-79.7%***	**5,300**	**1,120**	***-78.9%***	**29,340**	**5,580**	***-81.0%***	**6,720**	**1,510**	***-77.5%***
	[%]	**66.8**	**35.5**		**62.3**	**29.4**		**78.1**	**46.3**		**63.3**	**28.5**	
Sum all sources	**[t P/a]**	**18,800**	**7,160**	***-61.9%***	**8,510**	**3,810**	***-55.2%***	**37,550**	**12,040**	***-67.9%***	**10,630**	**5,300**	***-50.1%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

Table 4: Phosphorus inputs via various pathways, their contributions to the total input and their changes for the German parts of the North Sea, Baltic Sea and Black Sea basins and all of Germany for the periods 1983-1987 and 1993-1997.

Pathway		North Sea			Baltic Sea			Black Sea			Germany		
		1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change	1983-87	1993-97	Change
Groundwater	[t P/a]	5,560	4,820	*-13.3%*	340	330	*-4.0%*	680	590	*-12.1%*	6,580	5,740	*-12.7%*
	[%]	7.1	15.9		8.3	20.2		6.3	11.2		7.0	15.4	
Tile drainage	[t P/a]	3,320	3,070	*-7.4%*	90	100	*+5.7%*	100	90	*-9.2%*	3,510	3,260	*-7.1%*
	[%]	4.2	10.1		2.2	6.0		0.9	1.7		3.8	8.8	
Erosion	[t P/a]	5,440	5,770	*+6.1%*	390	420	*+7.5%*	1,660	1,910	*+14.9%*	7,490	8,100	*+8.1%*
	[%]	6.9	19.0		9.5	25.9		15.6	35.9		8.0	21.7	
Surface runoff	[t P/a]	1,870	2,400	*+28.8%*	35	70	*+111.0%*	620	810	*+30.8%*	2,520	3,290	*+30.4%*
	[%]	2.4	7.9		0.9	4.6		5.8	15.2		2.7	8.8	
Atmospheric deposition	[t P/a]	230	160	*-29.4%*	70	41	*-39.3%*	30	29	*-5.7%*	330	230	*-29.2%*
	[%]	0.3	0.5		1.6	2.5		0.3	0.5		0.3	0.6	
Urban areas	[t P/a]	8,040	3,460	*-56.9%*	330	190	*-42.9%*	830	370	*-55.0%*	9,190	4,020	*-56.3%*
	[%]	10.2	11.4		7.9	11.5		7.8	7.0		9.8	10.8	
Sum diffuse sources	**[t P/a]**	**24,450**	**19,700**	***-19.5%***	**1,250**	**1,150**	***-8.5%***	**3,910**	**3,800**	***-2.8%***	**29,620**	**24,640**	***-16.8%***
	[%]	**31.0**	**65.0**		**30.4**	**70.7**		**36.7**	**71.5**		**31.7**	**66.2**	
Municipal WWTP`s	[t P/a]	48,150	9,520	*-80.2%*	2,550	430	*-83.3%*	6,150	1,410	*-77.0%*	56,850	11,350	*-80.0%*
	[%]	61.1	31.4		61.9	26.3		57.8	26.6		60.8	30.5	
Direct industrial discharges	[t P/a]	6,160	1,100	*-82.1%*	320	48	*-85.0%*	580	100	*-82.7%*	7,070	1,250	*-82.3%*
	[%]	7.8	3.6		7.8	3.0		5.5	1.9		7.6	3.4	
Sum point sources	**[t P/a]**	**54,310**	**10,620**	***-80.4%***	**2,880**	**470**	***-83.5%***	**6,730**	**1,510**	***-77.5%***	**63,920**	**12,610**	***-80.3%***
	[%]	**69.0**	**35.0**		**69.6**	**29.3**		**63.3**	**28.5**		**68.3**	**33.8**	
Sum all sources	**[t P/a]**	**78,770**	**30,320**	***-61.5%***	**4,130**	**1,620**	***-60.7%***	**10,640**	**5,310**	***-50.1%***	**93,540**	**37,250**	***-60.2%***
	[%]	**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**		**100.0**	**100.0**	

1 Introduction

The *International Conference on the Protection of North Sea* (*ICN*) and *Helsinki-Commission* (*HELCOM*) agreed on a 50% reduction in nitrogen and phosphorus inputs to the North Sea and Baltic Sea for the period 1985/1987 to 1995. The fulfilment of this agreement is a political necessity in relation to sea conservation. A requirement of this plan was to test to what extent the nutrient loadings of the North and Baltic Seas had been reduced in relation to inputs to German freshwaters in the last 10 years. Since a reduction in nutrient loading and the consequent eutrophication is necessary not only in the seas but also in the rivers, future measures should be identified through analysis of regions with high loadings.

The nutrient loading of water bodies is caused by inputs from point and diffuse sources. Since the knowledge of the size of inputs from individual pathways in the particular catchments is a prerequisite for the working out of further measures for the reduction of nutrient loading, a model system for the estimation of emission into the water bodies was established, based on the studies of HAMM (1991) and WERNER & WODSAK (1994). Comparison of the results of HAMM (1991) for the old German states and of WERNER & WODSAK (1994) for the new German states was however hindered by their use of different reference periods and also by methodological differences. It was however the wish of the providers of the contract to modify the method such that all examined catchments can be used for the periods around 1985 and 1995. Further the previous methodological problems for certain areas should be overcome through a unified approach and a GIS-supported consideration of the area-based differences in conditions in the individual catchments. Analysis of the nutrient inputs of the covered catchments should yield a closed picture for all areas, from the cause of the nutrient inputs to the observed nutrient loadings.

Accordingly, a catchment based nutrient balance was necessary for agricultural lands for the period 1985 to 1995 and also the derivation of the relationships between this nutrient balance and the various diffuse pathways in relation to geomorphological, soil and hydrological conditions in the particular catchments. At the same time, an explanation was sought for the discrepancies between the sum of the nutrient inputs and the realised loadings in the rivers and to derive an preliminary model approach for possible nutrient losses and retentions witin the river systems.

At the beginning of the project in mid 1996, the feasability of GIS-supported analyses for large areas, the availability of digital maps and the data requirements were assessed. Therefore, the estimation of various nutrient input pathways for German catchments with a size of ca. 1,000 km^2 to the large river catchments was a considerable challenge. Without the support of the staff of the German Environmental Agency and also above all also the environmental agencies of the sixteen German states the carrying out of this type of study would not have been possible. In addition, we worked together with the *Gesellschaft für*

Boden- und Gewässerschutz e.V. and the company *geodaten, integration & analyse.* They were very effective partners who fulfilled their tasks well and were always available to help.

In this report, the model system **MONERIS** (**Mo**delling of **N**utrient **E**missions in **RI**ver **S**ystems) is described which was developed over a two and a half year period. MONERIS is designed for the analysis of nutrient inputs in catchment areas of more than 500 km^2 and has the capacity to be applied to other substances.

MONERIS takes account of a total of eight input pathways or sub-models – atmospheric deposition, erosion, surface runoff, groundwater, tile drainage, urban areas, municipal wastewater treatment plants and direct industrial discharges. With the exception of inputs through atmospheric deposition and direct industrial discharges, for which results of other studies were directly used, MONERIS carries out a balance for each input pathway, i.e. nutrient influx in the catchment and output, i.e. nutrient inputs in surface waters. Through this it is possible to calculate specific retentions and losses on the way from the source to input to appearance in the water body and also possible future inputs with changed conditions in the form of scenarios. The nutrient loads leaving the catchment were calculated from the determined sum of inputs from all individual pathways including internal retention and losses of the water body.

The sub-models developed validated with available measurements but not for observed nutrient loadings. These were merely used for comparison with model results. All model coefficients were derived for the 1993-1997 period. For the 1983-1987 period, these coefficients were used for MONERIS but with altered nutrient inputs.

2 Database

2.1 Spatial input data

For the project, the following data were used in connection with Geographical Information Systems (GIS):

- Landuse after CORINE-Landcover (Data on German soil cover, *Federal Statistical Agency*, 1997; Phare Natural Resources, Land Cover, *European Commission*, 1996; Corine Land Cover of Europe, *European Topic Centre on Land Cover*, Kiruna, Sweden, 1997)
- Landuse from Landsat TM 1989 (*IFEIF*)
- General soil map BÜK 1.000 from the *Federal Institute for Geosciences and Natural Ressources (Bundesanstalt für Geowissenschaften und Rohstoffe, BGR)*
- Map of the Medium-scale agricultural site mapping (MMK 100, State Geological Offices of the new German states)
- Map of the Medium-scale agricultural site mapping (MMK 25, *IFEIF*)
- Hydrogeological map of Europe from the *National Institute of Public Health and the Environment* (*RIVM*, Netherlands)
- River network and catchment area boundaries from the *German Federal Environmental Agency (FEA)*
- River network and elevations from TK25AS (*IFEIF*)
- Digital elevation model (DEM) from USGS
- ArcGemeinde (*ESRI*-Germany)
- Statistical data for communities and districts (State Statistical Offices)
- Tile drainage area in selected catchment areas of the new German states
- Results from interviews on tile drainage areas of agricultural areas for the old German states (BACH ET AL., 1998)
- Soil erosion for selected areas of communities or districts (DEUMLICH ET AL., 1997); Bavaria, (AUERSWALD, K. & SCHMIDT, F., 1986); Baden-Württemberg (GÜNDRA ET AL., 1995)
- Community soil erosion information for the Polish area of the Odra catchment. (OKRUSZKO & DIRKSEN, 1999; personal communication DEUMLICH, 1999)
- Digital soil erosion maps for Baden-Württemberg, Germany and western Europe (personal communication KLEIN, 1998)
- Regionally differentiated nitrogen and phosphorus surpluses from agricultural areas (BACH ET AL., 1998)
- Long-term development of nitrogen and phosphorus surpluses in Germany and the individual German states (BACH ET AL. (1998) and calculated according to information from statistical year books)

- Results on atmospheric deposition of nitrogen oxides and Ammonium with a resolution of 150 km for 1985 and 50 km for 1996 from EMEP of the *Norwegian Meteorological Institute (DNMI)*
- Data on sewer systems and connected inhabitants at the level of three star code for the river basins and precipitation areas of the *State Water Working Group (Länderarbeitsgemeinschaft Wasser, LAWA)* from the State Statistics Offices.

Data for all areas covered were transferred in a uniform projection (ARC). Through overlay of the catchment boundaries with these data, all values were estimated direct for the catchments. For rivers passing through national borders attempts were made to extend the digital database to the adjoining areas of neighbouring countries. For that, representative values are necessary for the entire river catchment. However, this is only possible if the data attained for these countries are comparable to those for Germany, as for example with CORINE-Landcover.

The available data includes landuse data (CORINE-Landcover) from satellite photographs for the years 1989-1992 for Germany, Austria, France, the Czech Republic, Poland, Switzerland and also the Benelux Countries from the *State Statistics Offices*, the PHARE-Program of the European Union and the *European Topic Centre on Land Cover* (see Map 2.1). These were used for both study periods because area related data were not separately available.

Landsat TM 1989

In addition to the CORINE data, landuse data from Landsat TM 1989 are available for the catchments of the River Spree and River Salza. The resolution is 30 m and is in ERDAS 7.1-digital format. The classification of the *Environmental Research Institute* (*ESRI*), Kranzberg was used with the classes "built-up areas", "agricultural areas", "permanent fallow", "woodland", "water-bodies" and "wetlands".

BÜK and MMK

For the analysis of soil type in the catchment areas, general soil maps for Germany (BÜK 1000) were available with 72 soil classes and a scale of 1:1,000,000 of the *Federal Institute of Geosciences and Natural Resources* (see Map 2.2). In addition, for the new German states, the Medium-scale agricultural site mapping (MMK) with a scale of 1:100,000 for agricultural areas are used. These are available from State Geology Offices. For the River Spree catchment area there is also an MMK map with a scale of 1:25,000.

Hydrogeology

For the differentiation of areas with consolidated and non-consolidated rocks of the catchment areas, the RIVM hydrogeological map was used (see Map 2.3).

River network, catchment boundaries and monitoring stations

The model data for the rivers and also for the hydrological area sub-divisions are based on the German base map with a scale of 1:1,000,000. The essential basis is the freshwater-net map D1000 of the German Environmental Agency. Additionally data from the following sources were used:

- ARC/INFO-cover NETZ of the river network map of the FEA.
- ARC/INFO-cover of the Polish river network map (scale 1:500,000) (*IFEIF*)
- Digital river network map of Switzerland (Rhine, Danube, *German Statistics Office*, GEOSTAT project)
- ARC/INFO-Cover of rivers in the Czech catchment areas of the Elbe and Odra (*IFEIF*)
- Small scale analogue maps of the coarse network in the Danube and Rhine areas (Austria, France).

Map 2.4 gives a complete overview. In addition, the digitised rivers from the topographic map TK25AS of the former GDR were used for the Spree and Salza catchment areas.

The FEA Cover EZG1000 serves as an initial separation of all catchment areas. In this data the entire German territory is described according to the 3. hierarchy of the State water working group. The location of the watersheds was derived according to the *FEA* from the DEM1000. Therefore, the size of catchment areas in the Cover EZG1000 do not always correspond with those from State Offices. Additionally the boundaries of the catchment areas from the following data bases were incorporated:

- Cover of the FEA-database "River network 1:1.000.000"
- Cover of the IFEIF-database "Polish river network 1:500.000"
- Analogous overview map of the rainfall areas of the Rhine, Danube and Elbe (especially in the upper reaches and Austrian, Swiss and French Areas).
- Analogous watershed maps of the Czech Republic (1:500,000)

As additional borders from all used monitoring stations, further catchment boundaries were constructed. The geographical location of the monitoring stations in the water network was derived from qualitative very different sources. The primary information comes either as stored coordinates in various geographic reference systems or as verbal descriptions of the location relative to water bodies and towns. For this project, all locations were transferred in a uniform project-coordination system.

After the generation of the additional catchment borders in the catchment database, a fine correction of the location was necessary for many monitoring stations. The correction was based on the assumption that every monitoring station lies exactly on the cut-off point of the middle line of the river and the catchment boundary. In individual cases, existing information over the location on the left or right river-bank was not considered because of the small scale of the river network map. The catchment areas and monitoring stations used are shown in Map2.5.

DEM

The digital elevation model GTOPO30 of the *U.S. Geological Survey* was used for an overview of relief in the catchment areas, (see Map 2.6).

In addition, an elevation model with a scale of 1:10,000 was used for the Salza catchment area. For the Spree, a DEM with a grid size of 30 m was used based on the digital contours of the topographical maps TK25AS of the former GDR.

ArcGemeinde

The ArcGemeinde database from ESRI was used for the spatial presentation and the catchment based analysis of administrative data. This database includes the administrative boundaries for the German States, districts and communities in digital format in a scale of 1:500,000.

Statistical data on municipalities and districts

In addition to the digital database of areas and linear objects community data on the population (see Map 2.7), landuse, cultivation and the livestock (see Map 2.8) were available in tabular form. The data were supplied by the State Statistics Offices. For the old German states (former West Germany) this information is available for 1985 and 1995. For the new German states (former GDR) this information is only available for 1995 for political reasons. With the help of ArcGemeinde this information was used in the GIS on an area basis and could be aggregated in the various catchment areas.

Tile-drainage areas in selected catchments

With regard to the extent of tile drainage in Germany, there are different available data for the old and new German states. For the new German states, information from the GDR statistical yearbooks on drained areas were used. The area information are divided into districts and support the drainage measures which were carried out between 1960 and 1989. Table 2.1 gives an overview of drained areas in the districts of the former GDR.

Table 2.1: Tile drained areas in the districts of the former GDR (from GDR Statistical yearbooks, 1960-1989).

District	Agricultural area	Tile drainage area	Proportion of agricultural area drained
	[km²]	[km²]	[%]
Cottbus	3.971	337	8
Dresden	4.107	743	18
Erfurt	5.287	623	12
Frankfurt/Odra	4.050	186	5
Gera	2.243	517	23
Halle	6.146	295	5
Karl-Marx-Stadt	3.384	686	20
Leipzig	3.409	673	20
Magdeburg	7.932	944	12
Neubrandenburg	7.293	1.135	16
Potsdam	7.129	453	6
Rostock	5.459	1.290	24
Schwerin	5.906	1.142	19
Suhl	1.825	285	16

In addition to the Statistical Yearbooks, overview maps of drained areas in parts of the former GDR were used. These maps were prepared from the melioration factories. These are based on topographical maps with a scale of 1:10,000 or 1:25,000 in which areas drained in the period 1960 to 1989 are shown. These maps have been partially taken over by the newly founded Water and Soil Associations of the new German states. In part, these documents however have been lost through German reunification. As a result of this and the limited record of drained areas, for the area of the new German states, detailed area-based data on drained areas is available only from a representative sample survey (see Map 2.9).

For the catchment areas in the old German states, the extent of the drained areas estimated by BACH ET AL. (1998) will be drawn upon. This was constructed on the basis of a survey of the agricultural administrations (see Map 2.10).

Soil erosion maps

Information on soil erosion must rely on a number of different data bases. In all published data, the empirical erosion model of the uniformed soil erosion equation (USLE) has been used. Through this, nearly comparable descriptions can be made (SCHWERTMANN ET AL., 1987).

The soil erosion in the new German states based on community data were used according to DEUMLICH & FRIELINGHAUS (1994). These soil erosion data were integrated into the GIS with ArcGemeinde.

For soil erosion in the Polish catchment area of the Odra the community based data from (OKRUSZKO & DIRKSEN, 1999) and DEUMLICH (personal communication, 1999) were used and integrated in the GIS.

For Bavaria, the original digital soil erosion map is as yet usable only in analogue form (personal communication MARTIN, 1998). The tabular, district based published values (AUERSWALD & SCHMIDT, 1986) can be integrated into the GIS with ArcGemeinde for further analysis.

In contrast, for Baden-Württemberg one can use digital data from the Internet published "Soil Erosion Atlas of Baden-Württemberg" of GÜNDRA ET AL. (1995) (http://www.geog.uni-heidelberg.de/~hartmut/atlas.html). The maps from this source can be downloaded as ARC/INFO convertable data. These maps show the "soil erosion weighted by cropland" in a 2x2 km grid (personal communication GÜNDRA, 1998).

Soil erosion in the new German states, Bavaria, Baden-Württemberg and the Polish part of the Odra catchment are shown in Map 2.11.

Two digital maps of soil erosion after USLE from the *Fraunhofer Institute of Ecotoxicology* (personal communication Klein, 1998) were provided to the IFEIF. One is an soil erosion map for Germany with a resolution of 1 km. For western Europe, a soil erosion map with a 3 km resolution is available. It shows in particular erosion from fallow land (C-factor = 1). The two maps were merged into a single map with a uniform resolution of 1 km and integrated into the project coordination system.

Atmospheric deposition

Results for atmospheric deposition of nitrogen oxide and ammonium were delivered from the *Norwegian Meteorological Institute* (*DNMI*) with a resolution of 150 km for 1985 and 50 km for 1996. The total nitrogen deposition for 1996 is shown in Map 2.12.

2.2 Database for the quantification of nutrients via point sources

2.2.1 Municipal wastewater treatment plants in Germany

The database used comprises of information from individual wastewater treatment plants (WWTP) and their locations. Detailed records of individual treatment plants are considered separately for 1985 and 1995. For every recorded WWTP, the following information are placed in a data bank:

1. Name of plant
2. Name and address of the plant operator

3. Geographical location of the WWTP through assignment from the community indexes
4. Plant capacity as inhabitant equivalents (EW_{AB})
5. Wastewater purification process of the WWTP

For a portion of the recorded wastewater treatment plants, some of the following additional specifications are given:

A. Treated wastewater volume per year (Q_{GES})
B. Treated external water volume per year (Q_F).
C. Rate of utilisation (AU)
D. Connected inhabitants (E_{KA}) or inhabitant equivalents
E. Nitrogen parameters (concentration, yearly load)
F. Phosphorus parameters (concentration, yearly load)
G. Nutrient loading level from the *German Association for Water, Wastewater and Waste (Abwassertechnische Vereinigung, ATV)*

An overview of all recorded municipal wastewater treatment plant locations in 1995 is given in Map 2.13.

The assembling of all data follows from the literature. The principal sources for 1995 are the publications "Kläranlagen-Nachbarschaften" of the *ATV* groups of states and known publications of the German states. Moreover, information of the catchment area commissions (*ICPR, ICPD*), from individual WWTP operators and of the *Institute WAR of the Darmstadt University of Technology* are used. Table 2.2 gives an overview of the used sources in relation to the information used for 1995.

The compilation of municipal WWTP for 1985 is based on information of the *ATV* groups of states and the *German Commission for the Protection of the Rhine (Deutsche Kommission zum Schutz des Rheins, DKSR)* for West-Germany and West-Berlin. For the former GDR region, an existing database is used which was placed in the commission of the German Federal Environmental Agency (FEA) by BRODTMANN & KARRAS (1991). This contains a compilation of individual treatment plant locations in connection with further information such as year of putting in operation, the used treatment stages, the number of connected inhabitants and the treated wastewater volume. The compiled data reflect the state of wastewater purification at the end of the eighties. For the purpose of this study, only the records are used for all WWTP operating before 1986. The information on remaining plants are nevertheless used for the reference year 1985. It is assumed that in the period 1985 to 1990 in the former GDR, the situation of the municipal wastewater treatment plants, regarding the technology employed, purification performance and the connection-grade, had not essentially changed (see also the GDR statistical yearbooks for 1985 to 1990). In addition, the information of the FEA-records could be complimented with 1995 data for treatment plants in the current German states Saxony, Saxony-Anhalt and Thuringia. Table 2.3 provides an overview of the sources used for 1985.

Table 2.2: Sources of information used for 1995 (Column denotation- see pages 8 and 9).

Source	States	1	2	3	4	5	A	B	C	D	E	F	G
ATV-BW (1995)	BW	X	X		X	X			X		X	X	X
ATV-BY (1996)	BV	X	X		X	X	X						X
ATV-HERPSL (1995)	HE, RP, SL	X	X		X	X							X
ATV-NORD (1995)	HB, HH, LS, SH	X	X		X	X	X						X
ATV-NORDOST (1996)	BB, BE, MW, ST	X	X		X	X	X						X
ATV-NW (1994)	NW	X	X		X	X			X				X
ATV-SNTH (1996)	SX, TH	X	X		X	X							X
LANDTAG BB (1996)	BB	X			X								
LUA BB (1997)	BB	X			X								
BY MINIST-LU (1996)	BV	X			X	X							
LFW BY (1997)	BV						X				X	X	
HE MINIST-UEJFG (1996)	HE	X	X	X	X	X							
LAUN MV (1997)	MW	X					X				X	X	
NW MINIST-URL (1997)	NW	X			X	X	X						
LFW RP (1997)	RP	X			X	X							
SL MINIST-UEV (1996)	SL	X			X	X				X			
LUAG SN (1997)	SX	X			X	X							
ST MINIST-RLU (1997)	ST	X			X	X							
LFU TH (1996)	TH	X			X	X				X			
IKSD (1998)	BW, BV	X			X	X	X		X		X	X	
IKSE (1995)	BB, BE, BV, HH, MW, LS, SH, SX, ST, TH	X			X	X	X		X		X	X	
BWB (1997)	BB, BE	X			X	X	X			X	X	X	
BEB (1995)	HB	X	X			X	X			X	X	X	
HSE (1995)	HH	X	X			X	X			X	X	X	
WAR (1995)	All German States	X			X		X	X	X		X		

Table 2.3: Sources of information used for 1985 (for column headings see pages 8 and 9).

Source	States	1	2	3	4	5	A	B	C	D	E	F	G
ATV-BW (1987)	BW	X	X		X	X			X				
ATV-BY (1986)	BV	X	X		X	X							
ATV-HERPSL (1988)	HE, RP, SL	X	X		X	X							
ATV-NORD (1985)	BE (W), HB, HH, LS, SH	X	X		X	X			X				
ATV-NW (1986)	NW	X	X		X	X							
LUAG SN (1997)	SX	X			X	X							
ST MINIST-RLU (1997)	ST	X			X	X							
LFU TH (1996)	TH	X			X	X				X			
BRODTMANN & KARRAS (1991)	BB, BE (O), MW, SX, ST, TH	X			X	X	X			X			
DKSR (1988)	BW, BV, HE, NW, RP, SL	X			X								

An overview of the number and size of the treatment plants considered for 1995 can be taken from Table 2.4. Altogether 8,189 WWTP from all over Germany with a total capacity of ca. 154 million inhabitant equivalents (EW) have been recorded. These comprise about 80% of the total number of known treatment plants in Germany, if compared to statistical information.

Although the number of wastewater treatment plants is incomplete, there are nevertheless close to 100% of the known plant capacity recorded. That means that all important large treatment plants in the data collection can be considered. In particular for Bavaria, Mecklenburg-Western Pomerania and Schleswig-Holstein in which the recorded treatment plant number is comparatively low, lies the considered plants capacity over 90% of the total.

Table 2.4: Wastewater treatment plants registered in 1995 (STAT-ABW, 1995).

State	Number of WWTP (wastewater statistics)	Number of registered WWTP	Registration grade	WWTP size (wastewater statistics)	Registered WWTP size	Registration grade
			%	(10^3 EW)	(10^3 EW)	%
Brandenburg	265	265	*100%*	5.708	5.770	*101%*
Berlin	4	4	*100%*	2.975	2.975	*100%*
Baden-Württemberg	1.217	1.210	*99%*	21.296	21.375	*100%*
Bavaria	2.837	1.625	*57%*	28.940	27.163	*94%*
Bremen	4	4	*100%*	1.612	1.650	*102%*
Hesse	746	769	*103%*	10.411	10.372	*100%*
Hamburg	2	2	*100%*	3.000	3.000	*100%*
Mecklenburg-Western Pomerania	393	159	*40%*	2.898	2.848	*98%*
Lower Saxony	836	727	*87%*	15.505	15.825	*102%*
North Rhine-Westphalia	932	936	*100%*	35.861	36.161	*101%*
Rhineland-Palatinale	918	913	*99%*	7.140	7.163	*100%*
Schleswig-Holstein	802	241	*30%*	5.925	5.405	*91%*
Saarland	77	80	*104%*	1.526	1.632	*107%*
Saxony	614	662	*108%*	5.257	5.318	*101%*
Saxony-Anhalt	346	343	*99%*	4.043	3.829	*95%*
Thuringia	279	249	*89%*	3.163	3.211	*101%*
Germany	**10.272**	**8.189**	***80%***	**155.260**	**153.699**	***99%***

The registration grade for 1985 can only be given for plant number as there are no available data on plant size. For the former West Germany including West Berlin this comprises 69% of plants, corresponding to a total of 6,105 single inputs. At the covered scale, no registrations grade can be given 953 determined treatment plant in the area of the former GDR. Information on the number of known WWTP is missing. An overview of the registered treatment plants in 1985 is given in Table 2.5.

Table 2.5: Wastewater treatment plants registered in 1985 (STAT-ABW, 1987).

State	Number of WWTP (wastewater statistics)	Number of registered WWTP	Registration grade
			%
Berlin (West)	2	2	*100%*
Baden-Württemberg	1.239	1.235	*100%*
Bavaria	2.904	1.249	*43%*
Bremen	4	3	*75%*
Hesse	656	632	*96%*
Hamburg	6	3	*50%*
Lower Saxony	1.013	782	*77%*
North Rhine-Westphalia	1.207	1.028	*85%*
Rhineland-Palatinale	999	958	*96%*
Schleswig-Holstein	747	150	*20%*
Saarland	61	63	*103%*
Old German states including Berlin (West)	8.838	6.105	*69%*
GDR including Berlin (East)	-	953	-
Germany	**-**	**7.058**	**-**

Statistical information

On the basis of the rules of the environmental statistics and the German statistics rules, will a four year survey be carried out on the public wastewater purification with the institutes and bodies of the public rights and companies, the plants of the public wastewater purification operators. The results of this questionnaire are presented in the so-called processing table programme by 16 tables (as at 1995) for regional and thematically differentiated.

Within this study data for 1987, 1991 and 1995 are used from the processing table programme of the German states. Information of the used statistical tables is shown in Table 2.6. All data are subdivided after the one to three star codes for the river basins and precipitation areas of the *LAWA*.

Table 2.6: Table from the processing table program of the statistics of the public wastewater purification (1995).

Name	Content	Year
Table 5.2/1: Communities with public sewer systems	• Number of communities and inhabitants • Number of inhabitants connected to public sewers • Number of inhabitants connected to public WWTP	1987 1991 1995
Table 5.2/5a: Areas of the wastewater treatment plants according to type of treatment and size class	• Number of WWTP • Treated inhabitants and inhabitant equivalents • Treated wastewater volume	1987 1991 1995
Table 5.2/6: Annual loads of the harmfulness of treated water (for TP and DIN)	• Inflow and outflow concentrations • Annual loads	1991 1995

In addition, for the area of the former GDR, statistical information on the connection grade of the inhabitants to public wastewater treatment plants and also in the various types of treatment plants for 1989 will be used. These data are available at the district level and will be assembled according to BRODTMANN & KARRAS (1991). They will be used for the reference year 1985 for which it can be concluded, just as with the single registration grade, that the connection grade changed little from 1985 to 1989.

Databases of the federal states

For the states of Hesse and Bavaria there are aggregated data for 1995 from the WWTP operators. From the databases - in Hesse from the *Hesse State Environment Office*, in Bavaria from the *State Office of Water Management* - all relevant treatment plant data will be collected together and administered. Next to general information, such as for example the plant size or the installed treatment technology, the results of official monitoring and self-monitoring will be stored.

The following summary data are given according to size class and plant-type for the above-mentioned states:

- Annual wastewater volume
- Annual dirty-water volume
- Weighted average of outflow concentrations of nitrogen and phosphorus

2.2.2 Municipal wastewater treatment plants outside Germany

An overview of the nutrient inputs of municipal WWTP outside Germany in the Danube, Rhine and Elbe river basins is given in Table 2.7.

Table 2.7: Nutrient inputs ($EKK_{N,P}$) from municipal wastewater treatment plants in the river basins of the Danube, Rhine and Elbe in other countries.

Country	Catchment area	EKK_P 1985	EKK_P 1995	EKK_N 1985	EKK_N 1995	Source
		[t P/a]	[t P/a]	[t N/a]	[t N/a]	
Switzerland	Rhine	2,310	900	15,300*	14,300	IKSR (1989, 1999)
France & Luxemburg	Rhine	5,340	2,900	21,200*	16,400	IKSR (1989, 1999)
Austria	Danube	1,160	450	3,800	3,500	KROIß ET AL. (1997)
Czech Republic	Elbe	2,400	2,020†	19,700	13,300†	NESMERAK ET AL. (1995)

* only ammonium † Mean for 1991 to 1993

For the parts of the Rhine basin in Switzerland and France, nutrient inputs from municipal wastewater treatment plants will be assembled for 1985 and 1995 from national water protection commissions and the *ICPR* (AGENCE DE L'EAU, 1988; IKSR, 1989; IKSR, 1992; IKSR, 1999).

With the majority of the studied catchments of the Danube basin, parts lie in Austria. Accordingly, the nutrient inputs of wastewater treatment plants in these parts of catchment areas are to be considered. For individual sub-catchments of the Danube river basin, nutrient inputs have been quantified by KROIß ET AL. (1997). These authors have kindly given us data for municipal WWTP for more than 10,000 inhabitant equivalents in the Inn catchment area (ZEßNER, personal communication). This information can be directly assigned to individual catchment areas. Out of the above, the total nutrient inputs from point sources for the Inn catchment above Kirchdorf will be determined according to KROIß ET AL. (1997).

For the Elbe catchment within the Czech Republic, the results of the studies of NESMERAK ET AL. (1994), BLASKOVA ET AL (1998) and *ICPE* (IKSE, 1995) will be used.

2.2.3 Industrial direct dischargers

For the determination of N- and P-inputs from industrial wastewater the studies of ROSENWINKEL & HIPPEN (1997) and the *ICPR* (IKSR, 1999) for 1995 can be used. For the period before 1990, the results of von HAMM ET AL. (1991) and *ICPR* (IKSR, 1989) are available as well as the input inventory of *ICPE* (IKSE, 1992) and BEHRENDT (1994).

For inputs in other countries, information from *ICPR* (IKSR, 1989, 1999) and *ICPE* (IKSE, 1992, 1998) as well as published results (KROIß ET AL., 1997; NESMERAK ET AL., 1994; BLASKOVA ET AL., 1998) will be used.

An overview of the recorded nutrient inputs from direct industrial dischargers are shown in Table 2.8.

Table 2.8: Nutrient inputs ($EID_{N,P}$) in the river basins from direct industrial discharges in Germany and other countries.

Country	Catchment area	EID_P 1985 [t P/a]	EID_P 1995 [t P/a]	EID_N 1985 [t N/a]	EID_N 1995 [t N/a]	Source
Old German states		5,000		75,000		HAMM ET AL. (1991)
New German states		2.500		40,300		BEHRENDT (1994)
Germany	Rhine		594		13,291	ROSENWINKEL & HIPPEN (1997)
Germany	Rhine	3,250		40,485*		IKSR (1989, 1999)
Germany	Elbe		219		5,367	ROSENWINKEL & HIPPEN (1997)
Germany	Elbe		90++	2,.000	3,200++	IKSE (1992, 1995, 1998)
Germany	Weser		50		1,229	ROSENWINKEL & HIPPEN (1997)
Germany	Vechte		1		15	ROSENWINKEL & HIPPEN (1997)
Germany	Ems		18		300	ROSENWINKEL & HIPPEN (1997)
Germany	North Sea		32		339	ROSENWINKEL & HIPPEN (1997)
Germany	Baltic Sea		4		54	ROSENWINKEL & HIPPEN (1997)
Germany	Odra		44		1,084	ROSENWINKEL & HIPPEN (1997)
Germany	Danube		101		1,271	ROSENWINKEL & HIPPEN (1997)
Switzerland	Rhine	150	35	1,065*	1,000	IKSR (1989, 1999)
France	Rhine	1,280	410	37,500	4,400	IKSR (1989, 1999)
Austria	Danube	70	24	2,800	750	KROIß ET AL. (1997)
Czech Republic	Elbe	600	510+	12,000	10,400+	NESMERAK ET AL. (1995)
Czech Republic	Elbe	380**	320++	10,500**	7,100++	IKSE (1998)

* only ammonium ** 1989 + Mean for 1991 to 1993 ++ Mean for 1994 and 1997

2.3 Monitoring data

2.3.1 Groundwater

Data on groundwater concentrations from the State Environment Offices were used. Only stations were considered which represent the upper groundwater aquifer and not characterised through urban or industrial locations. Through that a distorted picture of the average groundwater concentration in the areas of monitoring stations through single high values can be avoided. The following parameters (so far these are available from the State Office measuring programmes) were required for the period 1980 to 1997: Nitrate, nitrite, ortho-phosphate, total phosphate, ammonium, chloride, iron, iron (II), TOC, DOC and temperature.

For the calculation of average nutrient concentrations in the investigated catchments in the period around 1985, information on ortho-phosphate is available for 933 German stations. For nitrate, the number of stations amounts to 833. For the period around 1995 there are ortho-phosphate values for 1,682 stations and 2,108 stations with nitrate values. Map 2.14 gives an overview of all considered monitoring stations.

For the Swiss part of the Rhine catchment area, information regarding ortho-phosphate and nitrate was taken from PRASUHN ET AL. (1996) for six small catchments of Lake Constance and from PRASUHN & BRAUN (1994) for 39 stations in catchment areas within the Bern canton.

For the determination of seepage water level, data on precipitation and air temperature were used from the "Monthly weather reports" of the *German Weather Service (Deutscher Wetterdienst, DWD)* for about 1,600 stations in the period from 1980.

2.3.2 Catchments and data of surface water monitoring

For this study, a total of 165 monitoring locations in German catchment areas was chosen. Every monitoring station was assigned with a clear address. This number is composed from the three star LAWA-code for the catchment area and an internal 2-place number. If the discharge is measured at another station than the water quality a conversion is necessary. To calculate the discharge at the water quality station the flow at the discharge monitoring station is multiplicated with a conversion factor (see Tables 2.10 - 2.15). If the conversion factor is not known, it will be determined from the relationship of the catchment area of water quality monitoring and discharge monitoring stations. For the chosen monitoring stations, measurements for 1982-1997 on the concentration of nutrients in the rivers and the discharge was required from the competent State Offices and International Commissions for the protection of the Elbe, the Mosel, the Rhine and the Saar. Since the sampling intervals, the methods and the measured parameters differ both between the individual German states and over time, not for all monitoring stations the same parameters or number of measurements were available. Some of the monitoring stations were set-up during study period or were not sampled throughout this time. The data, often not digital were uniformly processed for further use.

In addition to the discharge and water quality data from the routine measurement programmes, there are daily flow and suspended solids data for 31 additional catchment areas. Such data were ordered from the *Federal Agency for Hydrology (Bundesanstalt für Gewässerkunde, BfG)* and the *State Office of Water Management* of Bavaria. The monitoring stations are shown in Table 2.9. Map 2.15 gives an overview of their locations. The water quality and flow monitoring stations are practically identical. For 19 of these monitoring points there are data sets for more than 20 years.

Since the catchments of the 31 river were not represented in the ARC/INFO coverage of the catchments, these were newly determined on the basis of the fine river net map and existing catchment boundaries. In addition, these "new" monitoring points were given an exact address number. These catchments were not integrated into the existing ARC/INFO coverage.

Table 2.9: Monitoring stations with daily discharge and suspended solid measurements.

Address	River	Monitoring station	Period	A_{EZG} [km²]
11404	Iller	Kempten	1970-92	953
11602	Mindel	Offingen	1970-92	952
11802	Woernitz	Harburg	1987-92	1,566
13405	Altmuehl	Aha	1975-92	684
14601	Vils	Dietldorf	1987-91	1,096
15202	Regen	Regenstauf	1971-91	2,658
15408	Gr. Laber	Schoenach	1988-92	406
16686	Glonn	Hohenkammern	1971-91	392
16902	Isar	Plattling	1971-91	8,839
17215	Gr. Vils	Vilsbiburg	1971-92	318
17402	Ilz	Kalteneck	1970-92	762
18483	Traun	Stein	1970-92	378
18604	Saalach	Unterjettenberg	1970-92	940
18606	Saalzach	Burghausen	1970-92	6,644
18802	Rott	Ruhstorf	1970-92	1,053
19101	Danube	Jochenstein	1974-96	77,086
23999	Neckar	Rockenau	1971-96	12,710
24162	Itz	Coburg	1990-92	365
24202	Regnitz	Pettstadt	1970-92	7,005
24204	Regnitz	Huettendorf	1988-92	3,870
24206	Rednitz	Neue Muehle	1989-92	1,845
24210	Aisch	Laufermühle	1970-92	954
24211	Wiesent	Muggendorf	1970-92	664
24703	Main	Kleinheubach	1973-96	21,505
26903	Mosel	Brodenbach	1981-96	27,088
27904	Rhine	Emmerich	1982-96	159,555
37303	Ems	Versen	1966-96	8,369
49105	Weser	Intschede	1970-96	37,495
56902	Saale	Calbe	1991-95	23,718
59312	Elbe	Hitzacker	1963-95	131,950
69001	Odra	Schwedt	1991-94	112,950

The Danube

The size of the catchment areas of the 35 monitoring points in the Danube river basin ranges from 762 to 77,086 km². An overview of the monitoring station locations is given in Map 2.16. Table 2.10 shows water quality and discharge data in the Danube basin which could be used.

Table 2.10: Monitoring stations, discharge and water quality data in the Danube catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
11304	Danube	Hundersingen	Hundersingen	2,629	1.00	1991	1996		
11301	Danube	Oepfingen	Berg	4,248	1.05	1990	1996		
11404	Iller	Kempten	Kempten	953	1.00	1983	1997	1983	1997
11402	Iller	Wiblingen	Wiblingen	2,115	1.00	1983	1997	1983	1997
11503	Danube	Ulm	Neu-Ulm	7,578	1.00	1983	1996	1983	1997
11501	Danube	Boefinger Halde	Neu-Ulm	8,107	1.00	1983	1997	1983	1997
11602	Mindel	Offingen	Offingen	952	1.00	1983	1997	1983	1997
11702	Danube	Dillingen	Dillingen	11,315	1.00	1983	1997	1983	1997
11802	Woernitz	Ronheim	Harburg	1,566	1.00	1983	1997	1983	1997
11901	Danube	Schaefstall	Danubewoerth	15,150	1.00	1983	1997	1983	1997
12303	Lech	Fuessen	Fuessen	1,417	1.00	1983	1997	1983	1997
12901	Lech	Feldheim	Feldheim	3,926	1.00	1983	1997	1983	1997
13302	Danube	Neustadt	Kehlheim	21,792	1.00	1983	1997	1983	1997
13401	Altmuehl	Groegling	Beilngries	2,504	1.00	1983	1997	1984	1997
14302	Naab	Unterkoebelitz	Unterkoebelitz	2,004	1.00	1983	1997	1982	1997
14402	Schwarzach	Warnbach	Warnbach	821	1.00	1983	1997	1982	1997
14601	Vils	Dietldorf	Dietldorf	1,096	1.00	1983	1997	1982	1997
14902	Naab	Heitzenhofen	Heitzenhofen	5,426	1.00	1983	1997	1983	1997
15202	Regen	Regenstauf	Regenstauf	2,658	1.00	1983	1997	1983	1997
15901	Danube	Deggendorf	Pfelling	38,125	1.00	1983	1997	1983	1997
16502	Isar	Baierbrunn	Muenchen	2,803	1.00	1983	1997	1983	1995
16601	Amper	Moosburg	Inkofen	3,088	1.00	1983	1997	1983	1997
16902	Isar	Plattling	Plattling	8,839	1.00	1983	1997	1983	1997
17202	Vils	Grafenmuehle	Grafenmuehle	1,436	1.00	1983	1997	1983	1997
17301	Danube	Passau	Passau	50,586	1.00	1983	1997	1983	1995
17402	Ilz	Kalteneck	Kalteneck	762	1.00	1983	1997	1983	1997
18101	Inn	Kirchdorf	Oberaudorf	9,905	1.00	1983	1997	1983	1997
18302	Inn	Eschelbach	Eschelbach	13,354	1.00	1983	1997	1983	1989
18402	Alz	Seebruck	Seebruck	1,399	1.00	1983	1997	1983	1997
18404	Tiroler Achen	Staudach	Staudach	944	1.00	1983	1997	1983	1997
18602	Salzach	Laufen	Laufen	6,113	1.00	1983	1997	1983	1997
18603	Saalach	Freilassing	Staufeneck	1,131	1.04	1983	1997	1983	1997
18802	Rott	Ruhstorf	Ruhstorf	1,053	1.00	1983	1997	1983	1997
18902	Inn	Passau-Ingling	Passau-Ingling	26,049	1.00	1983	1997	1983	1997
19101	Danube	Jochenstein	Achleiten	77.086	1.00	1983	1997	1983	1997

The Rhine

The studied basin of the Rhine up to the monitoring station at Bimmen comprises 159,127 km². Map 2.17 shows the locations of the 34 monitoring stations. For most of these, the data are at least for the period up to 1997, for some however data is only available from 1990 onwards (see Table 2.11). The water quality and flow data of individual monitoring points show besides gaps for some parameters, so that not all loadings can be calculated for both time periods. The number of measured values ranges from weekly to monthly measurements.

Table 2.11: Monitoring stations, discharge and water quality data in the Rhine catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
21902	Rhine	Reckingen	Reckingen	14,718	1.00	1983	1996	1983	1995
23704	Rhine	Karlsruhe	Karlsruhe	50,196	1.00	1983	1996	1983	1996
23806	Neckar	Deizisau	Plochingen	3,995	1.00	1983	1996	1983	1992
23803	Neckar	Kochendorf	Lauffen	8,510	1.08	1983	1996	1983	1996
23801	Neckar	Mannheim	Heidelberg	13,957	1.01	1983	1996	1983	1996
24104	Main	Schwuerbitz	Schwuerbitz	2,420	1.00	1983	1997	1983	1997
24101	Main	Hallstadt	Kemmern	4,399	1.04	1983	1997	1983	1997
24203	Regnitz	Hausen	Huettendorf	4,472	1.20	1983	1997	1983	1997
24202	Regnitz	Pettstadt	Pettstadt	7,005	1.00	1983	1997	1983	1997
24303	Main	Viereth	Trunstadt	11,956	1.00	1983	1997	1983	1996
24401	Fränk. Saale	Gemuenden	Wolfsmuenster	2,141	1.00	1983	1997	1983	1997
24602	Tauber	Waldenhausen	Waldenhausen	1,798	1.00	1983	1997	1986	1997
24702	Main	Kahl a. Main	Kleinheubach	23,152	1.06	1983	1995	1983	1996
24706	Kinzig	Hanau	Hanau	925	1.00	1983	1995		
24901	Main	Bischofsheim	Frankfurt	27,140	1.10	1983	1995	1983	1996
25102	Rhine	Mainz	Mainz	98,206	1.00	1983	1995	1983	1996
25802	Lahn	Limburg-Staffel	Kalkofen	4,875	0.92	1983	1995	1983	1996
25901	Rhine	Koblenz	Koblenz	109,806	1.26	1985	1995	1990	1995
26101	Mosel	Palzem	Perl	11,623	1.00	1983	1995		
26407	Saar	Saarbruecken	Saarbruecken UP	3,818	0.96	1983	1995	1983/92	1987/93
26409	Blies	Reinheim	Reinheim	1,798	1.00	1983	1993		
26411	Nied	Niedaltdorf	Niedaltdorf	1,337	1.00	1983	1993	1983	1989
26481	Saar	Kanzem	Fremersdorf	7,490	1.07	1983	1993	1983	1996
26901	Mosel	Koblenz	Cochem	28,100	1.04	1983	1995	1983	1996
27101	Rhine	Bad Honnef	Bonn	140,756	1.00	1983	1995		
27202	Sieg	Menden	Menden	2,862	1.01	1983	1995	1983/90	1988/96
27301	Wupper	Obladen	Opladen	827	0.95	1985	1995	1990	1994
27303	Rhine	Duesseldorf-Flehe	Duesseldorf	145,750	0.99	1990	1994	1983	1996
27401	Erft	Eppinghoven	Neubrueck	1,828	1.15	1985	1995	1980	1994
27605	Ruhr	Villigst	Villigst	1,988	0.99	1985	1995	1990	1994
27601	Ruhr	Muendung	Hattingen	4,485	1.08	1985/90	1987/95	1991	1995
27680	Emscher	Muendung	Muendung	858	1.00	1985	1995		
27801	Lippe	Wesel	Schermbeck 1	4,886	1.02	1985	1993	1983/90	1988/94
27903	Rhine	Lobith-Bimmen	Rees	159,127	1.00	1983	1995	1990	1994

The Weser

In the Weser catchment area, 27 monitoring stations have been chosen (see Map 2.18). Up to Hemelingen, the last station not influenced by tides this catchment covers an area of 38,415 km² (see Table 2.12). The quality data were often first available from 1984 onwards, some only for the second time period. The discharge is often only available up to 1996, so that sometimes, the loadings cannot be calculated for the entire time period. The studied measurement programmes are also otherwise not comparable for all parameters between the two studied time periods.

Table 2.12: Monitoring stations, discharge and water quality data in the Weser catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
41011	Werra	Meiningen	Meiningen	1,170	1.00	1983	1996		
41009	Werra	Dorndorf	Vacha	2,246	1.00	1983	1996		
41007	Werra	Philipsthal	Vacha	2,258	1.03	1992	1996		
41006	Werra	Gerstungen	Gerstungen	3,039	1.00	1983	1997	1996	1997
41080	Werra	Treffurt	Heldra	4,266	0.99	1983	1996	1983	1996
41002	Werra	Letzter Heller	Letzter Heller	5,478	1.00	1983	1997	1983	1997
42004	Fulda	Rotenburg	Rotenburg	2,160	1.00	1992	1996	1983	1995
42001	Fulda	Wahnhausen	Guntershausen	6,933	1.09	1983	1997	1983	1997
42005	Schwalm	Felsberg-Altenburg	Uttershausen	1,299	1.32	1992	1996		
43001	Weser	Hemeln	Wahmbeck	12,550	0.96	1983	1997	1983	1997
47301	Weser	Porta	Porta	19,162	1.00	1983	1997	1983	1996
47601	Grosse Aue	Steyerberg	Steyerberg	1,446	1.00	1984	1997	1989	1996
48204	Oker	Ohrum	Ohrum	813	1.00	1984	1997	1983	1996
48202	Oker	Gross Schwuelper	Gross Schwuelper	1,734	1.00	1984	1997	1983	1996
48301	Aller	Langlingen	Langlingen	3,288	1.00	1984	1997	1983	1996
48601	Oertze	Stedden	Feuerschuetzenbostel	766	1.04	1984	1997	1983	1996
48808	Leine	Leineturm	Leineturm	990	1.00	1984	1997	1983	1996
48807	Rhume	Elvershausen	Elvershausen	1,115	1.00	1984	1997	1983	1996
48804	Leine	Poppenburg	Poppenburg	3,463	1.00	1984	1997	1983	1996
48805	Innerste	Sarstedt	Heinde	1,263	1.41	1984	1997	1983	1995
48802	Leine	Neustadt	Neustadt	6,043	1.00	1984	1997	1983	1995
48903	Boehme	Boehme	Hollige	562	1.09	1984	1997	1983	1996
48901	Aller	Verden	Rethem	15,220	1.05	1984	1997	1996	1997
49103	Weser	Hemelingen	Bremen	38,415	1.00	1983	1997	1996	1996
49401	Wuemme	Truperdeich	Hellwege-Schleuse	908	1.00	1984	1997	1983	1996
49603	Hunte	Tungeln	Huntlosen	1,878	1.05	1984	1997	1983	1996
49601	Hunte	Reithoerne	Huntlosen	2,344	1.37	1985	1997	1983	1996

The Elbe

Map 2.19 shows the locations of the 37 monitoring stations in the Elbe catchment. This covers an area of 135,000 km² up to the last station not influenced by tides. Of this area, 51,000 km² lies within the Czech Republic. As already explained for the other catchment areas, the data are not sufficient for a comparison of all parameters for the two time periods (see Table 2.13).

Table 2.13: Monitoring stations, discharge and water quality data in the Elbe catchment area.

Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
53706	Elbe	Schmilka	Schoena	51,391	1.00	1985	1997	1983	1997
53702	Elbe	Torgau	Torgau	55,211	1.00	1987/91	1988/95		
53801	Schw. Elster	Gorsdorf	Loeben	5,453	1.26	1985/87/93	1985/90/97	1996	1997
54101	Zwi. Mulde	Sermuth	Wechselburg	2,361	1.12	1987	1996	1983	1995
54205	Zschopau	Muendung	Kriebstein	1,846	1.05	1988	1996	1987	1996
54202	Freib. Mulde	Erlln	Erlln	2,983	1.00	1987	1996	1983	1995
54901	Mulde	Dessau	Bad Dueben	7,399	1.16	1989/93	1990/97	1987	1997
56102	Saale	Blankenstein	Blankenstein	1,013	1.00	1983	1996	1983	1995
56302	Saale	Camburg-Stöben	Camburg-Stöben	3,977	1.00	1983	1996		
56407	Gera	Muendung	Erfurt	1,089	1.29	1983	1996	1983	1995
56401	Unstrut	Freyburg	Laucha	6,327	1.02	1983	1995	1983	1995
56502	Saale	Naumburg	Naumburg	11,449	1.00	1983	1995	1983	1995
56609	Wei. Elster	Greiz uh	Greiz uh	1,255	1.00	1983	1996	1983	1995
56604	Wei. Elster	Zeitz	Zeitz	2,479	1.00	1983	1995	1983	1995
56601	Wei. Elster	Ammendorf	Oberthau	5,384	1.09	1983	1995	1983	1995
56704	Saale	Trotha	Trotha	17,979	1.00	1983	1995	1983	1996
56801	Bode	Neugattersleben	Stassfurt	3,297	1.02	1984	1995	1989	1995
56901	Saale	Gr. Rosenburg	Calbe	23,718	1.00	1983	1997	1983	1997
57302	Elbe	Magdeburg	Magdeburg	94,942	1.00	1983	1997	1983/95	1993/97
57602	Ohre	Wolmirstedt	Wolmirstedt	1,503	1.00	1984	1995	1983	1995
57903	Elbe	Tangermuende	Tangermuende	97,780	1.00	1984	1994	1983	1996
58101	Havel	Hennigsdorf	Borgsdorf	3,108	1.03	1983	1995	1983	1996
58210	Spree	Cottbus	Cottbus	2,269	1.00	1983/89	1987/95	1983	1996
58208	Spree	Leibsch	Leibsch	4,529	1.00	1989	1997	1989	1997
58232	Osk	Wernsdorf	Wernsdorf	70	1.00	1983	1997	1983	1997
58214	Dahme	Neue Muehle	Neue Muehle	1,362	1.00	1989	1997	1983	1997
58201	Spree	Neuzittau	Hohenbinde	6,401	1.00	1983	1997	1983	1997
58402	Nuthe	Muendung	Muendung	1,811	1.00	1983	1995	1983	1994
58905	Dosse	Saldernhorst	Wusterhausen	1,099	1.93	1983	1995	1983/89	1985/92
58901	Havel	Toppel	Havelberg	24,297	1.01	1983	1997	1984	1997
59101	Elbe	Schnackenburg	Neu-Darchau	125,482	0.93	1983	1997	1983	1997
59108	Biese	Osterburg	Dobbrun	924	0.58	1984	1995	1983	1995
59201	Elde	Doemitz	Doemitz	2,990	1.02	1983	1995	1983	1995
59302	Jeetzel	Lueggau	Luechow	1,660	1.28	1984	1997	1983	1996
59308	Sude	Bandekow	Garlitz	2,253	3.06	1983	1995	1983	1995
59311	Elbe	Zollenspieker	Neu-Darchau	135,024	1.03	1983	1997	1983	1997
59404	Ilmenau	Rote Schleuse	Bienenbuettel	1,545	1.08	1984	1997	1983	1996

The Ems and other North Sea rivers

In the area of the Ems and other smaller rivers which flow into the North Sea (see Map 2.20) including those not flowing into one of the main stream catchments inside Germany (Rur, Niers, Vechte) were summarised. A total of 12 catchment areas were studied with a size range of 468 to 9,207 km². There is sometimes insufficient data for calculation of the loadings (see Table 2.14).

Table 2.14: Monitoring stations, discharge and water quality data in the catchment area of the Ems and other North Sea rivers.

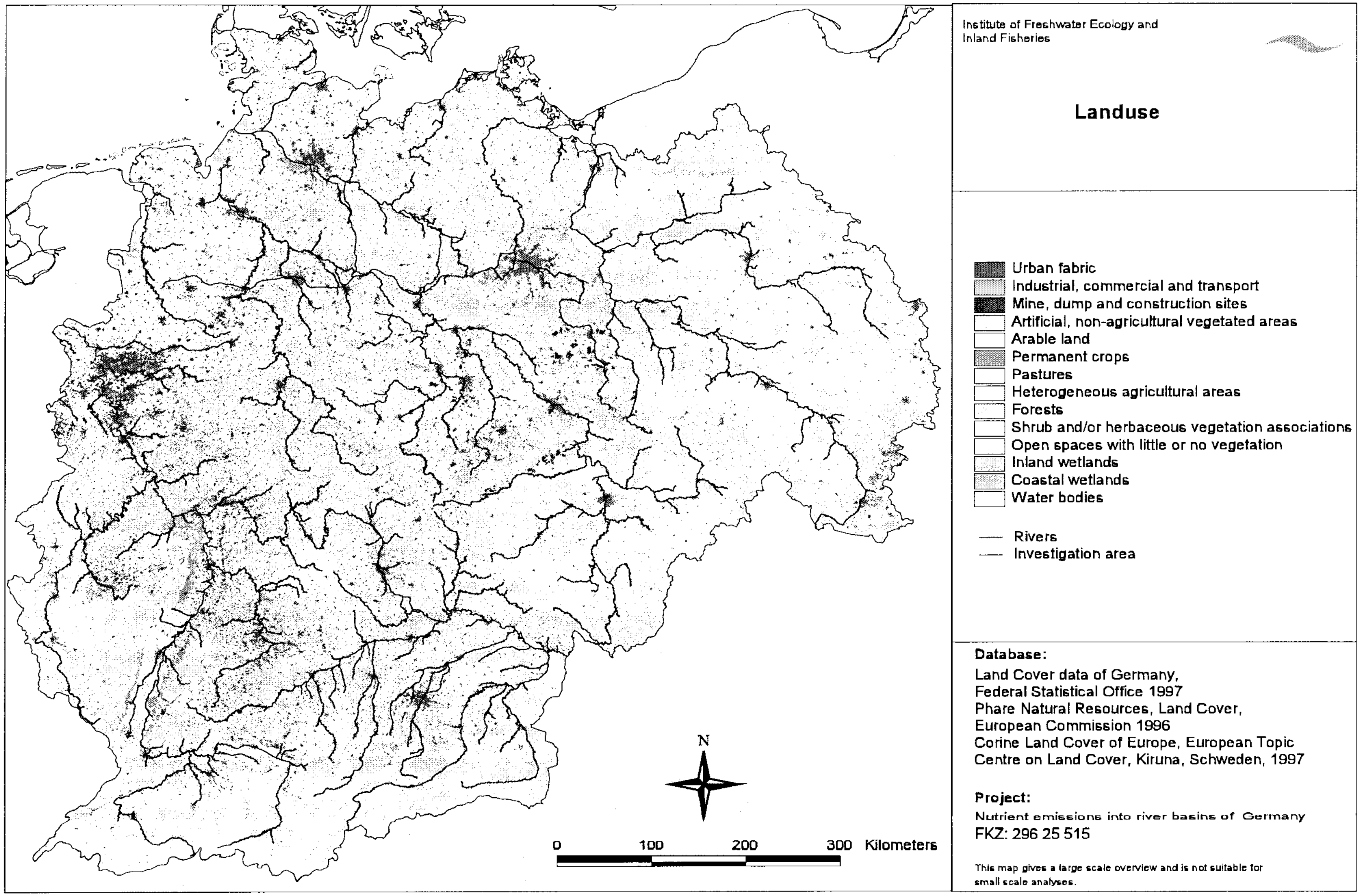
Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
33001	Ems	Hanekenfaehr	Dalum	4,870	0.98	1984	1997		
36901	Hase	Bokeloh	Bokeloh	2,968	1.00	1984	1997	1983	1997
37302	Ems	Hilter	Herbrum	8,695	0.95	1984	1997		
37602	Ems	Herbrum	Herbrum	9,207	1.00	1984	1997		
38001	Leda	Leer		2,078		1984	1997		
28202	Rur	End-Steinkirchen	Stah	2,300	0.72				
28602	Niers	Pegel Goch	Pegel Goch	1,203	1.00	1985	1995	1983	1994
29001	Vechte	Laar	Emlichheim	1,762	1.20	1984	1997	1983	1997
95202	Eider	Nordfeld		941					
95201	Eider	Toenning		1,918					
95203	Treene	Friedrichstadt	Treia	797	1.68				
95601	Soholmer Au	Schluettsiel	Soholm	468	1.61				

The Odra and other Baltic Sea rivers

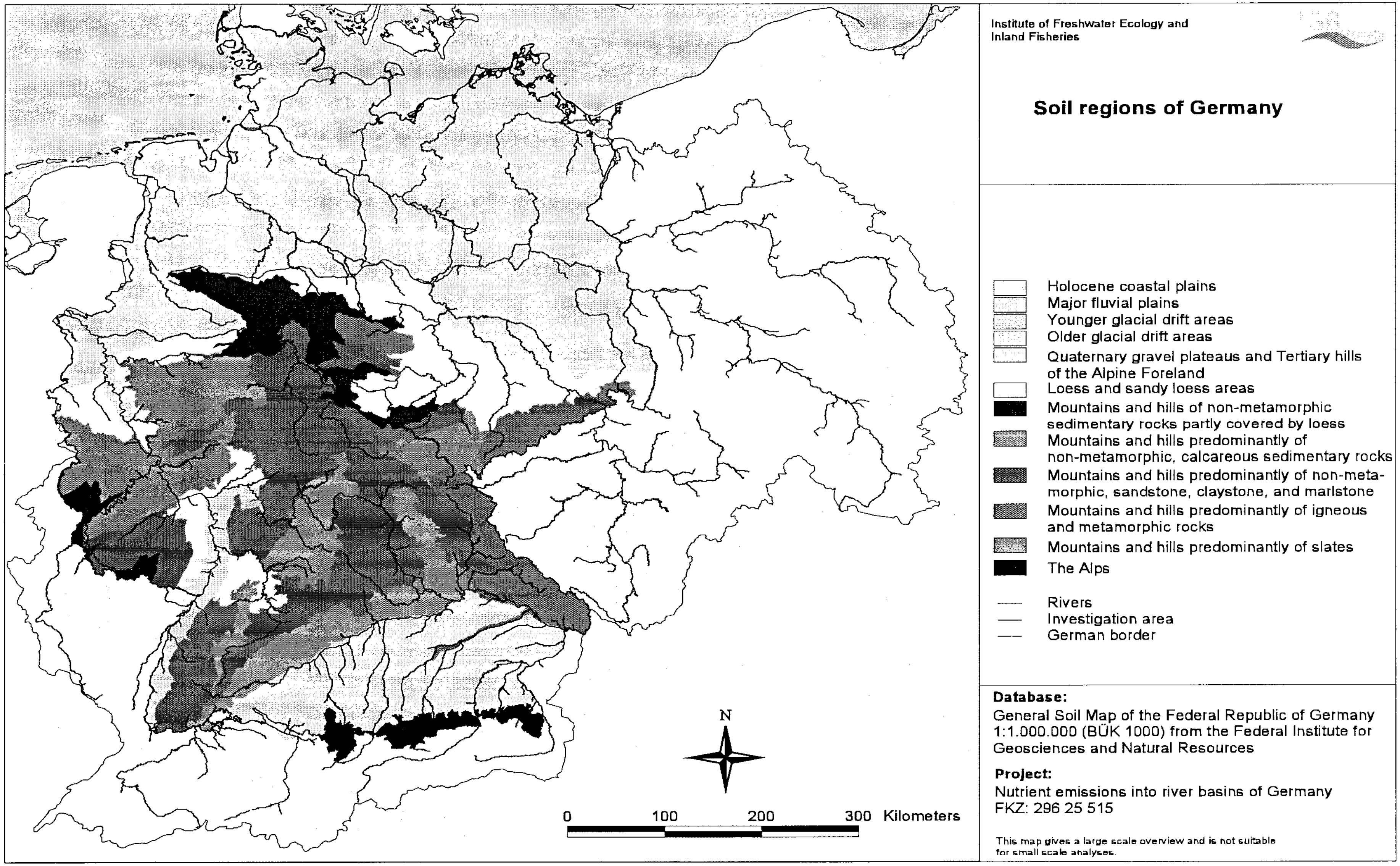
Map 2.21 shows the Odra and other smaller rivers which flow into the Baltic Sea. The catchment areas range in size from 156 to 112,950 km². For some catchments there is insufficient data for calculation of the loadings (see Table 2.15).

Table 2.15: Monitoring stations, discharge and water quality data in the catchment area of the Odra and other Baltic Sea rivers.

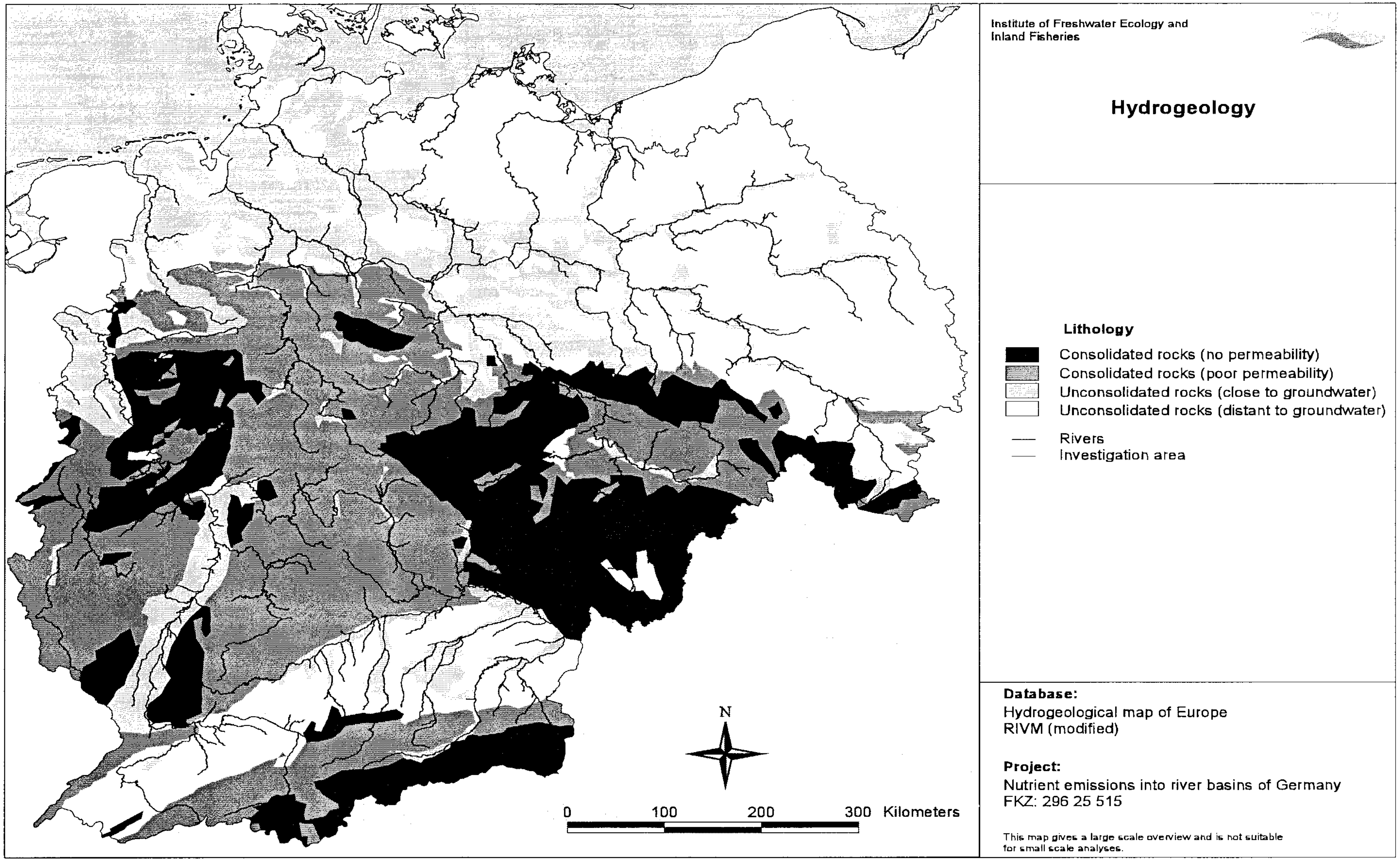
Addr.	River	Quality monitoring station	Discharge monitoring station	A_{EZG}	Conversion factor	Quality data		Daily discharge data	
				[km²]		from	to	from	to
66003	Neisse	Goerlitz	Goerlitz	1,621	1.00	1983/95	1991/96		
66001	Neisse	Muendung	Guben 1	4,579	1.08	1983	1995		
67101	Odra	Eisenhuettenstadt	Eisenhuettenstadt	52,033	1.00	1983/94	1992/95	1983	1996
67901	Odra	Kietz	Kietz	53,752	1.00	1983	1995		
69003	Odra	Hohenwutzen	Hohensaaten	110,443	1.00	1983	1994	1983	1995
69001	Odra	Schwedt	Hohensaaten	112,950	1.03	1983	1995	1983	1995
96101	Schwentine	Kiel	Preetz	714	1.56	1991	1994		
96204	Trave	Sehmsdorf	Sehmsdorf	726	1.00	1991	1994		
96205	Stepenitz	Dassow	Boerzow	701	1.59	1983	1995	1983	1995
96301	Wallensteingr.	Wismar	Hohen Viecheln	156	1.48	1984	1995	1933	1994
96401	Warnow	Kessin	Rostock OP	3,140	1.00	1983	1996	1995	1996
96501	Barthe	Barth	Redebas	292	1.36	1983	1995	1985	1995
96502	Recknitz	Ribnitz	Bad Suelze	669	1.50	1983	1995	1983	1995
96503	Ryck	Greifswald		231	7.23	1983	1995	1984	1994
96602	Tollense	Demmin	Klempenow	1,809	1.29	1983	1995	1983	1995
96603	Trebel	Wotenick	Kirch Baggendorf	992	4.96	1983	1995	1983/92	1989/95
96601	Peene	Anklam	Klempenow	5,110	3.64	1983	1995	1983	1995
96802	Randow	Eggesin	Pasewalk	668	2.04	1983	1995	1984	1994
96801	Uecker	Ueckermuende	Pasewalk	2,401	1.67	1983	1995	1983	1995
96901	Zarow	Grambin	Brohm	748	7.38	1983	1995	1983	1995



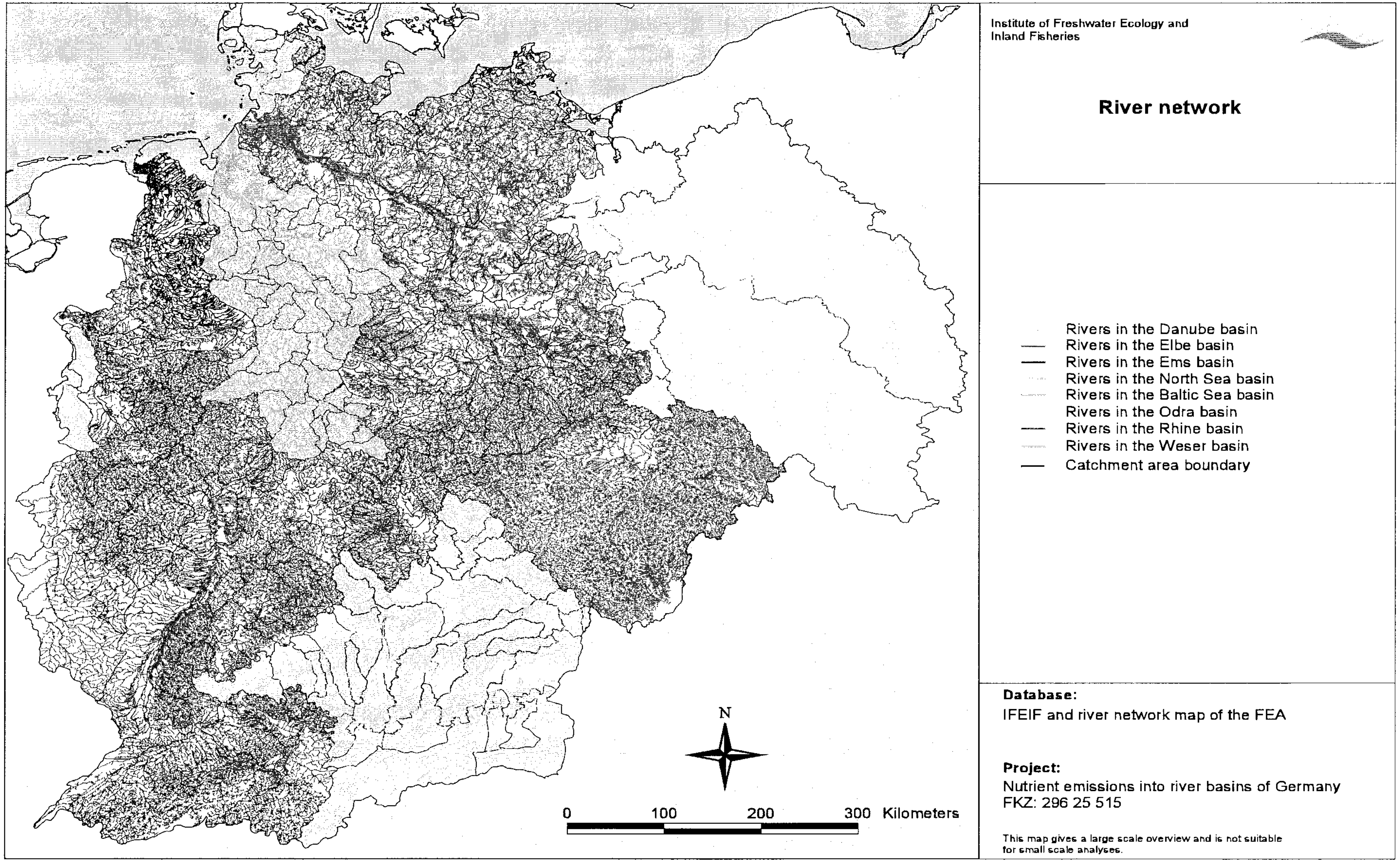
Map 2.1: Landuse



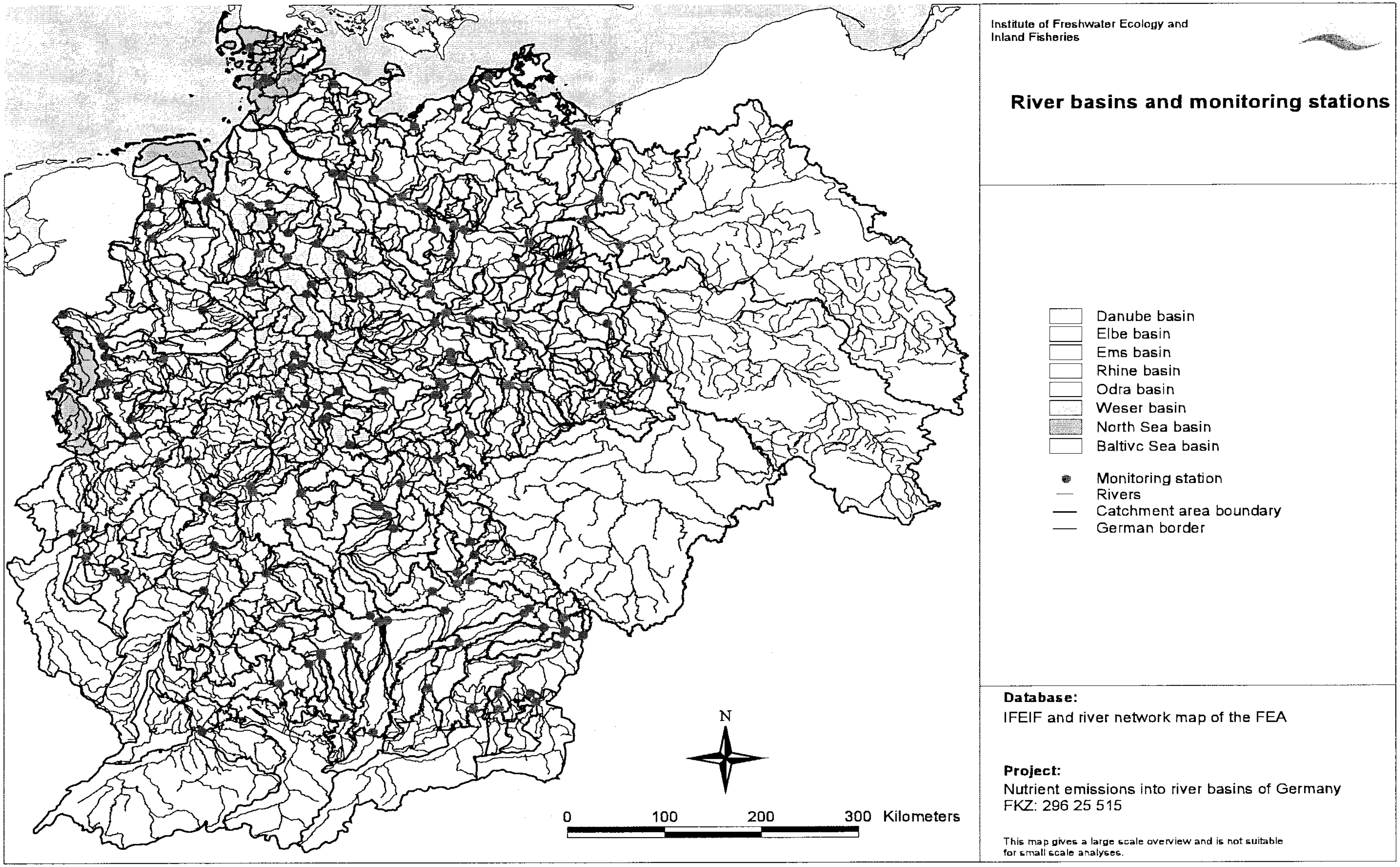
Map 2.2: Soil regions of Germany.



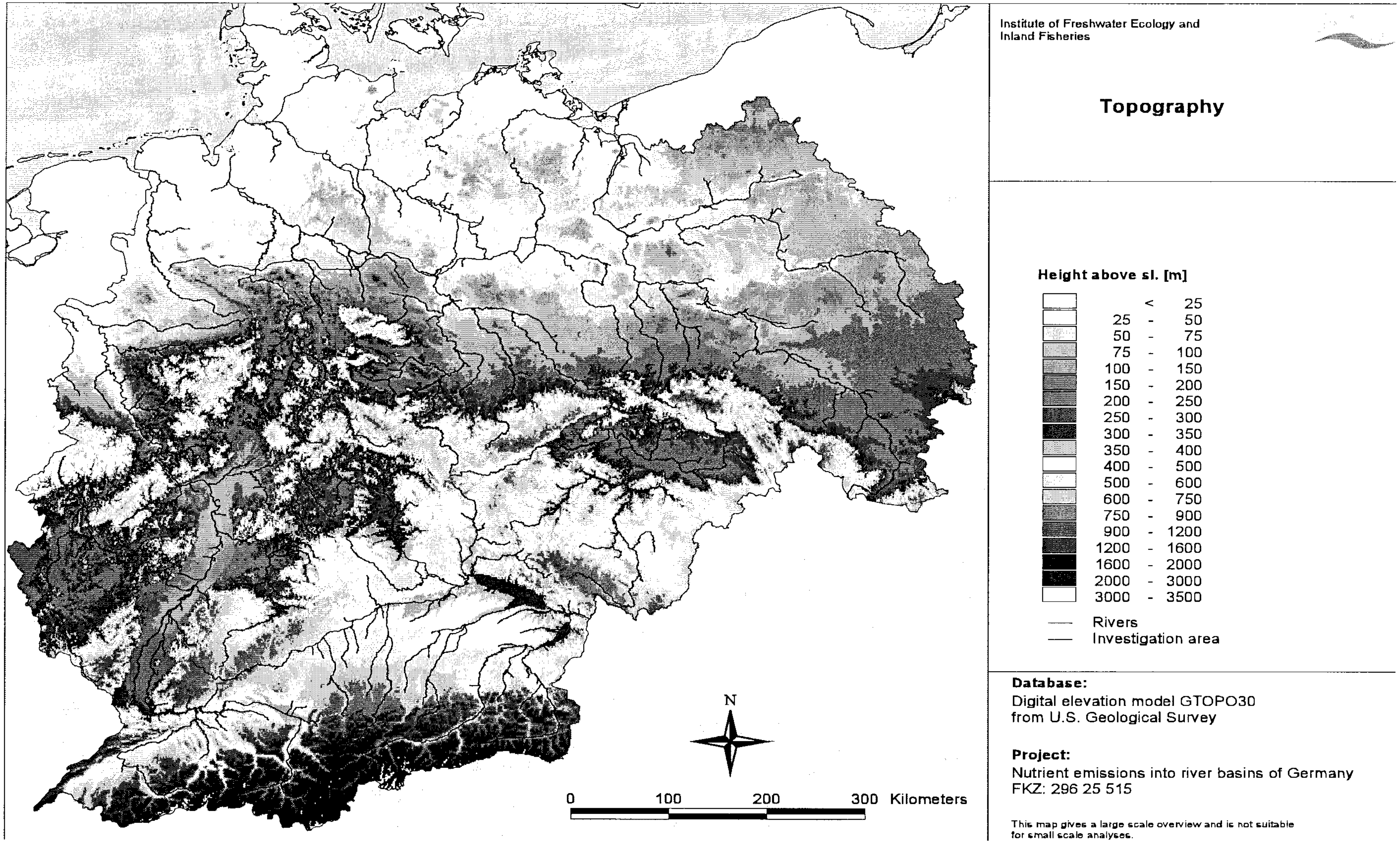
Map 2.3: Hydrogeology.



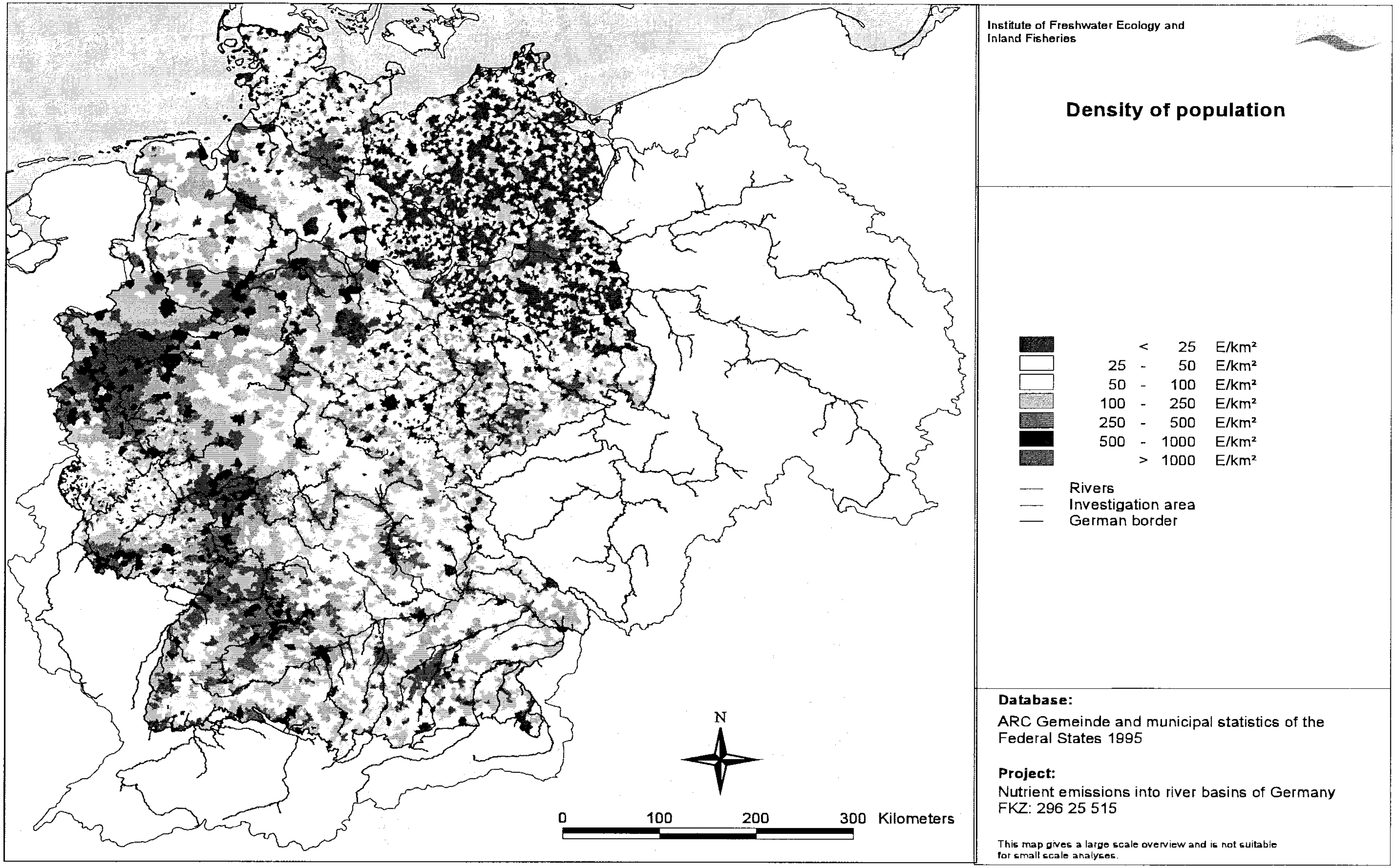
Map 2.4: River network.



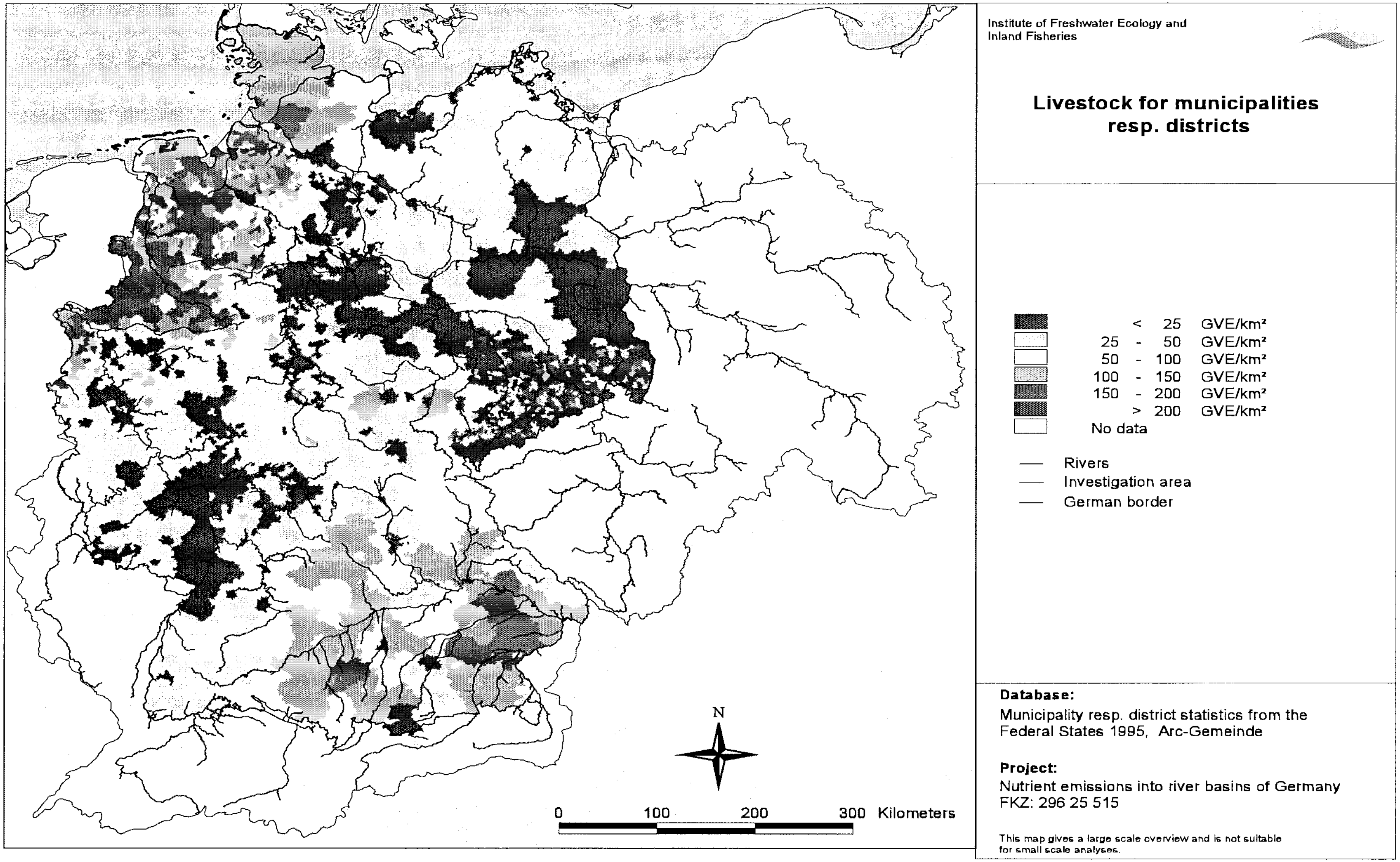
Map 2.5: River basins and monitoring stations...



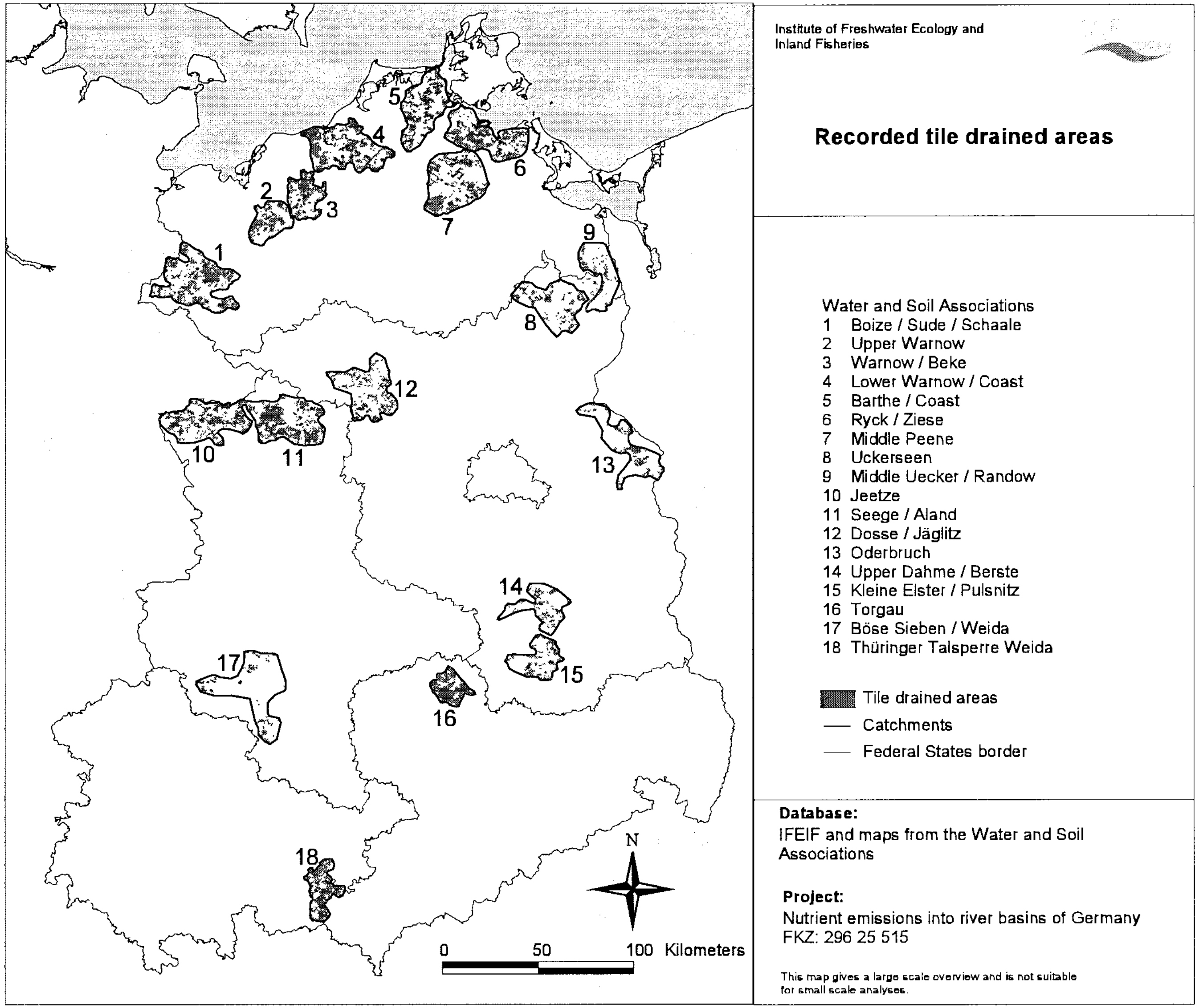
Map 2.6: Topography..



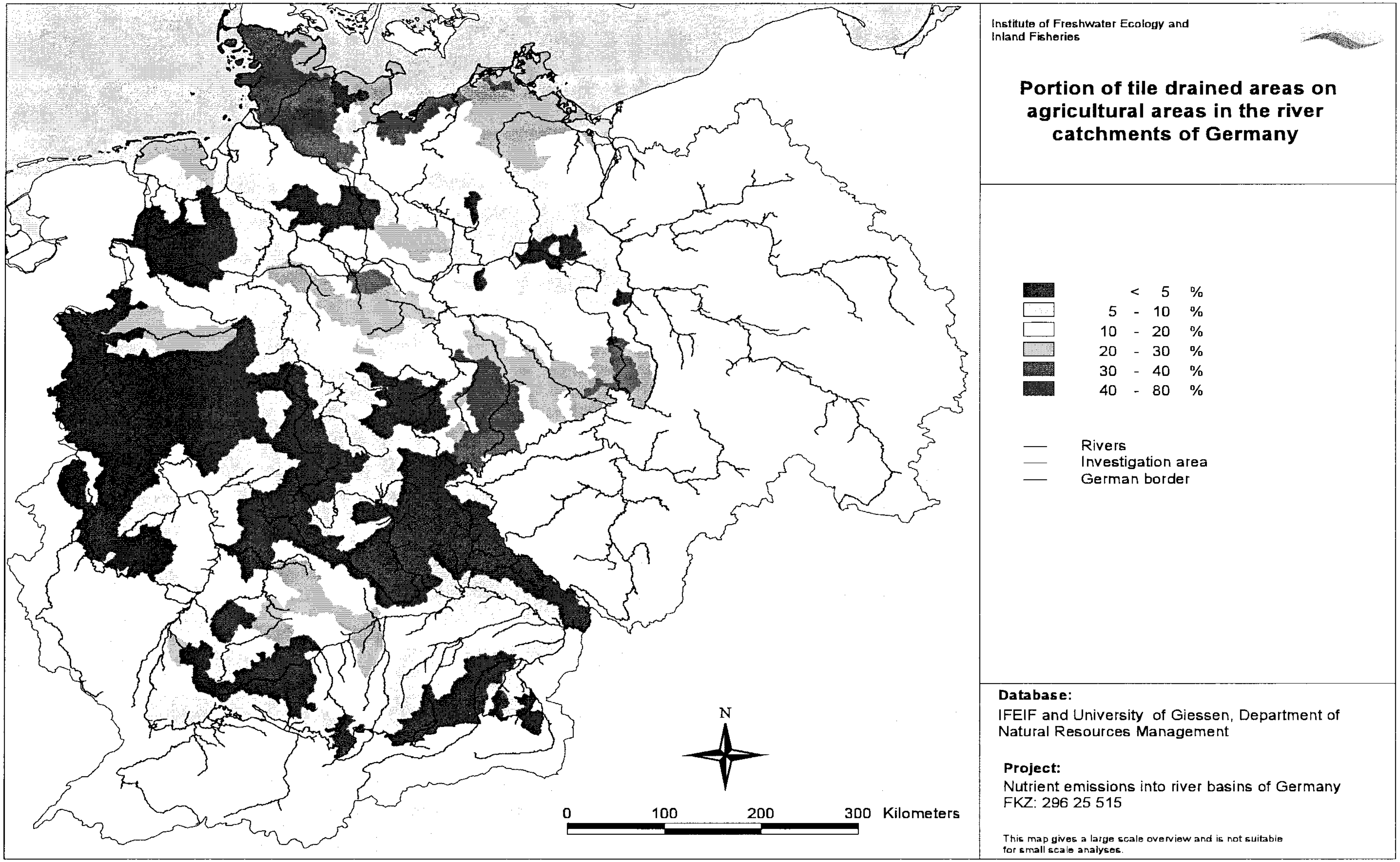
Map 2.7: Density of population.



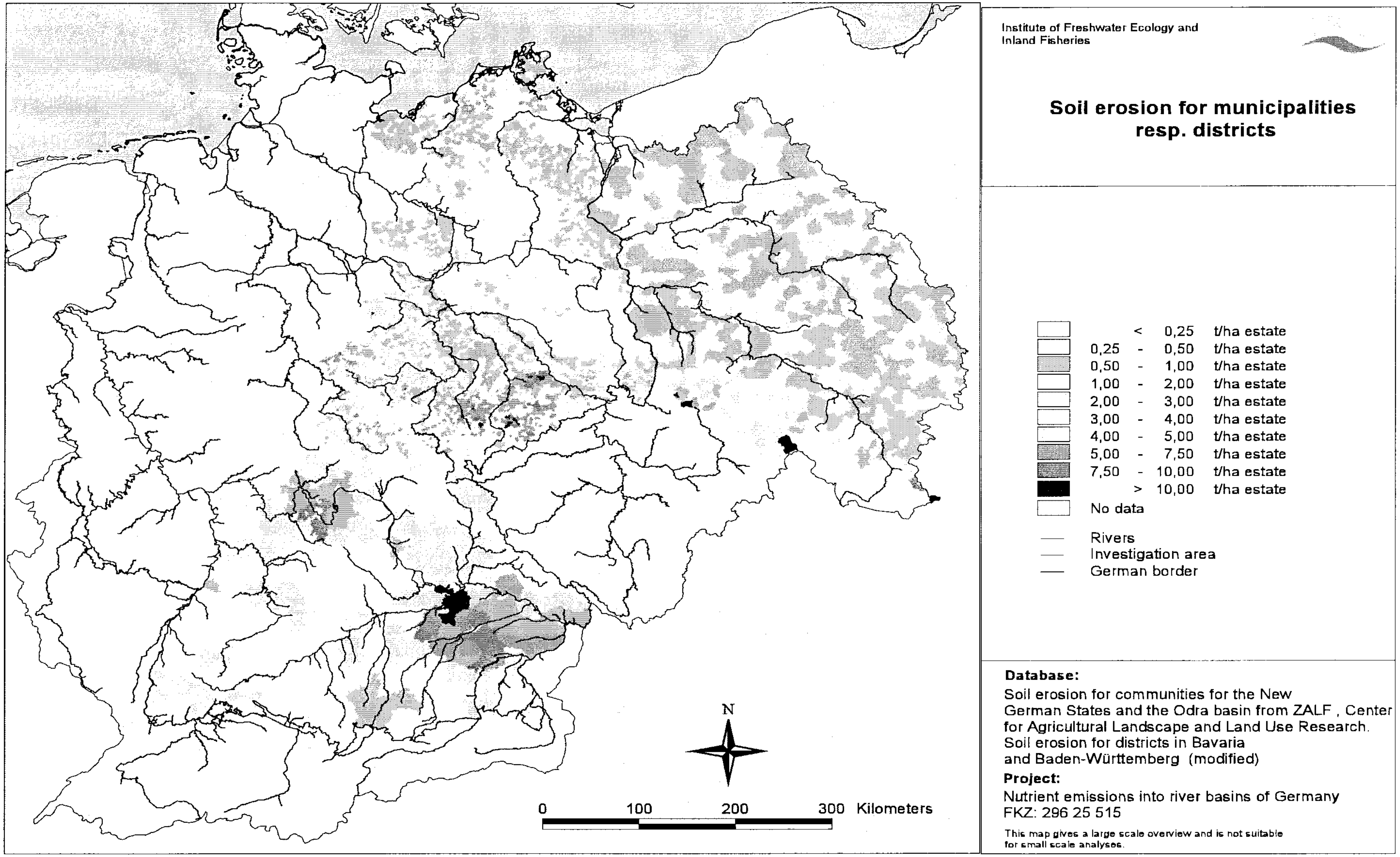
Map 2.8: Livestock for municipalities resp. districts.



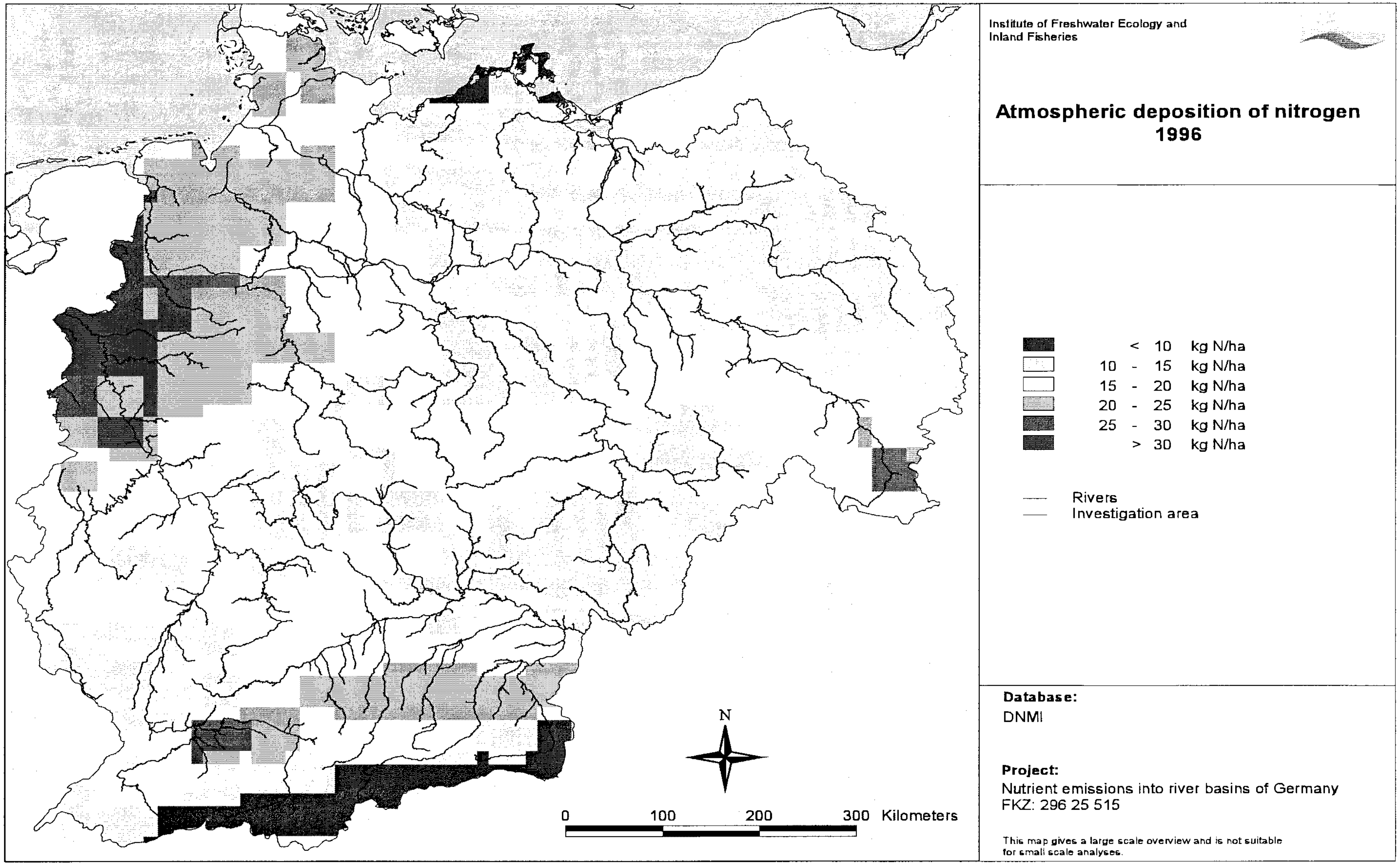
Map 2.9: Recorded tile drained areas.



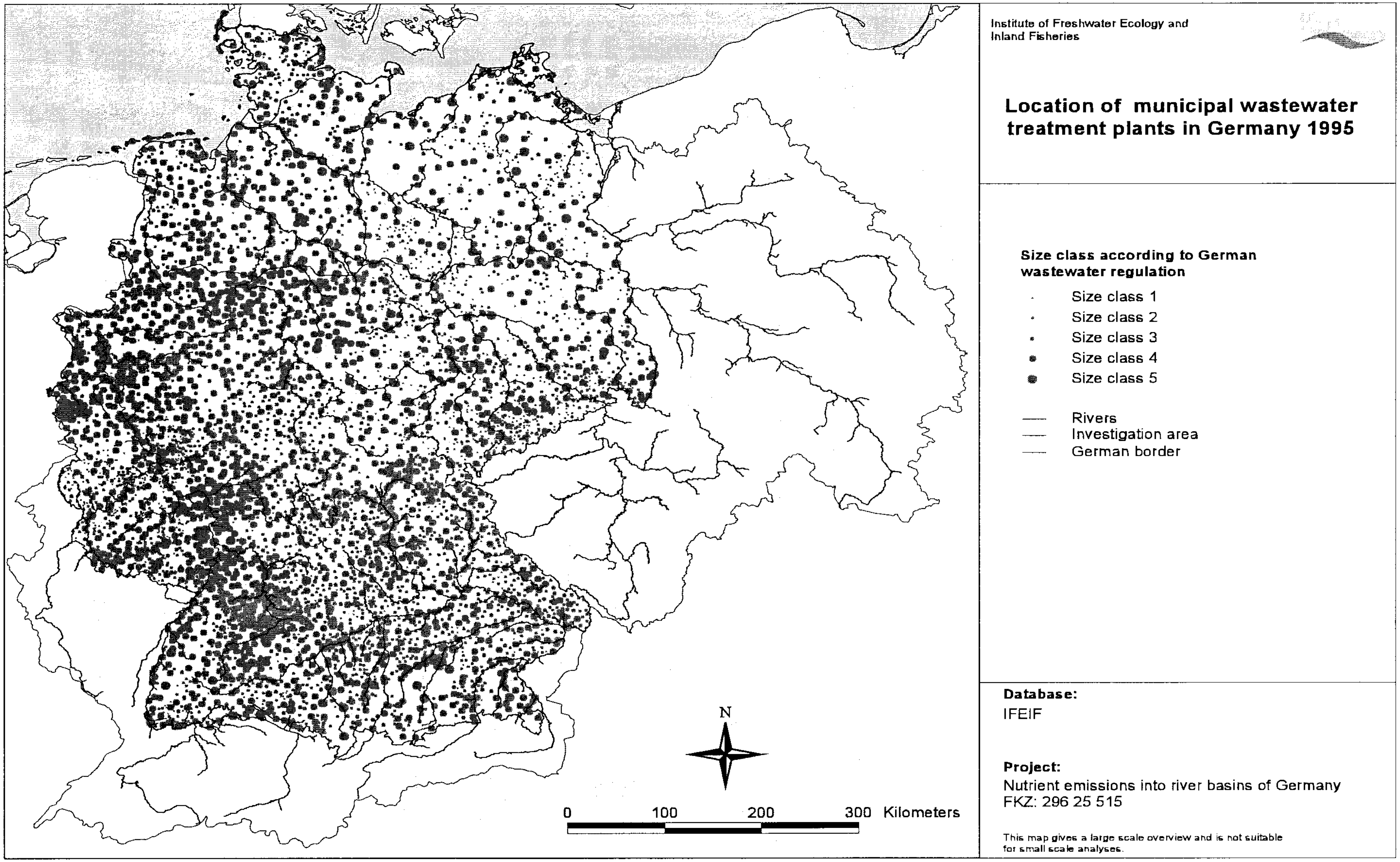
Map 2.10: Portion of tile drained areas on agricultural area in the river catchments of Germany.



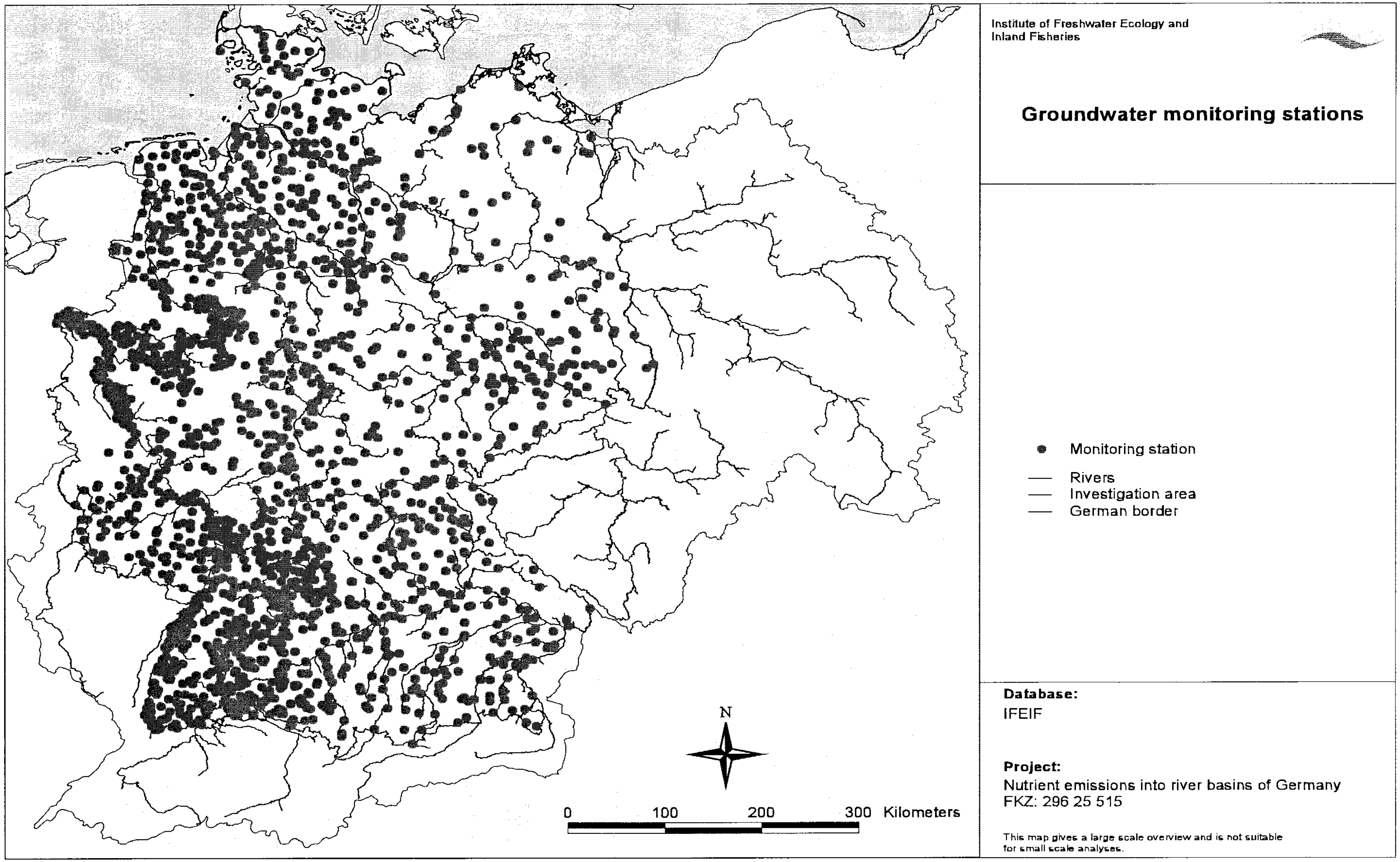
Map 2.11: Soil erosion for municipalities resp. districts.



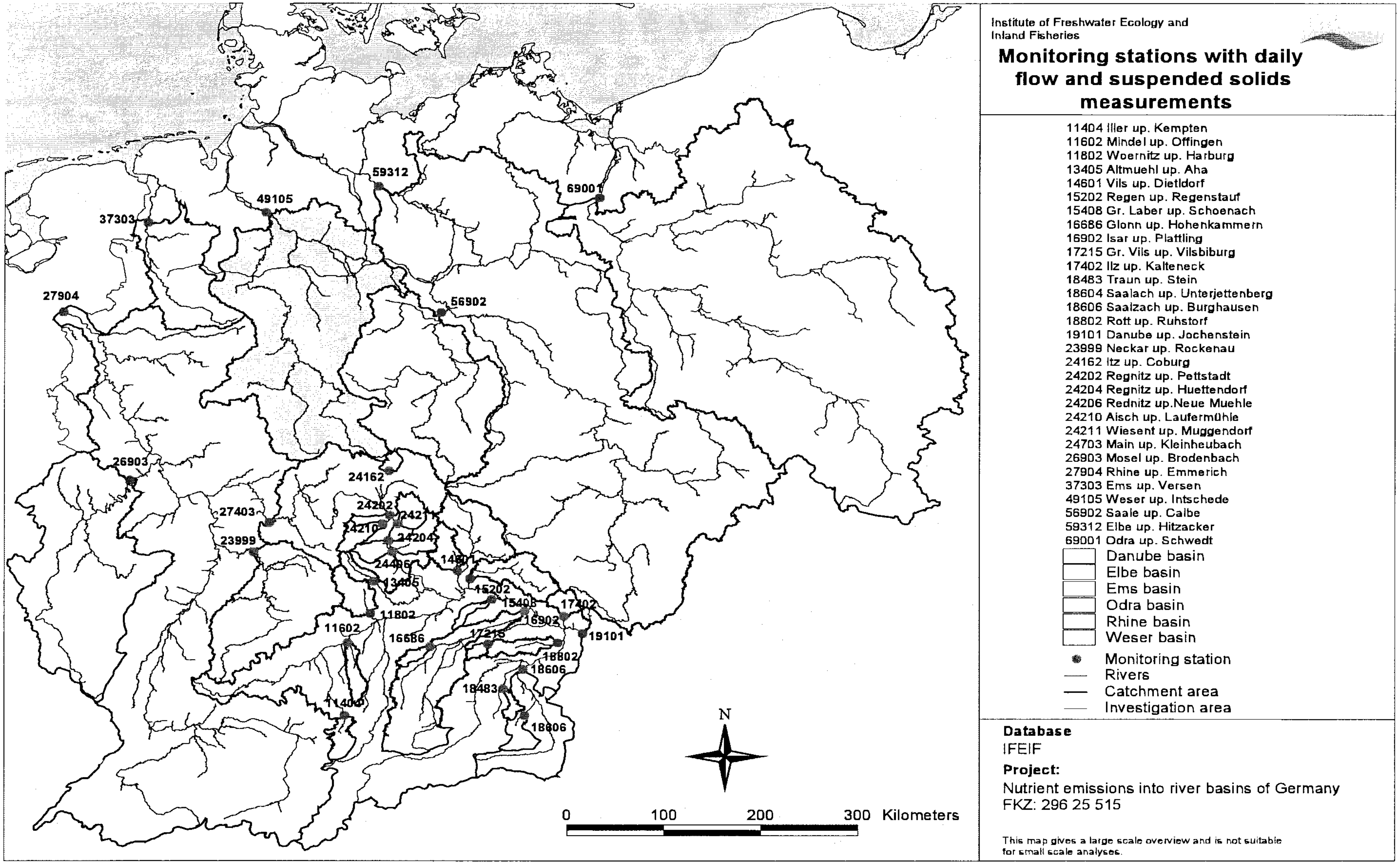
Map 2.12: Atmospheric deposition of nitrogen 1996.



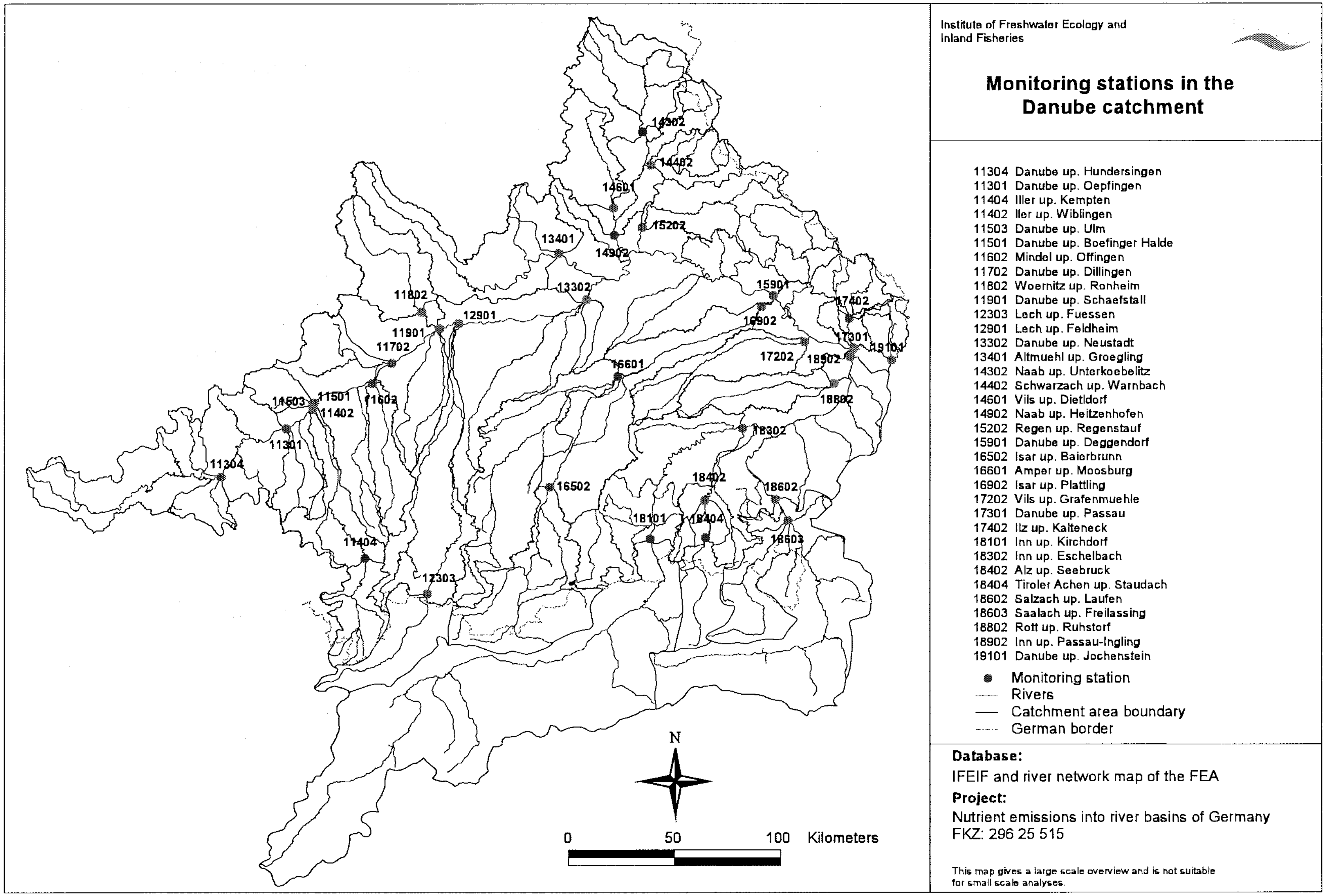
Map 2.13: Location of municipal wastewater treatment plants in Germany 1995.



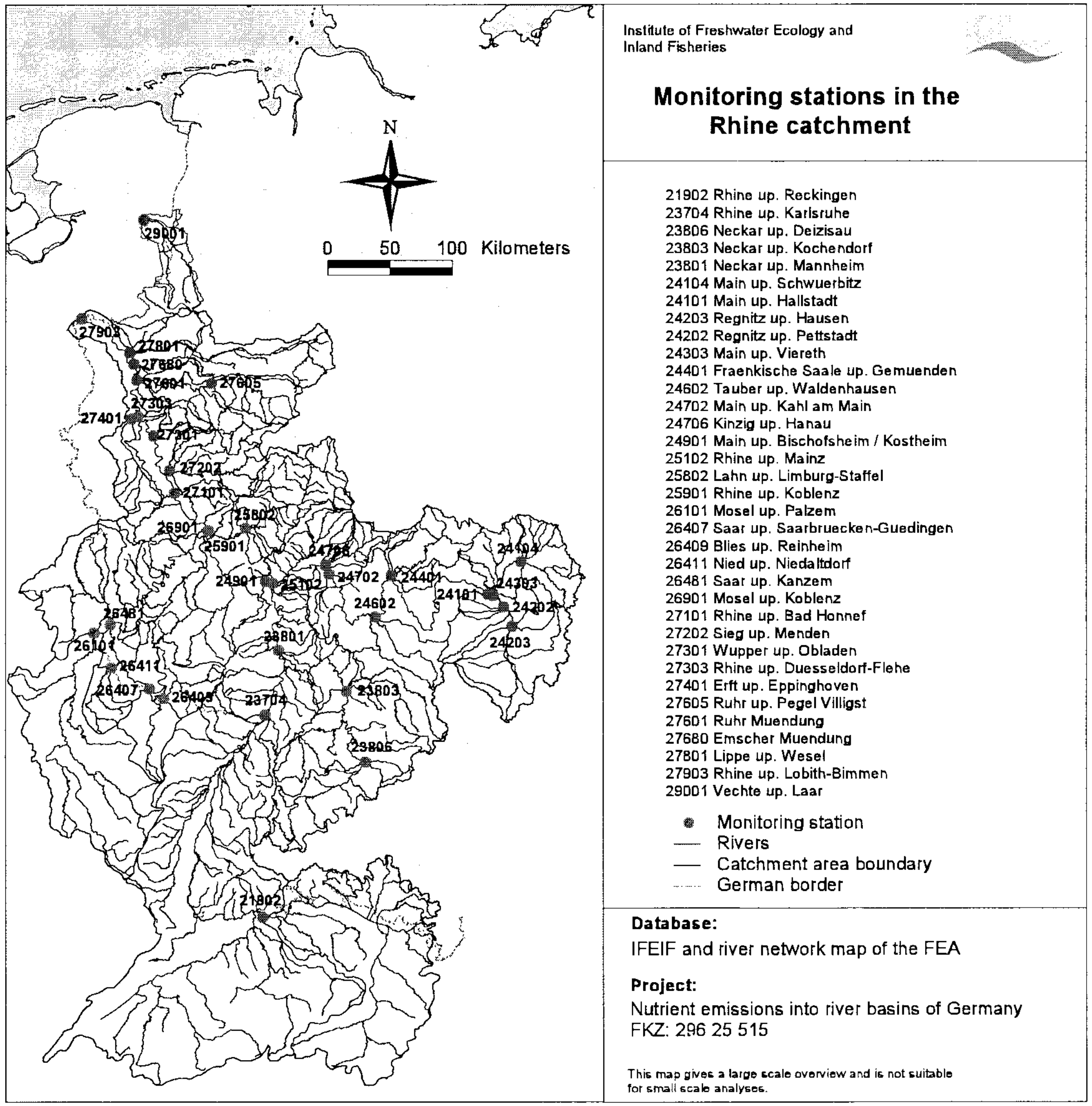
Map 2.14: Groundwater monitoring stations.



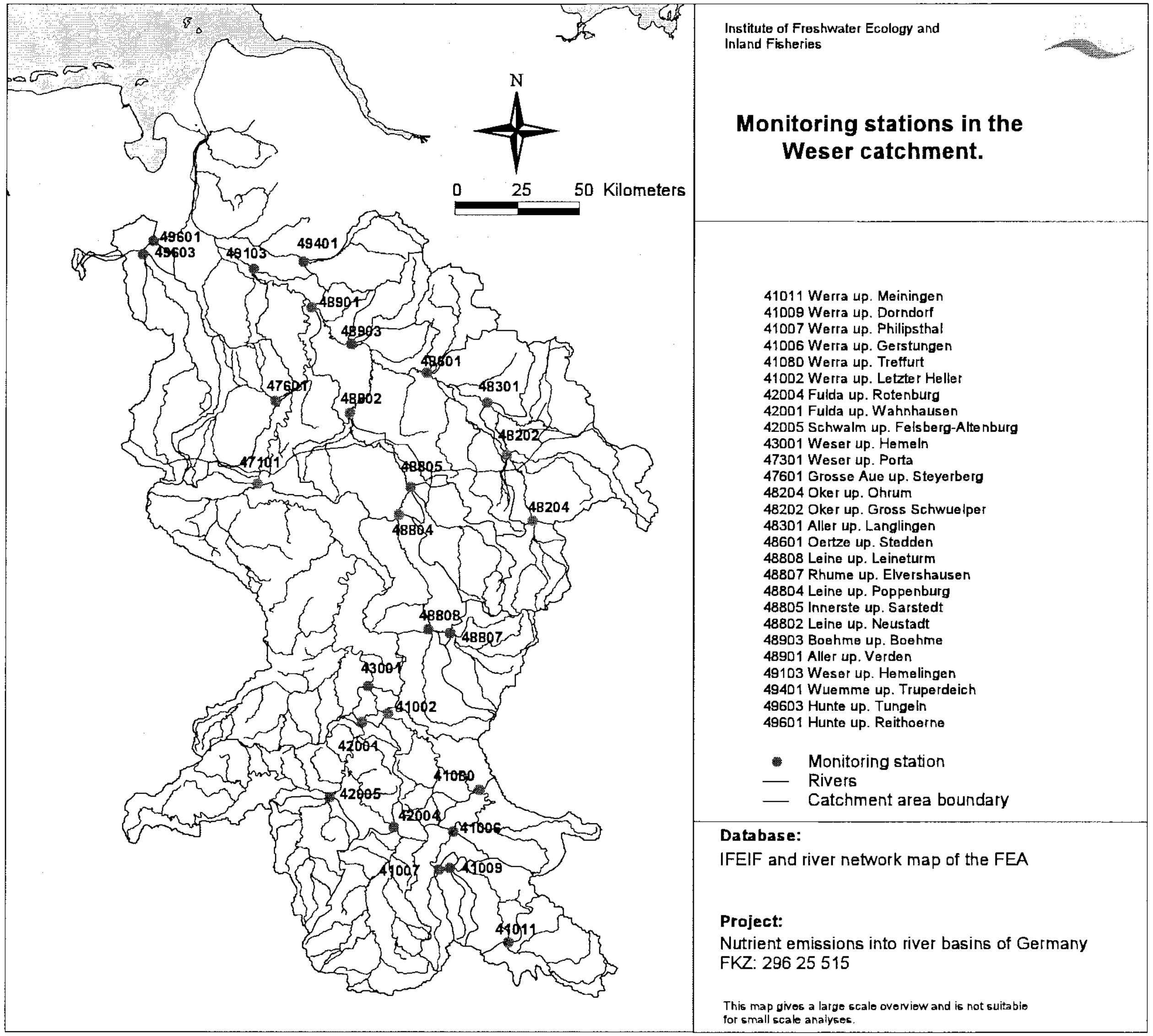
Map 2.15: Monitoring stations with daily flow and suspended solids measurements.



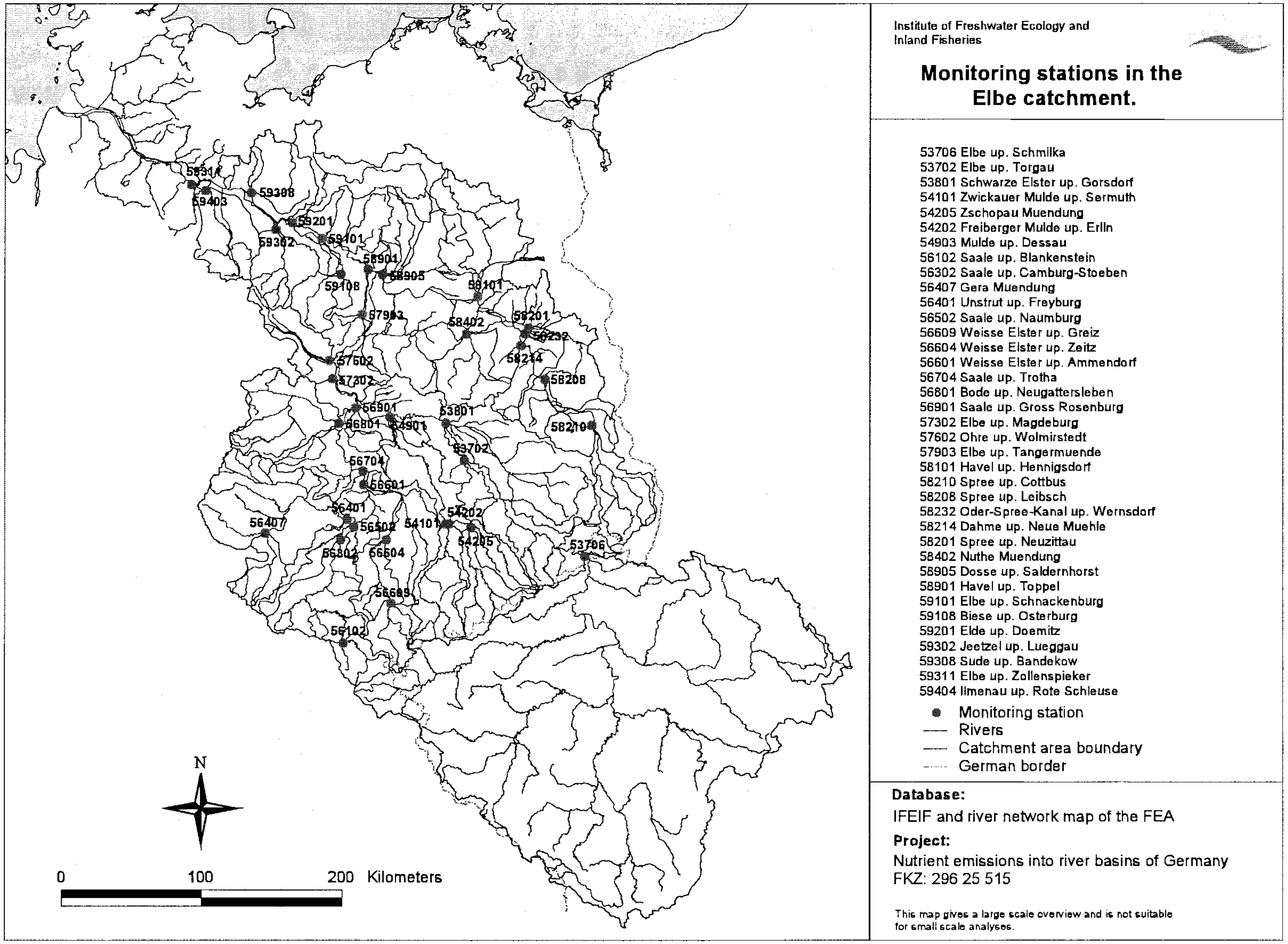
Map 2.16: Monitoring stations in the Danube catchment.



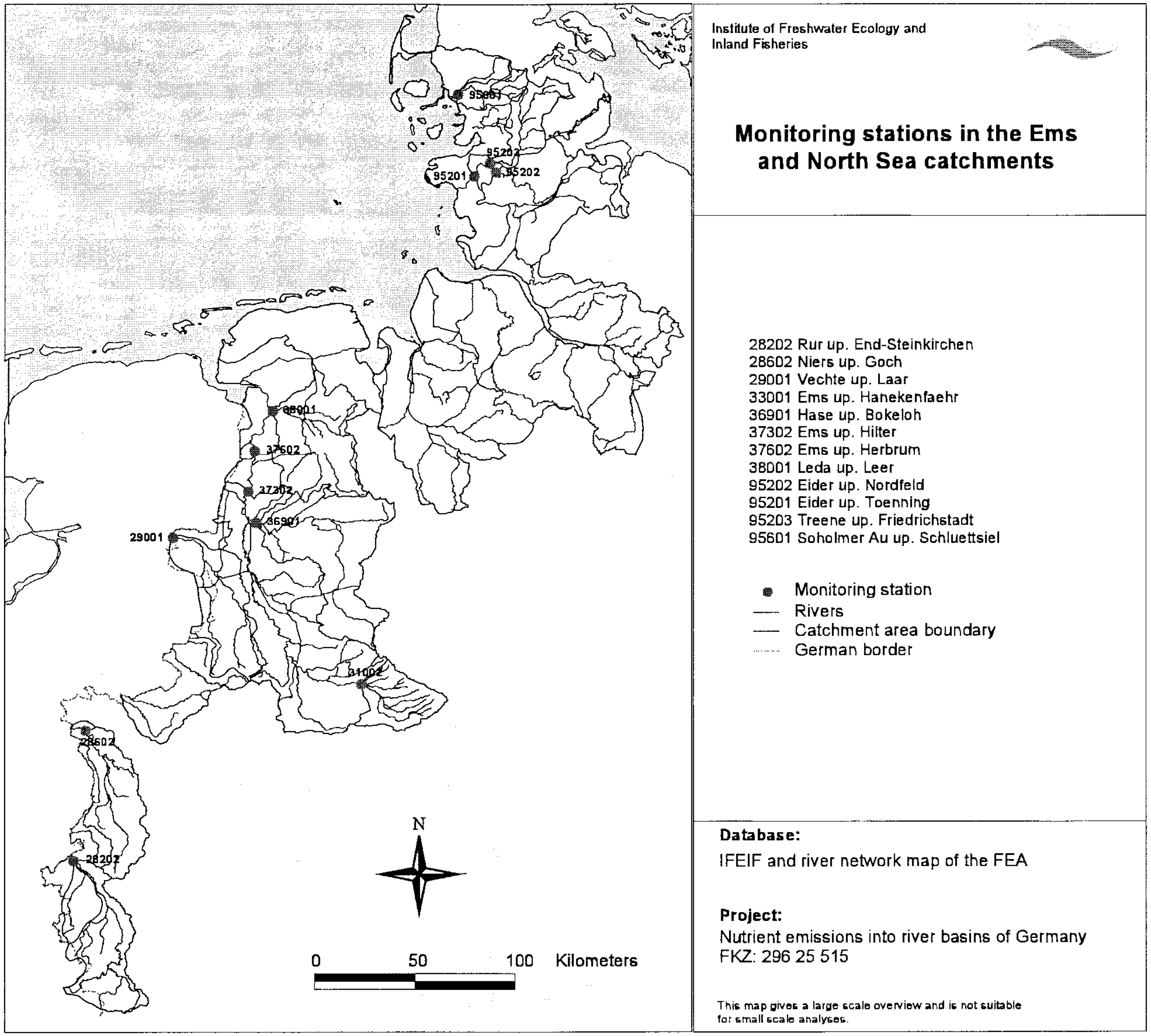
Map 2.17: Monitoring stations in the Rhine catchment.



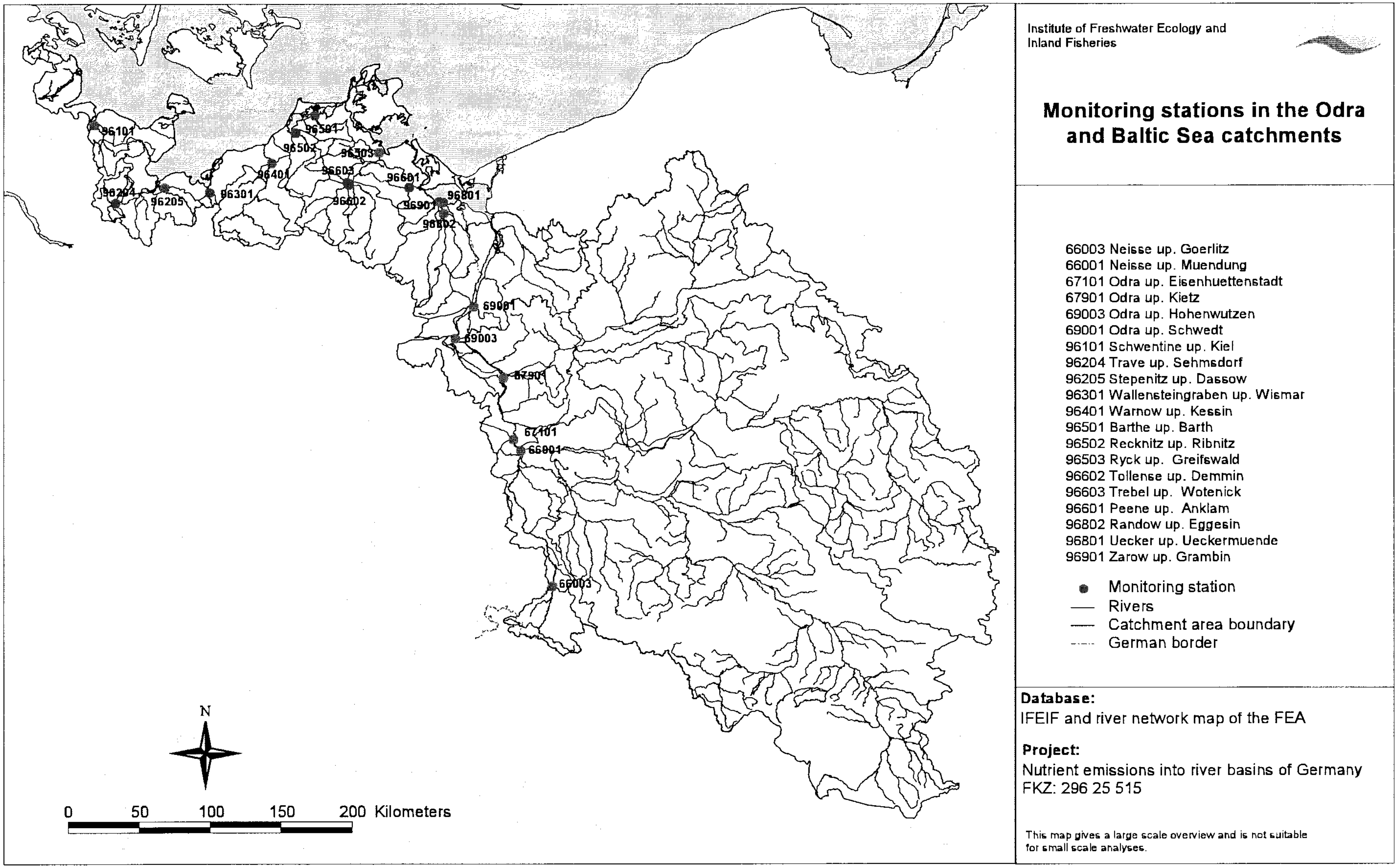
Map 2.18: Monitoring stations in the Weser catchment.



Map 2.19: Monitoring stations in the Elbe catchment.



Map 2.20: Monitoring stations in the Ems and North Sea catchments.



Map 2.21: Monitoring stations in the Odra and Baltic Sea catchments.

3 Methods

3.1 Emission method

The model MONERIS (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) was developed for the investigation of the nutrient inputs via various point and diffuse pathways in German river basins. The basis for the model are data on runoff and water quality for the studied river catchments and also a Geographical Information System (GIS), in which digital maps as well as extensive statistical information are integrated (see Section 2).

While the point inputs from municipal waste water treatment plants and from industry are directly discharged into the rivers, the diffuse entries of nutrients into the surface waters represent the sum of various pathways which have been realised over the individual components of the runoff. The distinction of these individual components is necessary because both the concentrations of materials and the processes are at least clearly distinguished from one another. As a consequence, there are at least four different paths to consider (see Figure 3.1):

- Direct nutrient input on the water surface area by atmospheric deposition,
- Nutrient input into the river systems by surface runoff,
- Nutrient input via interflow which represents a fast subsurface flow component and
- Nutrient inputs via base flow (groundwater) realized by the slow subsurface flow component.

This distinction is not sufficient for the material inputs coupled to surface runoff and the interflow. With surface runoff, inputs of dissolved substances via surface runoff and entries of bound nutrients and suspended particulate matter via erosion must be distinguished. Further it are to be considered that the processes coupled to surface runoff depend on the nature of the area. Accordingly, surface runoff and coupled input from paved urban areas must be separately quantified.

Interflow can originate both under natural conditions and through human activities. In particular, inputs from tile drainage must be considered separately. The quantification of the input of substances via natural interflow and the drains is particularly complex. On the one hand, there do not yet exist model results on the share of interflow of the total runoff for all German river catchments. On the other hand, there is also a lack of data and models to determine the areas drained by tiles in the German river catchments. During this study, an attempt will be made to estimate the proportion of tile-drained areas in the German catchment areas. However, regionalized estimates of nutrient inputs via natural interflow could not yet be carried out because hydrological models for the calculation of the interflow share of the total runoff are not available for all German river basins.

In addition to the inputs from the tile-drained areas, all other subsurface flows will be summarized in the groundwater inputs. That means that the groundwater paths contain to regional different part also the inputs via natural interflow.

Estimates for the following specific inputs (see Figure 3.1) are possible for the catchment areas now covered:

- Point sources
- Atmospheric deposition
- Erosion
- Surface runoff
- Urban areas
- Tile drainage areas
- Groundwater

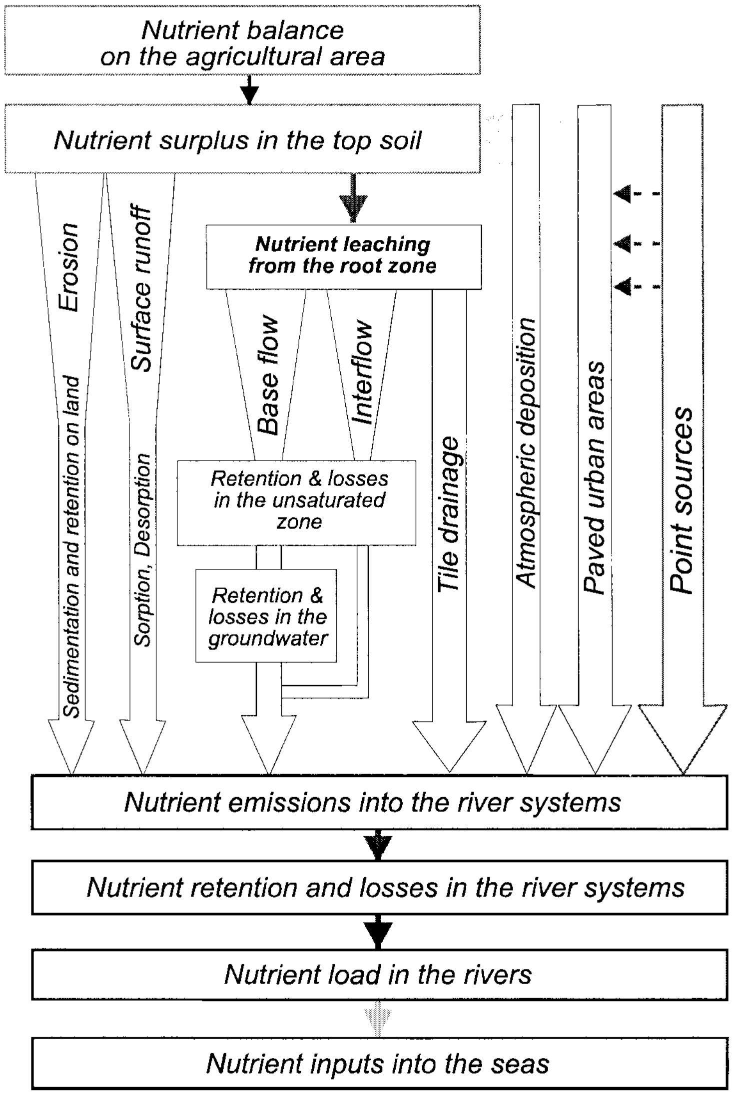


Figure 3.1: Pathways and processes considered in the model MONERIS.

In the diffuse inputs, various transformations-, loss and retention processes are characterized. To quantify and forecast the nutrient inputs in relation to their cause requires knowledge of these transformation and retention processes. 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 modelling will be complimented and modified and if necessary attempts will be made to derive new applicable conceptual models for the estimate of nutrient inputs via the individual diffuse pathways.

WERNER & WODSAK (1994), BEHRENDT (1996A), BRAUN ET AL (1991), PRASUHN & BRAUN (1994) and PRASUHN ET AL (1996) have already successfully undertaken the estimation of inputs, not only for administrative units but also for river catchments. With a view to the expected Water Framework Directive of the European Union, this study also focuses on the estimate of nutrient inputs in river catchments, where a size of about 1,000 km^2 has been chosen for the lower limit of the investigated river basins. This has, in contrast to the preceding Germany studies (e.g. HAMM, 1991), the advantage that measurements for these rivers can be used as a control of results and on the other side that maps can be presented showing the regional differences in the nutrients inputs in all German river basins. These allow the derivation of regionally different measures for the reduction of nutrient inputs.

3.1.1 Inputs via point sources

3.1.1.1 Nutrient inputs via municipal wastewater treatment plants in Germany

The basis for the estimation of the phosphorus and nitrogen inputs from municipal wastewater treatment plants (WWTP) is the determination of the necessary entry parameters. For this, a database is generated for every recorded WWTP on which further calculations are based. It comprises the following information:

- Rate of utilisation (AU)
- Treated population equivalents (EW_{AU})
- Treated population equivalents (inhabitants) (E_{KA})
- Treated population equivalents (indirect industrial discharges) (EGW)
- Yearly quantity of water treated partitioned into:
  (1) Domestic wastewater (Q_H)
  (2) Industrial and commercial wastewater (Q_{GEW})
  (3) External water (Q_F)
  (4) Urban wastewater (Q_T)
  (5) Storm wastewater (Q_N)
  (6) Total wastewater (Q_{GES})

Basic calculations

The quantification of all above stated parameters is based on the plant size (EW_{AB}) and two assumptions which can be derived from wastewater statistics.

The first assumption is that the rate of utilization (AU) used for all treatment plants is 75%. The wastewater statistics for 1995 support this assumption. Table 3.1 summarises the plant size for all WWTP´s in Germany, the treated number of population equivalents (EW_{AU}) and the resulting degree of capacity utilisation for the five declared size classes of the German wastewater regulations (Abwasserverordnung - AbwV); values range from 74% to 78%.

The second assumption concerns the division of the connected population equivalents (EW_{AU}) into connected inhabitants (E_{KA}) and population equivalents caused by direct industrial discharges (EGW). It shall be accepted that this part of the population depends on the size of the total treated population equivalent value. Also, this assumption validates the 1995 wastewater statistics. For the size classes given in Table 3.1 the connected inhabitants and the resulting E_{KA}/EW_{AU}-relationship are shown. It shows with increasing plant size, a smaller proportion of treated population equivalents.

Table 3.1: Wastewater statistics for 1995: Capacity, treated population equivalents and rate of utilization from the AbwV size classes (STAT-ABW, 1995).

WWTP size class		EW_{AB}	EW_{AU}	E_{KA}	AU	E_{KA}/EW_{AU}
From EW	To EW	[10^3 EW]	[10^3 EW]	[10^3 E]	[%]	[%]
0	999	1.614	1.252	1.155	78%	92%
1.000	4.999	6.949	5.209	4.283	75%	82%
5.000	9.999	6.184	4.726	3.489	76%	74%
10.000	99.999	57.872	42.832	27.192	74%	63%
100.000	∞	82.692	63.104	36.102	76%	57%

On the basis of the met assumptions, the values of EW_{AU}, E_{KA} and EGW can be estimated for every treatment plant. The calculation of the treated population equivalent value (EW_{AU}) is carried out with the use of this relationship.

$$EW_{AU} = AU \cdot EW_{AB} \quad \textbf{(3.1)}$$

With the EW_{AU} the number of connected inhabitants (E_{KA}) can be determined for every recorded treatment plant in connection with the removal size-class dependant E/EW_{AU}-relationship from Table 3.1.

$$E_{KA} = EW_{AU} \cdot \left(\frac{E_{KA}}{EW_{AU}}\right) \quad \textbf{(3.2)}$$

In the region of the former GDR there is information available on the number of connected inhabitants for most treatment plants for 1985. Where the data is missing, it shall not be estimated from the E_{KA}/EW_{AU} relationship (Table 3.1) but from the size class differentiated E_{KA}/EW_{AU}-average, which shall be determined from the existing E_{KA}/EW_{AU}- information of the GDR-wastewater treatment plants.

The number of treated population equivalents (EGW) is the difference between the treated inhabitants and the connected population equivalents

$$EGW = EW_{AU} - E_{KA} \quad \textbf{(3.3)}$$

After the estimation of the basic values of EW_{AU}, E_{KA} and EGW for every recorded wastewater treatment plant, additional adjustments are carried out. These aim to tune the values calculated on the basis of the assumptions inside a balance area to the appropriate statistical information.

The fit succeeded for the balance year 1995 and also for 1985 for the region of the old West German states for the areas of the three star LAWA-code. Information from the wastewater statistics for the years 1987 and 1995 give comparable data. For the size of EW_{AU} and E_{KA} , the sum of all treatment plants lying inside a three star LAWA-code are determined and compared with the corresponding information from the wastewater statistics. With non-accordance of both the rate of utilisation (AU) and the E_{KA}/EW_{AU}-relationship for each WWTP lying within the considered LAWA-code, shall be changed so that the values for EW_{AU} and E_{KA} correspond with the values given by wastewater statistics. For this, the function "Zielwertsuche" of the spread-sheet program *Microsoft Excel 97* was used. For the area of the former GDR, the fit succeeded in the balance year 1985 with the adaptation of the according district based of the wastewater statistical information for 1989.

When the statistic-fitted values for EW_{AU}, E_{KA} and EGW are known, the statistically calculated specific wastewater quantities of the individual balance areas are used for the estimation of wastewater quantity. For this, information on the domestic wastewater (Q_H) of connected inhabitants (E_{KA}), the industrial-commercial wastewater (Q_{GEW}) of the treated population equivalents caused by industrial discharges (EGW) and also the external and storm water (Q_F, Q_N) on the connected population equivalent values (EW_{AU}) were used.

It should be pointed out here, that all the values resulting from the estimations are only hypothetical. Every treatment plant is unique, depending on sewer networks, the input area of living inhabitants and existing industrial and commercial businesses. In general, the statistically based assumptions and calculations can only provide an approximate portrayal of the actual conditions of the treatment plants.

Calculation of nutrient inputs

The estimation of N- and P-inputs from municipal wastewater treatment plants is mainly achieved with the three methods summarised schematically in Figure 3.2.

Which estimation method can be applied for a WWTP depends on the nature of existing data. While Method 3 can be applied independently of existing data for all treatment plants, Method 1 requires existing outflow concentrations and Method 2 requires existing ATV nutrient loading levels. Moreover it is possible to determine treatment plant N- and P-loadings from the literature. For 1985 estimations, only Method 3 can be applied.

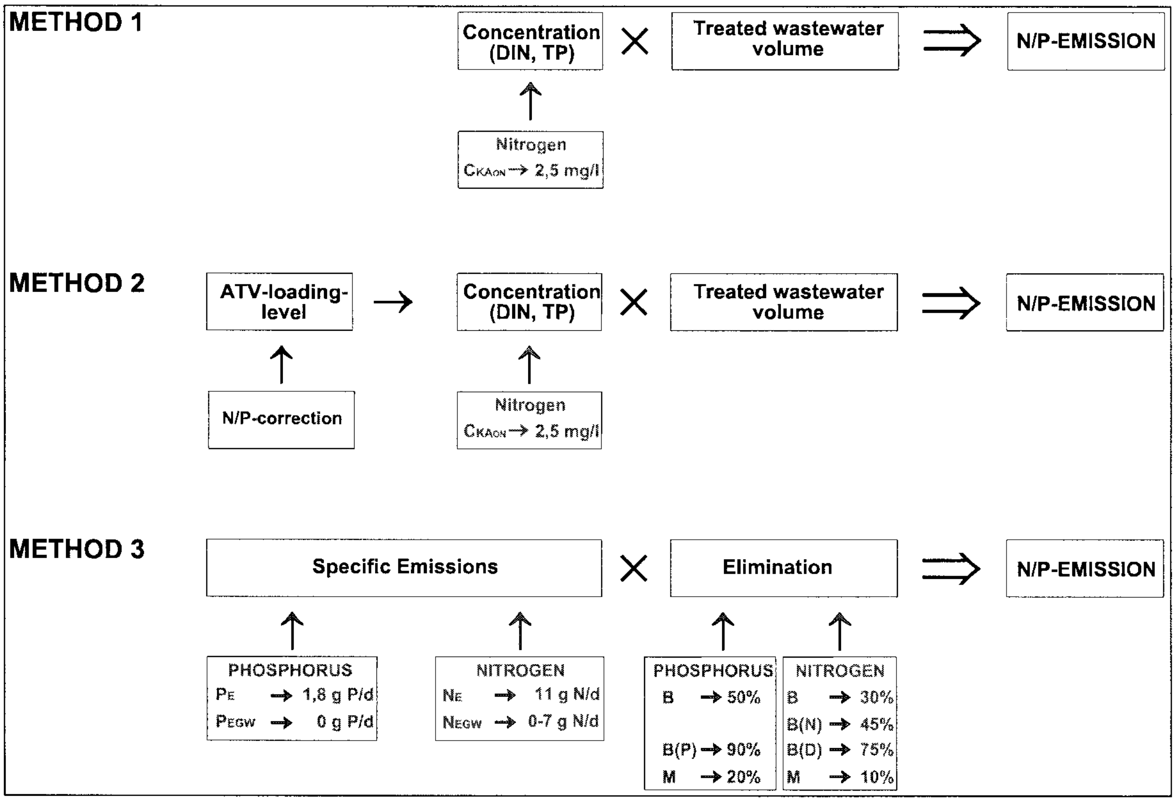


Figure 3.2: Scheme of estimation methods for municipal WWTP´s (instructions for Method 3 valid for 1995; *B: Biological WWTP; B(P): with P-Elimination; B(N): with nitrification; B(D) with denitrification; M: mechanical WWTP).*

Method 1: Outflow concentrations

The yearly load of total nitrogen and/or phosphorus of a municipal WWTP is calculated on the basis of outflow concentrations in combination with the quantity of wastewater treated.

With these methods, the origin of the used data must however be taken into account. Concentration values taken from the ATV-literature correspond to the values measured in the framework of the investigations accomplished under the control of the plant operators. According to the regulations of the German states for plant control, only inorganic nitrogen components - ammonium, nitrite and nitrate - are recorded. As in this study however, the total nitrogen loadings should be calculated. Therefore, it is necessary to add the organic nitrogen. In the literature, an average outflow concentration of $C_{KA_{ON}} = 2$ mg N/l is declared (SCHLEYPEN, 1995; PÖPEL ET AL., 1996). In this work, a value of 2.5 mg N/l was used. This comes from the yearly means of 1.8 to 4.2 mg N/l from the eight Berlin WWTP´s (BWB, 1997).

For the loading estimation, required information on total water quantity (Q_{GES}) will be taken from the data of the individual recordings or basic calculations.

Method 2: ATV-nutrient loading levels

The ATV carries out so-called treatment plant performance comparisons. In this, the results of the plant-controlled measurements of the outflow concentrations of inorganic nitrogen ($C_{KA_{DIN}}$) and total phosphorus ($C_{KA_{TP}}$) are summarised in the so called "Nutrient Loading Level" (NLL). The NLL characterises the nutrient emissions of each treatment plant as one value.

For the determination of nutrient loading levels, the ATV uses the following procedure: The yearly average of the outflow concentrations of $C_{KA_{DIN}}$ and $C_{KA_{TP}}$ are graded in the appropriate nutrient loading level according to the key shown in Table 3.2. Next, the arithmetical mean is taken from the individual loading levels for nitrogen and phosphorus. It yields an average nutrient loading level which in contrast to the information in Table 3.2 is given in half levels (1; 1.5; 2; 2.5; 3; 3.5; 4; 4.5; 5) because of the formulation of the mean.

Table 3.2: Key for the ATV-nutrient loading levels (ATV, 1996).

NLL	Residual Pollution	$C_{KA_{TP}}$	$C_{KA_{DIN}}$
		[mg/l]	[mg/l]
1	Very low	≤ 0,5	≤ 8
2	Low	0,6 - 1,0	9 – 13
3	Medium	1,1 - 2,0	14 – 18
4	High	2,1 - 5,0	19 – 35
5	Very high	> 5,0	> 35

For loading calculations from the average nutrient loadings, it is necessary to separate them into individual N- and P-loading levels and consequently transform concentration information. The simple application of Table 3.2 is not possible because one would assume that the separate nutrient loading levels for nitrogen and phosphorus are identical to the average nutrient loading levels. This assumption is false. Rather, the average loading levels of various combinations of N- and P-levels can mean different combinations of separate N- and P-loading levels (e.g. an average loading level 3 can theoretically mean both a mean from 2 and 4 and also from 1 and 5).

For the determination of individual loading levels for nitrogen and phosphorus, the scheme in Table 3.2 will therefore be modified, such that the deployed purification procedure of the treatment plant is considered as follows:

- Treatment plants *employing a specific denitrification process*: through the enhanced nitrogen elimination the separate N-loading level is better than the declared average loading level is. Due to the relationship to the average nutrient loading level at the same time the separate P-loading level diminishes.

- Treatment plants *employing phosphorus elimination treatment*: This treatment improves the phosphorus elimination of a treatment plant. With this, the P-loading level is reduced compared to the average level. Consequently the N-loading level is increased.
- Treatment plants employing *neither or both cleaning procedures:* That means no wastewater content level changes in opposition to the other. The average loading level will pertain for both nitrogen and phosphorus.

The extent of the cleaning-procedure-dependant increase or decrease in average nutrient loading level complies with this value. Levels 2, 3 and 4 yield a modification of ± 1 and with the half values (1.5 to 4.5) of ± 0.5. For the loading levels 1 and 5 there is no modification regardless of the cleaning procedure.

Table 3.3 shows all resulting separate N- and P-loading levels in dependence with the purification procedure used and the average nutrient loading levels.

Table 3.3: Modified key for concentration calculation from the ATV-nutrient loading levels *(abbreviations see Figure 3.2).*

Average NLL	N-loading level with				P-loading level with			
	Only B(D)	Only B(P)	B(D)+B(P)	None	Only B(D)	Only B(P)	B(D)+B(P)	None
1	1	1	1	1	1	1	1	1
1,5	1	2	1	2	2	1	1	2
2	1	3	2	2	3	1	2	2
2,5	2	3	2	3	3	2	2	3
3	2	4	3	3	4	2	3	3
3,5	3	4	3	4	4	3	3	4
4	3	5	4	4	5	3	4	4
4,5	4	5	4	5	5	4	4	5
5	5	5	5	5	5	5	5	5

After calculation of the separate loading levels for nitrogen and phosphorus, it is necessary to convert the information to concentrations. For that, in particular for nutrient loading levels 2, 3 and 4, the average concentrations for these levels from Table 3.2 are used. For level 1 the highest and for level 5 the lowest concentration are employed. As already explained, a value of 2.5 mg N/l for organic nitrogen has to be added. From all this information, the nitrogen and phosphorus carriage of the treatment plants can be calculated.

Method 3: Specific emissions

The nitrogen and phosphorus loads of the municipal wastewater treatment plants can be determined from the specific emissions of every connected inhabitant and population equivalents. In addition, the loadings must take into account the removal of solid wastes and wastewater in collection pits and small treatment plants. With this information, together with the purification-performance of the procedures of individual WWTP, the N- and P-loadings can be calculated.

The population specific phosphorus output (AG_{EP}) can be determined for 1995 from the following four components according to SCHMOLL (1998):

- *Human excretion:* With the assumption that food intake and human excrement are of the same weight, the average inhabitant specific P-emission can be precisely determined on the basis of the average food requirements. For Germany as a whole, a total of 1.61 g P per person per day in digestible components of food was determined for 1994 at the level of wholesale disposal (DGE, 1996). Of this total, ca. 15% is fed to animals or spoiled (personal communication ULBRICHT, 1997), so each inhabitant takes in about 1.37 g P per day. In the "National Consumption Study", for the period 1985 to 1989 in the old German states, it was determined that, on average, each inhabitant consumes 1.18 g P/inhabitant/day (DGE, 1996). From these two figures, an average of 1.28 g P/inhabitant/day is consumed and excreted . Following the publication of BERNHARDT (1978), a figure of 1.6 g P/inhabitant/day has been cited and used in the German literature (GLEISBERG, 1989; HAMM ET AL., 1991; BEHRENDT, 1994a; ATV, 1997). The value appears unjustifiable after publication of the "National Consumption Study".
- *Food leftovers:* This component comprises two parts. The first is the difference between the theoretical consumable components of food of 1.61 g P/inhabitant/day and the true consumed food of 1.28 g P/inhabitant/day. This discrepancy includes the quantities of spoiled food or food fed to animals. One can take that about a third of this quantity (0.11 g P/inhabitant/day) ends up in the household wastewater. The second part to be considered is cleaning losses and peelings. These can be calculated using the information of HAENEL (1980) for the average quantities of cleaning and peeling materials of every food group of the digestible part of single food groups (DGE, 1996). It can be concluded that one third of the cleaning losses and peeling materials (0.08 P/inhabitant/day) ends up in the household wastewater. That leaves a figure of 0.19 g P/inhabitant/day for food leftovers.
- *Detergents:* Phosphorus is found in dish-washing machine and household cleaning detergents in the form of triphosphates and phosphonates. In Germany in 1996, about 50 kt of dish-washer machine detergent was sold. Of that 29.3 kt was pentasodium triphosphate containing concentrated dishwashing detergent with a PO_4 content of about 45%. With the use of the P-molar fraction of 0.26 for pentasodium triphosphate, that gives for 1996 a quantity of 3.4 kt P/y (personal communication IKW, 1997). This yields an inhabitant-specific loading of about 0.12 g/inhabitant/day. Washing detergents now contain next to no phosphorus. However, these detergents contain on average 0.35% phosphonates. In 1996, 612 kt of household detergent were used in Germany containing 2.2 kt phosphonates. Using an average molar fraction of the four most important phosphonates (ATMP, HEDP, EDTMP, DTPMP) of 0.32, one can calculate a

value of 0.02 g P/inhabitant/day (IKW, 1997; ALDER ET AL., 1996). That gives a total for 1996 of 0.14 g P/inhabitant/day for detergents.

- *Washing and cleaning water:* This fraction represents 0.15 g P/inhabitant/day as taken from HAMM ET AL. (1991)

The total inhabitant-specific P-ouput for 1995 in total is therefore 1.80 g P/inhabitant/day. This theoretical figure can be compared with the values for eight Berlin wastewater treatment plants. Data for daily P-outflows for 1995 will be used. The total outflow contained 2.264 t/P/y (BWB, 1997). With 3.34 million connected inhabitants, that yields a specific P-output of 1.85 g P/inhabitant/day. This value puts an upper limit if one considers the industrial P-fraction in the outflow. From the treatment plant data-bank from the state of Hesse, a value of about 1.70 g P/inhabitant/day for outflow is calculated. This is in the same range as the theoretical estimated specific P output.

For the reference year 1985, separate P-outputs for the former GDR region and the old German states are used. Outputs for the washing and cleaning materials are taken from the literature. The values for the other three components are the same as for 1995 to guarantee a better comparison between the two reference years. An overview of the specific P-outputs from the literature for 1985 and 1995 is shown in Table 3.4.

Table 3.4: Overview of inhabitant-specific phosphorus outputs (HAMM ET AL., 1991; BEHRENDT, 1994a; ATV, 1997).

AG_{E_P}-components	AG_{E_P} 1985/OGS	AG_{E_P} 1985/NGS	AG_{E_P} 1989/OGS	AG_{E_P} 1989/NGS	AG_{E_P} 1996/GER	AG_{E_P} 1985/OGS	AG_{E_P} 1985/NGS	AG_{E_P} 1995/GER
	Outputs from literature [g P/person/day]					Used P-outputs [g P/person/day]		
Human excrement	1,60	1,70	1,60	1,74	1,60	1,28	1,28	1,28
Food leftover	0,30		0,30		0,30	0,19	0,19	0,19
Detergents	1,60	2,31	0,45	2,31	0,30	1,60	2,31	0,14
Dirty and cleaning water	-	-	0,15	-	-	0,15	0,15	0,15
Total (rounded)	**3,5**	**4,0**	**2,5**	**4,1**	**2,2**	**3,3**	**4,0**	**1,8**

Values for the human excrement in the old German states for 1985 are used based on the conclusion that between 1985 and 1995 the feeding habits have not substantially changed. With the transfer of the values to the region of the former GDR, it is assumed that feeding and nutrition habits of both German regions can not be distinguished. BEHRENDT (1994a) gives approximately 15% higher values for the sum of human excrement and food wastes for 1985. However, within the total output there is a negligibly low difference of only 5%.

The inhabitant-specific nitrogen output (AG_{EN}) comes firstly from human excrement and urine. These show only relatively small fluctuations and are comparatively uniformly given in the literature. HAMM ET AL. (1991) calculated from nutritional requirements a specific nitrogen output of 12.0 g N/person/day and the ATV of 11.0 g N/person/day (ATV, 1997). For the calculation in this work a value of 11.0 g N/person/day will be used.

Nutrient inputs via indirect industrial discharges expressed as population equivalents covered N- and P-outputs can only be estimated with much difficulty. For these fractions, information on population-equivalent-specific N- and P-outputs are not sufficiently known. In no case should the indirect effects be estimated by using inhabitant-specific information. This would lead to a considerable overestimation of the inputs. For phosphorus, according to HAMM ET AL. (1991) it can be accepted that inputs via indirect industrial discharges are negligibly low in comparison to household wastewater. That means that the population equivalent (EGW) specific P-output amounts to 0 g/EGW/d. Regarding nitrogen, as a first approach, an EGW-specific output can be estimated from the N-influent data from the data collection of WAR and the Berlin wastewater treatment plants. Coming out from the relationship:

$$AG_{EW_N} \cdot EW_{AU} = (AG_{E_N} \cdot E_{KA}) + (AG_{EGW_N} \cdot EGW) \qquad \textbf{(3.4)}$$

where AG_{EW_N} = inhabitant equivalent specific N-output [g N/(EW· d)],
AG_{E_N} = inhabitant specific N-output [g N/person/d)],
AG_{EGW_N} = EGW specific N-output [g N/(EGW· d)] and
E_{KA} = connected inhabitants.

AG_{EGW_N} can be successfully calculated with use of Equation 3.3:

$$AG_{EGW_N} = \frac{EW_{AU} \cdot (AG_{EW_N} - AG_{E_N}) + EGW \cdot AG_{E_N}}{EGW} \qquad \textbf{(3.5)}$$

EW_{AU} is a well-known component of the data collection, AG_{E_N} is 11 g/inhabitant/day and AG_{EW_N} can be calculated for every wastewater treatment plant from the N-influent loadings. The sum of the treated EGW can be estimated from the EGW/EW_{AU}-relationship given in the wastewater statistics of the German states. In total, an average value of ca. AG_{EGW_N} = 7 g N/(EGW· d) is calculated. This value is determined only from information for WWTP treating more than 100,000 population equivalents (size class 5). For smaller facilities the lower AG_{EGW_N}-values are used.

- Size class 4: AG_{EGW_N} = 5 g N/(EGW· d)
- Size class 3: AG_{EGW_N} = 3 g N/(EGW· d)
- Size class 2: AG_{EGW_N} = 1 g N/(EGW· d)
- Size class 1: AG_{EGW_N} = 0 g N/(EGW· d)

In addition to the loads coming from inhabitants which are directly connected to a municipal WWTP through sewers, for an overall balance it is necessary to consider the faecal solids sludge from domestic small-scale clarification plants or collection tanks transported to municipal WWTP for further treatment. For the quantification, the following assumptions will be used: The wastewater of the inhabitants which are not connected to the sewer system is collected in collection tanks. The proportion of people whose dirty water is collected in water-tight tanks for the old German states was 60% in 1985 and 80% in 1995 and in the new German states 20% and 40% respectively. For the rest of the population, it is assumed that the waste-water is collected in non-watertight tanks. The wastewater of the water-tight tanks holds the full N- and P-output and 100% should be carried to municipal WWTPs. The faeces of the non water-tight tanks hold about 0.75 g P/(person· d) and 2 g N/(person· d) (BERNHARDT, 1978). In the old German states they carried up to 80% in 1985 and up to 90% in 1995 to WWTP. The equivalent figures for the new German states are up to 50% in 1985 and 70% in 1995. For the population connected to the sewage system but not to municipal wastewater treatment plants it is assumed that their domestic wastewater are first treated in cesspits or small-scale treatment plants before going to the sewerage. In these, collected faeces should have the same N- and P- content as the non-watertight tanks. On the basis of the met assumptions and the corresponding information from the wastewater statistics about the particulars of considered inhabitants, the N- and P- inflow loadings from the population not directly connected to municipal WWTP can be calculated.

With the information on specific outputs, the phosphorus and nitrogen influent loadings of the wastewater treatment plant can be calculated from the existing treatment plant data and also with the estimated basic data. For the calculation of emissions, it is necessary to know the elimination performance of the installed procedures of the wastewater treatment plants.

For nitrogen, the data in Table 3.5 are used. The nitrogen cleaning capacity in activated sludge plants is difficult to determine. It is dependant on sludge age and therefore on tank volume but the required information were not available. Plants which do not carry out nitrification for the whole year attain an elimination of 25-30%, plants with whole year nitrification about 35% but also up to 55% if a partly denitrification of the activated sludge tank volume is used. Therefore, for WWTPs with "nitrification" an average cleaning capacity of 45% is used. With targeted denitrification, about 40% of the activated sludge tanks as denitrification zone is used and it shall reach an N-elimination performance of at least 70%. In the Berlin and Hamburg treatment plants for an average year, 77-81% nitrogen is eliminated (BUWAL, 1996; BWB, 1997; HSE, 1995).

Regarding the removal performance for phosphorus shown in Table 3.6, an improvement between 1985 and 1995 is clear, e.g. with the activated sludge plants of 35% to 50%. This is explained by the reduction of P-concentration in treatment plant inflows in recent years. The P/TOC-inflow ratio has also sunk, which is the selected factor for the degree of biological P-elimination through incorporation of phosphorus into biomass. Low P/TOC-ratios result in comparatively higher P-elimination rates (SIEGRIST & BOLLER, 1996). 90% will be used for the targeted ongoing P-elimination (chemical precipitation or biological). Calculations from the data for Berlin WWTP and the Hesse treatment plant data bank yield 81% to 97% P-removal.

Table 3.5: N-removal performance for various types of wastewater treatment plants.

Plant type	N-removal			Source
	1985 NGS	1985 OGS	1995 GER	
Wastewater pond (unaerated)	50%	50%	50%	WWA ANSBACH (1997)
Wastewater pond (aerated)	30%	30%	30%	WWA ANSBACH (1997)
Activated sludge plant	30%	30%	30%	BISCHOF (1993), BEHRENDT (1994a), BUWAL (1996)
Activated sludge plant (partly biological)	20%	-	-	BEHRENDT (1994a)
Activated sludge plant (fully biological)	30%	-	-	BEHRENDT (1994a)
Mechanical treatment	10%	10%	10%	BISCHOF (1993), BEHRENDT (1994a)
Submerged trickling filter/ Percolating filter plant	25%	25%	25%	BISCHOF (1993), BEHRENDT (1994a), BUWAL (1996)
Treatment using plants	45%	45%	45%	FELDE ET AL. (1996)
Treatment on wastewater farms	80%	-	-	BEHRENDT (1994a)
Nitrification	-	45%	45%	BUWAL (1996)
Denitrification	-	75%	75%	BUWAL (1996), KRAUTH & BAUMANN (1993)

Table 3.6: P-removal performance for various types of wastewater treatment plants.

Plant type	P-removal			Source
	1985 NGS	1985 OGS	1995 GER	
Wastewater pond (unaerated)	25%	25%	45%	BERNHARDT (1978), WWA ANSBACH (1997)
Wastewater pond (aerated)	25%	25%	45%	BERNHARDT (1978), WWA ANSBACH (1997)
Activated sludge plant	20%	35%	50%	BERNHARDT (1978), BEHRENDT (1994a), SIEGRIST & BOLLER (1996), GLEISBERG (1989), ATV (1997)
Activated sludge plant (partly biological)	15%	-	-	BEHRENDT (1994a)
Activated sludge plant (fully biological)	20%	-	-	BEHRENDT (1994a)
Mechanical treatment	10%	15%	20%	BERNHARDT (1978), BEHRENDT (1994a), SIEGRIST & BOLLER (1996), HAMM (1989), ATV (1997)
Submerged trickling filter/ Percolating filter plant	15%	30%	45%	BERNHARDT (1978), WERNER & WODSAK (1994), SIEGRIST & BOLLER (1996), GLEISBERG (1989), ATV (1997)
Treatment using plants	75%	75%	75%	FELDE ET AL. (1996)
Treatment on wastewater farms	90%	-	-	BEHRENDT (1994a)
P-Elimination	90%	90%	90%	BEHRENDT (1994a), ATV (1997)
Microfiltration	-	-	95%	ATV (1997)

With use of the information given above, the nutrient inputs can be estimated for every WWTP. With the calculations for the reference year 1995, corrections will be made for selected treatment plants. These are taken from the requirements of the German wastewater regulations (Abwasserverordnung - AbwV). From this, all water treatment plants which show

ATV-nutrient loading of 1 to 3, maintain the required outflow concentrations of nitrogen and phosphorus. In individual cases, the water treatment plants can achieve a better purification performance than the average given in Table 3.5 and Table 3.6. Table 3.7 shows maximum possible elimination performance in dependence of the ATV N- and P-loading-level and the installed treatment procedures of the WWTP.

The correction will be as follows: For all wastewater treatment plants which are subject to the requirements of the AbwV, computer generated outflow concentrations are determined for nitrogen and phosphorus based on the previous estimations using Method 3. In the case that calculated concentrations exceed allowable limits of AbwV, a new loading calculation using the cleaning capacities given in Table 3.7 is carried out. In other cases, the theoretically necessary purification performance is higher than in Table 3.7. Here, the maximum possible purification performance from a new loading calculation is used.

Table 3.7: Maxima for N- and P- purification performance of the corrected calculation.

N-/P-loading-level	Maximal purification performance for				
	Nitrogen by procedure			Phosphorus by procedure	
	B	B(N)	B(ND)	B	B(P)
1	68%	70%	85%	65%	98%
2 and 3	55%	68%	80%	60%	95%

Loadings used

For every treatment plant, information on at least one and up to four loading-parameters can be made. For all plants for 1985 and 1995, a N- and P-load has been assigned according to Method 3. Depending on the available data for the individual plants in 1995, additional loadings with Method 1 and/or 2 have been calculated. Furthermore, there is information available in the literature for 1995 for 325 water treatment plants. In the following, every treatment plant is assigned only one value for nitrogen and phosphorus. For this, explicit loading-information from the *ICPE*, *ICPD* or from the operators are used with highest priority. Where explicit information on loads are not available the mean value of the results of methods 1, 2 and 3 are used. Since the estimations from Methods 1 and 2 are based both on concentration information only an arithmetic mean from these was used for the calculation of the total average value.

River catchment routine

The geographical situation of every recorded wastewater treatment facility is determined through assignment of the municipality to a location. Through a linkage of the municipality registers with the records from ArcGemeinde, every treatment plant in Geographical

Information Systems (GIS) can be portrayed as a point (label) and so is unambiguously assigned to a river catchment. The points do not however represent the exact location of the WWTP since the labels from the ArcGemeinde are placed more or less by chance in the middle of the community area. The area of a municipality and so with that also its label - can lie in two or more catchment areas. For treatment plants with a plant capacity of $EW_{AB} \geq$ 10,000 population equivalents (p.e), whose community location lies in more than one catchment area, a scrutiny is made and if necessary, a correction of the label position is carried out. With the other treatment plants (that means EWAB < 10,000 p.e.) it is assumed that the label from ArcGemeinde adequately represents the treatment plant location.

3.1.1.2 Nutrient inputs via municipal wastewater treatment plants outside Germany

The investigation of nutrient inflows from municipal wastewater treatment plants in other countries for the large river catchments of the Danube, Rhine and Elbe is carried out as described in the literature cited in Section 2.2.2. The division of inputs in the individual river catchment areas which lie partly in other countries is made according to the size of the urban areas (from CORINE-Landcover) in the large river catchment areas in these countries.

3.1.1.3 Nutrient inputs via direct industrial dischargers

The direct industrial nutrient inputs from Germany and other countries are taken from the literature (see Section 2.2.3). If data has already been published for individual catchment areas, this will be used directly. Where only summary data available for extensive areas (e.g. for OGS, NGS and large river catchments in other countries), the division of inputs in the individual catchment areas will be based on the urban areas after CORINE-Landcover.

3.1.2 Inputs via diffuse sources

The considered pathways for diffuse nutrient inputs (see Figure 3.1) are, as far as possible, those already studied by WERNER ET AL. (1991) and WERNER & WODSAK (1994) for the old and new German states. However, the methods and database for estimation of at least some paths are clearly different. Further, some uncertain pathways are not considered at all (e.g. direct agricultural inputs). Therefore, it is essential that the same methods are used both for the period around 1995 and for the earlier period around 1985 to investigate previous changes in the size of inputs and with that, the effectiveness of introduced measures.

The formulation of the methods, at first, succeeds especially for the two nutrients nitrogen and phosphorus. Since the behaviour of phosphorus and nitrogen in the environment is very different, the methods for the two elements are not always the same. In general, the same methods can also be used for other substances, e.g. heavy metals, if the essential model coefficients can be determined and the environmental behaviour of the substances is similar to nitrogen or phosphorus.

The starting point for the modelling of nutrient inputs into every river basin is an estimate of the water balance:

$$Q = Q_{GW} + Q_{DR} + Q_{RO} + Q_{URB} + Q_{AD} \quad (3.6)$$

where Q = average measured runoff [m³/s],
Q_{GW} = base flow and natural interflow [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
Q_{AD} = result of the balance between direct precipitation on the freshwater surfaces and the evaporation from these surfaces [m³/s].

The individual components of this water-balance are calculated from the precipitation by means of empirical equations as average values for a particular period of five years with the exception of the base flow. This is essential because the calculation approach should exclude errors caused by periods shorter than 5 years in hydrological and meteorological time series.

The base flow Q_{GW} will be calculated for every catchment from the difference between the measured total runoff and the values of other flow components. For areas between two monitoring stations, the total runoff will be determined from the flow differences of the particular river basins upstream of the monitoring station. Through these actions, failures of flow measurements are transferred to the flow of in-between areas, such that even negative flow values and also from the balance calculation, negative values for the base flow can occur. In some cases, very high positive or negative deviations between the calculated base flow and the rate of leakage water (calculated according to WENDLAND ET AL. (1993) are found (see Section 3.1.2.6). Here, the base flow of the in-between areas are corrected so that the flow balance between the parts of the river basin is only slightly influenced and the divergence of the downstream basins is less than 10%.

3.1.2.1 Nutrient surpluses on the agricultural area and their long term change

Most diffuse nutrient input is caused through agriculture. Therefore, the model for the quantification of nutrient inputs in the river systems must consider these agricultural activities in an appropriate way. One of the main factors, which determines the size of the nutrient loadings from diffuse sources, is the yearly surplus of nutrients on agricultural areas. Since an essential task of this study is the regional differentiation of nutrient surpluses in individual river basins, it is also necessary to regionalize the nutrient surpluses. This task was carried out within the framework of this study by a group from the *Association for Soil and Water Protection*. The description of the database and methods and also the results of the quantification of nutrient surpluses are so extensive that a detailed description is omitted in the framework of this report. The report "Regionalized balances of nitrogen and phosphorus surpluses of agriculture in the municipalities and districts of Germany" of BACH ET AL. (1998) is already completed for the partial task. A summarised overview of the nitrogen and phosphorus surpluses from agricultural areas for the year 1995 is shown in Maps 3.1 and 3.2. The regional differences in nutrient surpluses in agricultural areas shown in BACH ET AL. (1998) were overlaid with the boundaries of the catchment areas to determine the average surpluses in the individual river basins for this reference year.

Besides the regional differences in the nutrient surpluses, an investigation of the time related changes of the nutrient surpluses in the agricultural areas is also essential for the quantification of the changes of the nutrient inputs in the river basins. This task was partly carried out also by BACH ET AL. (1998). However, a regional differentiation could not be done because the changes in nutrient surpluses were calculated for all old German states for 1970 to 1995 and for the entire area of Germany for the period 1990 to 1995. On this basis, the yearly surpluses were calculated in the new German states for 1990 to 1995 in consideration of agricultural areas in the old and new German states. The results for long-term changes in nitrogen surpluses since 1970 and also 1990 are shown in Tables 3.8 and 3.9 (parts highlighted in grey).

As will be shown in Section 3.1.2.6, the considered period for the changes in the nutrient surplus from 1970 or 1990 is still too short. The results of BEHRENDT (1988) for the changes in the nutrient surpluses in the old and new German states and also in the Netherlands and Denmark from 1948 to 1985 were used to lengthen the period of nutrient surplus analysis. The method used by BEHRENDT (1988) differs very little from that described in BACH ET AL. (1998). Only some coefficients for the nutrient content of crop yield and livestock excrement are different.

For the old German states, a direct comparison of determined nutrient surpluses given by BACH ET AL. (1998) and BEHRENDT (1988) for the period 1970 to 1985 is possible. These comparisons are shown in Figures 3.3 and 3.4. It is clear that the estimated surpluses for phosphorus for the whole period from 1970 to 1985 and also for nitrogen from 1970 to 1976 are almost identical. From 1976 to 1985, a 10% higher nitrogen surplus is calculated BY BACH ET AL. (1998). On the grounds of a good agreement between the nutrient surplus estimates, the values given by BEHRENDT (1988) will be used for the nitrogen and phosphorus surpluses in the old German states before 1970 and the numbers of BACH ET AL. (1998) from the year 1970 onwards to extend the time-period.

Regarding the new German states, there was a much greater difference in the numbers for nutrient surpluses between 1989 and 1990 (see Figures 3.3 and 3.4). This is not due to different methodology but to the very dramatic changes in agriculture in the new German states leading back to the changes in 1989. Both the use of mineral fertilizer and livestock numbers were very greatly reduced at this time. In the studies on long-term changes of nutrient surpluses in the new German states there was therefore an immediate reduction in the surpluses from a level of 101 to 38 kg N/(ha· a) and from 22 to -4 kg P/(ha· a). The results given by BEHRENDT (1988) were used to extend the surpluses given by BACH ET AL. (1998) from 1990 in the past.

Base-data for the long-term changes in nutrient surpluses are shown in Figure 3.5 and Tables 3.8 and 3.9. These data are used for the following analysis. In addition, Table 3.8 and Figure 3.5 give the values for nitrogen surpluses as means from the 10, 20 and 30 previous years. These mean values are used for a rough estimate of residence times in the unsaturated zones and in groundwater by the comparison of long term changes of nitrate concentrations in rivers with time series of nutrient surplus considering the effects of previous years.

For phosphorus, which is accumulated in the upper soil layers until a saturation level is reached, the P surpluses from 1948 onwards are used. P-accumulations in topsoil are shown in Figure 3.6 and Table 3.9 and from these, the P-content of soil and their changes over time are approximately estimated.

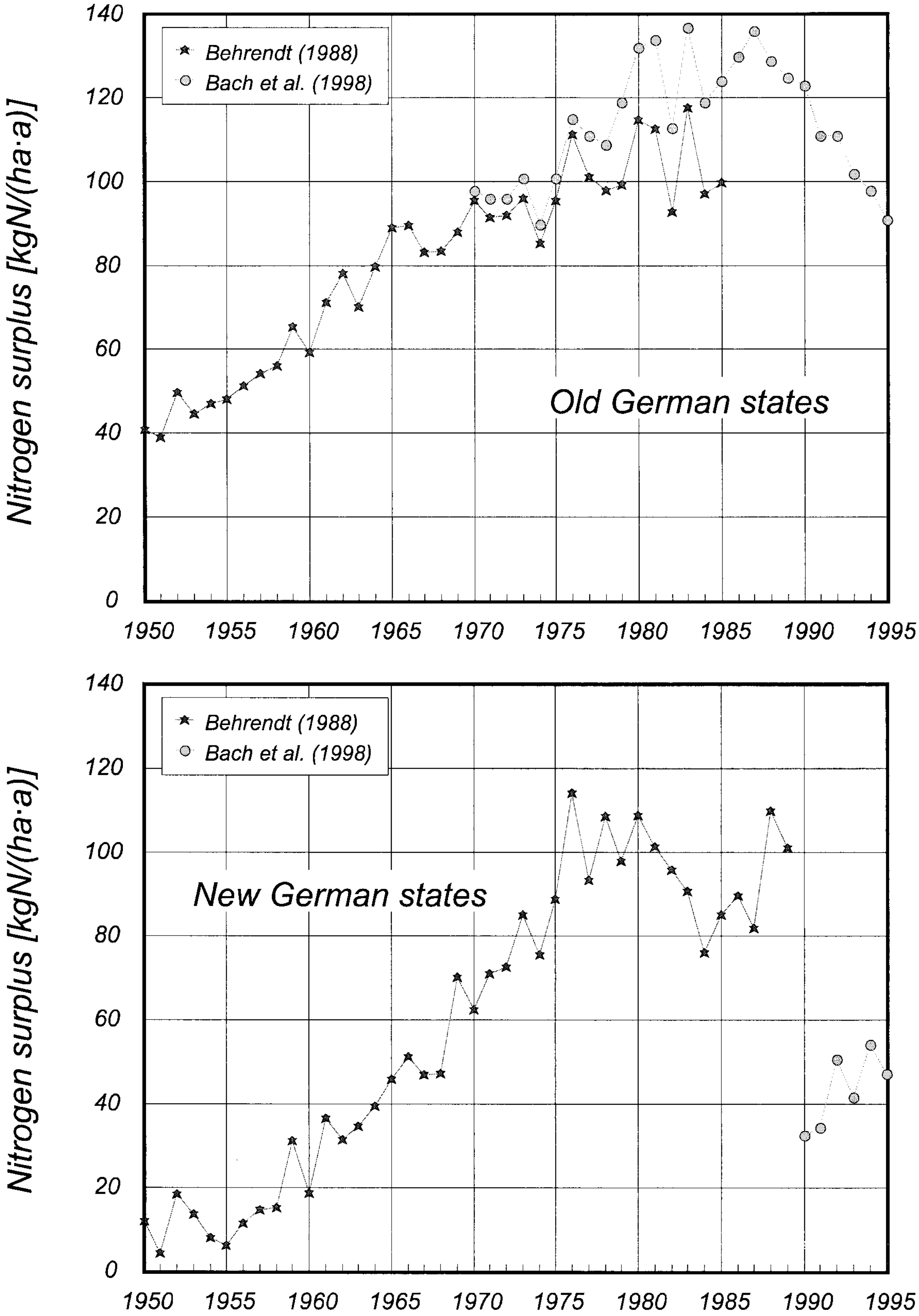


Figure 3.3: Long-term changes in the nitrogen surpluses of agricultural areas of the old and new German states from 1950 to 1995 (according to BACH ET AL., 1998; BEHRENDT, 1988).

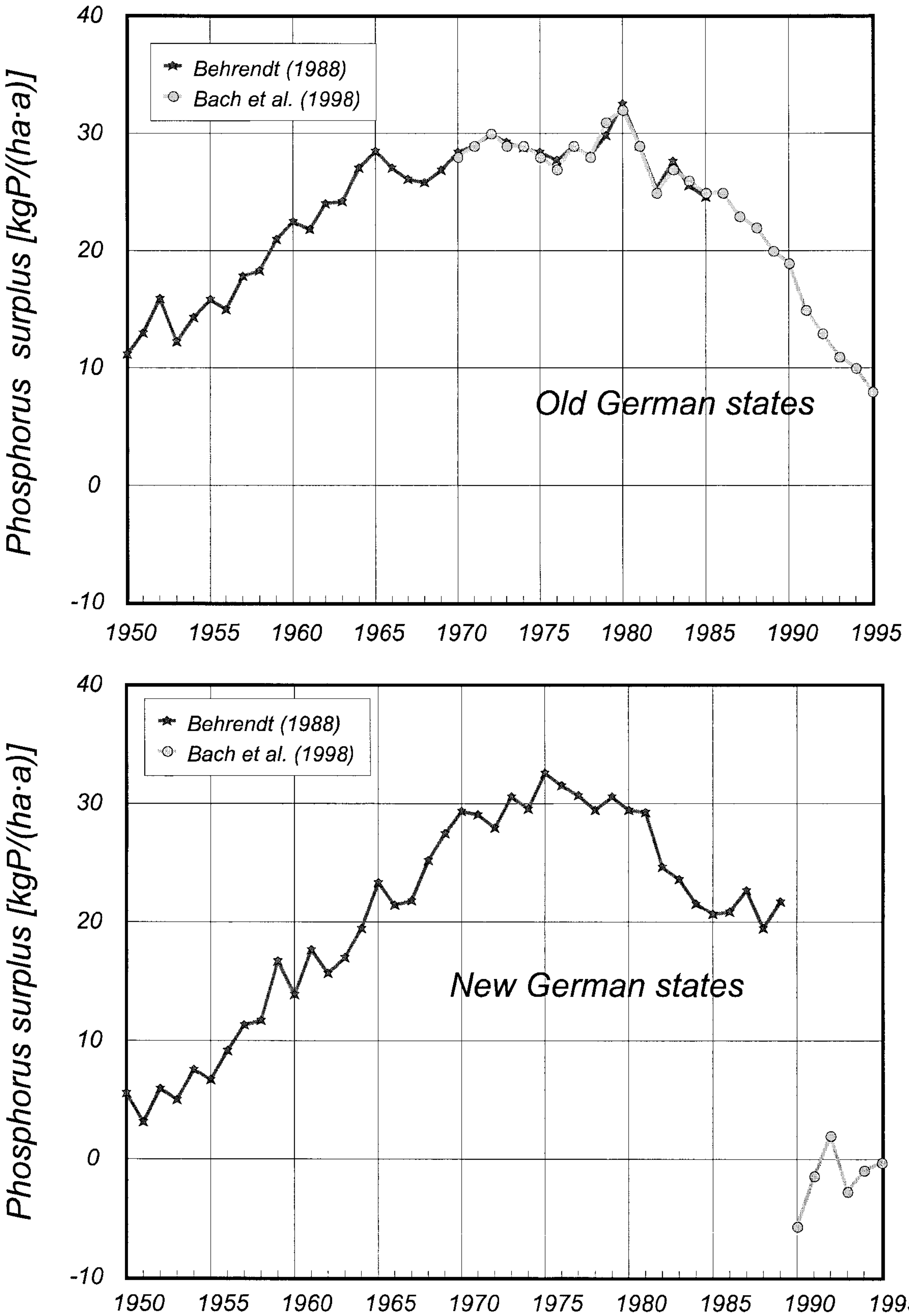


Figure 3.4: Long-term changes in the phosphorus surpluses of the agricultural areas of the old and new German states from 1950 to 1995 (according to BACH ET AL., 1998; BEHRENDT, 1988).

Table 3.8: Long term changes of nitrogen surplus in agricultural areas in the old and new German states referred to BACH ET AL. (1998) (highlighted in grey) and BEHRENDT (1988) and means of the 10, 20 and 30 previous years.

Year	N-surplus in the new German states				N-surplus in old German states			
	Annual value	Mean of 10 previous years	Mean of 20 previous years	Mean of 30 previous years	Annual value	Mean of 10 previous years	Mean of 20 previous years	Mean of 30 previous years
	[kg N/(ha· a)]				[kg N/(ha· a)]			
1950	12				41			
1951	4				39			
1952	19				50			
1953	14				45			
1954	8	11	10	10	47	42	28	22
1955	6	10	10	10	48	43	30	23
1956	11	11	10	10	51	45	32	25
1957	15	11	11	10	54	46	34	26
1958	15	12	11	11	56	47	36	28
1959	31	14	12	11	66	50	39	30
1960	19	14	12	12	59	52	42	31
1961	37	17	14	12	71	55	45	33
1962	32	19	15	13	78	58	48	35
1963	35	21	16	14	70	60	50	37
1964	40	24	17	15	80	63	53	40
1965	46	28	19	16	89	68	55	42
1966	51	32	21	18	92	72	58	45
1967	47	35	23	19	85	75	60	48
1968	47	38	25	20	86	78	63	50
1969	70	42	28	22	90	80	65	53
1970	63	47	30	24	98	84	68	56
1971	71	50	34	26	96	86	71	59
1972	73	54	37	28	96	88	73	61
1973	85	59	40	30	101	91	76	64
1974	76	63	43	33	90	92	78	66
1975	89	67	48	35	101	93	80	68
1976	114	74	53	39	115	96	84	71
1977	94	78	57	41	111	98	87	73
1978	109	84	61	45	109	101	89	75
1979	98	87	65	48	119	104	92	78
1980	109	92	69	51	132	107	95	81
1981	101	95	72	54	134	111	99	84
1982	96	97	76	57	113	113	100	86
1983	91	98	78	59	137	116	104	89
1984	76	98	80	62	119	119	106	92
1985	85	97	82	64	124	121	107	94
1986	90	95	84	67	130	123	109	97
1987	82	94	86	69	136	125	112	99
1988	110	94	89	72	129	127	114	102
1989	101	94	91	75	125	128	116	104
1990	39	87	89	75	123	127	117	106
1991	35	80	88	75	111	125	118	107
1992	50	76	86	76	111	125	119	108
1993	42	71	84	76	102	121	119	109
1994	55	69	83	76	98	119	119	110
1995	48	65	81	77	91	116	118	110

Table 3.9: Long term changes of phosphorus surplus and phosphorus accumulation in agricultural areas since 1948 in the old and new German states referred to BACH ET AL. (1998) (highlighted in grey) and BEHRENDT (1988).

Year	New German states		Old German states	
	P-surplus	P-accumulation	P-surplus	P-accumulation
	[kg P/(ha· a)]		[kg P/(ha· a)]	
1950	6	15	11	32
1951	3	18	13	45
1952	6	24	16	61
1953	5	29	12	74
1954	8	37	14	88
1955	7	43	16	104
1956	9	53	15	119
1957	11	64	18	137
1958	12	76	18	155
1959	17	92	21	176
1960	14	106	22	198
1961	18	124	22	220
1962	16	140	24	244
1963	17	157	24	269
1964	19	176	27	296
1965	23	200	29	324
1966	21	221	27	351
1967	22	243	26	377
1968	25	268	26	403
1969	28	296	27	430
1970	29	325	28	458
1971	29	354	29	487
1972	28	382	30	517
1973	31	413	29	546
1974	30	442	29	575
1975	33	475	28	603
1976	32	507	27	630
1977	31	537	29	659
1978	30	567	28	687
1979	31	597	31	718
1980	30	627	32	750
1981	29	656	29	779
1982	25	681	25	804
1983	24	704	27	831
1984	22	726	26	857
1985	21	747	25	882
1986	21	768	25	907
1987	23	790	23	930
1988	20	810	22	952
1989	22	832	20	972
1990	-4	826	19	991
1991	-1	825	15	1.006
1992	2	827	13	1.019
1993	-3	824	11	1.030
1994	-1	823	10	1.040
1995	-0	823	8	1.048

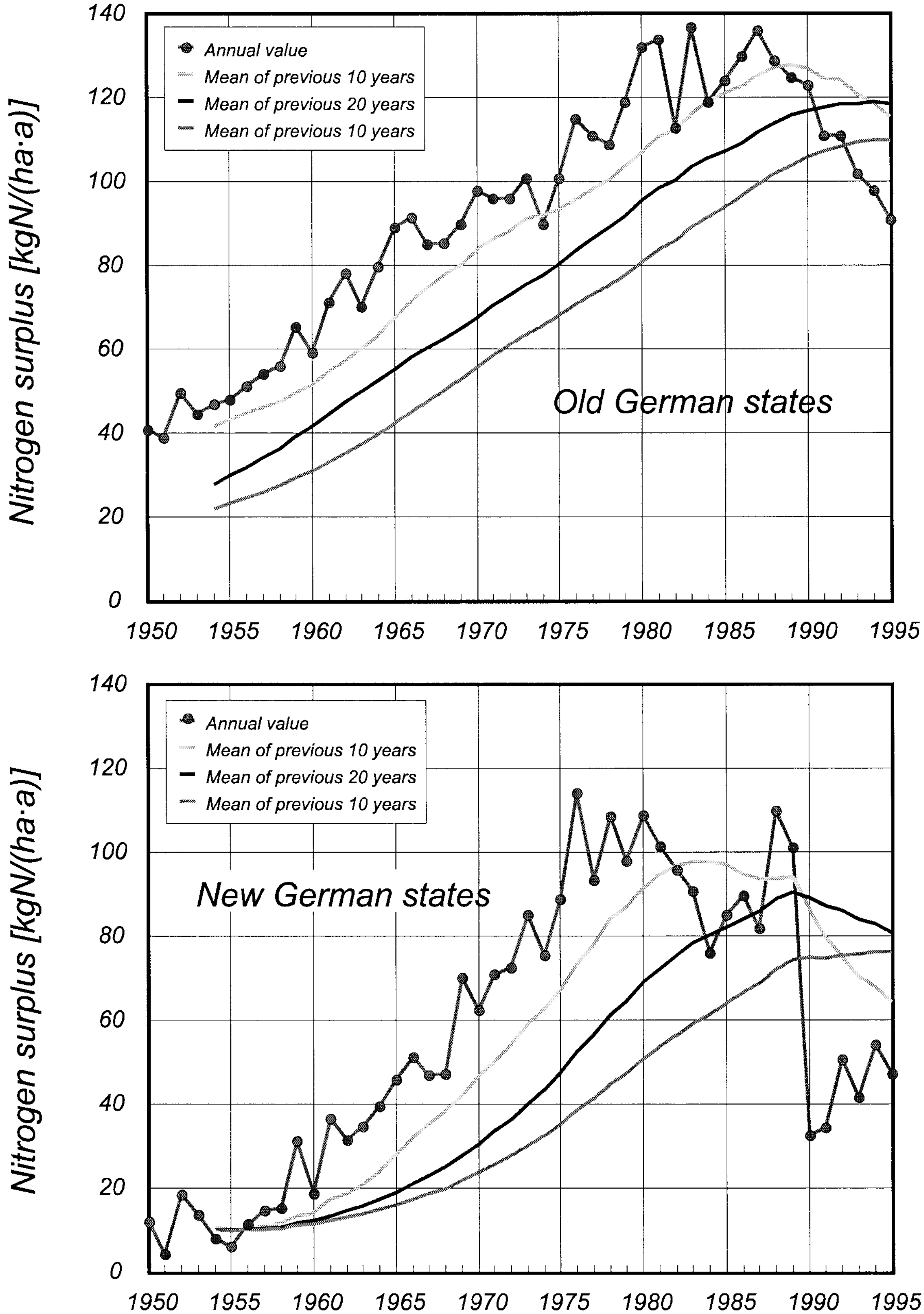


Figure 3.5: Long-term changes in the nitrogen surpluses of the agricultural areas of the old and new German states for 1950 to 1995 and also averages for the previous 10, 20 and 30 years (according to BACH ET AL., 1998; BEHRENDT, 1988).

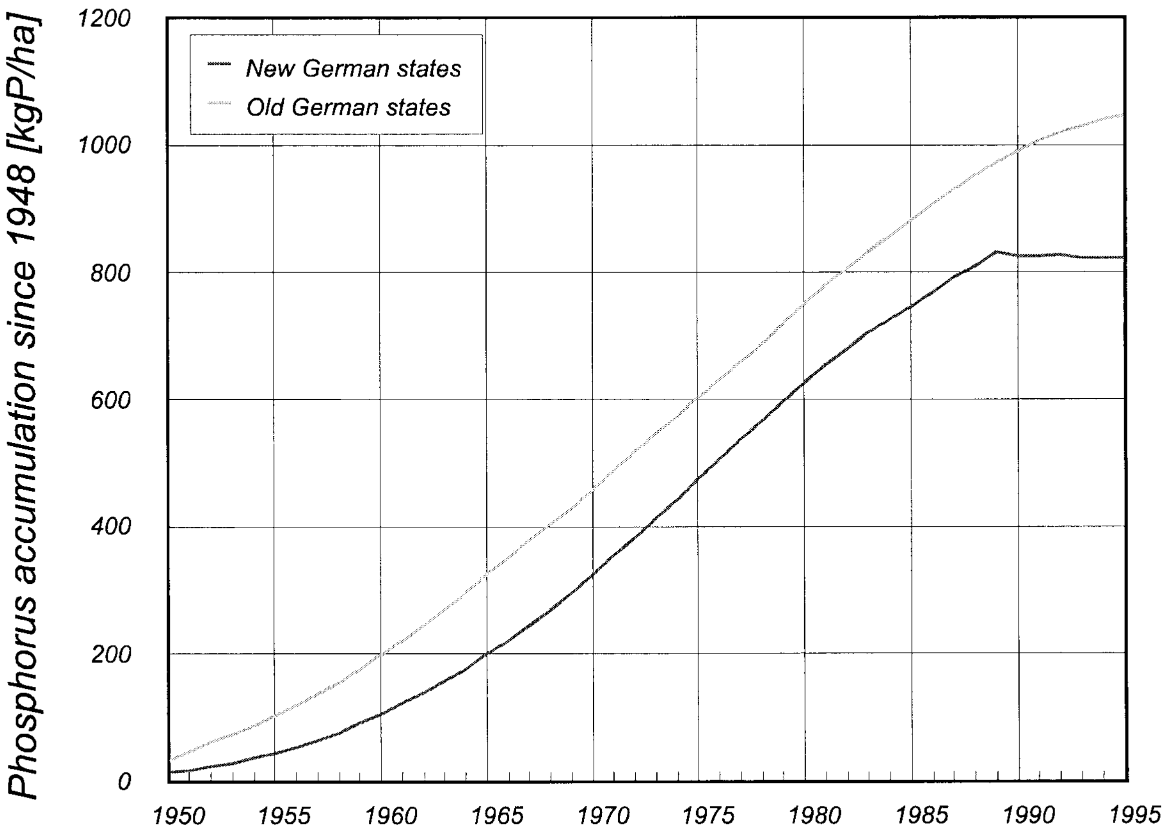


Figure 3.6: Phosphorus accumulation in the agricultural areas of the new and old German states since 1948.

3.1.2.2 Direct nutrient inputs to the surface waters via atmospheric deposition

The basis for the estimation of direct inputs into freshwaters by atmospheric deposition is the knowledge of the water surface area of a basin which is connected to the river system. The estimation of these areas is difficult. On the one hand, the land use map according to CORINE-Landcover only includes larger lakes and rivers and on the other hand, the statistics at the level of municipalities also cover the smaller water bodies, not generally connected to the river systems. Between both information sources, as shown in Figure 3.7, the river basins with a water surface area less than 1% are grossly underrepresented in the land use map.

Water surface areas calculated on the basis of the information from municipal statistics are probably overestimates. In addition, such information is not at present available for the parts of the basins outside of Germany.

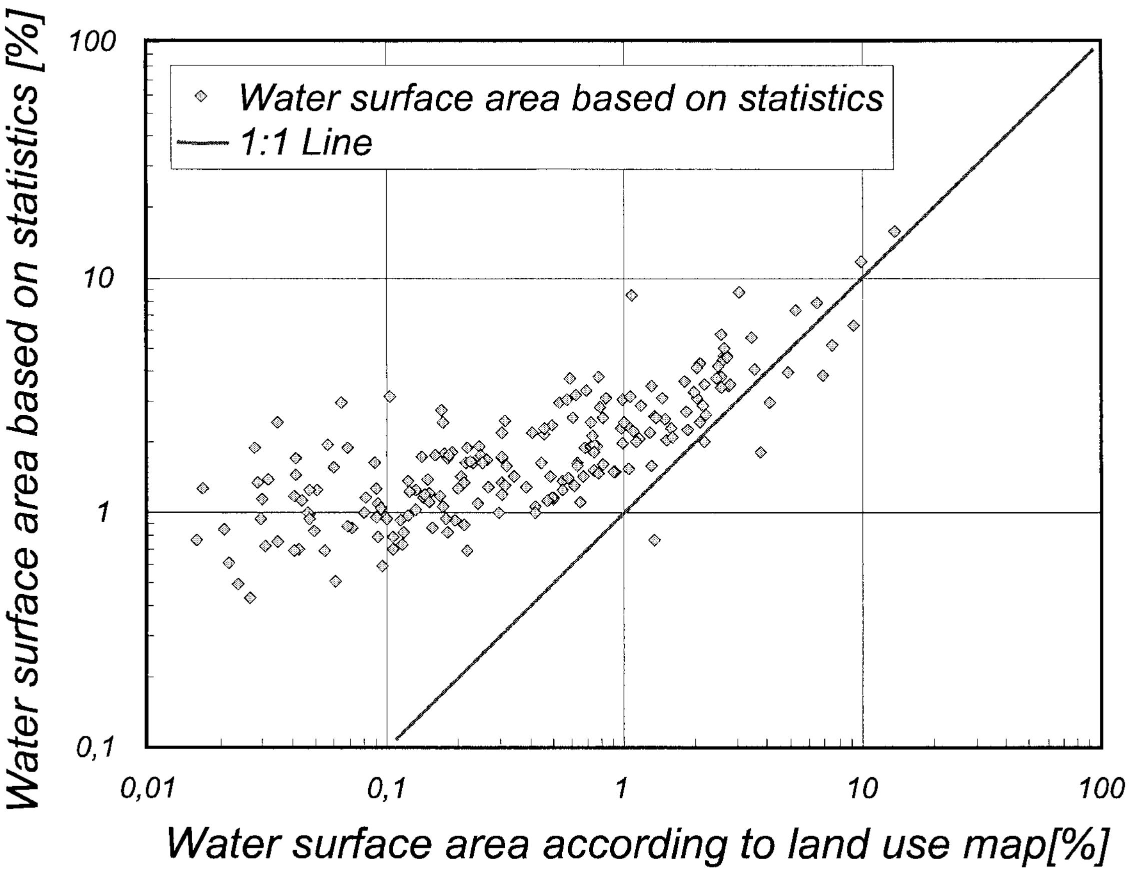


Figure 3.7: Relationship between the water surface area of German catchments estimated according to the digital landuse map and the statistics of municipalities.

Inputs calculated with the information from the land use map are underestimated because in particular, only the water surface areas for rivers more than a hundred metres wide and large lakes are recorded. Studies to correct the given water areas through a coupling to the river net map with the land use map have failed because the river net map in particular, does not contain first and some second order rivers (after STRAHLER, 1957). This shows a comparison carried out of a high-resolution river net map for the Spree catchment area (scale 1:25,000) with the river net map for all of Germany (UEBE ET AL., 1998). Further, the German river net map shows for the individual basins only a little variation of the river net density also for such areas in which there is a high water network density especially from ditch drainage (e.g. in areas of the Weser, Ems and the North Sea coast area).

The problem for a more precise determination of the water surface areas is not only related to the nutrient inputs through atmospheric deposition but also with the quantification of the nutrient retention of the water bodies themselves and must therefore be taken more notice of in subsequent studies. In this study, the following procedure will be carried out for the quantification of water areas. To begin with, the water areas will be determined from CORINE-land cover map. In addition, for the total water area, the flowing waters will be considered from the results of flow analysis according to BEHRENDT & OPITZ (1999) derived from BILLEN AT AL. (1995). After that, one can find out the area of flowing waters dependant on the catchment area according to the following:

$$A_W = A_{WSEE} + A_{WFGW} = A_{WCLC} + 0{,}001 \cdot A_{EZG}^{1{,}185} \quad \textbf{(3.7)}$$

where A_W = total water surface area [km²],
A_{WSEE} = water surface area from land use map [km²],
A_{WFGW} = surface area of flowing waters [km²],
A_{WCLC} = water surface area from CORINE-Landcover [km²] and
A_{EZG} = catchment area [km²].

On the basis of Equation 3.7, the water surface area of all basins located outside Germany will be determined. For catchment areas located inside Germany, the results from the community statistics will also be applied. For these areas, the water surface area is calculated from the mean of values from Equation 3.7 and the community statistics.

The calculation of the nutrient inputs from atmospheric deposition is carried out through multiplication of the averages of the sum of NOx-N and NH_4-N deposition and also the P-deposition by the average water surface area in every basin. The used deposition rates will be elucidated from the following.

Phosphorus

Phosphorus deposition is rarely measured and there is hardly any blanket coverage information available on P-deposition in German catchment areas. Information on the total phosphorus deposition (wet and dry deposition) is hardly known from the literature. The published data cover almost exclusively the P-concentrations in precipitation, i.e. wet deposition rates. Published figures for P-deposition rate range from 0.04 to 1.5 kg P/(ha· a) (RIGLER, 1974; GOLTERMANN, 1976; WAGNER & WOHLAND, 1976; BERNHARDT, 1978; AHL, 1979; FIEDLER ET AL., 1985; FIRK & GEGENMANTEL, 1986; PAULIUKEVICIUS ET AL., 1988). A detailed literature review on P-deposition in precipitation is given in KLEIN & WASSMANN (1986). From this review, the yearly P-deposition rate amounts to 0.04 to 6.64 kg P/(ha· a). In studies by the authors in the catchment area of the lake Tegeler See (Berlin), the deposition is, on average, 0.77 kg P/(ha· a).

On the basis of measured phosphate content of precipitation according to ZIERATH (1981), one can estimate for the area of the new German states with an average yearly precipitation of 660 mm, a wet deposition rate between 0.1 and 0.7 kg P/(ha· a). For this area, the wet deposition rate is comparable with the measured wet deposition rate of 0.1 to 0.8 kg P/(ha· a) for the Masurian lake region studied by GOSZCYNSKA (1983). From the comparison with wet deposition rates for other non-urban areas, GOSZCYNSKA (1983) comes to the conclusion that the estimated average level of wet deposition in the Masurian Lake District is low (mean: 0,17 kg P/(ha· a)).

In the Masurian Lake District, dry phosphate deposition caused by dust is two to three times as great as wet deposition (HILLBRICHT-ILKOWSKA, 1988). According to GRANT & LEWIS (1982), dry deposition (dust particles) comprises about 87% of the total soluble inorganic phosphorus and 56% of soluble organic phosphorus.

GOSZCYNSKA (1985) determined the possible TP-dry deposition in the Masurian lakes region as 0.2 to 0.8 kg P/(ha· a) (mean 0.4 kg P/(ha· a)). For total P-dry deposition, GRANT & LEWIS (1982) estimated an average value of 0.32 kg P/(ha· a) at 3,000 m altitude and far from urban agglomerations. For Lake Balaton, HORVATH ET AL. (1981; cited in KLEIN & WASSMANN, 1986) give a dry deposition figure of 0.08 kg P/(ha· a). Only slightly greater (0.11-0.12 kg P/(ha· a)) is the dry deposition for the area around Neusiedler See (MALISSA ET AL., 1984). In and around agglomerations of industry and human populations, a TP-dry deposition between 1.8 and 11.0 kg P/(ha· a) has been estimated (NOVOTNY & CHESTERS, 1981).

Total P-deposition rate may consequently - depending on land use of the concerned area - be between 0.3 and 3.0 kg P/(ha· a), in which one can take values of more than 2.0 kg P/(ha· a) for urban agglomerations. For the following calculations, a P-deposition of 0.7 kg P/(ha· a) for the period 1983-87 is used as an average value for the new German states (wet deposition 0.3 kg P/(ha· a); dry deposition 0.4 kg P/(ha· a)). For the old German states, a P-deposition of 0.4 kg P/(ha· a) for the second half of the eighties will be used according to WERNER E AL. (1991).

Concerning the changes in P-deposition over time, one must consider changes in the main sources of P-emissions. Principal sources of anthropogenically caused P-emission in the air are the burning of coal and wind-erosion. Therefore, for the assessment of changes in P-deposition over time, one must consider the development of dust emissions in Germany. On the basis of information from the German Statistical Yearbook one can determine a decrease of 30 % in dust emissions from 1985 to 1995 for the old German states and more than 90% for new German states. From that, it transpires that specific dust emissions in the old and new German states today are indistinguishable. Inland dust emissions contribute 50% to dust depositions, so one can estimate for 1995 a P-deposition form dust of 0.37 kg P/(ha· a).

Nitrogen

For the calculation of direct inputs of nitrogen via atmospheric deposition, model results from the model *DNMI* in the framework of the EMEP program for the years 1985 and 1996 (TSYRO, 1998a, b; BARTNICKI ET AL. 1998) will be used. The EMEP data are available in the form of digital maps with a unit length of 150 km for 1985 and 50 km for 1996 as NO_x-N- and

NH_4-N- deposition in kg N/(ha· a) (compare Map 2.12). The EMEP digital maps are overlaid with the boundaries of the studied catchment areas and so the average NO_x-N- and NH_4-N-deposition for every catchment area is estimated. For the old German states for the period 1983-1987, one can calculate an average nitrogen deposition of 24 kg N/(ha· a) which is identical to the value given by WERNER ET AL. (1991). For the new German states, a value of 22 kg N/(ha· a) is calculated. This is only a little higher than the figure of 19.5 kg N/(ha· a) for nitrogen deposition in 1985 given by BEHRENDT ET AL. (1994).

3.1.2.3 Nutrient inputs via surface runoff

The calculation of surface runoff is based on the simplified approach according to LIEBSCHER & KELLER (1979). With this, the surface runoff and the average total yearly runoff can be calculated using the average annual precipitation, the average summer half-year precipitation and the average winter half-year precipitation. For the calculation of total runoff, a regression of 30-year precipitation and runoff measurements in 144 over the German parts of the catchment areas is used. LIEBSCHER & KELLER (1979) give an average error of 27 mm/a and a correlation coefficient of r = 0.965 for the following empirical relationship:

$$q_G = 0{,}86 \cdot N_J - 111{,}6 \cdot \frac{N_{SO}}{N_{WI}} - 241{,}4 \qquad \textbf{(3.8)}$$

with q_G = average yearly specific runoff [mm/(m²· a)],
N_J = average annual precipitation [mm/(m²· a)],
N_{SO} = average precipitation in the summer half year [mm/(m²· a)] and
N_{WI} = average precipitation in the winter half year [mm/(m²· a)].

The surface runoff is calculated using the following power function (see Equation 3.9), from the US SOIL CONSERVATION SERVICE (1972) and also proposed by *German Association for Water Resources and Land Improvement (Deutscher Verband für Wasserwirtschaft und Kulturbau)* (DVWK, 1984):

$$q_{RO} = q_G \cdot 2 \cdot 10^{-6} \cdot (N_J - 500)^{1{,}65} \qquad \textbf{(3.9)}$$

where q_{RO} = specific surface runoff [mm/(m²· a)].

From the monthly mean precipitation, the average summer, winter and yearly mean values are calculated for all precipitation stations for the study periods. These will be interpolated for the areas with the model ARC/EGMO (BECKER & PFÜTZNER, 1987). As a result, a digital surface runoff map with a unit area of 3x3 km^2 is made with GIS ARC/INFO. This digital map is overlaid with the map of the basins areas and the average specific surface runoff is calculated in every basin. These procedure is carried out for both time periods.

For the estimation of the total surface runoff from the unpaved areas in a basin, it is assumed that these runoff components do not occur in forested and wetland areas or in freshwater bodies itself and mined lands (e.g. open cast pits). Then one can calculate the average total surface runoff from unpaved areas for every basin with the following equation:

$$Q_{RO} = q_{RO} \cdot (A_{LN} + A_{OF}) \cdot 1000 \qquad \textbf{(3.10)}$$

where Q_{RO} = surface runoff from non-paved areas [m³/a],
A_{LN} = agricultural area [km²] and
A_{OF} = open area (mountainous areas and areas with natural vegetation) [km²].

For the further calculations, it is assumed that 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. For that it is necessary to divide the agricultural areas into arable land and grassland. For the area-weighted concentrations of nitrogen and phosphorus in surface runoff, the following is valid:

$$C_{RO_{N,P}} = \frac{C_{ROACKER_{N,P}} \cdot A_{ACKER} + C_{ROGRÜN_{N,P}} \cdot A_{GRÜN} + C_{ROOF_{N,P}} \cdot A_{OF}}{A_{ACKER} + A_{GRÜN} + A_{OF}} \qquad \textbf{(3.11)}$$

where $C_{RO_{N,P}}$ = nutrient concentration in surface runoff [mg/l],
A_{ACKER} = area of arable land [km²],
$A_{GRÜN}$ = grassland area [km²],
A_{OF} = open area [km²],
$C_{ROACKER_{N,P}}$ = nutrient concentration in surface runoff from arable land [mg/l],
$C_{ROGRÜN_{N,P}}$ = nutrient concentration in surface runoff from grassland [mg/l] and
$C_{ROOF_{N,P}}$ = nutrient concentration in surface runoff from open land [mg/l].

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

$$ERO_{N,P} = \frac{C_{RO_{N,P}} \cdot Q_{RO}}{1000} \qquad \textbf{(3.12)}$$

where $ERO_{N,P}$ = nutrient input via surface runoff [t/a].

For the calculation of the surface runoff loadings the nutrient concentrations given in Table 3.10 are used for all catchment areas.

The nutrient concentrations given in Table 3.10 are derived from the following considerations.

Table 3.10: Estimation of used nutrient concentrations in surface runoff for arable land, grassland and open areas.

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

Phosphorus

It has already been ascertained by WERNER ET AL. (1991) that the extractable dissolved P-concentration is in a range from 0.8 to 1 g P/m³. BRAUN ET AL. (1991) assume for the Swiss Rhine basins downstream of the lakes that the P-concentration in the surface runoff is 0.5 g P/m³ for arable land and 2 g P/m³ for grassland. These results could be validated from the extensive studies on P-content and P-absorption capacity of soils in the northeast German flatlands (PÖTHIG & BEHRENDT, 1999). From these studies it can be derived that the water-extractable P-concentration depends very strongly on the P-saturation of the soil as shown in Figure 3.8.

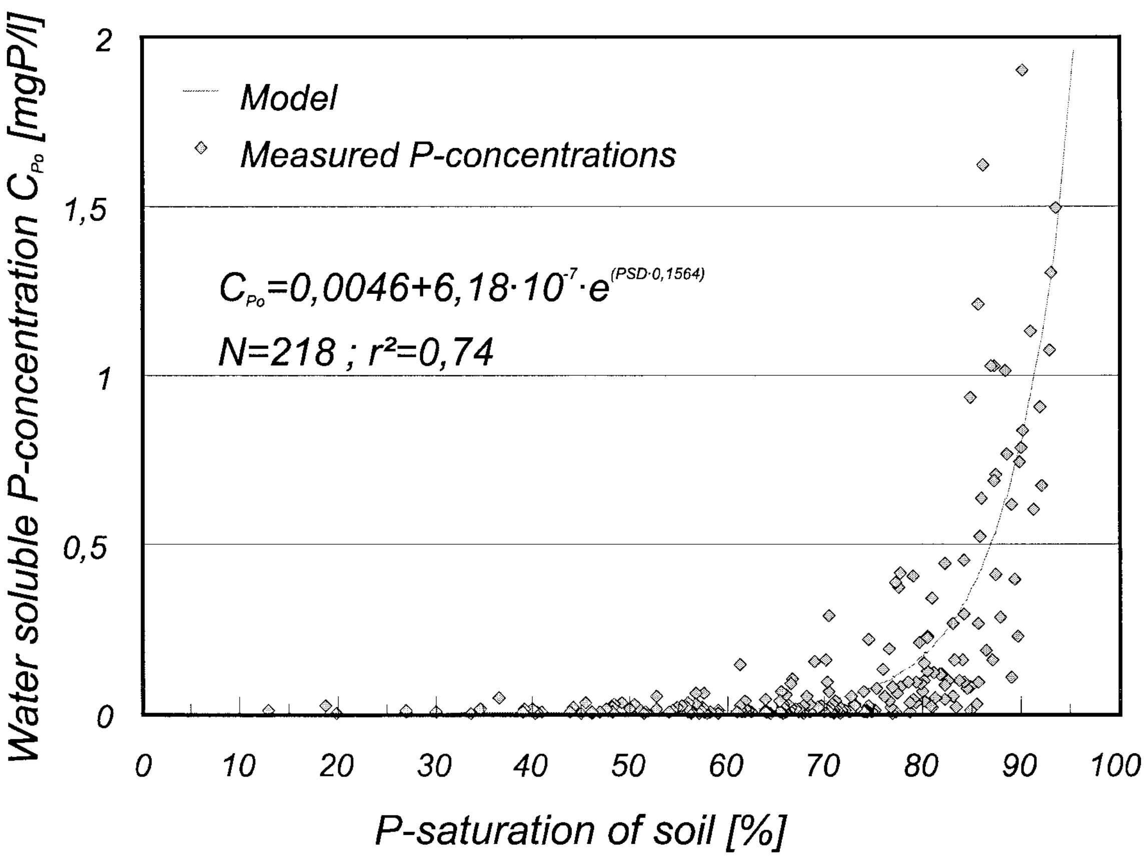


Figure 3.8: Dependence of the water-extractable P-concentration on the P-saturation of soils.

If one assumes that for arable areas, the topsoil layer shows on average a P-saturation of 90 to 95%, one can expect from the equations in Figure 3.8 a P-concentration of ca. 1 g P/m³ for the soil solution. GELBRECHT ET AL. (1996) proved that such concentrations are usually especially during storm water events in frozen soils and in puddles of arable land. If the soil is 80 percent saturated, the value of water soluble P-concentrations is reduced to 0.2 g P/m³ and with 50% saturation to around 0.05 g P/m³.

The values given in Table 3.10 for dissolved P-concentration in surface runoff from arable land, grassland and open areas are based on the assumption that in arable land, an average P-saturation of the topsoil layer is around 90%. For grassland, a P-saturation is assumed to be only 70% because of lower P-accumulation. For the natural open areas, the P-saturation in topsoil is assumed to be only 50% or lower.

Where the dissolved P-concentration in the top-soil are very strongly increased, particularly with a saturation of more than 60%, the estimates should be more detailed depending on area-specific information on the P-saturation in top soils. This would require the knowledge of the area-specific P-accumulation in the last 40 to 50 years or the soil P-content and its change over time and regional estimates of the P-sorption capacity. However, essential data for such a regionalization are not yet available.

Nitrogen

BRAUN ET AL. (1991) use a dissolved inorganic nitrogen concentration of 2 g N/m³ for both arable land and grassland. WERNER ET AL. (1991) assume that the N-concentration in surface runoff water from arable land is less than that for phosphorus (0.3 g N/m³). However, these authors do not consider the nitrogen in the NO_x-N and NH_4-N forms which are deposited by precipitation. Therefore, it is assumed in this study that N-concentration of natural open land is equal to the N-concentrations in the precipitation. For arable land, the N-concentration in the topsoil is also considered.

Nutrient inputs from mountainous areas caused by snow- and glacier-melt water

The water balance in the rivers which have sources in the high areas of the Alps (Upper Rhine, Aare, Lech, Isar, Inn, Saalach, Tiroler Achen, Salzach) is problematical because the total runoff cannot be carried out with Equation 3.8 alone. This is caused by additional flow from snow- and glacial-melt water. The averages from Equation 3.9 from the US SOIL CONSERVATION SERVICE (1972) are not considered as flow components. The analyses of the difference between total runoff and the other flow components indicates that the snow- and glacier-derived contributions to the total flow can be described with the following equation:

$$q_{SG} = 4 \cdot (N_J - 850)^{0,45} \qquad \textbf{(3.13)}$$

where q_{SG} = snow- or glacier-derived specific outflow [mm/(m²· a)].

The snow-derived total flow from the high mountain areas is calculated from the product of the estimated mountainous area from the land cover map (glaciers and rocky areas as well as shrubby vegetation) and the specific flow according to Equation 3.13.

The assumed nutrient concentrations are very small (around 0.01 g P/m³ for phosphorus and 0.1 g N/m³ for nitrogen) in comparison with the concentrations used for other flow components or pathways.

The nutrient inputs from the mountainous areas will be calculated from the product of snow-derived outflow and the nutrient concentrations.

3.1.2.4 Nutrient inputs via erosion

In the framework of this project, published information on soil losses is used as a basis for quantification of further area-related analyses of the soil and nutrient inputs into the river systems via erosion.

Preparation of maps on soil losses

To calculate soil loss in the basins the digital map for Germany of black-fallow area erosion potential was used according to the modified USLE from the *Fraunhofer Institute of Ecotoxicology* (KLEIN, personal communication). In addition, an European soil erosion map was used from the same institute for the parts of the catchment areas in other countries (apart from the Czech Republic and Poland). Both maps were initially transformed into a Lambert-Projection and into a uniform map with a scanning width of 1 km.

To make use of the values for black fallow area (C-factor = 1), the C-factor of the crops must be calculated from statistical information. The attribution of the C-factor follows DEUMLICH & FRIELINGHAUS 1994 (see Table 3.11).

The erosion maps will be linked to the C-factors for the municipalities within Germany and multiplied in accordance with USLE-instructions.

Table 3.11: Crop C-factors.

Crop	C-factor
Fallow	1.000
Winter wheat	0.092
Winter barley	0.080
Winter rye	0.042
Sommer barley	0.047
Oats	0.047
Winter rape	0.114
Potatoes	0.205
Sugar beet	0.218
Silo maize	0.338

As this procedure includes uncertainties, the soil loss values estimated by DEUMLICH & FRIELINGHAUS 1994 for the new German states and by GÜNDRA ET AL. 1995 for Baden-Württemberg were used as references.

For this, the soil loss values of the respective erosion maps will first be grouped on a district basis. Under consideration of the C-factors, calculated soil loss values of the *Fraunhofer Institute of Ecotoxicology* will be fitted in two steps with the help of a non-linear regression. The relationship between the calculated soil erosion values and the reference values is shown in Figure 3.9.

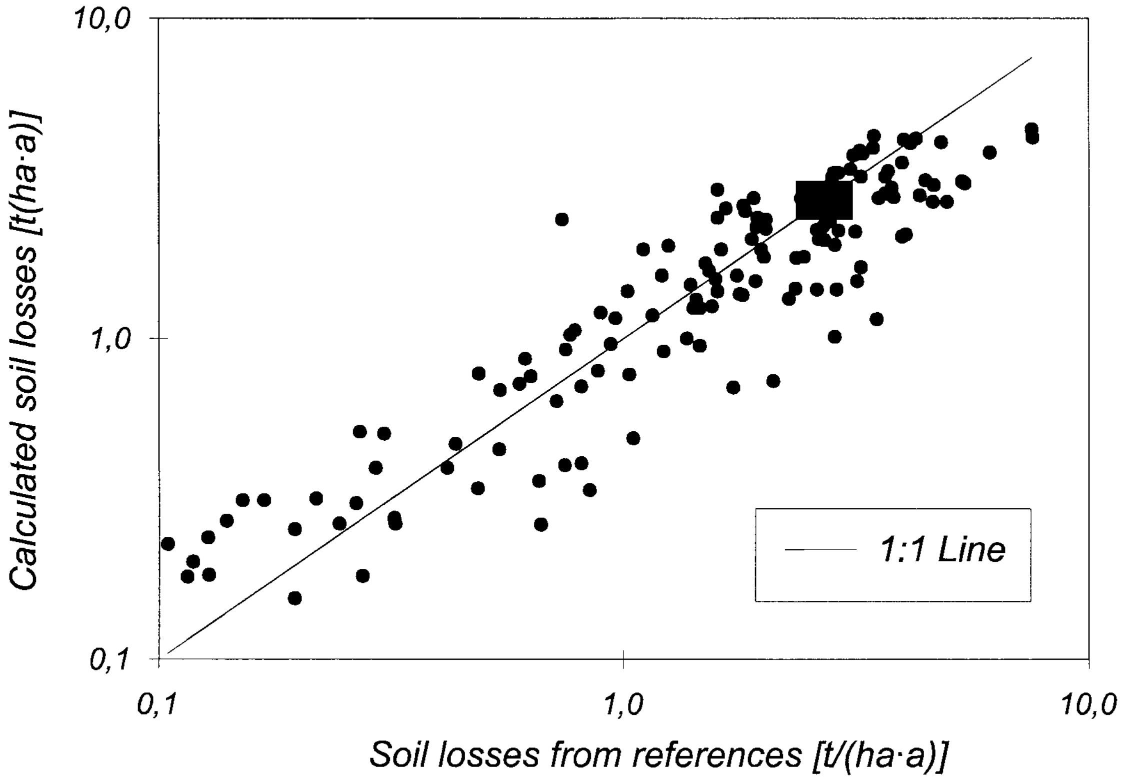


Figure 3.9: The relationship between erosion values according to DEUMLICH & FRIELINGHAUS (1994) and GÜNDRA ET AL. (1995) and the used soil losses (grouped by district).

On the basis of the fitted soil erosion maps (see Map 3.3), average soil loss values were determined for every basin. For the whole of Germany, a mean of 3.8 t/(ha· a) is estimated for the annual soil loss from arable land. In a further step, a new erosion map is developed in which the fitted soil losses were used only for the German states without published reference soil loss data. This map forms the basis for all further calculations (see Map 3.4). For areas with natural erosion (mountainous and rocky areas), a constant value of 2.0 t/(ha· a) is used.

A GIS-supported model for inputs of suspended solids into the river systems

For the calculation of the inputs of suspended solids into the river systems from the long-term average of the on-site soil loss according to USLE, the sediment input relationship "Sediment Delivery Ratio" (SDR) must be estimated for the basins (WALLING, 1983; 1996). Fundamentally, this relationship depends on the spatial dimension of a basin and also from the hydrological situation of the considered time period.

Up to the present, this relationship is calculated for German rivers with the sediment input equation after AUERSWALD (1992). This is derived from the relationship between the total load of suspended solids in Bavarian rivers and the calculated soil losses according to USLE:

$$SED = 700 + 8{,}5 \cdot A_{EZG} \cdot BA^{0{,}5} \qquad \textbf{(3.14)}$$

where SED = sediment input [t/a],
A_{EZG} = catchment area [km^2] and
BA = soil loss [t/(ha AL· a)].

However, the applicability of Equation 3.14 is questionable, at least for areas of the north east German lowlands because the sediment input is only a function of the size of the input areas and soil loss. With little soil loss (0.44 t/(ha AL· a) (this corresponds to 75% of all studied areas according to DEUMLICH & FRIELINGHAUS (1994) and with catchment areas of 18 km^2 the calculated sediment input is greater than the total soil loss in the area (HUBER & BEHRENDT, 1997).

On the basis of this fact, an uniform method is developed in this project which is applicable for all catchment areas. For the modelling of the potential sediment input in river systems, a GIS-supported method is proposed through a separation of areas which contribute to a soil loss into the river systems. Because the GIS-supported method needs digital records (water networks, land use-, soil- and elevation information) with a resolution of at least 1:25,000, the application of this method is limited up to now to 23 areas of the river Spree and six catchment areas of the river Salza (see Map 3.5).

On the basis of a digital relief analysis, grids are selected which possesses a distance of 30 m from a water-body, an agricultural usage and a slope greater than 1%. For these grids, their watersheds or source areas are estimated with the GIS-function WATERSHED. It is assumed that in the case of erosion events in these areas, the possibility exists of movement of eroded soil materials into the neighbouring water body. The area related sediment delivery ratio is defined through this action as part of the sum of the "source areas" in the input areas. This relationship is defined in the following as SAR_{GIS} (Sediment Area Ratio) and will be calculated according to Equation 3.15:

$$SAR_{GIS} = \frac{\sum A_{SOURCE}}{A_{EZG}} \qquad \textbf{(3.15)}$$

where SAR_{GIS} = area-related sediment delivery ratio,
A_{SOURCE} = source areas which are sensitive for soil input in the river system [km²] and
A_{EZG} = catchment area [km²].

For a transfer to other river basins, a modification of this method is necessary. For that, relationships between the SAR_{GIS} and easily determined characteristics of basins or parameters which are available for all of Germany were investigated for the existing 23 Spree river basins and six Salza sub basins. This was done by a stepwise, non-linear multiple regression analysis. Based on this, parameters were selected which have the highest influence on the SAR_{GIS}. The results of the GIS-based relief analysis for SAR_{GIS} and different characteristic parameters for the river basins are shown in Table 3.12.

Table 3.12: Comparison between SAR_{GIS} and various parameters of the catchment areas for the 23 part-areas of the Spree and the Salza.

Input area	A_{EZG}	SAR_{GIS}	Slope (SL)	A_{ACKER}
	[km²]	[%]	[%]	[%]
Obere Dahme	433	2	0,68	42
Moosegraben	21	2	0,49	70
Trebitzer Fließ	55	2	0,54	27
Lieberoser Fließ	156	3	0,43	22
Dehmnitzer Fließ (2)	17	6	0,34	53
Dehmnitzer Fließ	67	7	0,27	55
Oelse	117	7	0,54	43
Erpe	183	8	0,35	63
Zochegraben	42	11	0,26	74
Friedländer Fließ	86	14	0,36	55
Obere Spree	297	15	2,43	44
Weißer Schoeps	380	15	0,74	57
Schwarzer Schoeps	789	15	0,85	53
Dehmnitzer Fließ (1)	8	20	0,37	91
Spree downstream Schoeps	1.626	20	1,37	58
Spree upstream Schoeps	838	25	1,84	63
Weißer Schoeps (1)	144	27	1,35	80
Salza (3)	168	29	2,50	60
Pfaffendorfer Wasser	69	30	1,29	77
Salza (7)	243	31	1,35	74
Albrechtsbach	84	32	2,46	81
Salza (5)	66	33	1,32	55
Salza	568	33	1,58	72
Albrechtsbach (1)	2	37	5,02	41
Schwarzer Schoeps (1)	80	39	1,62	85
Salza (6)	69	42	0,73	84
Lobauer Wasser	274	44	1,86	85
Albrechtsbach (2)	2	54	3,52	87
Salza (1)	49	57	1,50	89

As a result of this regression analysis, the mean slope (from USGS-DEM, see paragraph 2.1) of a basin and the share of the arable land are identified as the parameters which explain the greatest part of the variance. By this, the parameter "slope" stands for the influence from the geomorphology (changes only over long time-scale) and the parameter "arable area" for the influence of area-specific, relatively short-term altered land uses in the potential of suspended solids input of a river basin.

The coefficients given in Equation 3.16 were determined with the help of a multiple parametric regression based on the method of least squares.

$$SAR_{MOD} = 0{,}05 \cdot (SL - 0{,}25)^{0{,}3} \cdot A_{ACKER}^{\;1{,}5} \qquad \textbf{(3.16)}$$

where SAR_{MOD} = sediment area ratio [%],
SL = mean slope from USGS-DEM [%] and
A_{ACKER} = area of arable land from CORINE-Land cover [%].

Figure 3.10 shows the relationship between the GIS-supported SAR_{GIS} and SAR_{MOD} estimated from the basin parameters in Equation 3.16. The values are scattered little around the 1:1 straight line.

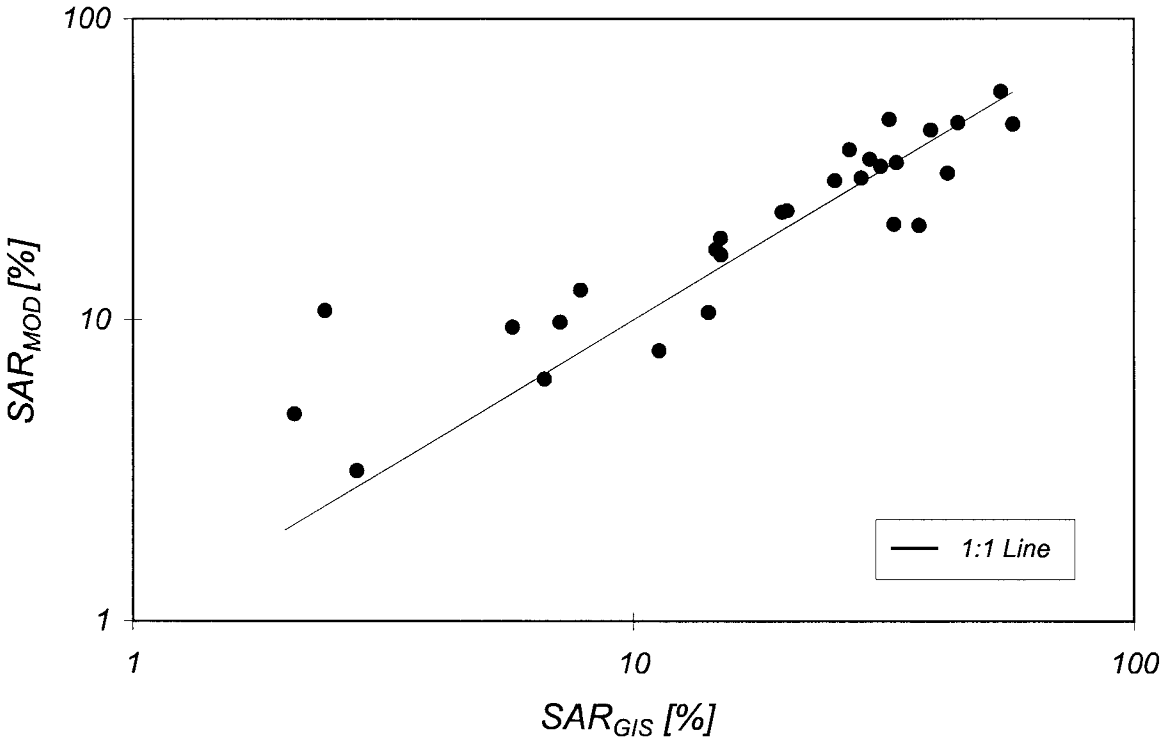


Figure 3.10: Comparison between SAR_{GIS} and SAR_{MOD}.

Calibration of the sediment-delivery ratio model in measured loads of suspended solids

Up to now, the SAR models allow only quantification of the potential of soil input but not the absolute value size of the inputs of suspended solids. In addition to the above-described method to estimated the soil inputs into the river system, long-term data of daily measurements of runoff and suspended solids were used for different 23 monitoring stations in Bavaria and Baden-Württemberg (see section 2.3). The size of the basins upstream of these monitoring stations varies between 318 and 77,086 km^2. Data for 17 of these monitoring stations span more than 20 years (see Table 2.9).

The use of long-term measurements was necessary because the soil losses estimated after USLE cover a time period of 20 years. Map 2.15 provides an overview of the location of the monitoring stations and their basins which are used for the calibration.

Since the measured content of suspended solids includes fractions of autochthonous material and particles entering through point sources, the calibration cannot be done based on the total load of suspended solids. The consequence would be an overestimation of the inputs via soil erosion.

Therefore, an attempt was made to derive a critical value for the runoff from the interdependence of daily runoff and concentrations or loadings of suspended solids. The critical runoff is the flow value above which surface runoff and inputs by soil erosion are probably in the river basin. For the estimate of the critical runoff, the daily values of the runoff will be summarised in runoff classes. For each particular runoff class, the average concentration or load of suspended solids is calculated. Subsequently, a critical runoff value is derived from the relationship between the concentrations and loadings against the runoff (see example in Figure 3.11).

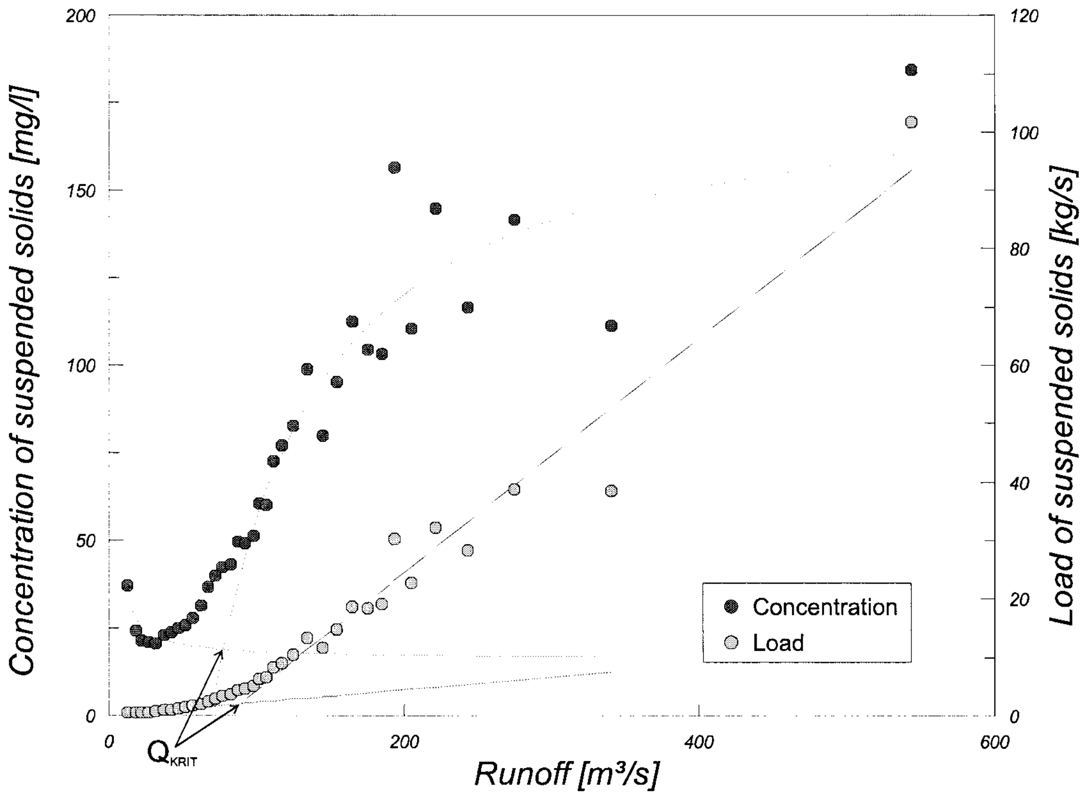


Figure 3.11: Determination of the critical runoff values - the Regnitz near Pettstadt as an example.

It was shown that in all cases, the relationship between runoff and concentration or loading is not linear.

For the loadings, a linear range can be discerned for the lower outflow classes. From a determined runoff class however, a second linear range can be observed with a greater increase. To estimate this runoff value (that means the critical runoff) for the lower and upper zones of runoff, a separate linear regression analysis was carried out. After this, the critical runoff value was estimated through the calculation of the break point of both straight lines.

The course of the concentration curves shows in contrast for the lower outflow classes either the form of a dilution curve or the form of a saturation curve. In the upper outflow classes, the curves always have the form of a saturation function. For the estimation of the critical runoff values from the concentrations, a linear function with the reciprocal value of the runoff was fitted in every case, not only in the lower part but also in the upper area and the cut-off point of both functions calculated. After the estimation of the critical runoff from the load-runoff or concentration-runoff relationship, the mean of the critical runoff is calculated for each basin. The results of the analysis to estimate the critical runoff (Q_{KRIT}) are shown in Table 3.13.

Table 3.13: Average and critical outflow values and also load components for the studied catchment areas.

River	A_{EZG}	MQ	Q_{KRIT}	$L_{J_{AFS}}$	$L_{BASIS_{AFS}}$	$L_{KRIT_{AFS}}$
	[km²]	[m³/s]	[m³/s]	[kt/a]	[kt/a]	[kt/a]
Große Vils	318	3	5	6	3	4
Itz	365	4	4	8	2	6
Traun	378	12	36	37	16	21
Glonn	392	3	6	6	3	3
Gr. Laber	406	2	3	3	2	1
Wiesent	664	7	12	6	4	2
Altmühl	684	4	11	3	3	0
Ilz	762	16	32	31	26	5
Saalach	940	36	90	237	150	87
Mindel	951	12	26	17	12	5
Iller	953	46	140	151	96	55
Aisch	954	5	16	12	7	5
Rott	1.053	9	20	27	17	10
Woernitz	1.578	11	33	16	9	6
Rednitz	1.845	9	13	11	6	5
Regen	2.658	39	62	29	21	8
Regnitz	3.870	24	51	26	21	5
Saalzach	6.644	244	548	1.349	680	668
Regnitz	7.005	50	83	70	41	29
Isar	8.839	173	356	200	157	43
Neckar	12.710	138	350	422	161	260
Main	21.505	165	349	268	160	108
Danube	77.086	1.436	2.900	3.423	2.378	1.044

The annual loadings of suspended solids ($L_{KRIT_{AFS}}$), mainly caused by soil erosion, can subsequently be determined as the integral of the regression slope for the lower and upper runoff class areas (see Figure 3.12). The load of suspended solids from autochthonous material (e.g. phytoplankton) and point sources ($L_{BASIS_{AFS}}$) can be subsequently calculated as the difference between the total and $L_{KRIT_{AFS}}$.

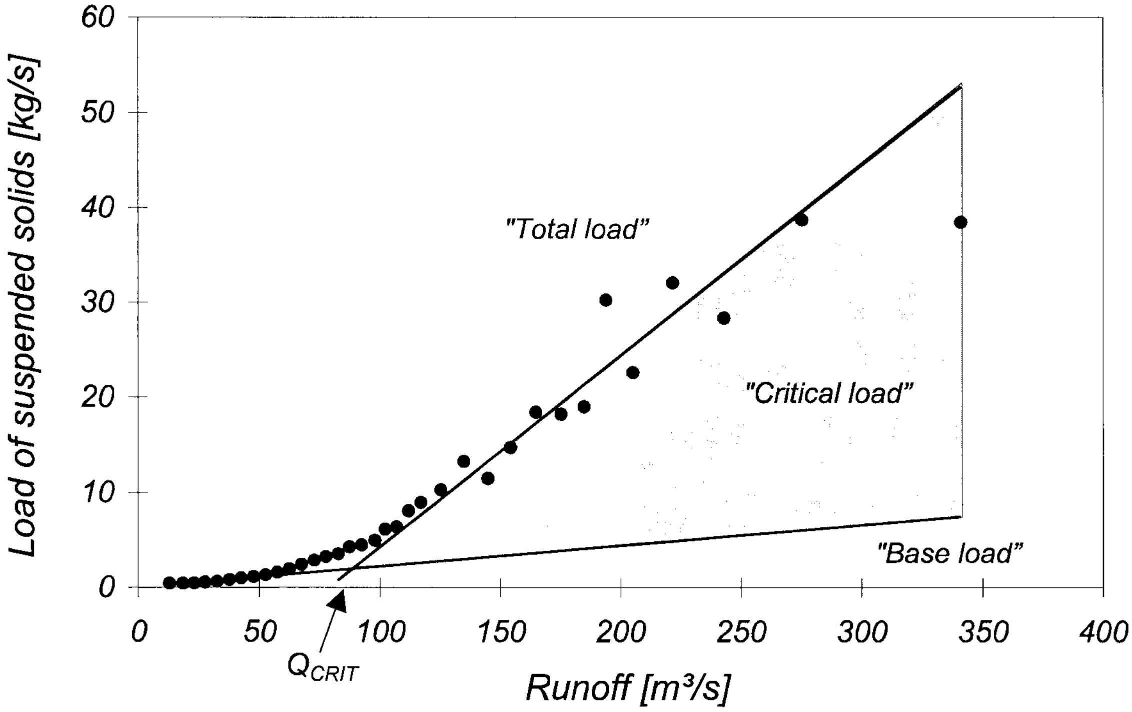


Figure 3.12: Various loading components for the example of Regnitz near Pettstadt.

For the calibration of the SAR model, the parameters for the river basins are determined and the average soil loss is calculated by the overlay of the map of potential soil erosion with the boundaries of the river basins using the GIS.

For that set up, the potential sediment input will be quantified from

$$SED_{POT} = BA \cdot SAR_{MOD} \tag{3.17}$$

where SED_{POT} = potential sediment input [t/(ha AL· a)].

The calculated potential sediment input is then compared with the estimated loadings of suspended solids caused by erosion ($L_{KRIT_{AFS}}$). With the help of a linear balance calculation (sum of least squares), the coefficient from SAR_{MOD} on the $L_{KRIT_{AFS}}$ will be calibrated. Figure 3.13 shows the result of the adjustment.

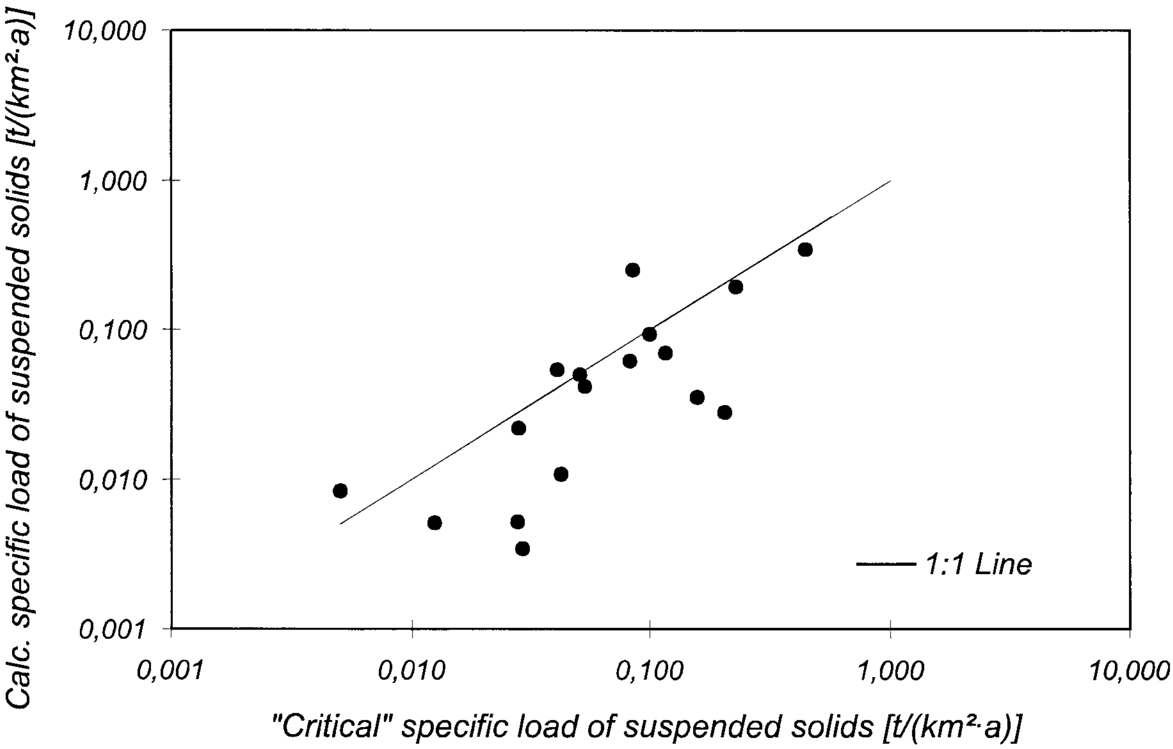


Figure 3.13: Comparison between the critical loads and the estimated sediment inputs.

It should again be pointed out from this that only the constant of the model is calibrated. All other model coefficients remain unchanged. For all catchment areas in the project, the sediment delivery ratios will be determined according to Equation 3.18:

$$SDR = 0{,}24 \cdot SAR_{MOD} = 0{,}012 \cdot (SL - 0{,}25)^{0{,}3} \cdot A_{ACKER}{}^{1{,}5} \qquad \mathbf{(3.18)}$$

where SDR = sediment delivery ratio [%],
SAR_{MOD} = sediment area ratio [%],
SL = mean slope from USGS-DEM [%] and
A_{ACKER} = area of arable land from CORINE-Land cover [%].

Consideration of changes in inputs of suspended solids over time

Since for the calibration of the SDR model only long-term time-series were used, it is still necessary to introduce weighting factors for the investigated time periods because the input of suspended solids is characterised by a high variability in time. As an example, in most rivers, inputs of suspended solids caused by erosion occur only during rare events of heavy precipitation and storm water runoff. The observed load of suspended solids in a river basin depends in addition on the long-term altered geomorphologic potential also on the hydrological components, which change greatly over time.

For consideration of this fact for both time periods, the number of storm water events according to ROGLER & SCHWERDTMANN (1981) is used.

$$Z_{NE} = 0{,}8 + 0{,}0197 \cdot N_J \tag{3.19}$$

where Z_{NE} = number of storm water events per year and
N_J = annual precipitation [mm].

The weighting factors for the both time periods can then be calculated as follows:

$$Z_{NE\,83-97} = 0{,}8 + 0{,}0197 \cdot N_{J\,83-97} \tag{3.20}$$

$$Z_{NE\,93-97} = 0{,}8 + 0{,}0197 \cdot N_{J\,93-97} \tag{3.21}$$

$$WF_{83\text{-}87} = \frac{Z_{NE\,83\text{-}87}}{Z_{NE\,83\text{-}97}} \tag{3.22}$$

$$WF_{93\text{-}97} = \frac{Z_{NE\,93\text{-}97}}{Z_{NE\,83\text{-}97}} \tag{3.23}$$

where WF = weighting factor for the observation period.

The total input of suspended solids due to erosion for the river basins can now be calculated according to Equation 3.24:

$$SED = BA \cdot SDR \cdot WF \tag{3.24}$$

where SED = sediment input [t/a],
BA = soil loss [t/a],
SDR = sediment delivery ratio [%] and
WF = weighting factor for the storm water events in the period.

Nutrient inputs by erosion cannot be directly calculated from the soil input and nutrient content of topsoil (AUERSWALD, 1989a). The transport of eroded soil materials is a selective process, enriched in finer grains (WERNER ET AL., 1991). Accordingly, this process leads to nutrient enrichment as the nutrients in topsoil are predominately bound to the clay fraction (SCHEFFER & SCHACHTSCHABEL, 1989). This process works more selectively the less the soil erosion is and can be calculated according to AUERSWALD (1989a, b) with Equation 3.25 from the long-term average soil erosion.

$$ER = 2{,}53 \cdot BA^{-0{,}21} \tag{3.25}$$

where ER = enrichment ratio and
BA = soil loss [t/(ha· a)].

First test calculations with Equation 3.25 show a clear underestimation compared to measured phosphorus and nitrogen loadings. Therefore, an attempt is made to calculate the enrichment from the average P-content of the suspended material and the P-content of the topsoil. The enrichment for a catchment area is calculated as the quotient between the P-content in suspended material and in topsoil. The enrichment is calculated according to Equation 3.26:

$$ER = \frac{P_{AFS}}{P_{ACKER}} \tag{3.26}$$

where P_{AFS} = phosphorus content of suspended solids [mg/kg] and
P_{ACKER} = phosphorus content of arable top-soil [mg/kg].

The calculation of the P-content of suspended solids

At first, the average phosphorus content of the suspended matter is calculated. For that, bi-weekly runoff, suspended matter, PO_4-P and TP data from the routine sampling programme are used.

For the calculation, only sub-basins of the Danube catchment area are considered where autochthonous materials comprise only a small part of the total. For the calculation of the P-content in the suspended materials, only data for the period 1993-1997 are used in which the influence of particulate phosphorus inputs from point sources is as low as possible. Further, such influences should be excluded by consideration of water quality data for runoff values which exceed the critical threshold value calculated from Table 3.13.

Therefore, the particulate phosphorus load (as the difference between the TP and PO_4-P-load) and the load of suspended solids are calculated when the measured runoff exceeds the calculated critical runoff. Then the average P-content of the suspended solids is calculated in which the particulate phosphorus load is divided *by the* load of suspended solids. Table 3.14 shows the P-content of the suspended solids for the sub basins of the Danube.

Calculation of P-content in topsoil

For the calculation of top-soil P-content for both study periods, the yearly P-surpluses and whose cumulative values are calculated on the basis of statistical information on mineral fertilizer applications, animal numbers and harvest withdrawals for the individual German states for the period 1955 to 1996 (see Section 3.1.2.1). Problematical was the determination of the P-content ("Base value") from arable areas for the year 1955, the calculated accumulation of the current P-content (see Section 3.1.2.1) for both study periods to quantify. As there is no information in the literature for the average P-content of arable areas for 1955, the following procedure for the calculation of this base-value is chosen.

WERNER ET AL. (1991) give an average P-content of 565 mg/kg for arable areas in the old German states for 1975. This value will also be used for the arable areas of the new German states.

The base-value can be calculated with the mean P-surpluses of the individual German states for 1975 and the values for 1955 from WERNER ET AL. (1991). The base-value for 1955 is set at 364 mg/kg. In addition, the calculation of this base value could be spatially differentiated for the catchment areas. However, relevant soil parameters such as in particular iron and calcium concentrations are not available. It is accepted that the P-content of a soil as well as other parameters also depend on clay-content. In the general soil map of Germany (BÜK) the clay content for the various soil types is included. Therefore, the soil map can be used as a digital spatially differentiated basis. Estimations from the soil map give 21% as the average clay content for arable areas. From this an P-average content of 364 mg/kg is assigned.

To calculate the P-content of arable soils for the base year of 1955 for every catchment area, the following phosphorus-clay-model will be used:

$$P_{ACKER55} = 10{,}2 \cdot TG_{ACKER} + 150 \tag{3.27}$$

where $P_{ACKER55}$ = phosphorus content of arable top-soil for 1955 [kg/ha] and
TG_{ACKER} = clay content of arable soil [%].

Then, the particular arable soil P-content for the studied time periods is calculated from the estimated P-accumulation of individual German states (see Section 3.1.2.1) and the spatially differentiated base-content using Equations 3.28 and 3.29:

$$P_{ACKER85} = P_{ACKER55} + P_{AKKU\,55-85} \tag{3.28}$$

$$P_{ACKER95} = P_{ACKER55} + P_{AKKU\,55-95} \tag{3.29}$$

where $P_{ACKER85}$ = phosphorus content of arable top-soil for 1985 [kg/ha]
$P_{ACKER95}$ = phosphorus content of arable top-soil for 1995 [kg/ha]
P_{AKKU} = P-accumulation in arable soil since 1955 [kg/ha]

A P-content of 150 mg/kg is assumed for mountainous and other natural areas. The P-content of top-soils in the catchment area for the investigated periods is calculated using Equation 3.30:

$$P_{BODEN} = \frac{A_{ACKER} \cdot P_{ACKER} + A_{GEB} \cdot P_{GEB}}{A_{ACKER} + A_{GEB}} \tag{3.30}$$

where P_{BODEN} = phosphorus content in the top-soil [kg/ha],
A_{ACKER} = area of arable land [ha],
A_{GEB} = mountain area [ha] and
P_{GEB} = phosphorus content of mountainous area top-soil [kg/ha].

These P-contents form the basis for the quantification of P-inputs by erosion.

Calculation of the N-content in top-soil

The quantification of the N-inputs by erosion is carried out for both studied periods from the information of N-content of arable soils according to the soil map. For mountainous and natural areas with no information available on soil building processes, a N-content of 250 mg/kg is assumed.

The N-content of topsoil in catchment areas is calculated for the study periods using Equation 3.31:

$$N_{BODEN} = \frac{A_{ACKER} \cdot N_{ACKER} + A_{GEB} \cdot N_{GEB}}{A_{ACKER} + A_{GEB}} \qquad \textbf{(3.31)}$$

where N_{BODEN} = nitrogen content in the topsoil [kg/ha],
A_{ACKER} = area of arable land [ha],
A_{GEB} = mountain area [ha] and
N_{GEB} = nitrogen content of mountainous area soil [kg/ha].

The derivation of an enrichment-ratio-model (ER-model)

The P-content of suspended material, surface soils and the enrichment ratios estimated for the sub-basins within the Danube catchment area are shown in Table 3.14.

A non-linear regression between the estimated ER and the specific load of suspended solids explains the most of the variance of the enrichment ratio. The following model is derived for the calculation of the enrichment ratio:

$$ER_P = 18 \cdot l_{AFS}^{-0,47} \qquad \textbf{(3.32)}$$

where ER_P = enrichment ratio for phosphorus and
l_{AFS} = specific load of suspended solids [t/(km$^2\cdot$ a)].

The relationship between the calculated ER and the specific load of suspended solids is shown in Figure 3.14.

For nitrogen, it is taken into account that the enrichment is not exactly identical as that for phosphorus. A derivation of a nitrogen-specific enrichment on the basis of measurements of nitrogen content of the filterable material and of the soil is however not possible because of the absence of measured data. Therefore, the enrichment of nitrogen content will be indirectly determined from the relation of the N/P-ratio of the soil to the N/P ratio of the erosion input in the water body from already known studies in the catchment areas. The basis for that is the information of the N/P ratio of the erosion inputs of 17 catchment areas of the unconsolidated rock region (WERNER & WODSAK, 1994) and the already derived N/P ratio in the soil of this catchment area. After that lies the average ratio of 2.35 for the two N/P ratios.

Table 3.14: Calculated enrichment ratios, P-content of suspended material and surface soils for the studied Danube catchment area in the period 1993-1997.

Address	River	Monitoring station	A_{EZG}	l_{AFS}	P_{ACKER} 1995	P_{AFS}	ER_P
			[km²]	[t/(km²· a)]	[mg/kg]	[mg/kg]	
11402	Iller	Wiblingen	2.211	85	669	1.900	2,84
11404	Iller	Kempten	973	179	694	1.500	2,16
11501	Danube	Boefinger Halde	7.938	28	730	3.800	5,20
11702	Danube	Dillingen	11.210	19	714	3.500	4,90
11802	Woernitz	Ronheim	1.566	7	838	7.600	9,06
11901	Danube	Schaefstall	15.007	13	730	2.500	3,43
12303	Lech	Fuessen	1.369	227	666	500	0,75
13401	Altmuehl	Groegling	2.884	5	776	5.100	6,57
14302	Naab	Unterkoeblitz	2.037	4	587	10.700	18,23
14402	Schwarzach	Warnbach	820	4	616	6.600	10,71
14601	Vils	Dietldorf	1.190	6	643	5.900	9,17
14902	Naab	Heitzenhofen	5.446	5	617	8.200	13,28
15202	Regen	Regenstauf	2.630	6	622	6.000	9,65
15901	Danube	Deggendorf	38.083	13	688	3.000	4,36
16502	Isar	Baierbrunn	2.794	6	654	2.500	3,82
16601	Amper	Moosburg	3.212	6	631	3.900	6,18
16902	Isar	Plattling	8.932	7	631	4.600	7,29
17202	Vils	Grafenmuehle	1.441	15	632	3.500	5,54
17301	Danube	Passau	49.568	8	676	4.000	5,92
17402	Ilz	Kalteneck	729	6	642	3.500	5,45
18101	Inn	Kirchdorf	10.215	63	717	1.300	1,81
18402	Alz	Seebruck	1.211	3	622	5.300	8,53
18404	Tiroler Achen	Staudach	925	139	819	1.900	2,32
18603	Saalach	Freilassing	1.212	139	615	1.500	2,44
18802	Rott	Ruhstorf	1.052	21	664	4.100	6,17
18902	Inn	Passau-Ingling	26.243	82	641	1.000	1,56
19101	Danube	Jochenstein	77.104	42	671	1.700	2,53

From that, the following model is assumed for the calculation of the enrichment of nitrogen:

$$ER_N = 7{,}7 \cdot l_{AFS}^{-0{,}47} \quad \textbf{(3.33)}$$

where ER_N = enrichment ratio for nitrogen.

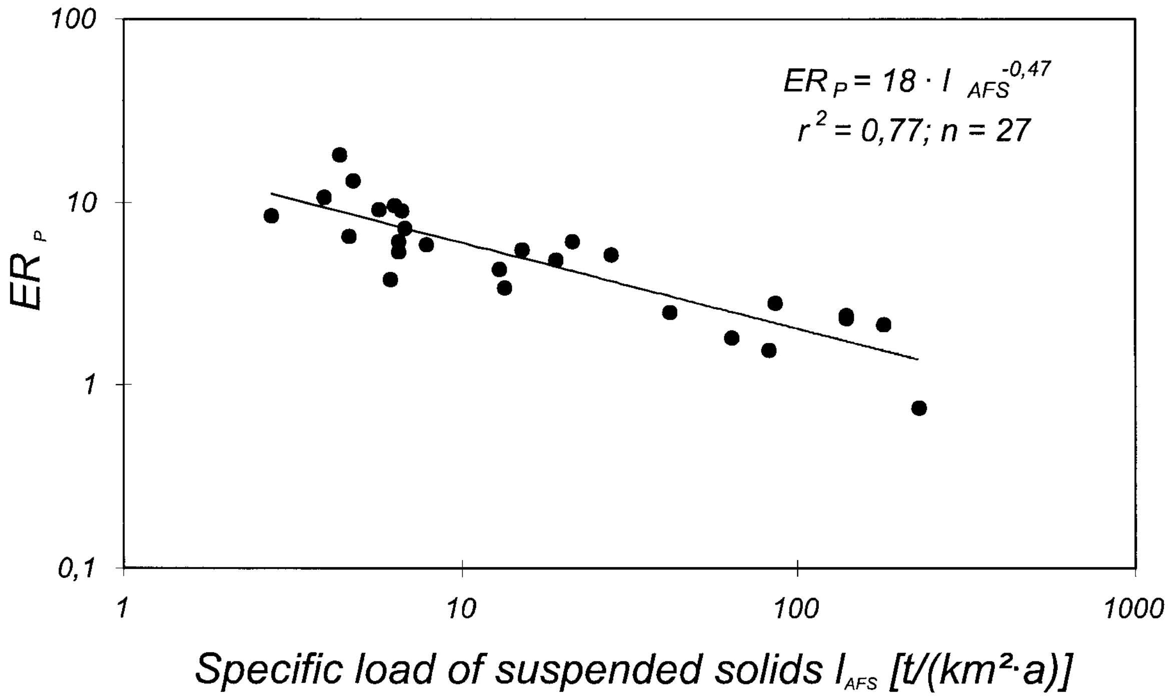


Figure 3.14: Relationship between the calculated Enrichment Ratios and the specific load of suspended solids.

Calculation of nutrient inputs by erosion

If it is assumed that Equation 3.32 can be applied for all catchment areas in Germany, the nutrient input by erosion can be calculated for each basin using Equations 3.34 and 3.35:

$$EER_P = P_{BODEN} \cdot ER_P \cdot SED \tag{3.34}$$

$$EER_N = N_{BODEN} \cdot ER_N \cdot SED \tag{3.35}$$

where $EER_{N,P}$ = nutrient input via erosion [t/a].

3.1.2.5 Nutrient inputs via tile drainage

For the quantification of nitrogen and phosphorus inputs through tile drainage, in dependence on previously estimates (WERNER ET AL., 1991; BEHRENDT ET AL., 1994), a method was developed based on the size of the drained area, the amount of drain water and the average nutrient concentrations of the drainage water from which a calculation of the total nutrient inputs is possible (see Figure 3.15).

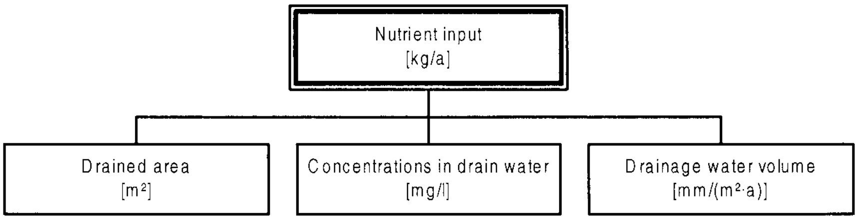


Figure 3.15: Schematic overview on calculation of the nutrient inputs via tile drainage.

The nutrient input from tile drainage will be calculated for every studied catchment from the product of the drained area, drainage water volume and the average nutrient concentrations.

Drained area

For the estimation of the size of drained areas of German catchments, various data bases with different approaches were used for the old and new German states.

For the new German states, data for drained areas is available from the GDR statistical yearbooks (see Section 2.1). However, due to lack of information on the location of drains, river-catchment specific information on the proportion of agricultural areas which is drained is not available. Details on the drained area for the new German states can be derived from the documents of the GDR melioration companies (see Section 2.1). Regarding this, the drained areas were digitized on the basis of survey maps of these areas (see Section 2.1). Map 2.9 gives an overview of the proportion of drained land for selected areas. The amount of drained areas and the proportion of agricultural areas drained in these test regions are listed in Table 3.15. For the whole territory of the new German states,

Table 3.15: Drained area (A_{DR}) as the proportion of agricultural land (A_{LN}) in studied catchments of the Water and Soil Associations of the new German states.

Water and Soil Association	A_{LN}	A_{DR}	A_{DR}/A_{LN}
	[km²]	[km²]	[%]
Böse Sieben / Weida	654	30	4.6
Uckerseen	557	39	7.0
Oderbruch	543	42	7.7
Mittlere Uecker / Randow	346	28	8.1
Obere Dahme / Berste	323	30	9.2
Dosse / Jäglitz	546	56	10.3
Kleine Elster / Pulsnitz	231	38	16.4
Jeetze	525	97	18.5
Mittlere Peene	730	145	19.9
Barthe / Küste	503	108	21.5
Ryck / Ziese	542	129	23.8
Obere Warnow	262	64	24.4
Boize / Sude / Schaale	650	161	24.8
Thüringer Talsperre Weida[1]	226	65	28.7
Untere Warnow / Küste	615	179	29.1
Seege / Aland	639	186	29.2
Warnow / Beke	280	84	3.,0
Torgau	177	107	60.5

[1] Thüringer Talsperrenverwaltung, Tambach-Dietharz

the information of drained area is not complete. Therefore, the transformation of the information on drained areas to the whole region were carried out by means of the soil map of the agricultural land of the new German states, which was digital available.

This soil map includes information according to the substrate and soil water characteristics. It is assumed that the soil water status gives evidence concerning the wetness-grade and with that, the drainage requirement.

The drained area in the catchments of the new German states was estimated with a multiple linear regression of the soil-types which are classified as wet soils. For that, the drainage map was first overlaid with the soil map by means of the GIS ARC/INFO through which the soil types of drained areas and the catchments can be determined. In Table 3.16, the soil types of the drained areas within catchments of the Water and Soil Associations are shown. From this it is clear that wet soil types have mostly been drained (on average 78%). The wet clays comprise the largest fraction (ca. 41%) of the drained areas.

The weighting of the soil types was finally carried out by means of a multiple linear regression. For this calculation, the data for a total of 15 Water and Soil Associations were used. The associations Böse Sieben/Weida and Uckerseen were excluded from the calculation on account of their extremely small drained areas, since it can be assumed that the set of maps on drained area is incomplete and do not reflect the total area of drainage. The data from the Torgau region was also not considered since it has a much higher proportion of drained agriculture area (60%) in comparison to the other associations. Therefore, it is assumed that this is an exception and is therefore not suitable for a transfer to the whole area. The results of the multiple linear regression analysis are mean weighting factors reflecting the drained proportion of soil types. The Table 3.17 shows that the wet loamy and clay soils are drained to about 50%, followed from the flood plain, peaty and wet sandy soils.

With the introduction of the weighted factors the drained area of is calculated according to Equation 3.36:

$$\boldsymbol{A_{DR} = (A_{MO} \cdot 0{,}1059) + (A_{AU} \cdot 0{,}1158) + (A_{STL} \cdot 0{,}5045) + (A_{GWS} \cdot 0{,}0902)} \qquad \textbf{(3.36)}$$

where: A_{DR} = drained area [km²],
A_{MO} = area of peat soil [km²],
A_{AU} = area of flood plain soil [km²],
A_{STL} = area of wet loamy soil [km²] and
A_{GWS} = area of wet sandy soil [km²].

Table 3.16: The proportion of agricultural land by soil group (AL) for the catchments of the Water and Soil Associations and the estimated drainage area (DR) in the new German states.

Water and Soil Association		Soil type					
		Freely drained	Flood plains	Peats	Wet loess	Wet clays	Wet sands
		[%]	[%]	[%]	[%]	[%]	[%]
Mittlere Peene	AL	39.3	0.0	16.1	0.0	39.3	5.3
	DR	24.9	0.0	10.2	0.0	58.9	6.0
Mittlere Uecker / Randow	AL	55.0	0.0	24.6	0.0	8.5	11.9
	DR	24.4	0.0	44.6	0.0	18.7	12.3
Barthe / Küste	AL	18.6	0.0	14.5	0.0	57.0	9.9
	DR	14.8	0.0	12.6	0.0	65.0	7.6
Ryck / Ziese	AL	30.5	0.0	15.3	0.0	37.4	16.8
	DR	29.1	0.0	16.4	0.0	36.5	18.0
Uckerseen	AL	53.3	0.0	9.9	0.0	34.8	1.9
	DR	28.7	0.0	9.8	0.0	57.7	3.9
Untere Warnow / Küste	AL	13.5	0.0	13.6	0.0	48.4	24.6
	DR	8.5	0.0	15.9	0.0	53.3	22.3
Warnow / Beke	AL	30.2	0.0	18.2	0.0	44.2	7.3
	DR	24.4	0.0	15.5	0.0	51.6	8.5
Boize / Sude / Schaale	AL	32.1	0.0	11.3	0.0	34.4	22.2
	DR	19.8	0.0	5.0	0.0	54.1	21.1
Obere Warnow	AL	46.1	0.0	12.1	0.0	39.4	2.4
	DR	32.6	0.0	13.0	0.0	54.1	0.2
Böse Sieben / Weida	AL	71.1	1.3	0.0	24.0	3.7	0.0
	DR	48.8	2.7	0.0	24.0	14.6	0.0
Oderbruch	AL	14.2	77.6	2.2	0.0	0.0	6.1
	DR	4.9	88.8	1.6	0.0	0.0	4.7
Obere Dahme / Berste	AL	37.8	0.2	9.6	0.0	20.7	31.7
	DR	15.7	0.4	8.5	0.0	31.4	44.1
Dosse / Jäglitz	AL	50.6	0.3	18.8	0.0	4.8	25.6
	DR	32.1	0.1	29.1	0.0	10.7	28.0
Kleine Elster / Pulsnitz	AL	20.7	1.1	2.4	0.0	22.3	53.5
	DR	10.3	0.9	2.7	0.0	32.5	53.5
Jeetze	AL	35.4	1.1	11.3	0.0	43.5	8.7
	DR	17.3	2.4	15.4	0.0	55.5	9.5
Seege / Aland	AL	6.7	36.3	1.0	0.0	40.2	15.8
	DR	5.7	17.2	0.9	0.0	64.3	12.0
Torgau	AL	18.1	17.8	0.0	0.0	21.6	42.5
	DR	16.9	12.5	0.0	0.0	27.4	43.2
Thüringer Talsperre Weida	AL	46.4	9.4	0.0	11.5	32.8	0.0
	DR	31.2	9.9	0.0	9.5	49.5	0.0
Mean value	DR	21.7	7.5	11.2	1.9	40.9	16.4
	AL	34.4	8.1	10.1	2.0	29.6	15.9

Table 3.17: Weighting factors for the different regional soil types.

Regional soil type	Weighting factor
Dry soils	0,0000
Peat soils	0,1059
Flood plain soils	0,1158
Wet loamy soils	0,5045
Soils with low groundwater table	0,0902

In the comparison, calculated drained areas for the catchments of the Water and Soil Associations were confronted with the digital capture estimated proportions (see Figure 3.16). The relative difference between the calculated and "real" proportion of drained area shown in Figure 3.16 is with a mean of 20%, relatively low, so that the application of the model for an estimation of the drained area in the new German states is justified. One must consider however that drainage capacity can not only be derived from natural conditions. In addition, anthropogenic factors have an important influence. Regarding this, the financial conditions and also planned uses in the region have to be considered as additional factors if available.

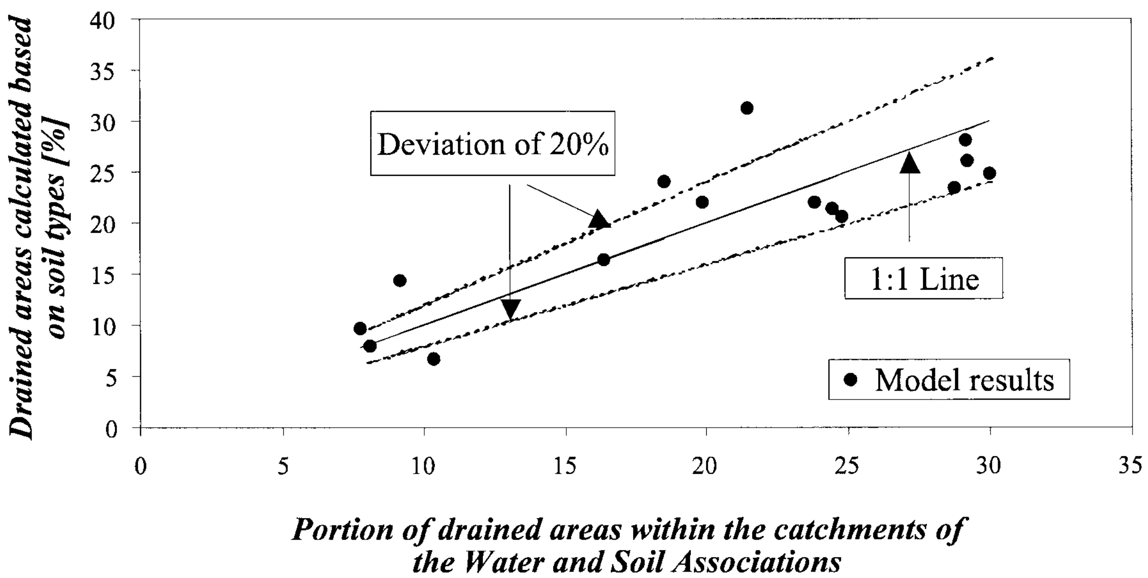


Figure 3.16: Relationship between actual and calculated proportion of agricultural land in catchment areas and Water and Soil Associations which is drained.

In the old German states are, maps or similar accessible data sources are available neither from the relevant authorities nor with drained land registries of research institutions, from which information on the proportion of drained areas for larger catchments can be obtained. As a result of this, BACH ET AL. (1998) carried out a survey at agricultural administrations concerning the drained area of arable land and pasture. From the survey results, the proportion of drained land for the old German states was estimated (see BACH ET AL., 1998).

Table 3.18 compares the estimated extent of drained areas for the new German states and the estimates of BACH ET AL. (1998) for the old German states with other estimates from the literature. The table shows that the results of BACH ET AL. (1998) are about 24% lower than those given by WERNER ET AL. (1991) for the old German states. On the other hand, the proportion of drained land calculated here for the new German states are 15 to 20% higher than those given in the GDR yearbooks and the estimates of WERNER & WODSAK (1994).

Table 3.18: Comparison of estimates of the size of drained areas for the old and new German states.

Area	Drained area (A_{DR})		
	Size used	Information from the literature	
	[ha]	[ha]	[ha]
Old German states	1,524,961 (BACH ET AL., 1998)	2,000.000 (WERNER ET AL., 1991)	
New German states	1,120,880 (this study)	931,523 (Statistical Yearbooks GDR)	974,000 (WERNER & WODSAK, 1994)

On the basis of the information of BACH ET AL. (1998) and the estimated weighting factors for the wet soil types, a digital map of drained areas was generated by means of GIS. The proportion of drained land for the individual catchment areas can now be estimated through overlaying the map of drained areas with the boundaries of the catchment (see Map 2.10).

Drain water flow

Information on the drain water flow is only occasionally found in the literature. WERNER ET AL. (1991) give an average drain water flow for middle Europe of 200 mm/a. For the Swiss catchment of the Rhine below the lakes, BRAUN ET AL. (1991) give an average drain water flow of 430 mm/a with a range of 250 to 600 mm/a. Concerning the available database, it is however meaningful to calculate the drainage contribution in relation to the meteorological conditions of the studied periods and than to take a constant value.

Such an attempt was made by NOLTE & WERNER (1991) who assumed that the drain water flow is 80% of the leakage to groundwater. This value however is very different from the results of SCHOLZ (1997), who concluded that the drain water flow in the state Mecklenburg-Western Pomerania was 1.55 times the flow of non-drained areas. PRASUHN & BRAUN (1994) concluded that in Switzerland, the drain water flow was about 35% of the precipitation.

With the following equations, the drain water flow is calculated according to KRETZSCHMAR (1977) on the basis of the summer and winter precipitation. From this, the drainage outflow of 50% of winter and 10% of the summer precipitation is obtained:

$$q_{DR} = 0,5 \cdot N_{WI} + 0,1 \cdot N_{SO} \qquad (3.37)$$

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

This approach takes into account the regional different distribution of rainfall and runoff. With the help of this information, a drain water flow of 90% of the leakage rate can be estimated for the old German states, similar to the value of 80% given by NOLTE & WERNER (1991). One can also determine a relationship of 1.34 for the north-east German catchments, a value near to that of SCHOLZ (1997). For the south-west of Germany the drainage contribution is 29% of the annual precipitation. This value is a little below that given by PRASUHN & BRAUN (1991) for the Swiss Rhine catchment.

Nutrient concentrations in drainage waters

Information on nutrient concentration in drain water is only available for individual catchment areas. Table 3.19 shows average phosphorus concentration in the drainage water.

Table 3.19: Average phosphorus concentrations (C_{DRP}) in drainage water from agricultural land.

Catchment area	C_{DR_P} [mg P/l]	Soil type	Source
Lower Spree	0.05–0.12	Sandy loam	DRIESCHER & GELBRECHT (1993)
Erpe	0.19–0.77	Sandy loam	Personal communication GELBRECHT (1997)
Dehmnitzer Mühlenfließ	0.06–0.32	Sandy loam	Personal communication GELBRECHT (1997)
Lower Spree	0.1	Sand	DRIESCHER & GELBRECHT (1993
North-west German Geest	0.06–0.16	Sand, clay	FOERSTER & NEUMANN (1981)
North-west German Geest	0.5–0.7	Sand	FOERSTER (1988)
North-west Germany	8.0–11.0	Bog soil	SCHEFFER (1976)
Region Oldenburg	4.0–14.9	Bog soil	FOERSTER & NEUMANN (1981)
Harbern/Hunte	7.45–11.78	Bog soil	RADERSCHALL (1994)
Average Germany	8.0	Bog soil	WERNER ET AL. (1991)
Rüschendorf/Hunte	3.05–4.61	Fen soil	RADERSCHALL (1994
Average Germany	0.5	Fen soil	WERNER ET AL. (1991)
Average Germany	0.2	Mineral soils	WERNER ET AL. (1991)
Switzerland/Rhine	0.037–0.1	No information	BRAUN ET AL. (1991)
Baseler Tafeljura	0.02	No information	BRAUN ET AL.(1994)

On the basis of this published information, the P-concentrations in drainage water for various soil types were calculated and are shown in Table 3.20.

The P-concentration in the catchments was calculated as an area-weighted mean on the basis of the values in Table 3.20 and the estimated areas of sandy soils, loams, fen and bog soils according to the soil survey map of Germany (BÜK 1000):

Table 3.20: Phosphorus concentrations used for drainage water for various soil types.

Soil type	Term	C_{DR_P} [mg P/l]
Sandy soils	C_{DRS_P}	0.20
Loam	C_{DRL_P}	0.06
Fen soils	C_{DRNM_P}	0.30
Bog soils	C_{DRHM_P}	10.00

$$C_{DR_P} = \frac{C_{DRS_P} \cdot A_{DRS} + C_{DRL_P} \cdot A_{DRL} + C_{DRNM_P} \cdot A_{DRNM} + C_{DRHM_P} \cdot A_{DRHM}}{A_{DRS} + A_{DRL} + A_{DRNM} + A_{DRHM}} \quad (3.38)$$

with C_{DR_P} = drainage water phosphorus concentration [mg P/l],
C_{DRS_P} = drainage water phosphorus concentration for sandy soil [mg P/l],
C_{DRL_P} = drainage water phosphorus concentration for loamy soil [mgP/l],
C_{DRNM_P} = drainage water phosphorus concentration for fen soil [mg P/l],
C_{DRHM_P} = drainage water phosphorus concentration for bog soil [mg P/l],
A_{DRS} = area of drained sandy soil [km²],
A_{DRL} = area of drained loams [km²],
A_{DRNM} = area of drained fen soil [km²] and
A_{DRHM} = area of drained bog soil [km²].

Published information on average nitrogen concentrations in drainage outflow are shown in Table 3.21. Remarkable differences show the nitrate values in drainage water from arable loams. The average nitrate values of loamy arable soils of 10 mg N/l given by von WERNER ET AL. (1991) are clearly lower than those of 25 to 34 mg/l from the studies of GELBRECHT ET AL. (1996), BOCKHOLT & KAPPES (1994) and THIELE ET AL. (1995).

The calculation of nitrogen concentration in drain water is based on the regionally differentiated N-surpluses (BACH ET AL., 1998). From the N-surpluses the potential nitrate concentration in leakage water is calculated according to FREDE & DABBERT (1998) which should correspond to the concentration in drainage water. It is assumed that the net mineralisation and net immobilisation in both studied time periods are negligibly low.

$$C_{DR_{NO3-N}} = \frac{(N_{ÜLN} - DNR) \cdot AF \cdot 100}{SW} \quad (3.39)$$

with $C_{DR_{NO3-N}}$ = nitrate concentration in drainage water [g N/l],
$N_{ÜLN}$ = nitrogen surplus of agricultural areas [kg N/(ha· a)],
DNR = denitrification rate [kg N/(ha· a)],
AF = exchange factor and
SW = leakage water quantity [l/(m²· a)].

Table 3.21: Average NO_3-N concentrations in drainage water ($C_{DR_{NO3\text{-}N}}$) from agricultural areas.

Area	Landuse	$C_{DR_{NO3\text{-}N}}$ [mg N/l]	Soil type	Source
East of Heinersdorf (Spree)		29.7	Loam	GELBRECHT ET AL. (1996)
West of Heinersdorf (Spree)		33.5	Loam	GELBRECHT ET AL. (1996)
Radlow (east of Scharmützelsees)		34.1	Loam	GELBRECHT ET AL. (1996)
Beeskower Platte		32.6	Loam	GELBRECHT ET AL. (1996)
Northern GDR districts	Arable	21.0	Loam	GRÜN ET AL. (1985)
Weida	Arable	24.2	Loam	SEIDEL & PÖTZSCH (1996)
Kösterbeck	Arable	36.3	Sandy loam	BOCKHOLT & KAPPES (1994)
Kösterbeck	Arable	25.2	Sandy loam	THIELE ET AL. (1995)
German average	Arable	10.0	Loam	WERNER ET AL. (1991)
Kösterbeck	Fallow	10.2	Sandy loam	THIELE ET AL. (1995)
Kösterbeck	Grassland	1.7	Sandy loam	BOCKHOLT ET AL. (1993)
Kösterbeck	Grassland	1.0	Sandy loam	BOCKHOLT ET AL. (1993)
Northern GDR districts	Arable	13.3	Sand	GRÜN ET AL. (1985)
Middle GDR districts	Arable	16.5	Sand	GRÜN ET AL. (1985)
German average	Arable	20.0	Sand	WERNER ET AL. (1991)
Flatlands	Grassland	3.8	Fen Soil	GRÜN ET AL. (1985)
Kösterbeck	Grassland	3.2	Fen Soil	THIELE ET AL. (1995)
Kösterbeck	Grassland	1.2	Fen Soil	THIELE ET AL. (1995)
Warnow	Grassland	5.4	Fen Soil	BOCKHOLT ET AL. (1993)
Warnow	Grassland	4.6	Fen Soil	BOCKHOLT ET AL. (1993)
Hunte (Harbern)	Grassland	9.6–11.2	Bog soil	RADERSCHALL (1994)
German average	Grassland	2.0	No information	WERNER ET AL. (1991)

For the leakage water level of the drained area, the drain water flow (see above) is used. The exchange factor can be estimated on the basis of the exchange frequency. This gives:

$$AF = 1 \quad if \quad AH \geq 100 \tag{3.40}$$

$$AF = \frac{AH}{100} \; if \; AH \leq 100 \tag{3.41}$$

with AH = exchange frequency.

The exchange frequency is calculated according to FREDE & DABBERT (1998) according to Equation 3.42:

$$AH = \frac{SW}{FK_{WE}} \cdot 100 \tag{3.42}$$

with FK_{WE} = field capacity in the root zone of soil [Vol.-%].

With consideration of an average drain depth of 80 cm the field capacity, exchange frequency and the exchange factor of the root-zone of soils of drained areas were calculated with the soil type groups according to the BÜK 1000 for every catchment as a mean value. The drain water flow was calculated according to Equation 3.36 for the leakage water flow. Since the drained area is predominantly in locations with ground water or stored water inputs, an average denitrification capacity can be determined. One can use a denitrification rate of 30 kg N/(ha· a) for such areas according to FREDE & DABBERT (1998). However, for some catchments, particularly in the Schleswig-Holstein coastal area, negative nitrate concentrations were calculated. To take this into account, the approach for the calculation of nitrate concentration in the seepage was modified so that the denitrification is considered in the form of an power coefficient DR which is less than 1.

$$C_{DR_{NO3-N}} = \frac{(N_{ÜLN})^{DR} \cdot AF \cdot 100}{SW} \qquad \textbf{(3.43)}$$

with DR = exponent for denitrification.

The coefficient (DR) was estimated to 0.85 from a comparison of drain water concentrations calculated according to Equations 3.39 and 3.43. According to the calculations described above, the nitrogen concentration in drainage water vary between 5 to 35 g N/m³ for the period 1993 to 1995. From this, in the low rainfall area of eastern Germany, despite the lower nitrogen surpluses, higher concentrations were estimated than for drainages in the Rhine, Danube, Weser and Ems catchments. This behaviour concurs with the results of measurements of other authors as shown in Table 3.21

For the calculation of nitrogen concentrations in drainages, it can be concluded that they react very quickly to nitrogen surpluses. Changes in the nitrogen surpluses between the both investigated five year periods should therefore have a direct effect on change in nitrogen concentrations. For the period 1983-1987 regionalized data on the nitrogen surplus was not available. Therefore this level was determined from the calculated long-term changes in nitrogen surpluses according to BACH ET AL. (1998) and BEHRENDT (1988) for the old and new German states. From that one can conclude that the nitrogen surplus in the period 1983-1987 was 36% greater in the old German states and 50% greater in the new German states than in 1995. With the consideration of these changes, the nitrogen concentrations in drainage were calculated in the same way as described above. This gives a range of nitrogen concentrations for the mid-eighties of 6 to 49 g N/m³.

3.1.2.6 Nutrient inputs via groundwater

Nutrient input through groundwater is calculated from the product of groundwater outflow, which as shown in Section 3.1 includes a natural interflow component, and groundwater nutrient concentration. For the concentration of nitrogen in groundwater, the link to the nutrient surplus of the land area and especially the agricultural land and its change should be established. This follows through the estimation of nitrogen concentration below the root-zone. For these nitrogen concentrations and to enable the quantification of N-surpluses, knowledge of the leakage water quantity in the individual catchment areas is necessary.

Determination of leakage water quantity

The calculation of the leakage water quantity (SW) follows the simplified approach of LIEBSCHER & KELLER (1979) with the modifications of WENDLAND ET AL. (1993). The equations for the estimation of the total flows and the surface flows have already been described in Section 3.1.2.3. For evaporation, the following is used:

$$V = N_J - q_G \quad \textbf{(3.44)}$$

with V = evapotranspiration [l/m²],
N_J = annual precipitation [l/m²] and
q_G = specific runoff [l/m²].

Since there are no arid locations in Germany based on long-term averages, a known minimum flow is taken into account. Regarding evaporation, the following boundary conditions are to be considered.

$$V_{MAX} < 0{,}95 \cdot N_J \quad \textbf{(3.45)}$$

$$V_{MAX} < 600 \quad \textbf{(3.46)}$$

with V_{MAX} = maximum annual evapotranspiration [mm/a].

In the case that evapotranspiration is greater than one of the realised maximal permissible values, the total flow for this situation is calculated as the difference between the annual precipitation and the maximal calculated evapotranspiration:

$$q_G = N_J - V_{MAX} \quad \textbf{(3.47)}$$

For this situation, the surface flow must be recalculated according to Equation 3.9. Finally, the leakage water level is determined according to:

$$SW = N_J - V - q_{RO} \quad \textbf{(3.48)}$$

with SW = leakage water quantity [l/m²] and
q_{RO} = specific surface runoff [mm/(m²· a)].

The grid related leakage water quantity will finally be overlayed with the catchments and thus the average annual leakage water level for every catchment is determined. This procedure will be carried out for the period 1993 to 1995 as well as for 1983 to 1987.

Determination of nutrient concentrations

The data on nutrient concentration in the topmost groundwater levels from the individual environmental agencies are in different data formats and must be converted to one format. Thereafter, the data set will be resolved. Values for which the concentration was below the detection limit the half of the detection limit was used. Further, extreme values were determined and excluded on further examination. Concentrations were defined as extreme values when they exceeded the sum of the mean and standard deviation.

As a result of this, a new calculation of mean values for the considered time periods was carried out for the individual stations. To be able to transfer the selected values on the basins upstream the individual monitoring station, the station mean values were imported for interpolation into a geographical information system (GIS). The interpolation procedure IDW was used in the GIS ARC/INFO. This procedure is based on a inverse distance-weighting for which a digital map from selected input data is generated.

A general problem is the selection of a suitable grid size. Occasional points with relatively high or low values can have a large effect on the value of cells at these points and the surrounding cells. The intensity of the influences depends on the size of the grid cells. The larger the length of the edges, the smaller influence each individual point has. For this problem, statistical studies were carried out regarding the point density and grid size for three German catchment areas (Aller, Saale, Neckar). In these catchments, the 50 highest and lowest values were selected and for these, the corresponding cell value for different grid sizes was calculated. From knowledge of the values of selected points and the surrounding points, the suitable cell size can be selected depending on the point density. As a result of these studies, considering the density of monitoring stations and the relatively large variation of measurements, an interpolation on a grid-size of at least 20 km was carried out.

Maps 3.6 and 3.7 show the results of the interpolation of average groundwater concentrations of dissolved inorganic phosphorus (SRP) and nitrate for a scale size of 20 x 20 km^2. On the basis of this digital map, the average concentrations for every catchment area were determined by overlaying the cover of the catchments with the grid map of concentrations.

Phosphorus

For phosphorus, Map 3.6 gives a simple, qualitative overview on the spatial differentiation of concentrations in groundwater, since in the current measurement programme of most German states, only the dissolved inorganic phosphorus is determined. This is however methodologically problematical since with the water samples exposed to air and especially with the anoxic conditions in groundwater, dissolved phosphorus will be transferred in particulate form and therefore with the measurement of dissolved inorganic phosphorus (SRP) alone, this is not taken account (GELBRECHT ET AL., 1991). To what extent this is also a problem at least with groundwater samples with low or high oxygen saturation occurs is at present not clear. Therefore, the concentrations of SRP in groundwater shown in Map 3.6 are only used as support for the derivation of phosphorus concentrations in groundwater.

DRIESCHER & GELBRECHT (1993) give a summary overview of the phosphorus concentrations under the influence of natural and anthropogenically influenced conditions.

On the basis of this information and other values in the literature (see WERNER ET AL., 1991; BRAUN ET AL., 1991) and also the groundwater concentrations given in Map 3.6, the concentrations of phosphorus in groundwater for the various soil types were calculated and are shown in Table 3.22.

Table 3.22: P-concentrations in groundwater for various soil types.

Soil type	Use	Expression	C_{GW_P} [g P/m³]
Sandy soils	Agricultural land	C_{GWS_P}	0.1
Loam	Agricultural land	C_{GWL_P}	0.03
Fen soils	Agricultural land	C_{GWNM_P}	0.1
Bog soil	Agricultural land	C_{GWHM_P}	2.5
	Woodland/open areas	C_{GWWAOF_P}	0.01

The P-concentration in the catchment areas was calculated on the basis of the values in Table 3.22 and the areas of sandy soils, loamy soils, fen and bog soils as area weighted average for the agricultural land according to Equation 3.49:

$$C_{GWLN_P} = \frac{C_{GWS_P} \cdot A_S + C_{GWL_P} \cdot A_L + C_{GWNM_P} \cdot A_{NM} + C_{GWHM_P} \cdot A_{HM}}{A_S + A_L + A_{NM} + A_{HM}} \qquad \textbf{(3.49)}$$

with
C_{GWLN_P} = groundwater phosphorus concentration for agricultural land [mg P/l],
C_{GWS_P} = groundwater phosphorus concentration for sandy soil [mg P/l],
C_{GWL_P} = groundwater phosphorus concentration for loamy soil [mg P/l],
C_{GWNM_P} = groundwater phosphorus concentration for fen soil [mg P/l],
C_{GWHM_P} = groundwater phosphorus concentration for bog soil [mg P/l],
A_S = area of sandy soil [km²],
A_L = area of loamy soil [km²],
A_{NM} = area of fen soil [km²] and
A_{HM} = area of bog soil [km²].

Drained agricultural land remains unconsidered (see Section 3.1.2.5).

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

$$C_{GW_P} = \frac{C_{GWLN_P} \cdot A_{LN} + C_{GWWAOF_P} \cdot A_{WAOF}}{A_{LN} + A_{WAOF}} \quad \textbf{(3.50)}$$

with C_{GW_P} = phosphorus concentration in groundwater [mg P/l],
C_{GWWAOF_P} = groundwater phosphorus concentration for woodland and open areas [mg P/l],
A_{LN} = agricultural area [km²] and
A_{WAOF} = woodland and open area [km²].

With anaerobic groundwater, in particular from deep levels it is to take into account after consideration of the data of the groundwater-watch programme of Mecklenburg-Western Pomerania and the studies of DRIESCHER & GELBRECHT (1993) that there are clear differences between the concentrations of dissolved inorganic phosphorus (SRP) and total phosphorus in groundwater. According to BEHRENDT (1996a) and DRIESCHER & GELBRECHT (1993), one can conclude that the total phosphorus concentrations are 2 to 5 times higher than SRP concentrations determined in the normal standard monitoring programmes. Information on areas of anaerobic groundwater is not available. However, one can determine areas with a higher probability of anaerobic conditions through a comparison of nitrate concentrations in groundwater and those in leakage water (see below). For the calculation of total phosphorus concentrations in groundwater it was therefore determined that in accordance with Equations 3.51 and 3.52, nitrogen concentrations in groundwater are less than 15% of those in leakage water and the TP-concentrations in groundwater are 2.5 times greater than the SRP-concentrations:

$$C_{GW_{TP}} = 2{,}5 \cdot C_{GW_{SRP}} \quad if\ C_{GW_N} \leq 0{,}15 \cdot C_{SW_N} \quad \textbf{(3.51)}$$

$$C_{GW_{TP}} = C_{GW_{SRP}} \quad if\ C_{GW_N} > 0{,}15 \cdot C_{SW_N} \quad \textbf{(3.52)}$$

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

With the information given above, the calculated TP-concentrations of 0.09 to 0.14 g P/m³ in the groundwater of Mecklenburg-Western Pomeranian rivers at are in the same range as the measured values (see BEHRENDT, 1996).

Nitrogen

Regarding nitrogen, the digital map (see Map 3.7) and the derived values for average nitrate concentration in groundwater are only an intermediate step to the formulation of a model for regionally differentiated nitrogen concentrations in groundwater. This is because changes in groundwater concentrations over time in the past and future are unknown. This requires the derivation of a relationship between the groundwater and leakage water nitrogen concentrations.

Knowledge of the residence time of water on the way from the root-zone to the groundwater and in the groundwater itself is essential for the derivation of such a relationship. The problem of determination of area-differentiated residence time in the unsaturated zone and in the aquifers at present is an area of intense research (WENDLAND ET AL, 1993; KUNKEL & WENDLAND, 1998; SCHWARZE ET AL., 1995; WERNER & WODSAK, 1994). Results which are applicable to German river basins are not yet available, with exception of the Elbe basins (WENDLAND &KUNKEL, 1998). Concerning the problem of residence time, an analysis of long-term changes in groundwater nitrate concentrations can give an orientation. These analyses were only carried out for 217 monitoring stations for the periods 1983 to 1987 and 1993 to 1997. The monitoring stations lie exclusively in the states of Baden-Württemberg and Bavaria. Map 3.8 shows the changes in nitrate concentration at these long-term groundwater monitoring stations.

Map 3.8 does not show a unified picture since there are both monitoring stations with increased and with decreased nitrate concentrations. It can however be seen that the most monitoring stations show a range of increasing or decreasing nitrate concentrations by about 20%. One can conclude from this that the groundwater nitrate concentrations in the 10 year period have changed little overall. The same conclusion can be drawn on the basis of an analysis of changes in average nitrate concentrations at the groundwater monitoring stations in the two states. These are shown in Table 3.23.

Table 3.23: Average changes in nitrate concentration in groundwater at the Baden-Württemberg and Bavaria observation stations since 1983.

State	Number of monitoring stations	CGW_{NO3-N}		Change
		1983-1987	1993-1997	
		[g N/m³]		[%]
Bavaria	72	4.29	4.38	+2
Baden-Württemberg	145	5.70	5.55	-3

According to BACH ET AL. (1998), these scarcely changed groundwater nitrate concentrations represent a decrease of 27% in the nitrogen surplus of agricultural land. From this, one can conclude that the 217 monitoring stations give a representative picture of the groundwater concentrations in these two states. Therefore, it can be concluded that the residence time of water in the unsaturated zone and in groundwater in this region is presumably longer than 10 years. Little altered concentrations would occur if one concludes that the groundwater concentration first reacts to the average surplus for the previous 20 years (see Figure 3.17).

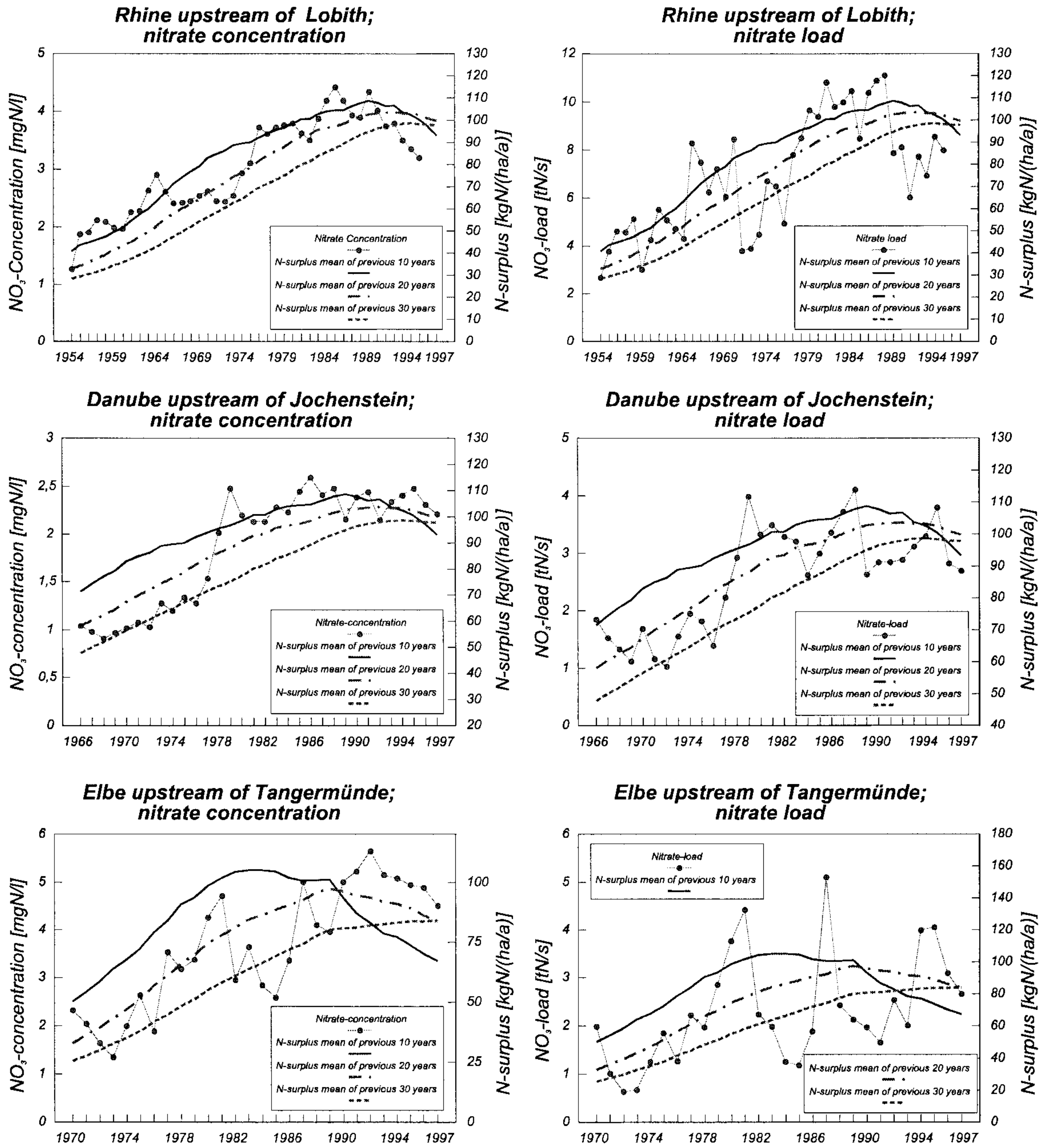


Figure 3.17: Comparison of long-term changes in nitrate concentrations or loadings with average N-surpluses of agricultural land for the Rhine/Lobith, Danube/Jochenstein and Elbe/Tangermünde stations.

A second approach for an approximate estimation of the water residence time in the unsaturated zone and in the aquifer was undertaken on the basis of long-term observations of nitrate concentrations and loadings in rivers. Sufficiently long-term observations of at least 25 years are only available for three monitoring stations. These are:

- the Lobith station on the Rhine, from which values from 1954 to 1995 were published for the *ICPR* (see *ICPR* tables for 1954 to 1995).
- the Jochenstein station on the Danube, for which values for 1966 to 1997 are available from the *State Office of Water Management* of Bavaria.
- the Tangermünde station on the Elbe, for which values for 1970 to 1995 are available from the *Environmental State Office Magdeburg*.

On the basis of a good correlation between the measurements at Magdeburg and Tangermünde, the nitrate concentrations and loads at Tangermünde for 1996 and 1997 were estimated.

Figure 3.17 shows the long-term changes in nitrate concentration and loadings at the three stations as well as the average nitrogen surplus of agricultural land for the previous 10, 20 and 30 years from BACH ET AL. (1998), also BEHRENDT (1988) (see Section 3.1.2.1).

From Figure 3.17 it is already clear that changes in Elbe nitrate concentrations and loadings only be related to nitrogen surpluses if these are considered for more than twenty years. For the Danube and particularly the Rhine, a similar conclusion from visual examination can not be derived. Therefore, a regression analysis was carried out on the relationships between the N-surpluses of different previous periods and the nitrate concentrations or loading. The results of this analysis are summarised in Table 3.24.

Table 3.24: Regression coefficients for the relationship between the nitrate concentration or loading and the long-term nitrogen surplus for the previous years for the Rhine at Lobith, the Danube at Jochenstein and the Elbe at Tangermünde.

Basin	Parameter	Average for previous 5 years	Average for previous 10 years	Average for previous 15 years	Average for previous 20 years	Average for previous 30 years
Rhine	NO_3-N-concentration	0.8169	0.8272	0.8377	0.8396	0.8038
Rhine	NO_3-N-loading	0.5741	0.5770	0.5720	0.5871	0.5550
Danube	NO_3-N-concentration	0.4707	0.8090	0.8582	0.8833	0.8374
Danube	NO_3-N-loading	0.3913	0.6079	0.6277	0.6494	0.5891
Elbe	NO_3-N-concentration	0.0159	0.1080	0.4225	0.6417	0.7236
Elbe	NO_3-N-loading	0.0008	0.0836	0.1583	0.2177	0.2265

From Table 3.24 it can be concluded that the regressions between the nitrate concentration or loading and the average nitrate surplus for the previous 20 years show the largest coefficients for the Rhine and Danube. The difference in the regression coefficients for the Rhine station Lobith are however so low that on this figure alone, one can not say whether the residence time is 5 years or 30 years. This is partly caused by the lack of data for this station for the very important most recent years (1996 and 1997).

The relatively large decrease in nitrate concentrations since 1990 (see Figure 3.17) can therefore presumably be attributed more to the decrease in point source inputs than to a decrease in groundwater inputs. For the Danube, with such a low proportion of point source inputs, one can clearly conclude from Table 3.24 that the retention time must at least be greater than 10 years. For the Elbe, one can ascertain from the relationship between retention time and nitrate concentration or loading that the retention times is 15 and more years. Regarding the Elbe, at least until 1990, the high proportion of nitrogen inputs from point sources had no serious influence on the nitrate concentration and loading over time. This is because this nitrogen input was predominantly as ammonium-N and owing to the low oxygen content also with transport in the river system there was presumably little nitrification.

Although the above studies give only an approximate description of the present situation with regards to the changes in nitrate concentration in groundwater, one can conclude overall that these changes can only be clarified if one assumes for the Rhine and Danube, a residence time of more than 10 years for water in the unsaturated soil zone. For the Elbe above Tangermünde, the catchment is dominated by areas of consolidated rock and loess and the residence time is more than 20 years.

As a result of the studies on water residence time in the unsaturated zone and aquifer, it can be concluded from the following that in the Rhine catchment, the average surplus for the 10 previous years, in the Danube catchment, the 20 previous years and in the Elbe catchment, the 30 previous years must be considered. The average surplus for the previous 30 years was also used for the Odra catchment and the Baltic coast catchments of Mecklenburg-Western Pomerania. For the Weser, Ems, the North Sea coastal area and the Baltic coastal area of Schleswig-Holstein, an average for the previous 20 years was used as for the Danube. Since at present a further differentiation of possible residence times within the catchments is not possible, the estimated average for the large-river catchment is employed, although there can be large regional differences within these areas.

In Section 3.1.2.1, a summary overview has already been given of the long-term changes in nitrogen surpluses of agricultural land in the old and new German states. The relationship of the N-surplus of the previous 20 years for the 1983 to 1987 and 1993 to 1997 periods covered gives for the old German states a value of 1.10 and for the new German states 0.98 (see Section 3.1.2.1 or Table 3.8). This means that although the surplus has been sharply reduced in recent years, particularly in the new German states, the average surplus for the previous 20 years is nearly the same. Comparison of the values for 1995 with the average for the previous 10, 20 and 30 years for the period 1983 to 1987 also gives a relationship which must be corrected for area-differentiated values according to BACH ET AL. (1998). This provides a starting point for a comparable situation to that for the nitrate concentrations in groundwater for 1993 to 1997 shown in Map 3.7. For the old German states, this implies that the surplus values must be increased by a factor of 1.33 (average for the previous 10 years for the Rhine) or 1.18 (average of the previous 20 years for all other OGS catchments). For the catchments of the new German states, the N-surplus for the previous 30 years is covered by a factor of 1.31 which is higher than the area-differentiated value of BACH ET AL. (1998). For the period 1993 to 1997, the correction factor is 1.57 for the new German states, 1.26 for the Rhine basin and 1.30 for the other river basins in West Germany. With this it is taken for granted that the N-surplus in both the new and old German states remained at the 1995 level. Since at present there is no area-differentiated surplus available for the past, the following calculations are used for the estimation of potential nitrate concentrations beneath the root-zone or in leakage water for all parts of catchments in the new and old German states.

Nitrate concentration in leakage water

The basis for the calculation of nitrate concentrations in non-drained areas is built on the defined correction factors for long-term changes in the regionally-differentiated N-surplus of agricultural land for the new and old German states and also on atmospheric deposition. Next, the average N-surplus is calculated from these three parameters on the basic outflow-carrying areas according to Equation 3.53:

$$N_{\ddot{U}GES} = \frac{N_{\ddot{U}LN} \cdot A_{LN} \cdot LKF + N_{DEP} \cdot (A_{EZG} - A_{LN} - A_W - A_{URBV} - A_{GEB})}{A_{EZG} - A_W - A_{URBV} - A_{GEB}} \quad \mathbf{(3.53)}$$

with
$N_{\ddot{U}GES}$ = total nitrogen surplus [kg/ha],
$N_{\ddot{U}LN}$ = nitrogen surplus of agricultural areas [kg/ha],
LKF = correction factor for the long-term changes in surpluses,
N_{DEP} = atmospheric nitrogen deposition [kg/ha],
A_{EZG} = catchment area [ha],
A_{LN} = agricultural area [ha],
A_W = total water surface area [ha],
A_{URBV} = impervious urban area [ha] and
A_{GEB} = mountain area [ha].

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

$$C_{SWPOT_{NO3-N}} = \frac{N_{\ddot{U}GES} \cdot AF \cdot 100}{SW} \quad \mathbf{(3.54)}$$

with
$C_{SWPOT_{NO3\text{-}N}}$ = potential nitrate concentration in leakage water for the total area with base flow [g N/m³],
AF = exchange factor and
SW = leakage water quantity [l/(m²· a)].

For the leakage water level, values are used from the previously given methods. The exchange factor (AF) and exchange frequency (AH) are determined analogously to the procedure given in Section 3.1.2.5. It should be noted that for this, an average rooting depth of 1 m is used. The so-calculated potential nitrate concentration in leakage water is shown in Map 3.9 as the average values for individual catchments in 1995.

Nitrate concentration in groundwater

For the derivation of a catchment-specific model for denitrification in soil, in the unsaturated zone and in the aquifer, the potential nitrate concentration in leakage water is compared to the nitrate concentration in groundwater. Figure 3.18 shows this relationship for the studied catchments. Areas chosen have more than 70 % with consolidated or unconsolidated rocks.

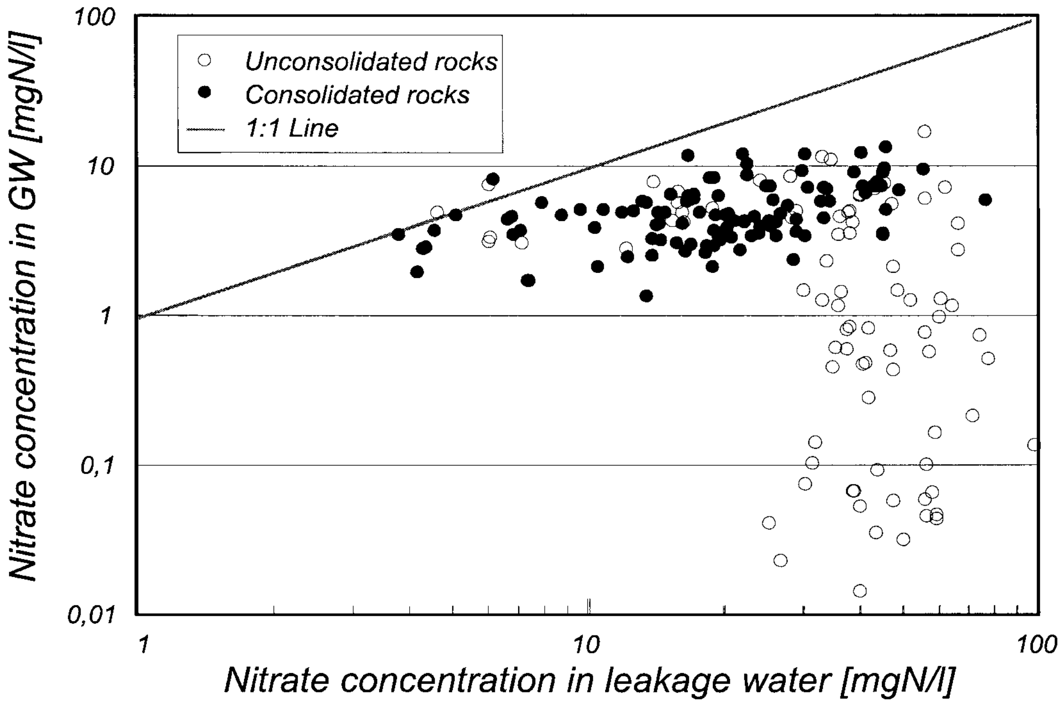


Figure 3.18: Relationship between the nitrate concentration in groundwater and the nitrogen concentration in the root-zone for the studied catchment areas.

For the catchments in the consolidated rock region, Figure 3.18 shows a relatively tight but non-linear relationship between the nitrate concentration in groundwater and leakage water. With increasing nitrate concentration in leakage water, the groundwater concentration exhibits an increasing deviation. For unconsolidated rock region, one can see two different groups. One group shows the same relationship as the basins in the consolidated rock region. With the second group, there is hardly any relationship. For this group, one can presume that there are anaerobic conditions in the groundwater. Here, the nitrate will be almost totally denitrified within the transition zone between aerobic and anaerobic conditions.

For every catchment, the relationship of the ratio between the nitrate concentrations in groundwater and leakage water with the quantity of leakage water is shown in Figure 3.19. The ratio of these parameters is greater than 100% for only three catchment areas. This indicates that here, the N-surplus is presumably underestimated for agricultural areas.

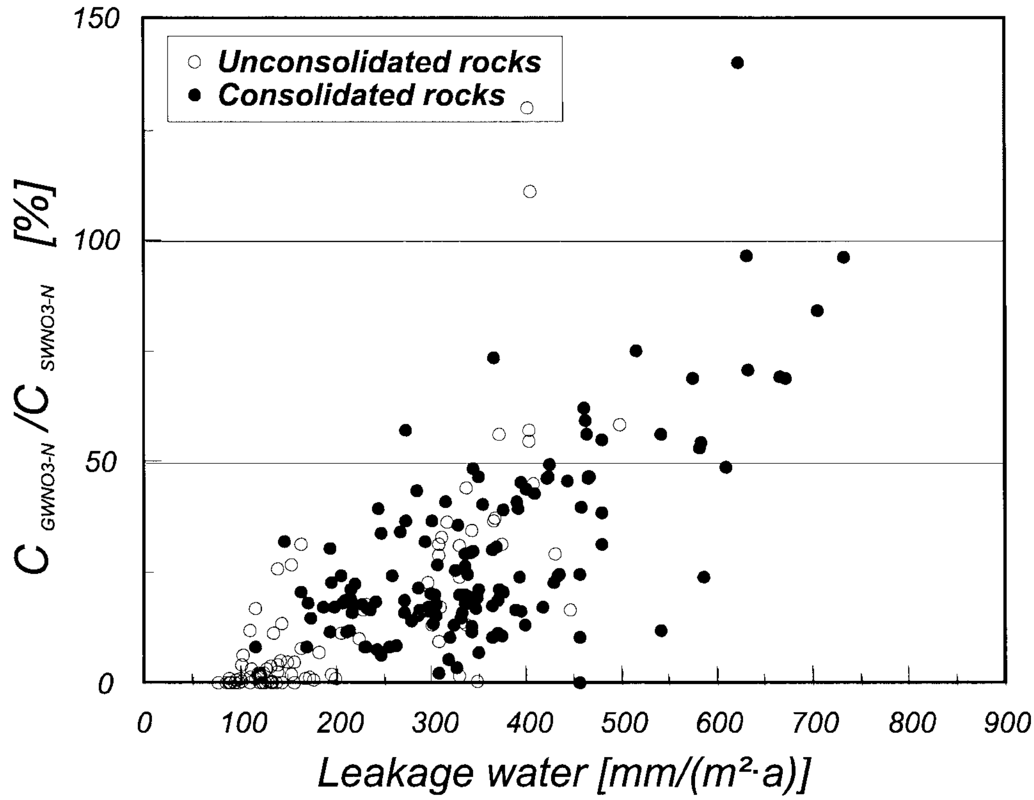


Figure 3.19: Dependence of the relationship of NO_3-N-concentrations in groundwater ($C_{GW_{NO3\_N}}$) and beneath the root-zone ($C_{SW_{NO3\_N}}$) on the leakage water level in the studied catchment areas.

It follows from Figures 3.18 and 3.19 that the relationship between nitrate concentrations in leakage water and groundwater must be included as a variable in the following derived transfer function.

In analogy with the previously given method for the derivation of the retention functions of lakes (VOLLENWEIDER, 1969) and rivers (BEHRENDT, 1996; BEHRENDT & OPITZ, 1999), can be assumed that the following relationship between groundwater and leakage water concentrations exists:

$$C_{GW_{NO3-N}} = \frac{1}{1 + R_{NO3-N}} \cdot C^{a}_{SWPOT_{NO3-N}} \tag{3.55}$$

with $C_{GW_{NO3\text{-}N}}$ = nitrate concentration in groundwater [g N/m³],
a = model coefficient and
$R_{GW_{NO3\text{-}N}}$ = retention or denitrification of nitrate in the unsaturated zone and in groundwater.

For $R_{GW_{NO3\text{-}N}}$, it is assumed that the retention is a function of the leakage water level and the hydrological conditions:

$$R_{GW_{NO3-N}} = k_1 \cdot SW^{k_2} \tag{3.56}$$

with k₁ and k₂ = model coefficients.

To characterise the hydrogeological conditions, two particular groups for the unconsolidated and consolidated rock region are chosen according to the hydrogeological map (see Map 2.3). For both types of rock region, one group with high permeability and another group with low water permeability is chosen.

The nitrate concentrations in groundwater can than be calculated according to Equation 3.57:

$$C_{GW_{NO3-N}} = \left(\sum_{i=1}^{4} \frac{1}{1 + k_{1i} \cdot SW^{k2i}} \cdot \frac{A_{HGi}}{A_{EZG}} \right) \cdot C^{a}_{SWPOT_{NO3-N}} \tag{3.57}$$

with A_{HG} = area of different hydrogeologically rock types [km²].

The coefficients a, k_1 and k_2 are determined by means of calculations of non-linear adjustment with the condition that the sum of squares should be minimal. For this, the solver unit of the spread-sheet programme was used. The model coefficients k_1 and k_2 are shown in Table 3.25. A value of 0.627 was determined for coefficient a.

Table 3.25: Model coefficients for the determination of N-retention in areas with various hydrological conditions.

Hydrological condition	k_1	K_2
Non-consolidated rock areas with good porosity	2,752	-1.54
Non-consolidated rock areas with poor porosity	68,560	-1.96
Consolidated rock areas with good porosity	6.02	-0.90
Consolidated rock areas with poor porosity	0.0127	0.66

Figure 3.20 shows the comparison of derivations from measurements and the calculated groundwater concentrations.

With a regression coefficient of 0.48, the relationship is not very tight. The derivation can on the one hand be based on the present very coarse model performance (same retention time for all catchments within the major river catchments); inadequate consideration of regional differentiation of conditions in the unsaturated soil-zone; very simple model for the leakage water level. On the other hand, there is also considerable uncertainty with the regional values for groundwater concentrations since the monitoring stations are, in the main, not representative and the measurements can be influenced by specific local conditions.

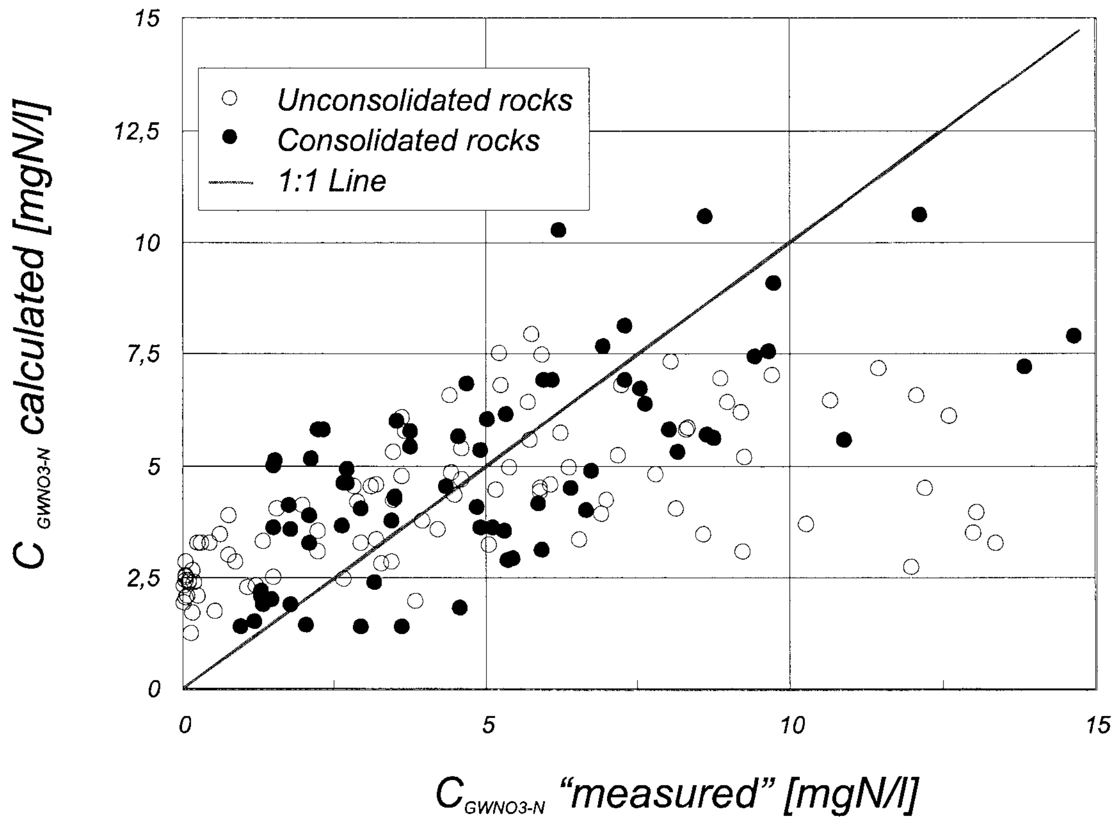


Figure 3.20: Relationship between the measured and calculated groundwater nitrate concentrations in groundwater and the calculated concentrations.

The too high calculated nitrogen concentrations in the unconsolidated rock regions where measured values are low are not a problem for the model since the regionalized concentrations are representative only for nitrate. As the analysis for groundwater monitoring stations in Mecklenburg-Western Pomerania shows, one can conclude that in particular for the groundwater samples with very low nitrate concentrations, most nitrogen is in the form of ammonium (BEHRENDT, 1996). Therefore, the observed concentrations of inorganic dissolved nitrogen only rarely have values of less than 0.5 g N/m^3. This confirms the conclusions of DRIESCHER & GELBRECHT (1993) and GELBRECHT & DRIESCHER (1996), who found that, in particular with anaerobic conditions, ammonium concentrations of 0.8 to 1 g N/m^3 in spring water and in groundwater are not unusual.

Although the model as yet has large uncertainties, it is used to determine the groundwater nitrogen concentrations on the basis of N-surpluses within the further procedure for the quantification of groundwater inputs. Based on this model it is possible to calculate scenarios for the future changes in groundwater nitrogen inputs. The model was also set up with the same coefficients for the calculation of groundwater concentrations for the 1983 to 1987 period. Only factors which characterise the long term development of N-surpluses of agricultural land and the EMEP-data for 1985 atmospheric deposition were changed.

Following the determination of P- and N- groundwater concentrations, it is now necessary to estimate the quantity of the runoff component for every catchment which characterize the sum of base flow and natural interflow to estimate the nutrient inputs by this pathway. The calculated level of percolate water seems not to be useful, because the calculation of total runoff based on the levels of percolate water shows often high deviations especially for such areas between two gauging stations for runoff. This is caused by errors of the runoff measurements and to simple approaches for the calculation of the runoff components.

Since the loading calculation for particular monitoring stations are based on measured runoff, an attempt was made to calculate the base flow within the catchments from the difference between the measured runoff and the individual runoff components:

$$Q_{GW} = Q - Q_{DR} - Q_{RO} - Q_{URB} - Q_{AD} \quad \textbf{(3.58)}$$

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

This was first carried out for all stations with the available outflow measurements. This value was compared with the calculated leakage water level. On average, it showed the calculated flow from groundwater and natural interflow carried about 85% of the leakage water. Finally, the runoff component for the areas between two or more monitoring stations was calculated from the balance of the runoff. Since errors accumulate for the in-between areas from the calculated runoff quantities, these values were manually corrected. In this way, the calculated runoff from groundwater and natural interflow was compared with the calculated quantity of leakage water and for the in-between area comparison and in the problematical cases corrected from the leakage water quantity and the neighbouring areas typical relationship between both sizes. At this procedure it was considered that the calculated values of total runoff do not differ more than 10% from the measured data.

As already mentioned, it must be considered that the calculated remainder of the runoff balance characterize in large part the base flow. However, it also includes the natural interflow, since this runoff component can not at present be calculated for all areas of German catchments covered.

3.1.2.7 Nutrient inputs via urban areas

For the estimate of the nutrient inputs from urban areas, different pathways will be calculated separately and later amalgamated. Figure 3.21 gives a general overview of the flows of materials in urban systems. From these, the inputs from unpaved urban areas are already considered with the inputs via groundwater. In addition, inputs from impervious urban areas discharged via the combined sewer system to the waste water treatment plants are already contained in the point source inputs from municipal waste water treatment plants.

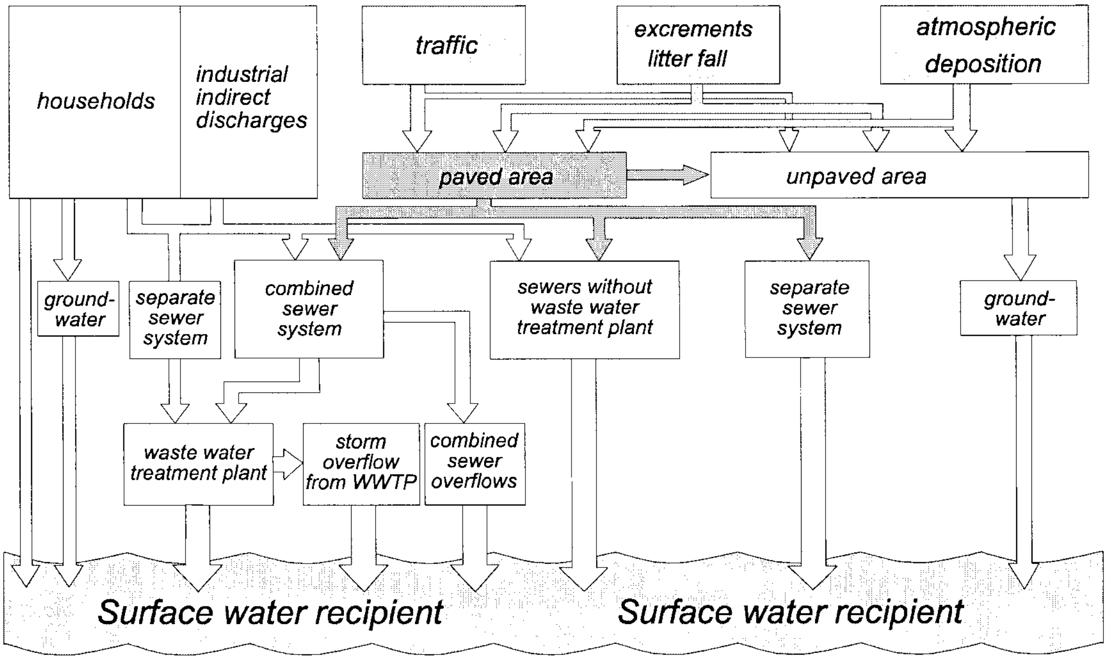


Figure 3.21: Input paths from urban areas.

In this section, the methods for the quantification of remaining pathways will be described, which are:

- Inputs from households and impervious urban areas connected neither to a sewer nor a waste water treatment plant,
- Inputs from households and impervious urban areas via combined sewer overflows,
- Inputs from household and impervious urban areas connected to sewers but not to a waste water treatment plant and
- Inputs from impervious urban areas via a separate sewer system

The basis for the calculation of all of these inputs is the estimate of the size of impervious urban areas. The land use map (see Map 2.1) shows various urban area categories. The built-up and transportation areas are similar to the impervious areas. However, it must be considered that such estimates also include non-impervious areas if the land use maps have a resolution of less than 500x500 m. Further, the level of imperviousness also depends on the type of development. The type of development (e.g. closed and open-block developments, detached and row-house developments) can be taken neither from the land use map nor from the information of municipality statistics.

Therefore, in the following, the approach of HEANEY ET AL. (1976) is used for the calculation of the impervious area. Using this, the part of the impervious area on the basis of the total urban area and the population density is calculated with Equation 3.59:

$$A_{URBV} = u_1 (u_2 \cdot E_{DICHTE})^{u_3 - u_4 \cdot log(u_2 \cdot E_{DICHTE})} \cdot A_{URB} \qquad \textbf{(3.59)}$$

where A_{URBV} = impervious urban area [km²],
A_{URB} = total urban area [km²],
E_{DICHTE} = population density [E/km²] and
u_1–u_4 = model coefficients.

An overview of the population density calculated as the number of people in urban areas for the different basins is given in Map 2.7.

For our studies, the coefficients from HEANEY ET AL. (1976) are used with conversion to the metric system. The coefficients are u_1=9.6, u_2=0.4047, u_3=0.573 and u_4=0.0391. The share of the calculated impervious urban area at the total urban area is on average 34% the maximum is 57%.

In the next section, the total impervious urban area is divided into the various types of sewer systems. For this, the statistics of the German states is used for the length of combined, waste water and separate sewers. The information is available for river basins according to the LAWA-code on three star level. For smaller catchment areas with a LAWA-code higher than 3, it is assumed that the proportions of combined and separated sewer systems are not different from the proportion of the basins with LAWA-code 3.

Further, the calculation of surface runoff as the proportion of precipitation is necessary. These values can be calculated according to HEANEY ET AL. (1976) for every catchment area from the level of impervious areas with Equation 3.60:

$$a_{URBV} = 0{,}15 + 0{,}75 \cdot \frac{A_{URBV}}{A_{URB}} \qquad \textbf{(3.60)}$$

where a_{URBV} = share of precipitation realized as surface runoff from impervious urban areas.

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

$$q_{URBV} = a_{URBV} \cdot N_J \qquad \textbf{(3.61)}$$

with q_{URBV} = specific surface runoff from impervious urban areas [l/(m²· a)] and
N_J = annual precipitation [l/(m²· a)].

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

In the following, the methods used for the estimation of inputs for the individual urban pathways are introduced.

Nutrient inputs via separate sewers

The main sources for the input of environmentally relevant materials into freshwater system in urban regions are atmospheric deposition, animal and plant wastes (excrement, fallen leaves etc.) and traffic. According to MALMQVIST (1982), atmospheric P-deposition in heavy rainfall comprises 25% of the total P-content of urban areas. This means that 75% of the P-inputs in freshwaters of urban areas originate from animal excrement and traffic. Consequently, different P-concentrations in storm water runoff can be expected in relation to landuse.

Information from the literature for the storm runoff of separate sewer systems gives estimates of P-concentrations between 0.1 and 1.7 g P/m³ (see Table 3.26). Measured P-concentrations for traffic areas appear to be a little higher than those for mixed areas.

Table 3.26: P-runoff concentrations in separate sewer systems.

Source	C_{T_P} [mg P/l]	Landuse
KRAUTH & KLEIN (1981)	0.25	Highway
KRAUTH & KLEIN (1981)	0.35	Highway
PAULSEN (1984)	0.5	Mixed area (Hildesheim)
PAULSEN (1984)	0.3	Transport (Hildesheim)
PAULSEN (1984)	0.8	Mixed area (Hildesheim)
KLEIN & WASSMANN (1986)	0.52	Mixed area (city)
GÖTTLE (1987)	1.5	Mixed area (München-Pullach)
GROTTKER (1987)	1.7	Transport (Hildesheim)
XANTHOPOULOS & HAHN (1993)	1.5	Transport (Karlsruhe)
XANTHOPOULOS & HAHN (1993)	0.3	Roof runoff
GEIGER (1990)	0.1-1.1	Literature values
MALMQVIST (1982)	0.1	
MALMQVIST (1982)	0.19	
HOGLAND & NIEMCZYNOWICZ (1980)	0.28	
VAN DAM ET AL. (1986)	0.45	
BROMBACH & MICHELBACH (1998)	2.4	Average of literature study

However, the database proves too small for a differentiation of the P-concentrations to be distinguished according to type of urban land use and traffic intensity. An appropriate separation was particularly useful for the new German states for 1985, whose P-input from traffic is likely lower because of lower traffic intensity (see BEHRENDT, 1994a).

On the grounds of great variation of P-concentrations, BROMBACH & MICHELBACH (1998) suggested that the inputs to the separated sewer system should rather be calculated on the basis of the specific inputs of the separate sewer systems.

The specific P-input from urban areas into freshwater bodies varies between 2.0 and 12.0 kg P/(ha· a) for normally polluted areas (KOPPE & STOZEK,1986). NOVOTNY & CHESTERS (1981) give values of 1.25 to 3 kg P/(ha· a) for urban areas with separate sewer systems. KLEIN & WASSMANN (1986) estimated a P-input of 1.2 to 2.8 kg P/(ha· a) from storm water sewers into the Tegeler See (Berlin) catchment area. According to PAULSEN (1984), P-input from impervious areas in Hildesheim ranged from 1.2 (streets) and 2.1 to 3.3 kg P/(ha· a) for mixed housing areas. LAUTRICH & PECHER (1974) calculated a P-input of 5.3 kg P/(ha· a) from the separated sewer system. MEIßNER (1991) estimated phosphorus outflows of 2.5 kg P/(ha· a) from an impervious area.

With the estimates given here, we follow the suggestion of BROMBACH & MICHELBACH (1998) for an average specific P-input of 2.5 kg P/(ha· a).

The sources of nitrogen inputs into freshwater bodies in urban areas are generally the same as for phosphorus. However, according to MALMQUIST (1982) unlike phosphorus, the influence of nitrogen deposition dominates the nitrogen inputs of urban areas. For nitrogen, the published concentrations in the separated sewers vary little (see Table 3.27).

Table 3.27: N-runoff concentrations in separate sewers systems.

Source	$C_{T_{DIN}}$	$C_{T_{TN}}$	Notes
	[mg N/l]		
PAULSEN (1984)	1.48		Transport (Hildesheim)
GROTTKER (1987)	4.2		Transport (Hildesheim)
KOPPE & STOZEK (1986)		2.1-4.3	
XANTHOPOULOS & HAHN (1993)	0.82		Transport (Karlsruhe)
XANTHOPOULOS & HAHN (1993)	4.5		Roof runoff
DAUBER ET AL. (1978)	1.80		
WEIBEL ET AL. (1966)		3.1	
MALMQUIST (1982)	1.84	2.4	
MALMQUIST (1982)	1.71	2.5	
VAN DAM ET AL. (1986)	2.92		
GÖTTLE (1978)	1.68		
BROMBACH & MICHELBACH (1998)		2.4	Average of literature study

Therefore, specific N-inputs are used for calculation of the nitrogen inputs. According to NOVOTNY & CHESTERS (1981), the N-input from urban areas in the Great Lakes catchment area ranged from 5 to 77 kg N/(ha· a). LOEHR (1974) determined a value of 7-9 kg N/(ha· a). From the rain water runoff from separated sewers, an N-input of 17-35 kg N/(ha· a) is calculated (KOPPE & STOZEK, 1986). AHL (1980) determined an N- runoff from urban areas in Sweden of 1.4 to 21.2 kg N/(ha· a).

Information from the literature can only conditionally be used because of the strong influences of the atmospheric N-deposition on the specific N-inputs. The basis for the calculation of the specific N-inputs through the separate sewer systems are therefore the values of the atmospheric N-deposition (see Map 2.12).

In addition to atmospheric deposition, inputs through leaf-fall and animal excrement are yet to be estimated. We accept a value of 4 kg N/(ha· a) for these inputs. The specific N-input from the impervious areas will be estimated using equation 3.62:

$$AS_{URB_N} = 4 + N_{DEP} \qquad \textbf{(3.62)}$$

where AS_{URB_N} = specific N-input from impervious urban areas [kg N/(ha· a)] and
N_{DEP} = atmospheric nitrogen deposition [kg N/(ha· a)].

For both studied time periods, the specific atmospheric deposition is initially required. The total phosphorus and nitrogen quantities discharged in every catchment area can be calculated by multiplication of the impervious urban area connected to separate sewer systems with the specific P- and N-inputs.

$$EUT_{N,P} = AS_{URB_{N,P}} \cdot A_{URBVT} \cdot 100 \qquad \textbf{(3.63)}$$

where $EUT_{N,P}$ = nutrient inputs via separate sewers [t/a] and
A_{URBVT} = impervious urban area connected to separated sewer system [km²].

Nutrient inputs via combined sewer overflows

Combined sewer systems collect the input from households, indirect industrial inputs and rain-water runoff and bring these water to the waste water treatment plant in normal weather conditions. The layout of the combined sewer system and the waste water treatment plant is such that with normal rainfall, the mixed water mostly flows through the treatment plant. With storm water events when only a small fraction is stored, the quantity of water flowing through the treatment plant is in accordance with regulations. The quantity of water which is untreatable or water which does not enter treatment plants is then discharged to water bodies via combined sewer overflow or through a bypass at the treatment plant.

The approaches of MOHAUPT ET AL. (1998) are the basis for the estimation of these nutrient inputs. After that, one can conclude that nearly all estimated surface runoff from impervious urban areas (Equation 3.61) is realized on the heavy rain days of the year. The number of days with storm water events is 65 according to these authors. On these 65 heavy rain days, the discharges do not last the whole day. On the other hand, one has to take into account that nutrient depositions and waste water of household remain longer in the sewer system during days with storm water, so that one cannot merely consider the time of the storm event. Therefore, the following model calculations use an effective number of storm water days.

The total water quantity in the combined sewer system during the days of storm water events can be calculated with Equation 3.64:

$$Q_{URBM} = q_{URBV} \cdot A_{URBVM} + Z_{NT} \cdot (E_{KA} \cdot q_E + a_{GEW} \cdot q_{GEW} \cdot 100 \cdot 86{,}4 \cdot A_{URB}) \qquad \textbf{(3.64)}$$

where Q_{URBM} = storm water runoff from combined sewer system [m³/s],
A_{URBVM} = impervious urban area connected to combined sewer system [km²],
Z_{NT} = effective number of storm water days,
E_{KA} = number of inhabitants connected to combined sewer system,
q_E = daily wastewater output per inhabitant [l/(E· d)],
Q_{GEW} = industrial-commercial wastewater [m³/s],
a_{GEW} = proportion of total urban area in commercial use and
q_{GEW} = specific runoff from commercial areas [l/(ha· s)].

A value of 130 l/(E· d) will be used for q_E. For the calculation of the quantity of commercial waste water, MOHAUPT ET AL. (1998) give a figure of 0.5 l/(ha· s) for q_{GEW} for 10 hours per day based on a total urban area in commercial use (a_{GEW}) of 0.8% or in other words 432 m³/(ha· d).

The discharge rate of a combined sewer system varies in relation to the removal grade, i.e. the retention volume of the combined sewer. The retention or storage volume holds back a fraction of the waste water during the storm water event and retards the flow to the treatment plant. One can estimate the discharge rate according to MEIßNER (1991) from Equation 3.65:

$$RE = \frac{\dfrac{4000 + 25 \cdot q_R}{0{,}551 + q_R}}{V_S + \dfrac{36{,}8 + 13{,}5 \cdot q_R}{0{,}5 + q_R}} - 6 + \frac{N_J - 800}{40} \qquad \textbf{(3.65)}$$

where RE = discharge rate of combined sewer overflows [%],
q_R = rainfall runoff rate [l/(ha· s)],
V_S = storage volume [m³] and
N_J = annual precipitation [l/(m²· a)].

From this, MEIßNER (1991) and BROMBACH & MICHELBACH (1998) give a retention volume of 23.3 m³/ha with 100% rate of discharge. With a removal grade of 10% there is no retention volume. According to HAMM ET AL. (1991), a rate of discharge of 25% corresponds to a retention volume of ca. 6 m³/ha. In their studies of the Lake Constance catchment area, BROMBACH & MICHELBACH (1998) estimated an average removal grade of 50% and a mean rainfall runoff rate of 1 l/(s· ha)

Since the discharge rate from Equation 3.65 also depends on precipitation, the discharge rate will be calculated for every catchment area. For that, the same rainfall runoff rate (1 l/(s· ha)) is assumed for all catchment areas.

For the estimation of the rate of discharge, data of waste water statistics from the German states for 1987, 1991 and 1995 are used.. Following that, values for the rate of discharge for these years are shown in Table 3.28. For the calculations, the information from 1987 will be applied for the time period 1983 to 1987.

Table 3.28: Storage volume of rainfall overflow tanks (V_S) and removal grade for individual German states in 1987, 1991 and 1995.

State	Rainwater storage volume (V_S)			Removal grade		
	1987	1991	1995	1987	1991	1995
	[10^3 m^3]			[%]		
Baden-Württemberg	1.456	2.374	2.639	55,2	83,8	94,8
Bavaria	522	1.431	1.882	20,0	51,3	66,9
Berlin		18	23	4,7	4,7	6,0
Brandenburg		8	17		6,1	11,4
Bremen	41	63	79	39,3	67,0	79,4
Hamburg	0	25	52	0,0	12,5	27,2
Hesse	215	834	1.046	13,7	49,5	60,4
Mecklenburg-Western Pomerania		6	13		3,6	11,6
Lower Saxony	28	116	126	10,7	46,7	53,3
North Rhine-Westphalia	631	2.280	3.036	17,7	60,4	78,9
Rhineland-Palatinale	218	500	695	21,5	46,5	62,0
Saarland		68	116	1,5	20,9	35,6
Saxony	19	19	96		2,0	11,9
Saxony-Anhalt		3	46		0,6	11,1
Schleswig-Holstein	29	51	61	20,2	40,8	50,8
Thuringia		9	59		1,3	9,4
Old German states	**3.145**	**7.742**	**9.732**	**25,0**	**58,4**	**72,5**
New German states	**61**	**61**	**253**	**2,0**	**2,0**	**9,6**
Germany	**3.206**	**7.803**	**9.984**	**20,5**	**47,8**	**61,6**

For the new German states, there is information available on retention volume of combined sewer storage for 1991. Since these numbers are so low, it will be assumed that these retention volumes are also usable for the period 1983 to 1987. Concerning the proportions of the individual German states in individual catchment areas, the rate of discharge for all studied catchment areas will be calculated for the periods 1983 to 1987 and 1993 to 1997.

The nutrient concentration in combined sewers during overflow events can be calculated with the previously given assumptions from:

$$C_{M_{N,P}} = \frac{((AG_{E_{N,P}} \cdot E_{KA} + C_{GEW_{N,P}} \cdot Q_{GEWM}) \cdot Z_{NT} + AS_{N,P} \cdot A_{URBVM} \cdot 100) \cdot \frac{RE}{100}}{Q_{URBM}} \quad \textbf{(3.66)}$$

where $C_{M_{N,P}}$ = nutrient concentration in combined sewers during overflow [g/m³],
$AG_{E_{N,P}}$ = inhabitant-specific N- or P-output [g/(E· d)],
$C_{GEW_{N,P}}$ = nutrient concentration in commercial wastewater [g/m³] and
Q_{GEWM} = runoff from commercial areas connected to combined sewers [m³/d].

An overview of parameters used for the calculation of nutrient concentrations in combined sewer system is given in Table 3.29.

Table 3.29: Discharge parameter values used for the calculations in the mixed system with discharge.

Nutrient	AG_E	C_{GEW}	AS_{URB}
	[g/(E· d)]	[g/m³]	[kg/(ha· a)]
Nitrogen	11	1,0	4+N_{DEP}
Phosphorus	1,8	0,1	2,5

To calculate the nutrient concentrations and the quantity of water discharged via combined sewer system, the number of effective days of storm water events (Z_{NT}) is required. For the estimation of this number of days, nutrient concentrations will be estimated according to BROMBACH & MICHELBACH (1998) in the case of different rates of discharge. With the assumption of a number of 50 effective heavy rain days, very similar results are attained (see Table 3.30). These, together with the previously given model calculated nutrient concentrations, represent the mean value for all catchment areas of the Danube and Upper Rhine.

Table 3.30: Comparison of the model results of BROMBACH & MICHELBACH (1998) and MONERIS for the nutrient concentrations in the combined sewer systems in the case of discharge for various removal grades and 50 effective heavy rain days.

Rate of discharge	MONERIS		BROMBACH & MICHELBACH (1998)	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
	[g N/m³]	[g P/m³]	[g N/m³]	[g P/m³]
0%	8.95	1.88	10.8	2.0
50%	6.67	1.40	6.9	1.5
100%	5.32	1.12	5.4	1.3

The total input of nutrients caused by combined sewer overflows in a catchment area can be calculated on the basis of Equation 3.64 and 3.66 as follows:

$$EUM_{N,P} = C_{M_{N,P}} \cdot RE \cdot Q_{URBM} \tag{3.67}$$

where $EUM_{N,P}$ = nutrient input via combined sewer overflows [t/a].

Nutrient inputs via sewers not connected to wastewater treatment plants

The waste water statistics identify people connected to water treatment plants and also the proportion of population connected to a sewer system but not to a waste water treatment plant. In the following, 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 with separate sewer systems (see above). The same is assumed for the specific values of the nutrient inputs from these areas.

In addition, the nutrient inputs from the inhabitants who have only a sewer connection must be considered. The proportion of human nutrient output transported mainly as particulate material to waste water treatment plants is already described in Section 3.1.1.1. 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 3.68:

$$EUK_{N,P} = AS_{N,P} \cdot A_{URBK} \cdot 100 + E_{URBK} \cdot AG_{ES_{N,P}} \cdot 0{,}365 + C_{GEW_{N,P}} \cdot Q_{GEWK} \tag{3.68}$$

where $EUK_{N,P}$ = nutrient input via impervious urban areas and from inhabitants connected only to sewers [t/a],
A_{URBK} = urban area connected only to sewers [km²],
E_{URBK} = inhabitants connected only to sewers,
Q_{GEWK} = annual runoff from commercial areas only connected to sewers [m^3/s] and
$AG_{ES_{N,P}}$ = inhabitant specific output of dissolved nutrients [g /(E· d)].

The specific human dissolved nutrient outputs were 1.05 g P/(E· d) and 9 g N/(E· d) for the period 1993 to 1997. For nitrogen, this value is also valid for the period 1983 to 1987. For phosphorus during this period, different values for the old German states (2.55 P/(E· d)) and new German states (3.25 g P/(E· d)) have to be taken into account.

Nutrient inputs via households connected neither to wastewater treatment plants or sewers

Up to now, only the proportion of people and urban areas connected to sewers have been considered. Inputs into water bodies may also come from people or areas connected neither to sewers nor waste water treatment plants.

As already mentioned in Section 3.1.1.1, new buildings at least must be completely connected to a water treatment plant or a closed septic tank. On the other hand, some old buildings still have septic tanks with drainage. For these, only dissolved nutrients reach water bodies after a number of different pathways through the soil. A fraction of the nutrients will be retained during the passage in the soil.

For impervious areas without sewer connections it must be taken into account that a fraction of the surface runoff nutrients is also retained by soil. For the nutrient inputs from these areas, the following applies (Equation 3.69):

$$EUN_{N,P} = (100 - R_{B_{N,P}}) \cdot (AS_{N,P} \cdot A_{URBN} \cdot 100 + E_{URBN} \cdot AG_{ES_{N,P}} \cdot 0{,}365 \cdot (100 - K_{ABF}))$$

where $EUN_{N,P}$ = nutrient input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants [t/a],
$R_{B_{N,P}}$ = nutrient retention in soil [%],
A_{URBN} = impervious urban area connected neither to a sewer nor to a wastewater treatment plant [km²],
E_{URBN} = inhabitants connected neither to sewers nor to wastewater treatment plants,
$AG_{ES_{N,P}}$ = inhabitant specific output of dissolved nutrients [g P/(E· d)] and
K_{ABF} = proportion of dissolved human nutrient output transported to wastewater treatment plants [%].

For this pathway it is assumed that indirect industrial inputs do not occur. A figure of 50% is used for retention of these nutrient inputs in soil because at present there is no available information on regional and temporal variation. The proportion of dissolved human nutrient output transported to wastewater treatment plants, i.e. how much of the collected wastewater or faeces are discharged to wastewater treatment plants, can be obtained from the information in Section 3.1.1.1.

3.2 Nutrient load of the rivers

The procedure for calculation of nutrient loads must distinguish between values determined from individual and from mixed samples. For individual samples, the load per year is calculated from Equation 3.70 using the runoff value for the day of water quality measurements. If the measured concentration for the nutrients is below the detection limit, a value of half the detection limit is used.

$$L_{J_{N,P}} = \frac{Q_{TGL}}{Q_{MEß}} \cdot \left(\frac{1}{J} \cdot \sum_{n=1}^{J} C_{t_{N,P}} \cdot Q_t \cdot U_f \right) \qquad \textbf{(3.70)}$$

where $L_{J_{N,P}}$ = annual nutrient load [g/s],
Q_{TGL} = average annual runoff based on daily measurements [m³/s],
$Q_{MEß}$ = average annual runoff based on daily runoff for the concentration measurements [m³/s],
n = number of measurements per year,

$C_{t_{N,P}}$	=	nutrient concentrations at sampling time t [mg/l],
Q_t	=	runoff at sampling time t [m³/s] and
U_f	=	factor for the correction of runoff data according to the size of the catchment area upstream the monitoring station.

This method for calculation of load is also the favoured method of OSPAR (1996) for calculation of loads into the North Sea. In a comparison of five various methods to estimate load for English rivers, LITTLEWOOD (1995) showed that only this method gave reliable load estimates. Other methods for load calculation (KELLER ET AL., 1997) will not be applied. These methods include e.g. the use of an average concentration and average annual runoff or the interpolation of the measured concentrations for the whole year. KELLER ET AL. (1997) applied various methods for load calculation to the data of the measurement programme of *ICPR* of 1995 and found that in most cases, the different methods give similar results. The annual loads should however be considered as estimated values. When weekly or fortnightly mixed sample values are available, the annual nutrient loads are calculated according to Equation 3.71:

$$L_{J_{N,P}} = \left(\frac{1}{J} \cdot \sum_{n=1}^{J} C_{MISCH_{N,P}} \cdot Q_{MISCH} \cdot U_f \right) \qquad \textbf{(3.71)}$$

where	$C_{MISCH_{N,P}}$	=	mixed sample nutrient concentration [mg/l],
	Q_{MISCH}	=	runoff during measuring period [m³/s].

From the annual values, the mean load for the studied time periods has to be estimated according to Equation 3.72. These periods are 1983 to 1987 and 1993 to 1997.

$$L_{U_{N,P}} = \frac{1}{U} \cdot \sum_{i=1}^{U} L_{J_{N,P}} \qquad \textbf{(3.72)}$$

where	$L_{U_{N,P}}$	=	average annual nutrient load during the studied period [g/s],
	i	=	number of years with measuring data in the study period.

Daily runoff data were not available for every monitoring station. Consequently, the described runoff weighting could not be overall applied. It will be tested how much the annual average of runoff for the days of quality measurement differ from the annual average runoff for daily runoff in the studied time periods.

Figure 3.22 shows that the variation is rarely more than 15%. Therefore, it will be assumed that for monitoring stations where no daily runoff is available, the load calculation is not highly influenced if the runoff for days of monitoring is only used. To carry out such a comparison for the observed loads, data from daily nutrient measurements at various monitoring stations are necessary. However, within this study such data were only available for the stations Bad Honnef and Lobith-Bimmen on the Rhine for the years 1990 to 1995. The comparison of calculated annual NH_4-, NO_3- and TP-load estimated from daily (D) and fortnightly (D14) measured concentrations, shows for a single year, a maximum variation of only 14% (see Table 3.31). Both over- and underestimates occur. Estimates for the whole time period 1991-1995 reduce the maximum variation to 4%. One can conclude from this that annual load only estimated with 26 measurements per year nearly corresponds with values from daily values at least for large catchment areas.

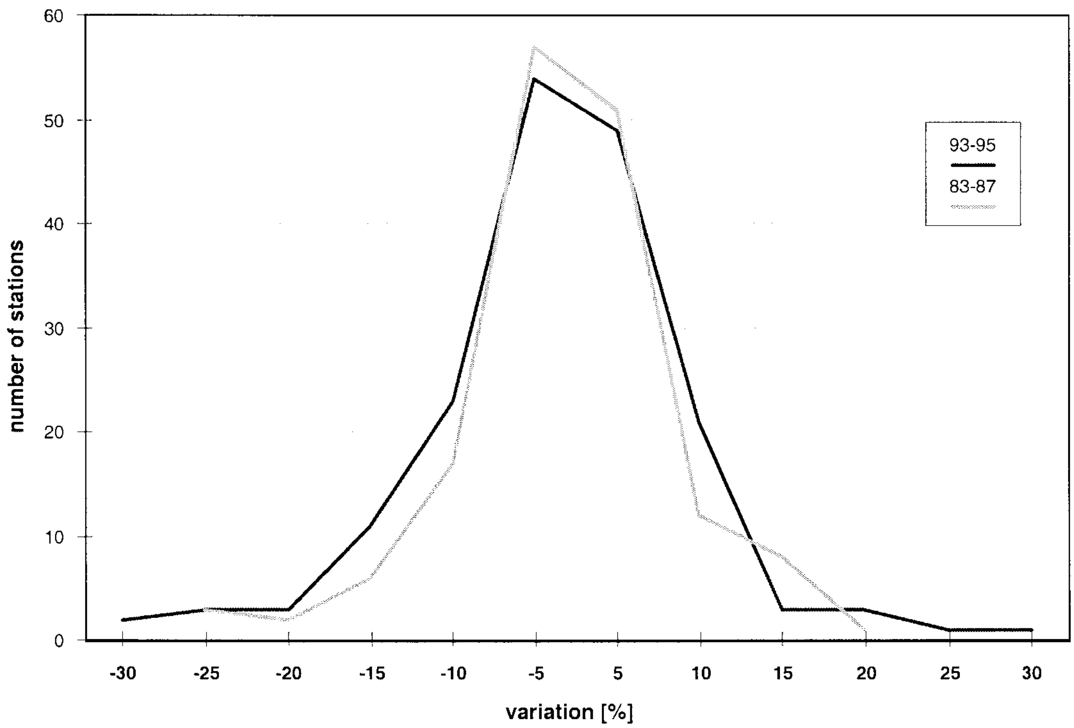


Figure 3.22: Variation in average runoff on a measurement day from average daily runoff in the studied time periods.

Table 3.31: Variation in loading-calculations from fortnightly (D14) and daily (D) measurements at Bad Honnef and Lobith-Bimmen.

Year	Difference of D14 from D loadings [%]					
	Monitoring station Bad Honnef			Monitoring station Lobith-Bimmen		
	NH_4-N	NO_3-N	TP	NH_4-N	NO_3-N	TP
1990	-8.1	1.9	-7.8	-2.3	-0.9	-4.1
1991	2.7	0.8	-0.8	-1.8	-0.6	-1.8
1992	4.9	-5.0	6.0	-6.5	-3.4	-1.0
1993	-13.8	0.1	3.8	-5.8	-1.0	2.4
1994	-2.4	0.4	-4.2	2.5	-0.8	-6.7
1995	-13.5	-2.4	12.0	-0.4	-0.1	0.7
1991-95	-4.1	-1.2	4.0	2.4	-1.1	-1.2

Such low variation in the load are validated by Danish studies (KRONVANG, personal communication). These gave less than 15 percent variation in the loadings from daily and fortnightly measurements for catchment areas greater than 1,000 km². This study is generally focused on monitoring stations with catchment areas of greater than 1,000 km². It can therefore be assumed that the used data give a good rendering of the real loads.

In addition, a comparison of loads calculated from fortnightly and daily measurements of suspended solids for various time periods was carried out. For this task, daily measurements from 18 monitoring stations (8 of this in the Danube basin) are used (see Table 3.32). The measurements at Jochenstein on the Danube and on other rivers outside the Danube catchment area were carried out by *Federal Agency for Hydrology (BfG)*, the other rivers were monitored by the *State Office of Water Management* in Bavaria.

For comparison values of 12 stations with fortnightly normal measurements of water quality were used. Those for the Danube catchment area also come from the *State Office of Water Management* of Bavaria and for other rivers from the corresponding State Environmental Agencies.

A comparison of the suspended solid concentrations from daily and fortnightly measurements for the same measurement days has already shown that the sampling methods or the time of sampling are different for the Bavarian data of suspended solids. The concentrations of suspended solids measured on the same day, clearly differ from one another. Similar variations occur between the existing data of the *BfG* for daily and the fortnightly measurements of other Environmental Agencies. Already from this it can be followed that the loads of suspended solids calculated from daily measurements (SS-D) clearly differ from those loadings calculated from fortnightly measurements (SS-14) on the grounds of the different methods or also different measuring times.

The mean values of the daily load (SS-D) for the periods will be estimated through comparison of the fortnightly measurement based mean loads (SS-14) (see Table 3.32, last column and Figure 3.23). In most cases, variations are considerable. Further the loads estimated from daily measurements are clearly underestimated.

To test whether this underestimate is caused by the resolution of the data over time or from the methods of measurement, an examination was also made by generation of fortnightly data series from of the daily measurements of suspended solids. From these, the suspended solid loads (SS-D14) will be recalculated. The comparison of these loads (SS-D14) with the average daily loads (SS-D) shows that the variation in the mean is truly smaller (Table 3.32).

The comparison of both fortnightly data sets again shows great variation and that the loads clearly differ from one another although the measurements were made on the same days. The differences between loads calculated from daily (SS-D) and fortnightly data (SS-14) are therefore probably caused by the different method of sampling or measuring suspended solids. These systematic methodological differences are shown in the variation of the calculated loadings of both fortnightly data sets (SS-14 and SS-D14) (Table 3.32 and Figure 3.23). In contrast, the time wise resolution of measurements plays a small role. From the database, it is clear that the variation is lower for the flatland rivers than for the mountainous rivers. In the flatland rivers, short-term fluctuation in runoff and concentrations rarely occur. Greater fluctuations occur for the mountainous influenced and regulated rivers (Neckar, Mosel).

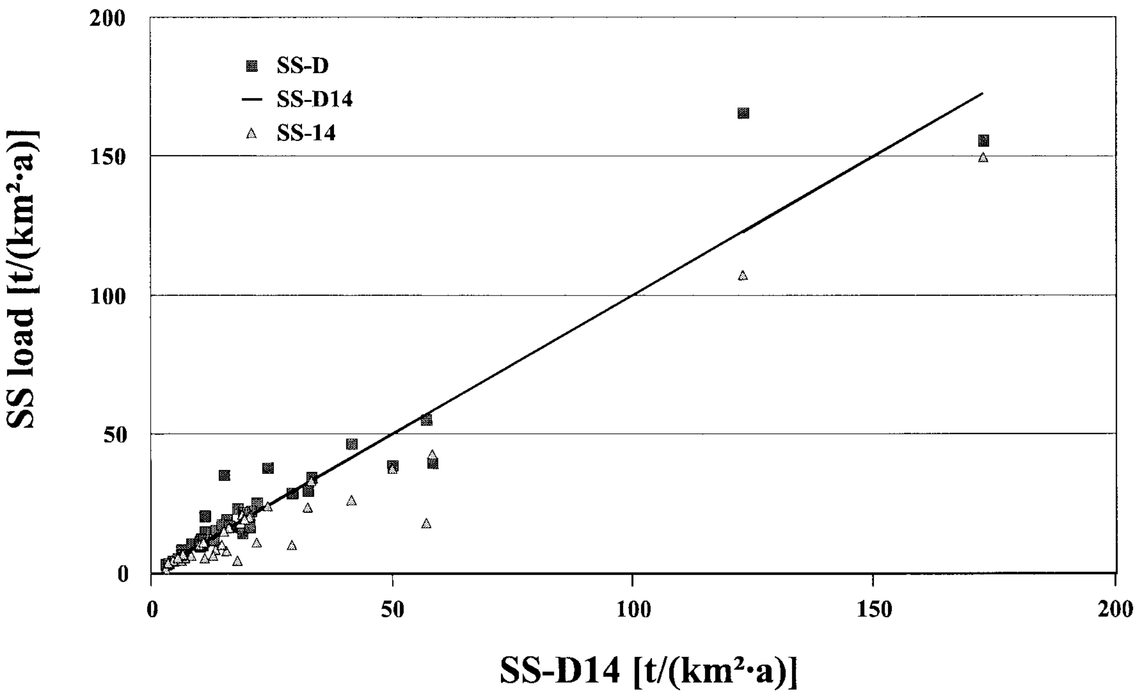


Figure 3.23: Comparison of suspended solid loadings calculated with different methods.

If these comparisons are transferred to nutrients, it can be concluded that for flatland rivers fortnightly measurements only slightly underestimate the real loading with particulate transported nutrient components for catchment areas of more than 1,000 km². For the catchment areas influenced by mountainous areas, there appears to be a 10% to 20% systematic under-estimation of the loads of particulate materials. In the individual considered time-periods, under- and overestimations of the particulate load can occur. A permanent greater underestimation of the particulate loads seems to occur only for rivers in mountainous areas with regulated flow conditions (e.g. Neckar, Mosel) on the basis of the fortnightly measurements.

Table 3.32: Variation of the suspended solid loads calculated from fortnightly (SS-14 and SS-D14) and daily (SS-D) measurements.

Location	River	Period	Variation [%]		
			SS-D14 from SS-D	SS-14 from SS-D14	SS-14 from SS-D
11404	Iller	1983-87	-25.9	-12.4	-35.1
11404	Iller	1988-92	10.7	-13.4	-4.0
11602	Mindel	1986-87	-13.1	-38.5	-46.5
11602	Mindel	1988-92	-22.6	-74.9	-80.6
14601	Vils	1988-91	-25.6	-51.2	-63.7
15202	Regen	1983-87	7.6	-51.7	-48.0
15202	Regen	1988-91	-22.6	-29.7	-45.6
16902	Isar	1984-87	-17.9	-49.9	-58.9
16902	Isar	1988-91	-15.7	-29.3	-40.4
17402	Ilz	1983-87	3.4	-68.4	-67.3
17402	Ilz	1988-92	1.4	-64.9	-64.4
18802	Rott	1983-87	9.1	-26.9	-20.2
18802	Rott	1988-92	-14.4	-48.7	-56.1
19101	Danube	1983-87	-11.4	-36.5	-43.8
19101	Danube	1988-92	28.6	-25.2	-3.7
19101	Danube	1993-95	47.2	-26.3	8.5
23999	Neckar	1989-92	-46.4		
23999	Neckar	1993-95	-57.1		
24703	Main	1983-87	-16.2	-6.8	-21.9
24703	Main	1988-92	-19.0	-24.6	-38.9
24703	Main	1993-95	29.5	11.4	44.2
26903	Mosel	1983-87	-4.3		
26903	Mosel	1988-92	-13.3		
26903	Mosel	1994-95	-37.0		
27904	Rhine	1983-87	-2.4		
27904	Rhine	1988-92	-6.1		
27904	Rhine	1993-95	-6.9		
49105	Weser	1983-87	20.5		
49105	Weser	1988-92	-7.6		
49105	Weser	1993-95	-6.9		
56901	Saale	1993-94	-11.0	-1.6	-12.4
59312	Elbe	1995	6.9	-23.0	-17.7
59312	Elbe	1983-87	0.3		
59312	Elbe	1988-92	-0.7		
59312	Elbe	1993-95	0.8		
37303	Ems	1984-87	5.6		
37303	Ems	1988-92	-2.5		
37303	Ems	1993-95	2.3		
69001	Odra	1993-94	-6.2	-54.7	-57.6

3.3 Nutrient retention and losses in river systems

With the previously given comparison between the estimated nutrient inputs and the load in catchment areas, considerable variation will be determined (BEHRENDT, 1996; BEHRENDT & OPITZ, 1999) which cannot be explained by an underestimate of the load or an overestimate of the inputs (BEHRENDT & BACHOR, 1998).

Figure 3.24 shows the relationship between the observed nutrient loads and nutrient inputs for various European catchment areas.

On the basis of data for nutrient inputs and load in 100 catchment areas with a size of 100 to 200,000 km², an empirical model is derived (BEHRENDT & OPTIZ, 1999) for the retention of nitrogen and phosphorus in relation to the specific runoff or the hydraulic load in the catchment area. The base for the model is the mass balance of a catchment area, after which 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:

$$L_{N,P} = EG_{N,P} - R_{N,P} = \sum EP_{N,P} + \sum ED_{N,P} - \sum R_{N,P} \quad \textbf{(3.73)}$$

where $L_{N,P}$ = nutrient load [t/a],
$EG_{N,P}$ = 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 3.73 one gets:

$$\frac{L_{N,P}}{EG_{N,P}} = \frac{1}{1 + R_{L_{N,P}}} \quad \textbf{(3.74)}$$

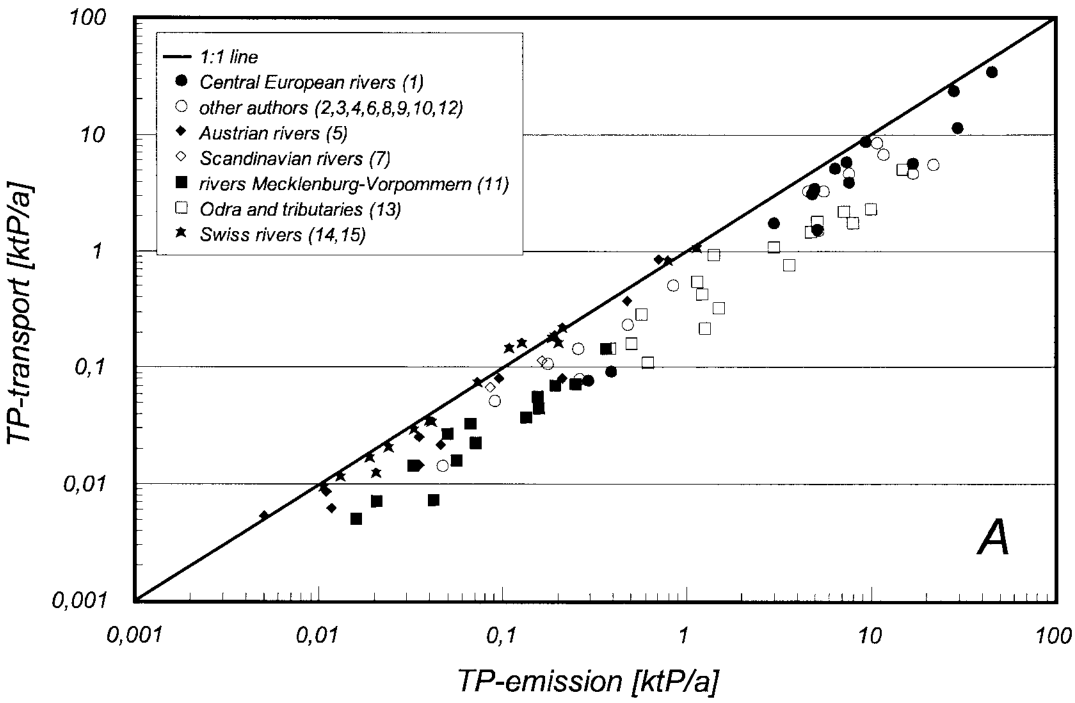
where $R_{L_{N,P}}$ = load weighted nutrient retention.

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

$$R_{L_{N,P}} = a \cdot x^b \quad \textbf{(3.75)}$$

where a, b = model coefficients.

Figures 3.25 and 3.26 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 Table 3.33, results for the estimation of the model coefficients are shown.



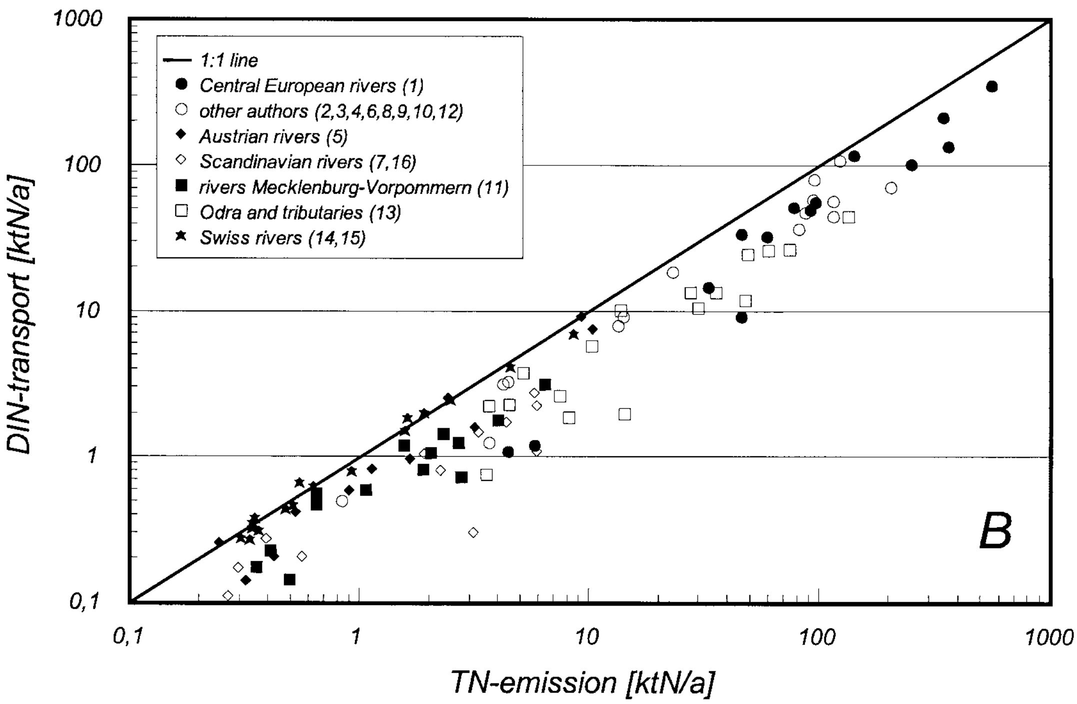
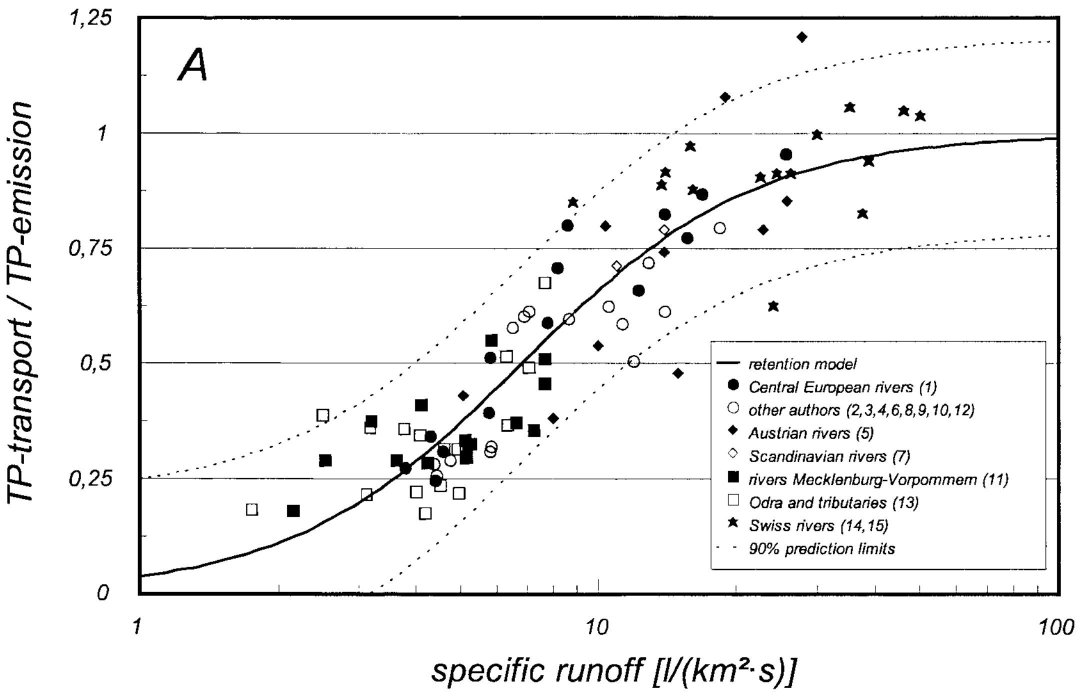


Figure 3.24: Relationship between nutrient inputs and the nutrient loadings for various catchment areas in Europe.



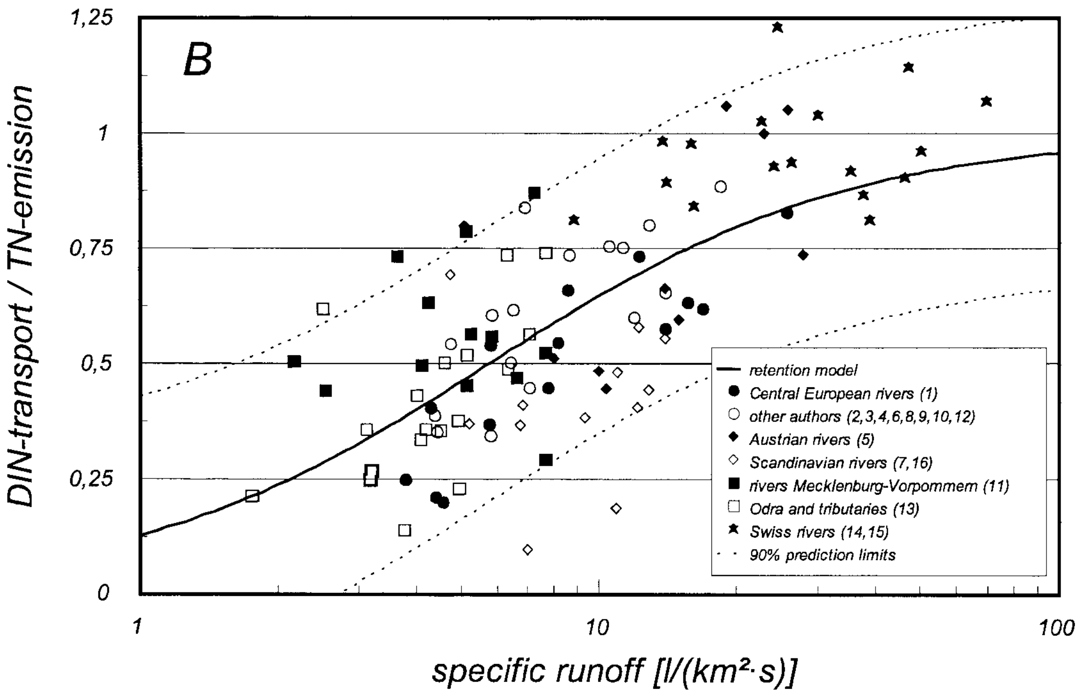


Figure 3.25: Dependence of the fractions of nutrient loadings to nutrient input from the specific runoff in the studied catchment areas.

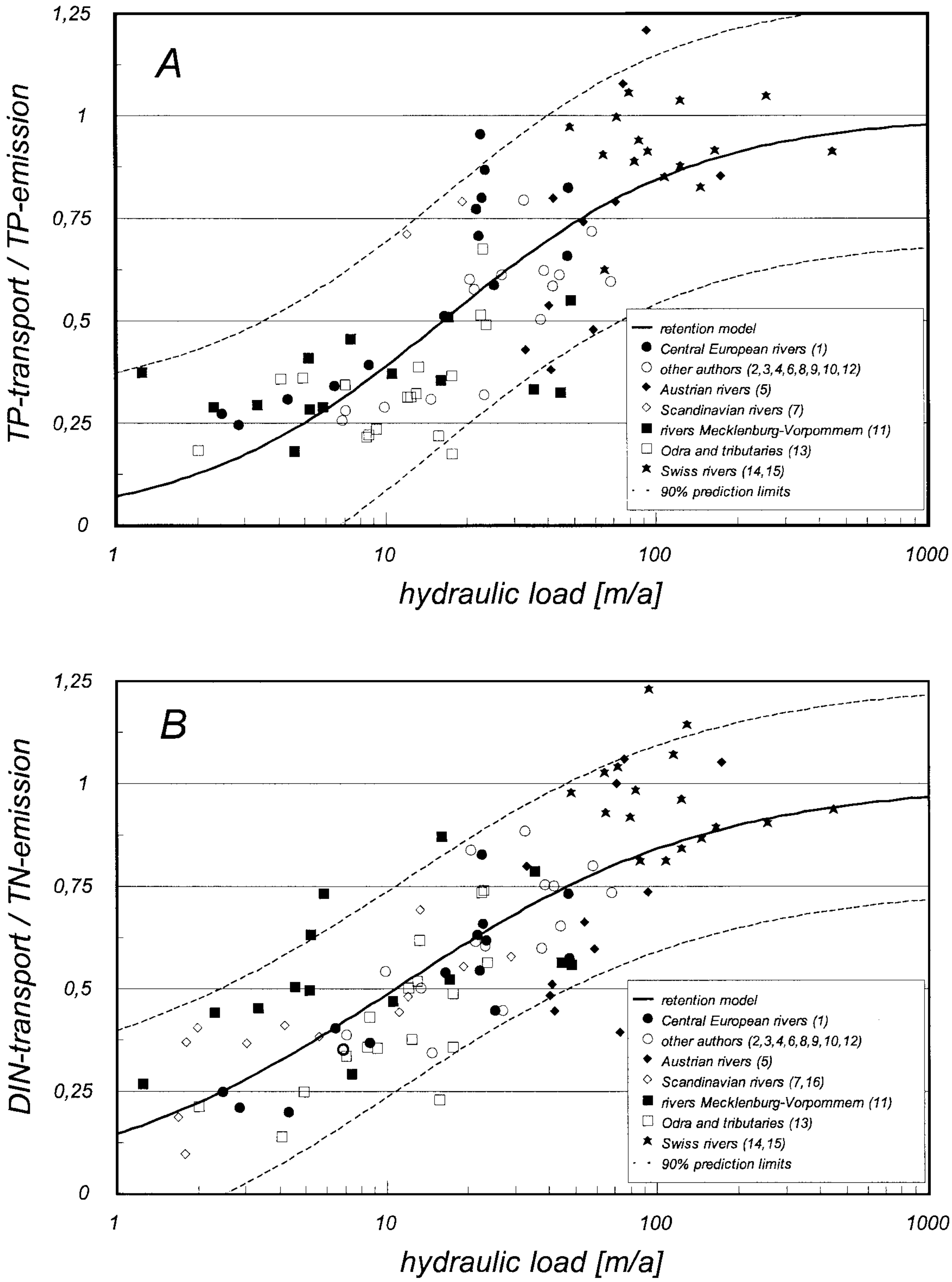


Figure 3.26: Dependence of the fractions of nutrient loadings to nutrient input from the hydraulic load in the studied catchment areas.

Table 3.33: Results of the regression analysis between nutrient retention in the river systems and the specific runoff (q) or the hydraulic load (HL).

	All catchment areas			Catchments < 1,000 km²			Catchments between 1,000 and 10,000 km²			Catchments > 10.000 km²		
X	Q	HL[1)]	HL[2)]	Q	HL[1)]	HL[2)]	q	HL[1)]	HL[2)]	Q	HL[1)]	HL[2)]
Phosphorus												
r²	0.8090	0.6148	0.6130	0.7529	0.5785	0.5671	0.7988	0.5884	0.5746	0.8765	0.6879	0.6699
n	89	89	89	29	29	29	32	32	32	28	28	28
a	26.6	13.3	16.6	41.4	57.6	21.1	21.7	9.3	17.2	28.9	26.9	13.9
b	-1.71	-0.93	-1.00	-1.93	-1.26	-1.00	-1.55	-0.81	-1.00	-1.80	-1.25	-1.00
Nitrogen												
r²	0.5096	0.6535	0.6173	0.3936	0.4423	0.3647	0.5763	0.6607	0.5395	0.4548	0.7373	0.7357
n	100	100	100	33	33	33	35	35	35	32	32	32
a	6.9	5.9	11.9	3.5	3.3	9.5	5.8	4.4	12.7	7.9	10.9	12.7
b	-1.10	-0.75	-1.00	-1.01	-0.65	-1.00	-0.96	-0.62	-1.00	-1.03	-0.94	-1.00

1) Results for the model according to Equation 3.75.

2) Results according to the model approach of KELLY ET AL. (1987).

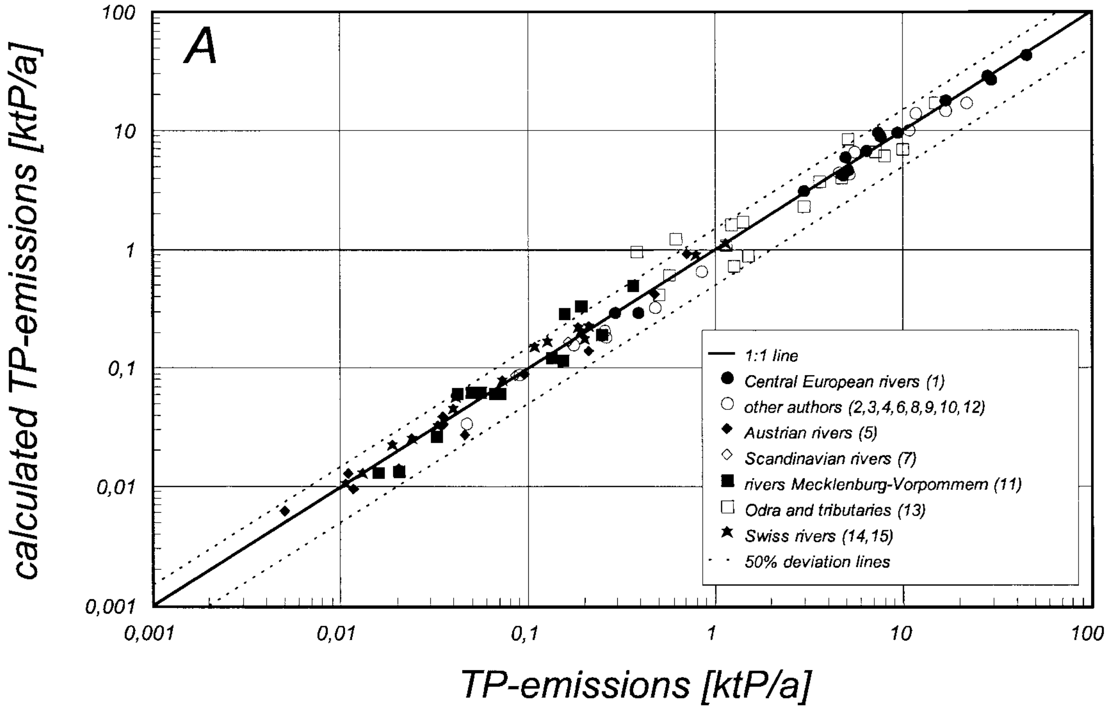
Figure 3.27 shows that on the basis of this derived model approach, it is possible to estimate the retention and the realised load in the surface water system of a catchment area from the nutrient inputs and the characteristic parameters specific runoff or hydraulic load.

If these approaches are applied, one can calculate the nutrient load from the nutrient inputs for all studied catchment areas and can compare the results with measured loads. That permits:

$$L_{N,P} = \frac{1}{1 + R_{L_{N,P}}} \cdot E_{N,P} \tag{3.76}$$

It should be noted here that so far, the model performance for nitrogen has been derived only for the load of inorganic dissolved nitrogen (sum of ammonium, nitrite and nitrate load). With the calculation of the load for nitrogen, the dependence on the hydraulic loading will be used. For phosphorus, the mean of the dependences on the specific runoff and on the hydraulic load is used for the load estimate.

Data included to support the analysis of the catchment area is found in BEHRENDT (1996b), BEHRENDT & BACHOR (1998), BILLEN ET AL. (1995), KROIß ET AL. (1997), PRASUHN & BRAUN (1994), PRASUHN ET AL. (1996), ISERMANN (1997), TONDERSKI (1997) BRAUN (1994), SVENDSEN ET AL. (1995), RADERSCHALL (1996), RUHRVERBAND (1998) and ARNHEIMER & BRANDT (1998).



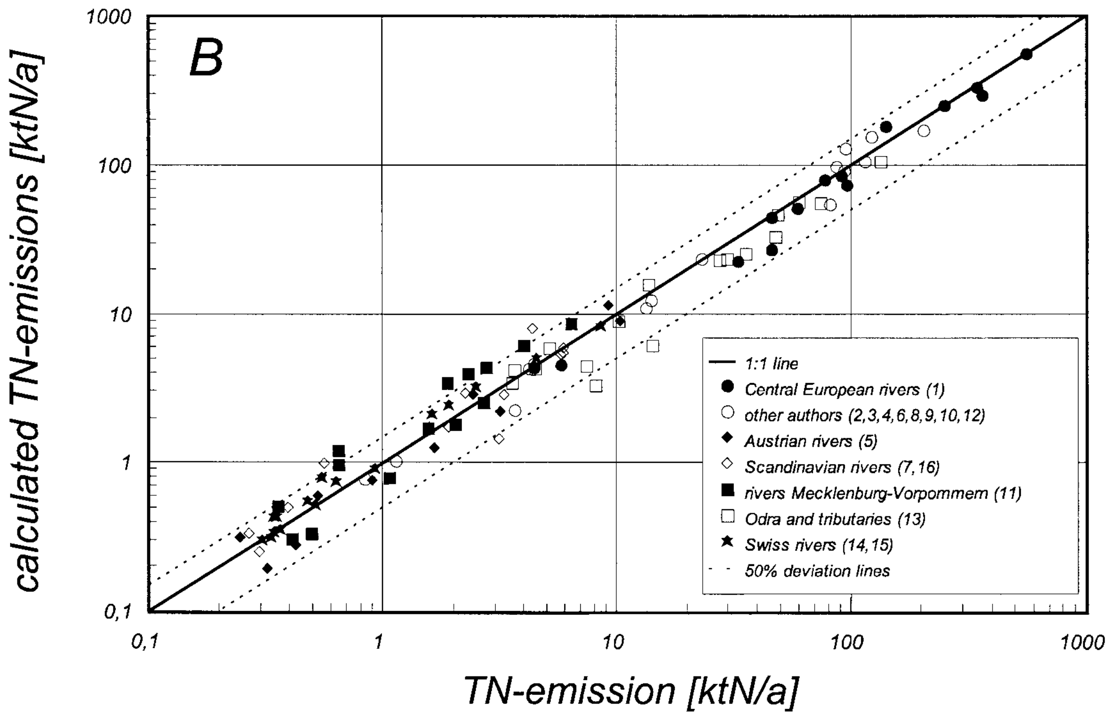
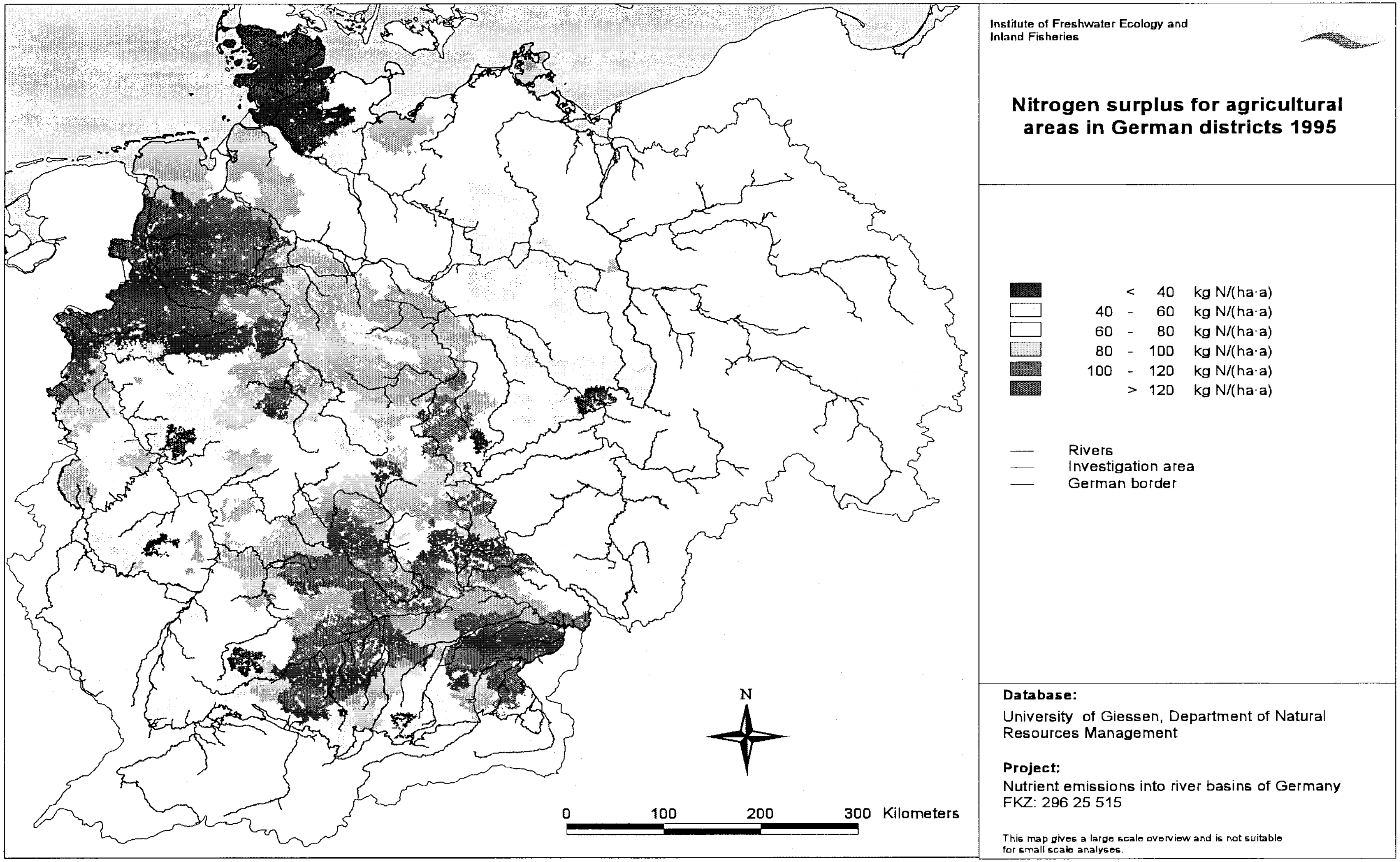
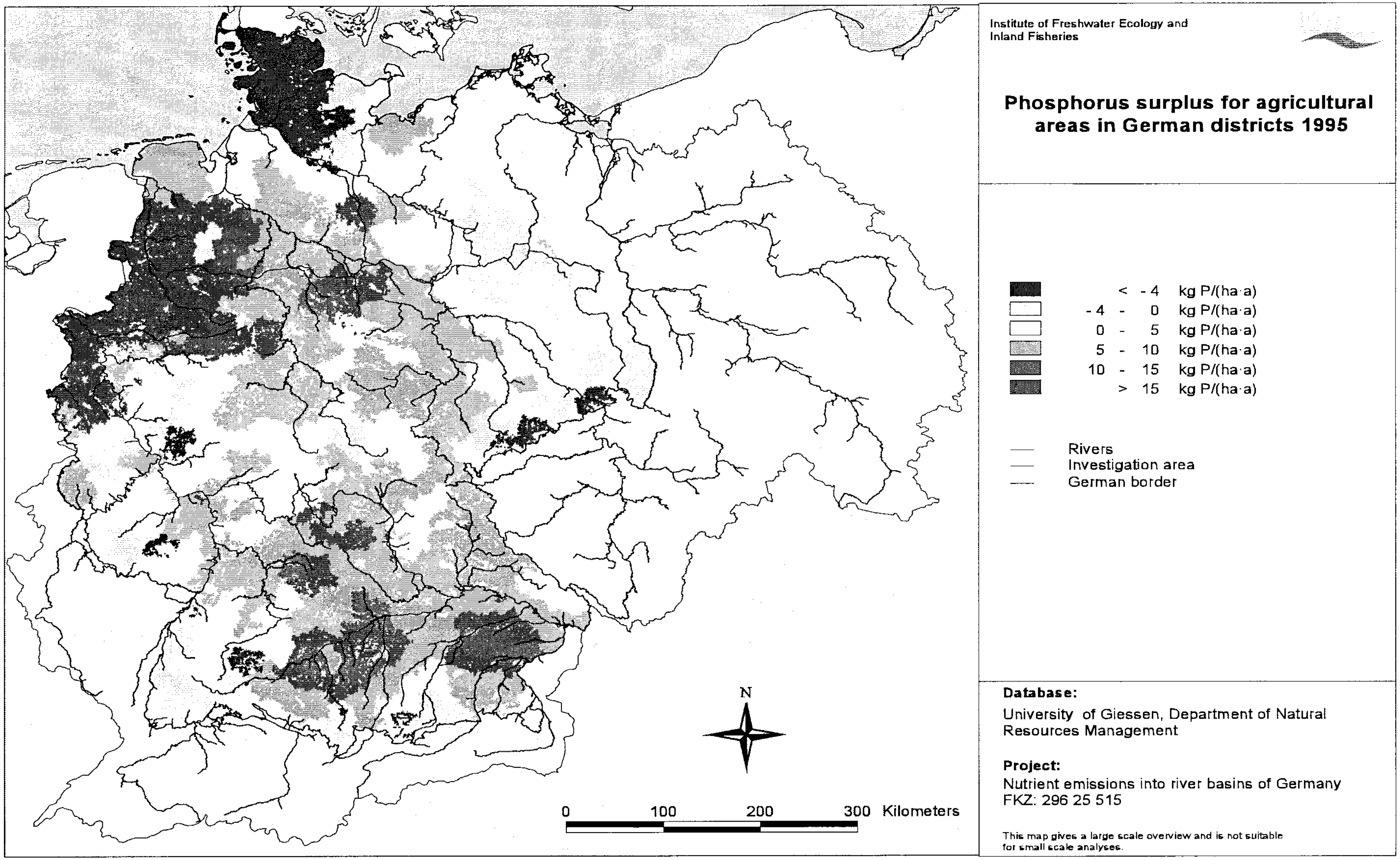


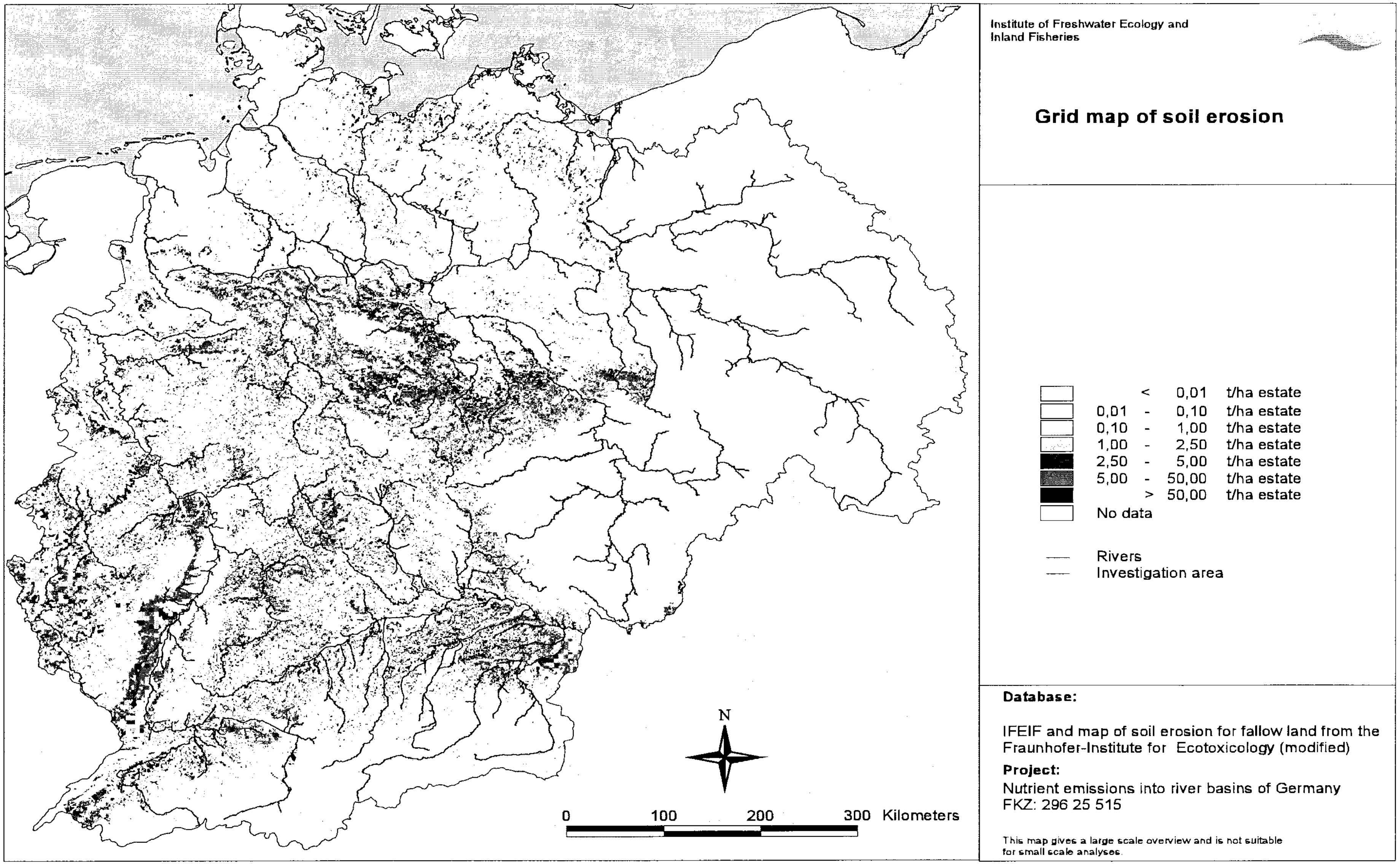
Figure 3.27: Relationship between the calculated and measured nutrient loadings for the studied European catchment areas.



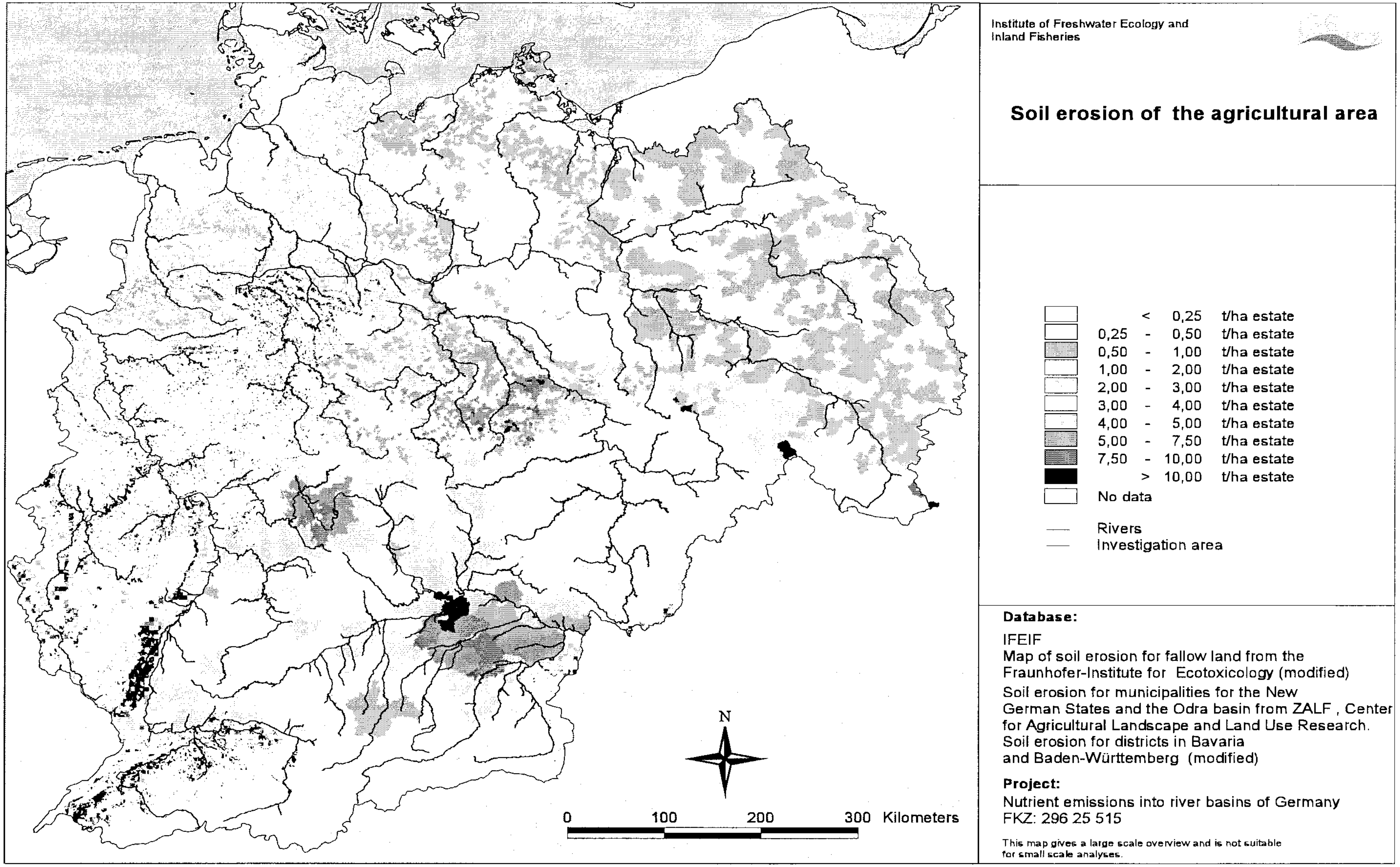
Map 3.1: Nitrogen surplus for agricultural areas in German districts 1995.



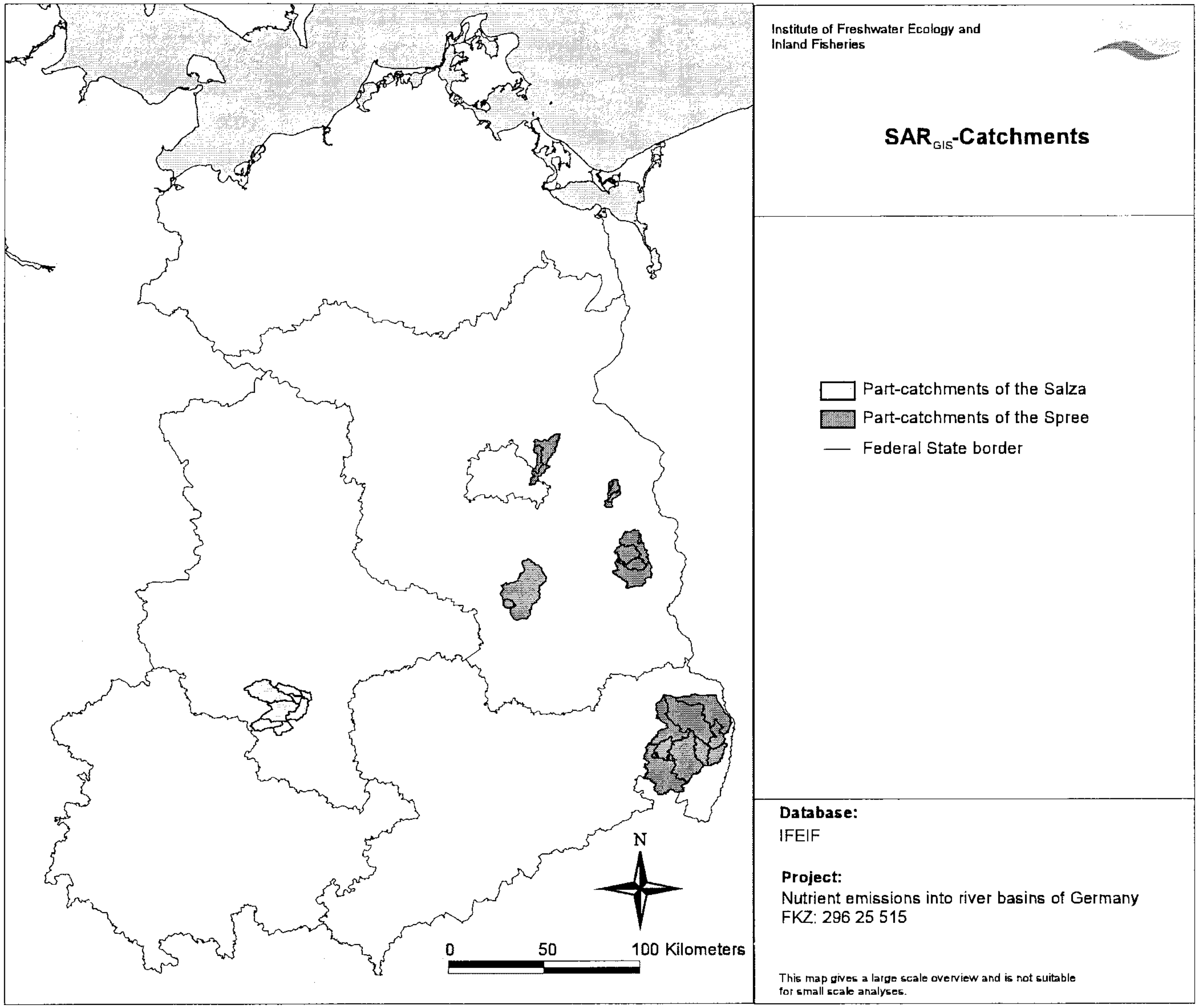
Map 3.2: Phosphorus surplus for agricultural areas in German districts 1995.



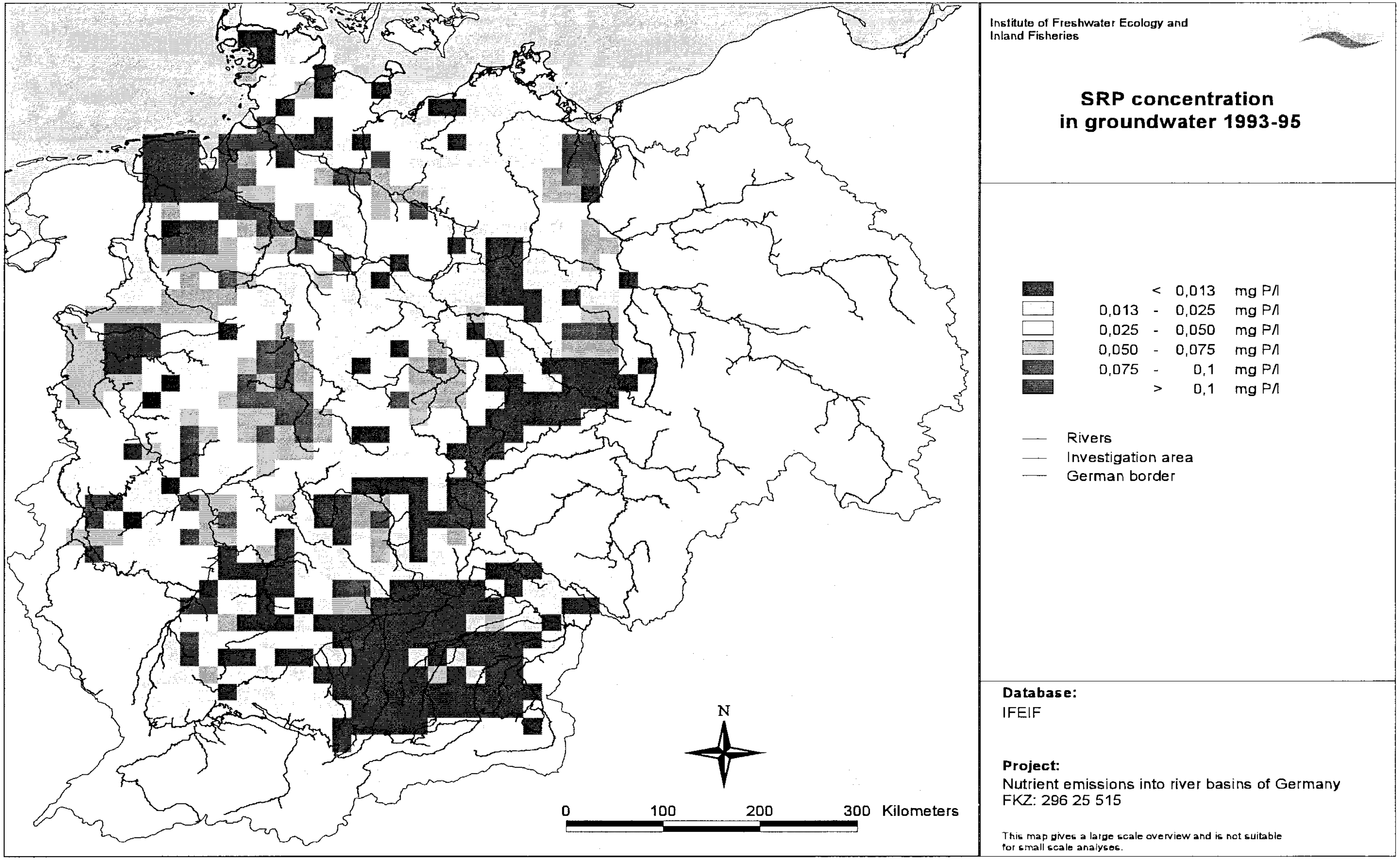
Map 3.3: Grid map of soil erosion.



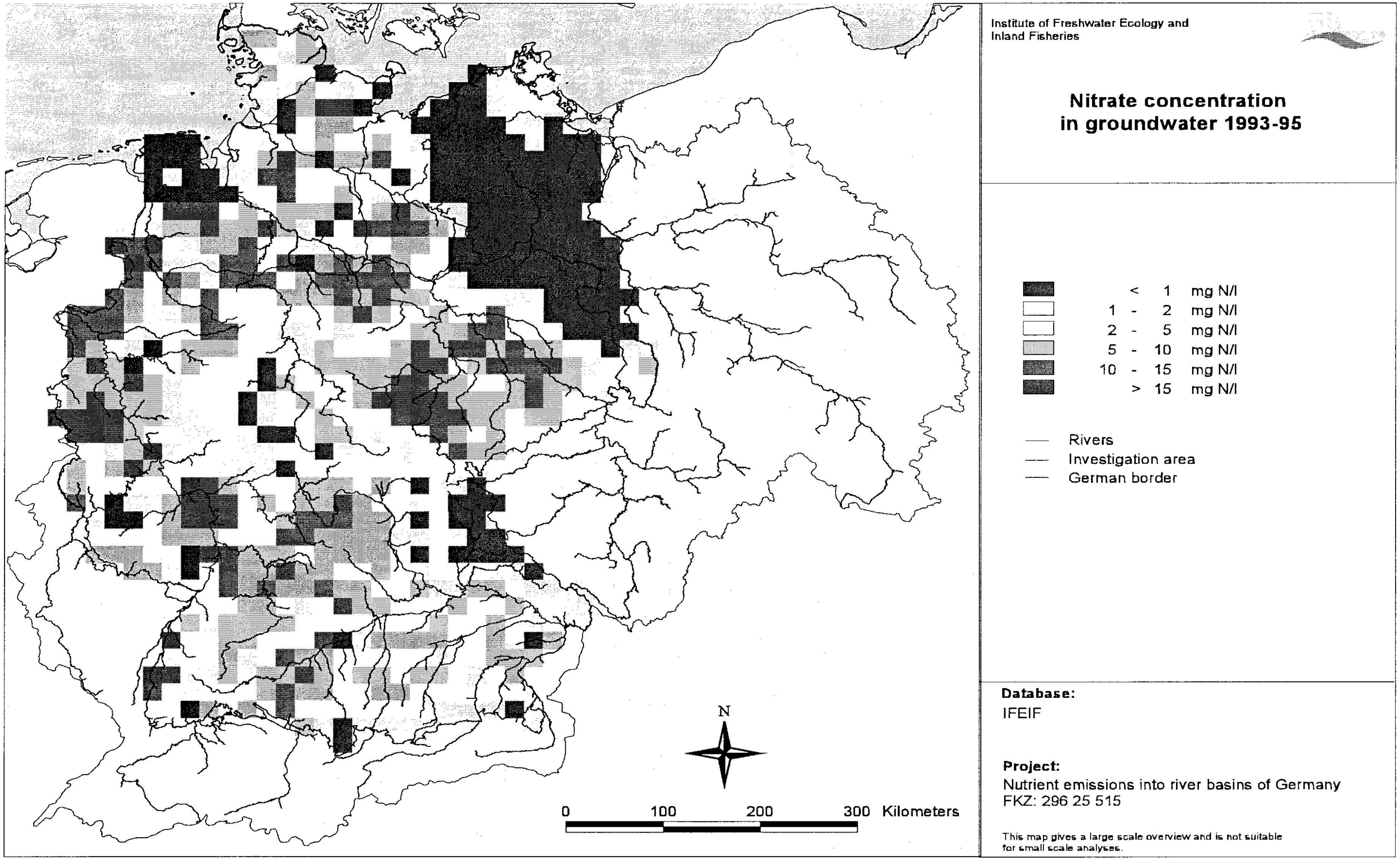
Map 3.4: Soil erosion of the agricultural area.



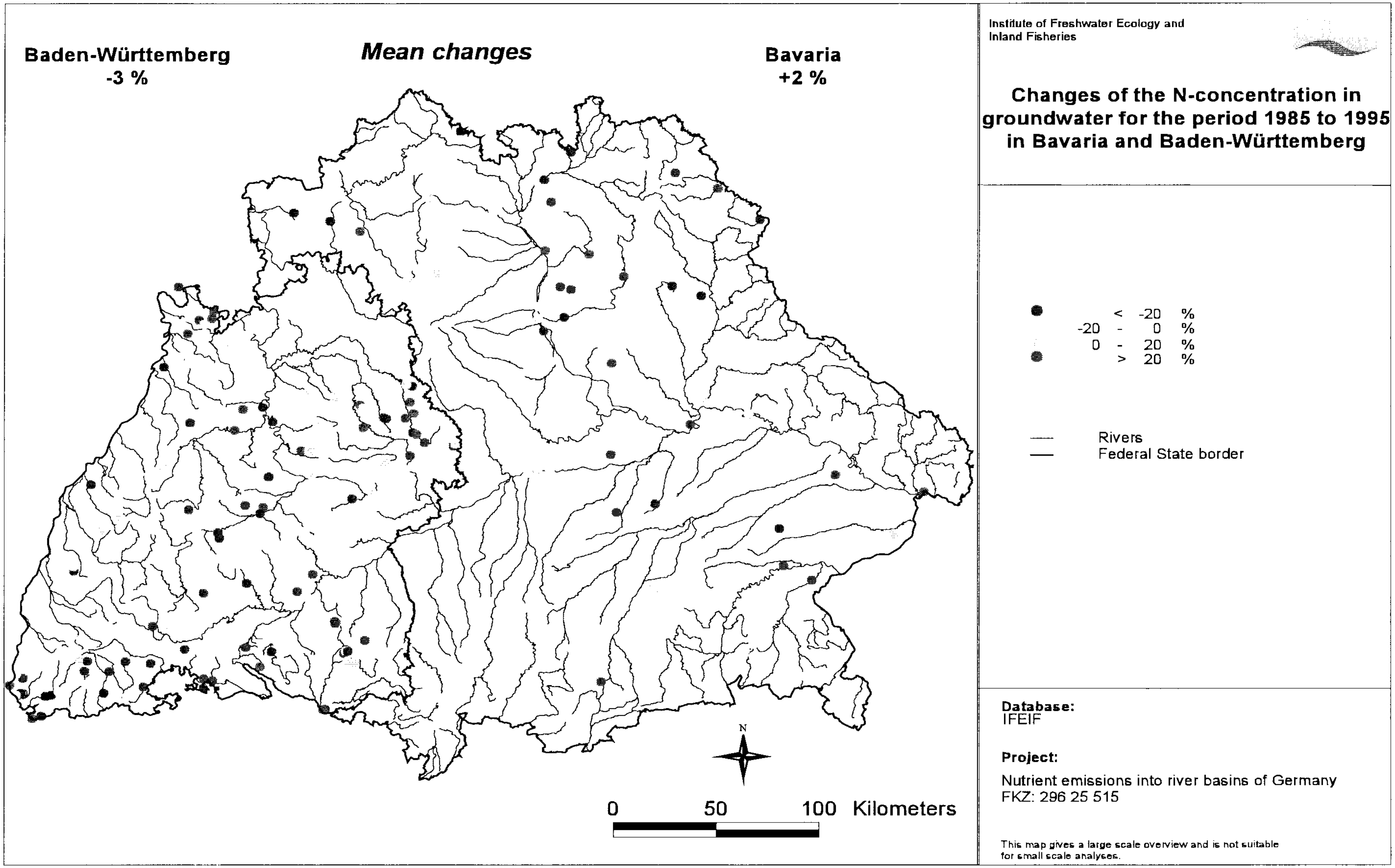
Map 3.5: SAR$_{GIS}$-Catchments.



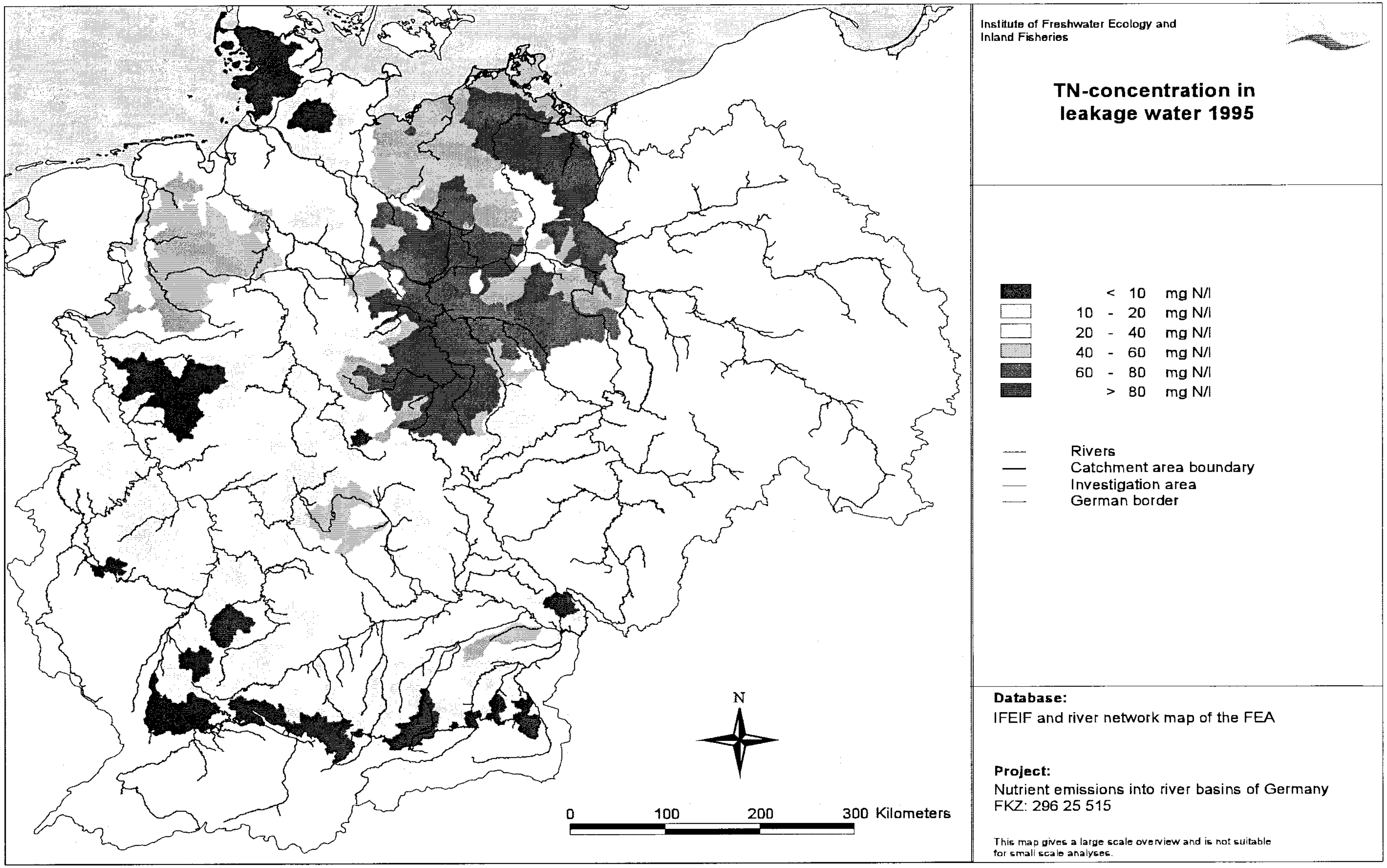
Map 3.6: SRP concentration in groundwater 1993-95.



Map 3.7: Nitrate concentration in groundwater 1993-95.



Map 3.8: Changes of the N-concentration in groundwater for the period 1985 to 1995 in Bavaria and Baden-Württemberg.



Map 3.9: TN-concentration in leakage water 1995.

4 Results

For an overview of nutrient inputs in Germany, 22 catchment areas in 6 river basins have been chosen (see Table 4.1 and Map 4.1). These represent both the main inflows and particularly for the last monitoring station, the whole river basin. With the Elbe, Ems and Weser, the last monitoring station corresponds to the last monitoring point not influenced by tides. In addition, all other rivers and areas draining directly into the North Sea and Baltic Sea will be summarised. From the sums of these and the large river basins, the total inputs in Germany and into the different seas are given.

Table 4.1: Catchment areas of the large river basins and their main tributaries.

ADDR.	River/Basin	Monitoring station	A_{EZG}
			[km²]
14902	Naab	Heitzenhofen	5,426
16902	Isar	Plattling	8,839
18902	Inn	Passau-Ingling	26,049
19101	Danube	Jochenstein	77,086
23704	Upper Rhine	Karlsruhe	50,196
23801	Neckar	Mannheim	13,957
24901	Main	Bischofsheim	27,140
26901	Mosel	Koblenz	28,100
27601	Ruhr	Muendung	4,485
27801	Lippe	Wesel	4,886
27903	Rhine	Lobith/Bimmen	159,127
37602	Ems	Herbrum	9,207
41002	Werra	Letzter Heller	5,478
42001	Fulda	Wahnhausen	6,933
48901	Aller	Verden	15,220
49103	Weser	Hemelingen	38,415
53801	Schwarze Elster	Gorsdorf	5,453
54901	Mulde	Dessau	7,399
56901	Saale	Gross Rosenburg	23,718
58901	Havel	Toppel (Havelberg)	24,297
59311	Elbe	Zollenspieker	135,024
69001	Odra	Schwedt	112,950
	North Sea coast		38,969
	Baltic Sea coast		23,475
	North Sea total		**380,741**
	Baltic Sea total		**136,523**
	Black Sea		**77,308**
	Germany		**356,804**

4.1. Emission method according to MONERIS

4.1.1 Inputs via point sources in Germany

4.1.1.1 Nutrient inputs via municipal wastewater treatment plants

The development of *nitrogen inputs* in Germany is shown in Table 4.2, Figure 4.1 and Maps 4.2 and 4.3. The N-inputs (EKK_N) in Germany decreased by about 32% from 303 to 205 kt N/a between 1985 and 1995. The average purification efficiency of wastewater treatment plants improved from 29% to 54%. The inhabitant specific nitrogen emission (N_E) - which discharges people directly via sewers wastewater treatment plants - was reduced by about 39% from 12.9 to 7.8 g N/(E· d).

Table 4.2: N-inputs (EKK_N), inhabitant specific N-emissions (N_E), average N-elimination performance (N-Elim.) of German WWTP´s, connected inhabitants (E_{KA}) and population equivalents caused by indirect industrial discharges (EGW) for 1985 and 1995.

ADDR.	River/Basin	EKK_N 1985	EKK_N 1995	EKK_N 1985-95	N_E 1985	N_E 1995	N_E 1985-95	N-Elim. 1985	N-Elim. 1995	E_{KA} 1985	E_{KA} 1995	EGW 1985	EGW 1995
		[t N/a]		*[%]*	[g N/(E· d)]		*[%]*	[%]		[10³· E]		[10³· EGW]	
14902	Naab	1,650	1,230	*-25.5*	13.1	8.1	*-37.9*	28	47	350	410	270	300
16902	Isar	9,430	8,010	*-15.1*	11.8	8.7	*-26.3*	29	44	2,190	2,530	1,240	1.200
18902	Inn	3,540	2,320	*-34.4*	14.3	7.5	*-48.0*	28	49	680	850	560	440
19101	Danube	32,750	24,420	*-25.4*	13.3	8.3	*-38.0*	29	49	6,730	8,090	4,950	4.920
23704	Upper Rhine	10,100	7,000	*-30.7*	13.3	8.1	*-38.6*	32	54	2,090	2,360	1,670	1.540
23801	Neckar	20,620	15,140	*-26.6*	12.1	8.1	*-33.5*	32	54	4,670	5,150	3,220	3.240
24901	Main	23,640	18,290	*-22.6*	12.0	8.8	*-27.2*	30	50	5,390	5,720	3,360	3.490
26901	Mosel	5,840	4,350	*-25.5*	12.2	7.6	*-37.4*	28	55	1,310	1,560	730	720
27601	Ruhr	6,170	6,020	*-2.6*	11.4	10.0	*-12.4*	30	40	1,490	1,650	870	860
27801	Lippe	6,790	5,310	*-21.8*	14.2	10.0	*-29.0*	30	42	1,310	1,450	1,070	570
27903	Rhine	138,250	98,010	*-29.1*	12.5	8.0	*-35.6*	30	54	30,360	33,410	20,440	19.830
37602	Ems	7,650	4,970	*-35.0*	13.5	6.9	*-49.2*	35	62	1,550	1,990	1,410	1.490
41002	Werra	1,740	1,020	*-41.3*	11.9	7.4	*-37.9*	22	52	400	380	190	130
42001	Fulda	3,230	3,330	*+3.0*	10.7	9.2	*-13.9*	35	51	830	990	380	370
48901	Aller	12,930	7,130	*-44.8*	11.7	5.9	*-49.7*	30	56	3,020	3,310	1,790	1.570
49103	Weser	26,310	17,050	*-35.2*	12.2	7.0	*-43.2*	31	54	5,890	6,710	3,700	3.400
53801	Schwarze Elster	1,410	910	*-35.1*	13.1	8.2	*-37.2*	17	50	290	300	100	60
54901	Mulde	4,120	4,250	*+3.2*	14.8	10.9	*-26.6*	15	29	760	1,070	380	110
56901	Saale	18,440	12,740	*-30.9*	16.1	11.5	*-28.5*	22	38	3,130	3,030	3,090	820
58901	Havel	16,590	8,080	*-51.3*	10.6	4.8	*-54.5*	32	56	4,290	4,590	1,740	570
59101	Elbe	49,330	32,230	*-34.7*	13.2	8.1	*-38.4*	26	46	10,260	10,890	6,510	2.420
69001	Odra	3,070	1,560	*-49.1*	19.8	10.2	*-48.2*	33	28	420	420	640	130
	North Sea coast	34,910	20,840	*-40.3*	13.3	7.0	*-47.1*	30	57	7,190	8,120	5,230	5,660
	Baltic Sea coast	11,000	5,760	*-47.7*	14.9	7.1	*-52.2*	24	52	2,020	2,210	1,640	1,010
	North Sea total	**256,460**	**173,110**	***-32.5***	**12.7**	**7.8**	***-39.0***	**30**	**54**	**55,260**	**61,120**	**37,290**	**32,800**
	Baltic Sea total	**14,070**	**7,320**	***-48.0***	**15.8**	**7.6**	***-51.6***	**26**	**49**	**2,450**	**2,630**	**2,280**	**1,140**
	Black Sea	**32,770**	**24,440**	***-25.4***	**13.3**	**8.3**	***-38.0***	**29**	**49**	**6,730**	**8,100**	**4,950**	**4,920**
	Germany	**303,300**	**204,860**	***-32.5***	**12.9**	**7.8**	***-39.4***	**29**	**53**	**64,440**	**71,850**	**44,520**	**38,850**

The part of the Danube basin within Germany had the smallest reduction in inputs with 25%. This is mainly attributable to a substantial (20%) increase in the number of connected inhabitants in the Danube catchment area during the considered time period. This increase is nearly twice the German average of 11%. Also, the emission level of 8.3 g N/(E· d) in the Danube basin was comparatively high in 1995. The basis for this is the decentralised organisation structure of the wastewater disposal and that in turn has led to a larger number of small wastewater treatment plants in size classes 1 and 2, which do not achieve the nitrogen elimination performance of larger plants.

While in the Rhine catchment area about 6% of the connected inhabitants are treated by wastewater treatment plants of size classes 1 and 2, this percentage is about 11% for the Danube catchment area. A further explanation possibly lies in the regulations concerning municipal wastewater by the states Bavaria and Baden-Württemberg (*Reinhalteordnungen kommunales Abwasser*), where the total German basin of the Danube is not declared as a sensitive area according to the European Union Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment. The consequence is that there are no concrete requirements regarding N-elimination of municipal wastewater treatment plants in the mentioned state regulations for the Danube catchment. It can be concluded from this that, at least up to 1995, investments in the extension or improvement of the wastewater treatment plants in Bavaria and Baden-Württemberg were focused on the increase of N-elimination in the "sensitive areas" of the Rhine and Elbe.

The connection relationships of 1995 verify the influence of the above mentioned state regulations. While in the Danube catchment only about 20% of all inhabitants are handled in denitrification capable plants, for the Bavarian and Baden-Württemberg catchments of the Elbe and Rhine the figure is 34%. The proportion of inhabitants with indirect waste disposal in wastewater treatment plants (faeces or faecal mud from septic tanks and small treatment plants) in the total N-inputs was about 6% in 1995 for the Danube catchment area. The proportion reached in the Naab and Inn catchment areas was up to 14%.

According to the proportion of the population supplied in 1995 in the Rhine basin with about 98 kt N/a, close to half of the German total of nitrogen inputs come from municipal wastewater treatment plants. The inputs were reduced by 29% compared to 1985. The highest specific loadings in 1995 were found in the Ruhr and Lippe catchment areas with 10.0 g N/(E· d) (see Map 4.3). These areas have among the lowest average nitrogen elimination with 36-38%. While in the Rhine catchment area in 1995, about 40% of the population were connected to denitrifying treatment plants, the proportions for the Ruhr and Lippe were only 13% and 24% respectively. Accordingly, in the Ruhr, the inputs were reduced by only about 3% compared to 1985; in the Lippe the reduction was 22% based on a halving of the considered population equivalent (EGW) in this period. The proportion of inputs from the people with indirect municipal wastewater treatment plant disposal is about 2% according to Figure 4.1 1985 and 1995 in the whole river basin of the Rhine.

In the Elbe basin, the nitrogen inputs in the considered time period were reduced by about 35% from about 49 to 32 to 32 kt N/a. This is a relatively large reduction in comparison with the other large river basins based to a large extent on the dramatic decline of the considered population equivalents of about 60% following the discontinuation of many industrial indirect discharges after German reunification. In 1995, the average nitrogen elimination for the whole river basins of the Mulde and Saale at 28% and 26% respectively are low compared to other parts of Germany. The basis for this lies in the particularly high proportion of inhabitants connected to mechanical wastewater treatment plant of 49% in the Mulde and 21% in the Saale catchments. Therefore, in 1995, these two catchment areas showed the highest specific emissions (see Map 4.3).

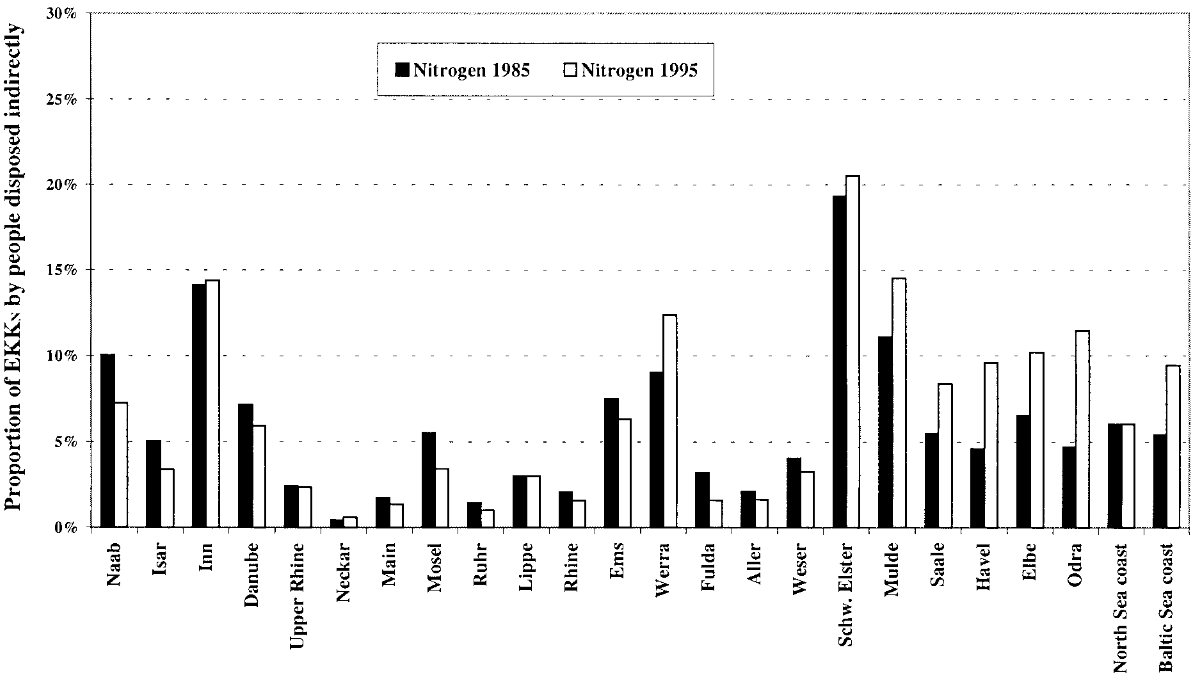


Figure 4.1: Proportion of EKK_N by the people disposed indirectly in municipal wastewater treatment plants on the whole nitrogen inputs for 1985 and 1995.

The N-inputs in the Mulde were not reduced between 1985 and 1995. This is related to a large increase in connection grade of the population since 1985 of about 40% and high input proportion from the indirect disposed inhabitants of 15% (see Figure 4.1). According to Table 4.2, the Havel catchment area achieved the greatest input reduction with 51%. This large reduction is due to the introduction of nitrogen elimination in the large wastewater treatment plants in Berlin through which an increase of nitrogen elimination from 32% to 64% was achieved. The specific emissions declined and reached a value of 4.6 g N/(E· d) in 1995 which is the lowest of all basins. Map 4.2 shows that some areas lying in the Havel catchment have a strikingly low average specific emission of 10.6 g N/(E· d) for 1985. This is attributable to the high proportion of wastewater treatment plants with land application of wastewater.

The development of *phosphorus inputs* from German public wastewater treatment plants is shown in Table 4.3, Figure 4.2 and Maps 4.4 and 4.5. The P-discharges (EKK_P) decreased between 1985 and 1995 by about 80% from 57 to 11 kt P/a. The average phosphorus elimination increased from 27% to 79% and the inhabitant specific P-emission (P_E) was reduced by about 82% from 2.4 to 0.4 g P/(E· d).

Table 4.3: P-inputs (EKK_P), inhabitant specific P-emissions (P_E), average P-elimination performance (P-Elim.) of German WWTP´s, connected inhabitants (E_{KA}) and population equivalents caused by indirect industrial discharges (EGW) for 1985 and 1995.

ADDR.	River/Basin	EKK_P 1985	EKK_P 1995	EKK_P 1985-95	P_E 1985	P_E 1995	P_E 1985-95	P-Elim. 1985	P-Elim. 1995	E_{KA} 1985	E_{KA} 1995	EGW 1985	EGW 1995
		[t P/a]		*[%]*	[g P/(E· d)]		*[%]*	[%]		[10³· E]		[10³· EGW]	
14902	Naab	340	100	*-69.7*	2.7	0.7	*-74.8*	33	68	350	410	270	300
16902	Isar	1,810	280	*-84.4*	2.3	0.3	*-86.5*	37	84	2,190	2,530	1,240	1.200
18902	Inn	650	150	*-77.7*	2.6	0.5	*-82.3*	38	79	680	850	560	440
19101	Danube	6,140	1,410	*-77.1*	2.5	0.5	*-80.9*	35	76	6,730	8,090	4,950	4.920
23704	Upper Rhine	1,420	340	*-75.8*	1.9	0.4	*-78.6*	50	82	2,090	2,360	1,670	1.540
23801	Neckar	4,000	820	*-79.4*	2.4	0.4	*-81.4*	36	79	4,670	5,150	3,220	3.240
24901	Main	4,580	910	*-80.1*	2.3	0.4	*-81.3*	34	80	5,390	5,720	3,360	3.490
26901	Mosel	1,250	410	*-67.4*	2.6	0.7	*-72.6*	32	69	1,310	1,560	730	720
27601	Ruhr	1,130	260	*-76.8*	2.1	0.4	*-79.1*	41	78	1,490	1,650	870	860
27801	Lippe	1,200	210	*-82.2*	2.5	0.4	*-83.9*	35	86	1,310	1,450	1,070	570
27903	Rhine	25,970	4,990	*-80.8*	2.3	0.4	*-82.6*	36	81	30,360	33,410	20,440	19.830
37602	Ems	1,320	240	*-82.1*	2.3	0.3	*-86.0*	40	84	1,550	1,990	1,410	1.490
41002	Werra	520	80	*-83.8*	3.5	0.6	*-82.9*	20	74	400	380	190	130
42001	Fulda	600	190	*-68.0*	2	0.5	*-73.2*	47	77	830	990	380	370
48901	Aller	2,380	480	*-79.8*	2.2	0.4	*-81.6*	38	78	3,020	3,310	1,790	1.570
49103	Weser	5,010	1,070	*-78.7*	2.3	0.4	*-81.3*	37	78	5,890	6,710	3,700	3.400
53801	Schwarze Elster	470	100	*-78.1*	4.4	0.9	*-78.8*	14	63	290	300	100	60
54901	Mulde	1,170	530	*-55.1*	4.2	1.3	*-68.1*	12	42	760	1,070	380	110
56901	Saale	4,160	840	*-79.9*	3.6	0.8	*-79.2*	18	64	3,130	3,030	3,090	820
58901	Havel	2,100	430	*-79.7*	1.3	0.3	*-81.0*	68	87	4,290	4,590	1,740	570
59101	Elbe	10,210	2,380	*-76.7*	2.7	0.6	*-78.0*	38	71	10,260	10,890	6,510	2.420
69001	Odra	440	170	*-61.5*	2.8	1.1	*-60.8*	38	46	420	420	640	130
North Sea coast		5,640	840	*-85.0*	2.1	0.3	*-86.7*	42	86	7,190	8,120	5,230	5,660
Baltic Sea coast		2,110	260	*-87.8*	2.9	0.3	*-88.9*	29	85	2,020	2,210	1,640	1,010
North Sea total		**48,150**	**9,520**	***-80.2***	**2.4**	**0.4**	***-82.1***	**37**	**80**	**55,260**	**61,120**	**37,290**	**32,800**
Baltic Sea total		**2,550**	**430**	***-83.3***	**2.9**	**0.4**	***-84.5***	**31**	**78**	**2,450**	**2,630**	**2,280**	**1,140**
Black Sea		**6,150**	**1,410**	***-77.0***	**2.5**	**0.5**	***-80.9***	**35**	**76**	**6,730**	**8,100**	**4,950**	**4,920**
Germany		**56,850**	**11,350**	***-80.0***	**2.4**	**0.4**	***-82.1***	**37**	**79**	**64,440**	**71,850**	**44,520**	**38,850**

With the analysis of P-inputs it is to be noted that the inhabitant specific emission (AG_{E_P}) differs both regionally and over time and is determined by the quantity of or the decrease in washing-detergent phosphorus usage (see Section 3.1.1.1). The decline in the P_E-values in the studied time period are therefore in catchment areas in the region of the new German states 55% and in the old German states 45%, attributable to the decrease of specific emissions. These values are a minimal estimate for the decrease of the inhabitant specific P-emissions. At least they are realised in basins independent on the connection to wastewater treatment plants with further P-elimination.

In the Danube river basin, P-inputs by WWTP´s were reduced by about 77% between 1985 and 1995. In 1995, 1.4 kt P/a were discharged. The level of P-elimination was 77%. That means an emission level of 0.5 g P/(E· d) was reached. According to Map 4.4, the highest specific emissions of 2.5 g P/(E· d) were found in the catchment areas of the Naab, the Große Vils, the Inn, the Iller and the lower Danube in 1985. This due to the particularly large proportion of loadings from people with indirect disposal (see Figure 4.2). In 1995, this stands out, especially for the Naab and Große Vils catchments. The continuing high proportion of people with indirect disposal in 1995 and also the low average P-elimination of 69% for the Naab leads to a high P_E-value of 0.7 g P/(E· d). In the Naab catchment, only 56% of inhabitants are connected to WWTP´s with further P-elimination; for the whole Danube basin, this figure is 80%. In the Isar catchment with a P_E-value of 0.3g P/(E· d), a loading reduction of 84% was achieved as well as an average P-removal of 84%.

Between 1985 and 1995, the inputs from municipal wastewater treatment plants in the Rhine river basin were reduced by about 80% from 26.0 to 5.0 kt P/a. The emission situation shown in Map 4.4 gives a relatively uniform picture for the Rhine area. Most catchment areas show specific emissions around 2.0-2.5 g P/(E· d) in 1985. The connected P-elimination reached 32-36%. Better emission levels were reached in the Ruhr and Lake Constance catchments. The *International Commission for the Protection of Lake Constance (ICPLC)* (IGKB, 1972) had already formulated the right approach on water protection in the late sixties and the effects on the P-elimination for municipal wastewater treatment plants already showed in 1985. In the Lake Constance area, the lowest P_E-values within the Rhine catchment were achieved with less than 1.0 g P/(E· d). In the Ruhr catchment, the protection of the 14 drinking water reservoirs in the catchment led to an amplified use of the targeted P-elimination. In the Mosel catchment, a low loading reduction of only 67% was achieved. In 1995, the average P-elimination performance at 68% lay below the values of the other Rhine tributaries which are around 80% as shown in Table 4.3. Also in connection with the high proportion of people (7%) with indirect disposal in the Mosel catchment (see Figure 4.3), an average P_E-value of only 0.7 g P/(E· d) was achieved in 1995.

In the Elbe river basin, the phosphorus inputs from municipal wastewater treatment plants decreased from 10.2 to 2.4 kt P/a between 1985 and 1995. This represents a reduction of 77%. If one compares the Elbe river basin, whose catchment area lies in large part in the new German states, with the Rhine which lies in the old German states, the Elbe emission level with a P_E-value of 0.6 g P/(E· d) was about a third higher than that for the Rhine area. In addition, the average P-elimination (72%) of the wastewater treatment plants of was clearly lower for the Elbe.

The Havel catchment contributed about 20% of the total P-inputs from wastewater treatment plants in the Elbe in 1985. A low value, if one considers that more than 40% of the inhabitants live in the Havel area. In comparison with all German catchment areas, the Havel with 1.3 g P/(E· d), had the lowest specific discharges and with 68%, the highest average P-elimination. The low emission level is particularly clear in Map 4.4. The basis for this good emission situation lies in the already introduced P-elimination in the Berlin area and the previously mentioned wastewater application on wetlands. Also in 1995, in the Havel a very good performance was achieved compared to Germany as a whole with a P_E-value of 0.3 g P/(E· d) and a P-elimination mean of 87%.

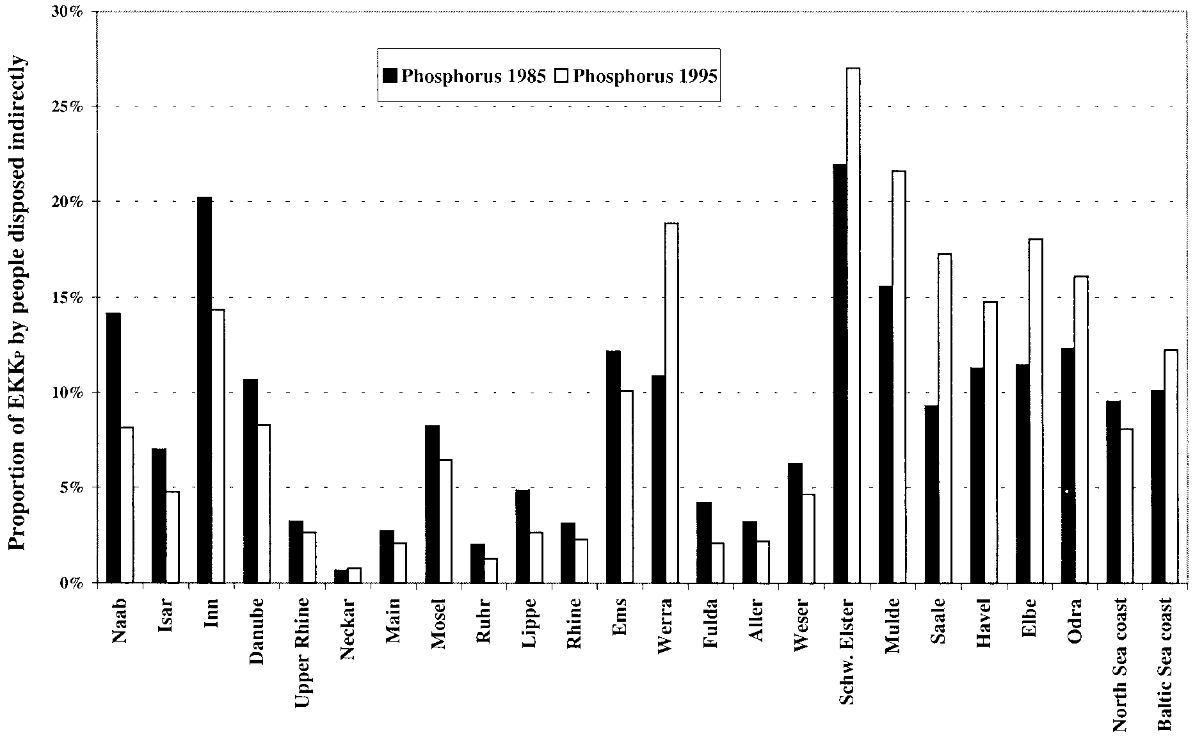


Figure 4.2: Proportion of EKK_P by the people disposed indirectly in municipal wastewater treatment plants on the whole phosphorus inputs for 1985 and 1995.

The Saale, Mulde and Schwarze Elster catchments show the highest specific emissions in Germany. The values range from 0.8 to 1.3 g P/(E· d) in 1995 (see Map 4.5). The truth is that in the largest WWTP of the Mulde area (Zwickau and Chemnitz), a third of the connected inhabitants were treated only by mechanical purification works. This is certainly the most important reason for this high level. In addition, according to Figure 4.2, the high proportion (up to 25%) of faecal sludge of non-connected inhabitants contributes to the high values.

Comparison with other results

Comparable information on N- and P- inputs of municipal WWTP for 1985 is available in the analyses of HAMM ET AL. (1991) and BEHRENDT (1994) and for 1995, the wastewater statistical information of the *German Association for Water, Wastewater and Waste (ATV)* from BORCHARDT & GEFFERS (1999), FUCHS & HAHN (1999), the RUHRVERBAND (1998) and the FEA (UBA, 1997).

Table 4.4: Comparison of results for N- and P- inputs of municipal wastewater treatment plants in Germany with other information.

Year	Area	EKK_N			EKK_P			Source
		Source	From Tab. 4.2	*Difference*	Source	From Tab. 4.3	*Difference*	
		[t N/a]		*[%]*	[t P/a]		*[%]*	
1985	OGS+BE (W)	235,000	249,820	*+6*	43,000	44,840	*+4*	HAMM ET AL. (1991)
1989	NGS+BE	57,420	57,810	*+1*	11,120	12,200	*+10*	BEHRENDT (1994)
1995	Germany	201,820	204,860	*+2*	9,850	11,350	*+15*	ATV (1996), STAT-ABW (1995)
1995	Germany	235,000	204,860	*-13*	17,000	11,350	*-33*	UBA (1997)
1995	Germany	193,840	204,860	*+6*	10,320	11,350	*10*	STAT-ABW (1995)
1995	Neckar	12,820	15,140	*+18*	910	820	*-10*	FUCHS & HAHN (1999)
1995	Lahn	2,790	3,410	*+22*	250	220	*-11*	BORCHARDT & GEFFERS (1999)
1997	Ruhr	6,370	6,010	*-6*	260	250	*-1*	RUHRVERBAND (1998)
1995	Danube	24,960	24,440	*-2*	1,500	1,410	*-6*	STAT-ABW (1995)
1995	Rhine	103,640	103,020	*-1*	5,050	5,180	*+3*	STAT-ABW (1995)
1995	Weser	18,280	21,590	*+18*	1,080	1,220	*13*	STAT-ABW (1995)
1995	Elbe	31,430	39,020	*+24*	1,920	2,620	*37*	STAT-ABW (1995)

It should be noted, that the information in Table 4.4 from the 1995 waste-water statistics does not correspond to the original but was modified to enable a comparison to be made with the values given in Tables 4.2 and 4.3. In particular, it must be considered that in the N-inputs from the statistics, only the sum of inorganic components is included. For information on total nitrogen, in addition, the proportion of organic nitrogen from the given water quantities and an average outflow concentration of 2.5 mg N/l was calculated (see Section 3.1.1.1). The comparable values of the *ATV* based on average outflow concentrations of $C_{KA_{DIN}}$ = 18,0 mg N/l and $C_{KA_{TP}}$ = 1,0 mg P/l, which is based on the self-regulated measurement of 5,822 treatment plants or 89% of the total number in Germany of known size. From the known concentrations and with consideration of the proportion of organic nitrogen, the quantities of N- and P- inputs were determined in combination with the statistics.

Comparison of information for 1985 and 1989 for both nitrogen and phosphorus stand in very good accordance with the values given in Tables 4.2 and 4.3. Also, the modified wastewater statistics and the ATV validate for all German areas for 1995 are of the same range as values determined in this study. With P-inputs there is a 33% size discrepancy with the FEA values. The reason is that the FEA values are originally based on the estimations of HAMM ET AL. (1991) and WERNER & WODSAK (1994) and from these predicted to 1995. Apparently for the prognosis, the development of P-elimination in the WWTP was underestimated due to the estimates of to high inhabitant specific emission (AG_{E_P}) (see Section 3.1.1.1). For the individual large river basins and catchment areas there was likewise a considerable agreement in comparison with the statistical information and the information of other authors. A notable exception is phosphorus in the Elbe catchment area. An explanation for this can be that 18% of inhabitants are not connected to WWTP (see Figure 4.2) which is not clearly reflected in the statistical information.

4.1.1.2 Nutrient inputs via direct industrial dischargers

An overview of nutrient inputs from direct industrial inputs in German catchment areas and their changes is given in Table 4.5.

Table 4.5: Nutrient inputs in German catchment areas via direct industrial discharges ($EID_{N,P}$) for 1985 and 1995 and their changes.

ADDR.	River/Basin	EID_P			EID_N		
		1985	1995	Change	1985	1995	Change
		[t P/a]		*[%]*	[t N/a]		*[%]*
14902	Naab	4					
16902	Isar	60	10	*-83.4*	100	26	*-73.4*
18902	Inn	380	70	*-81.6*	3,650	970	*-73.4*
19101	Danube	580	100	*-82.7*	4,780	1.270	*-73.4*
23704	Upper Rhine	240	100	*-57.5*	4,860	960	*-80.2*
23801	Neckar	480	50	*-89.5*	10,030	1.990	*-80.2*
24901	Main	600	200	*-66.7*	12,420	4.110	*-66.9*
26901	Mosel	170	50	*-70.7*	3,550	670	*-81.2*
27601	Ruhr	3					
27801	Lippe	8					
27903	Rhine	3,370	590	*-82.4*	69,450	13.740	*-80.2*
37602	Ems	100	18	*-82.4*	1,130	300	*-73.4*
41002	Werra	2	5	*+95.7*		16	
42001	Fulda	3					
48901	Aller	14					
49103	Weser	300	50	*-81.6*	4,890	1.320	*-73.1*
53801	Schwarze Elster	38	0,4	*-98.9*	860	660	*-23.9*
54901	Mulde	290	48	*-83.2*	8,150	810	*-90.0*
56901	Saale	710	70	*-90.7*	19,590	4.510	*-77.0*
58901	Havel	840	24	*-97.1*	6,350	2.240	*-64.8*
59101	Elbe	2,350	160	*-93.1*	46,760	9.000	*-80.7*
69001	Odra	100	44	*-55.4*	400	1,080	*+171.2*
North Sea coast		45	280	*+510.5*		720	
Baltic Sea coast		220	4	*-98.3*	900	50	*-94.0*
North Sea total		**6,160**	**1,100**	***-82.1***	**122,230**	**25,080**	***-79.5***
Baltic Sea total		**320**	**48**	***-85.0***	**1,300**	**1,140**	***-12.4***
Black Sea		**580**	**100**	***-82.7***	**4,780**	**1,270**	***-73.4***
Germany		**7,070**	**1,250**	***-82.3***	**128,310**	**27,490**	***-78.6***

The determination of nutrient inputs from direct industrial discharges is carried out as already described in Section 2.2.3. For 1985 and 1995, the results of the studies of ROSENWINKEL & HIPPEN (1997) and other literature information (IKSR, 1989, 1999; HAMM ET AL., 1991; IKSE, 1992; BEHRENDT, 1994) are used. In addition, with this pathway, nitrogen inputs from brown-coal mines were considered for areas with a large proportion of total land cover in such areas (personal communication, LEßMANN, 1999).

No values are given in Table 4.5 for catchment areas for which no information of direct industrial discharges was available. With the distribution of the earlier results on nutrient inputs by direct industrial discharges, frequently no clear assignment is possible or there was a lack of information on individual discharges. In such cases, an increase can be estimated e.g. for the Odra.

However, overall one can determine that the inputs through direct industrial discharges have clearly been reduced on the basis of the values in Table 4.5. So a reduction of 82% for nitrogen and 79% for phosphorus for all of Germany was recorded.

4.1.2 Diffuse inputs in Germany

4.1.2.1 Direct nutrient inputs to the surface waters via atmospheric deposition

Table 4.6 gives an overview on specific deposition rates of ammonium, nitrogen oxides and the sum of these for 1985 and 1996 for individual catchment areas from the EMEP-digital data. See also Map 2.12 for changes.

These specific deposition rates are the result of complex transport and dispersal calculations for the whole of Europe and are in different spatial resolution for the two considered years (1985: grid size 150 km; 1996: grid size 50 km). Therefore, changes in the deposition rates in some river catchments can in part be caused through the higher resolution in 1996. This is to be considered in relation to data interpretation.

For interpretation of changes in N-deposition rates one must consider that these are caused not only from changes inside Germany or inside the catchment areas but also through increase or decreases in N-emissions outside the catchments. Therefore, no clear attribution of changes to causes within Germany is possible.

Overall, one can conclude from this, that the ammonium deposition rates in Germany have decreased by 27% and that reductions in the catchment areas of the North and Baltic Sea coasts are clearly higher than in the Danube basin. On the other hand, the reductions in nitrogen oxide deposition rates in the Danube basins are more than double those of the rest of Germany so that one can conclude that the changes of the sum of ammonium and nitrogen oxide emissions are similar in the catchment areas of the North and Baltic Sea coasts and also in the Black Sea catchments.

Table 4.6: Average atmospheric N-deposition in 1985 and 1996 for German catchment areas (calculated on the basis of EMEP-data; TSYRO, 1998a, b).

ADDR.	River/Basin	1985			1996			Change	
		NH_{4DEP}	NOx_{DEP}	N_{DEP}	NH_{4DEP}	NOx_{DEP}	N_{DEP}	NH_{4DEP}	NOx_{DEP}
		[kg N/(ha· a)]						*[%]*	
14902	Naab	14.5	10.1	24.6	8.2	6.5	14.7	*-43.4*	*-36.1*
16902	Isar	12.7	11.0	23.7	13.9	6.0	20.0	*+9.5*	*-45.2*
18902	Inn	9.9	8.8	18.7	9.6	4.8	14.4	*-3.5*	*-45.1*
19101	Danube	12.3	9.7	22.1	10.7	5.7	16.3	*-13.4*	*-42.0*
23704	Upper Rhine	10.1	7.2	17.3	9.0	6.2	15.2	*-10.3*	*-14.1*
23801	Neckar	8.5	7.9	16.4	8.4	7.7	16.1	*-1.3*	*-2.9*
24901	Main	11.6	10.0	21.6	7.5	7.4	14.9	*-35.0*	*-26.0*
26901	Mosel	8.7	8.8	17.4	7.4	8.8	16.2	*-14.7*	*+0.4*
27601	Ruhr	21.2	12.1	33.3	11.1	12.0	23.1	*-47.5*	*-0.7*
27801	Lippe	22.3	11.1	33.4	13.2	12.2	25.3	*-40.9*	*+9.8*
27903	Rhine	11.0	9.0	20.0	8.5	8.4	16.9	*-22.3*	*-6.9*
37602	Ems	22.3	10.7	33.0	14.0	10.7	24.7	*-37.2*	*0.0*
41002	Werra	13.5	12.4	25.9	8.3	7.7	16.0	*-38.4*	*-37.8*
42001	Fulda	11.4	12.4	23.9	9.2	8.7	17.9	*-19.4*	*-29.8*
48901	Aller	14.6	9.7	24.3	9.6	8.8	18.5	*-33.9*	*-9.0*
49103	Weser	14.9	10.7	25.6	9.9	8.9	18.8	*-33.3*	*-17.1*
53801	Schwarze Elster	11.8	11.1	22.9	6.4	7.2	13.7	*-45.4*	*-35.0*
54901	Mulde	13.4	12.1	25.5	7.7	7.7	15.4	*-42.4*	*-36.4*
56901	Saale	12.9	11.8	24.7	8.4	7.5	15.8	*-35.0*	*-36.9*
58901	Havel	11.7	9.0	20.7	7.0	7.0	14.0	*-40.3*	*-22.5*
59101	Elbe	12.0	10.3	22.3	7.6	7.0	14.6	*-36.6*	*-31.9*
69001	Odra	9.7	7.9	17.6	7.8	6.8	14.6	*-20.0*	*-13.3*
North Sea coast		19.1	8.7	27.7	13.2	9.1	22.3	*-30.5*	*+4.5*
Baltic Sea coast		12.2	7.4	19.6	7.9	5.7	13.6	*-35.2*	*-23.3*
North Sea total		**12.8**	**9.6**	**22.5**	**9.0**	**8.1**	**17.0**	***-30.2***	***-16.3***
Baltic Sea total		**10.2**	**7.8**	**18.0**	**7.8**	**6.6**	**14.4**	***-23.2***	***-15.0***
Black Sea		**12.3**	**9.7**	**22.1**	**10.7**	**5.6**	**16.3**	***-13.5***	***-42.0***
Germany		**12.2**	**9.2**	**21.4**	**8.9**	**7.4**	**16.3**	***-26.6***	***-19.6***

Deposition rates of more than 20 kg N/(ha· a) occur in the Isar, in the lower catchment area of the Rhine, in the Ems area and also on the North Sea coast. On the other hand, the deposition rates in the catchment areas of the new German states are comparatively low at 13 to 16 kg N/(ha· a). In addition, the reductions in deposition rate for these catchment area are the largest. This is in all cases caused by the reduction in livestock numbers.

The results of the calculations of nitrogen and phosphorus inputs caused by direct atmospheric deposition rates in the surface water of the catchment areas are shown in Table 4.7. Since changes in the water area measurements from community statistics are also included, the changes in N-inputs of this pathway for individual catchment areas are not necessarily identical to the changes shown in Table 4.6. Overall, according to Table 4.7, the nitrogen inputs from atmospheric deposition were reduced by about 3,500 t N/a or by about 25% to 10,500 t N/a. The reduction of 20% in the Danube catchment was the lowest and with

29%, the Baltic Sea catchments the highest. For the individual catchment areas it can again be ascertained that the reduction in N-inputs from atmospheric deposition in the catchment areas of the new German states at 30% is higher than in the remaining catchment areas with the exception of the Naab.

Table 4.7: Nutrient inputs in German catchment areas via atmospheric deposition on water surfaces ($EAD_{N,P}$) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	EAD_P			EAD_N		
		1983-87	1993-97	Change	1983-87	1993-97	Change
		[t N/a]		*[%]*	[t N/a]		*[%]*
14902	Naab	3	2	*-5.7*	160	100	*-39.5*
16902	Isar	7	6	*-7.0*	420	360	*-14.6*
18902	Inn	6	6	*-7.5*	330	330	*+0.2*
19101	Danube	30	29	*-5.7*	1,790	1,440	*-19.8*
23704	Upper Rhine	11	11	*-7.2*	520	420	*-18.6*
23801	Neckar	3	3	*-3.1*	130	140	*+3.1*
24901	Main	9	8	*-4.7*	470	340	*-27.6*
26901	Mosel	3	3	*-6.0*	130	120	*-8.6*
27601	Ruhr	2	2	*-6.8*	200	140	*-29.8*
27801	Lippe	2	2	*-6.6*	170	130	*-23.5*
27903	Rhine	48	46	*-5.4*	2,760	2,300	*-16.8*
37602	Ems	4	4	*+2.2*	310	250	*-18.6*
41002	Werra	3	1	*-46.9*	90	60	*-37.2*
42001	Fulda	2	2	*-5.1*	150	110	*-24.0*
48901	Aller	6	6	*-1.1*	380	310	*-18.9*
49103	Weser	16	14	*-9.7*	960	740	*-22.5*
53801	Schwarze Elster	7	4	*-47.1*	240	140	*-41.1*
54901	Mulde	5	2	*-47.2*	170	100	*-39.5*
56901	Saale	17	9	*-47.1*	600	380	*-36.4*
58901	Havel	50	29	*-46.3*	1,610	1,110	*-31.1*
59101	Elbe	130	70	*-45.9*	4,060	2,700	*-33.3*
69001	Odra	5	3	*-47.1*	130	90	*-28.9*
North Sea coast		29	26	*-10.4*	1,960	1,510	*-22.9*
Baltic Sea coast		60	39	*-38.7*	2,080	1,470	*-29.5*
North Sea total		**230**	**160**	***-29.4***	**10,040**	**7,510**	**-25.2**
Baltic Sea total		**70**	**41**	***-39.3***	**2,210**	**1,560**	***-29.4***
Black Sea		**30**	**29**	*-5.7*	**1,790**	**1,440**	***-19.9***
Germany		**330**	**230**	***-29.2***	**14,050**	**10,510**	**-25.2**

With the phosphorus inputs from atmospheric deposition, there has been a reduction in the specific deposition rate from 0.7 (new German states) or 0.4 (old German states) to 0.37 kg P/(ha· a) for all catchment areas. Accordingly, the reduction in P-inputs through direct atmospheric deposition to the water surfaces is about 28% in all catchment areas. Differences are attributed to the changed area size of surface water in the community statistics.

According to the foregoing estimations, one can conclude that for phosphorus, the inputs from atmospheric deposition at present are 230 t P/a and since the mid-eighties have decreased by about 100 t P/a.

4.1.2.2 Nutrient inputs via surface runoff

With the calculations of nutrient inputs through surface runoff, a comparison is possible with the earlier published values from WERNER ET AL. (1991) or WERNER & WODSAK (1994) for the old and new German states (see Table 4.8). These show that the quantified nitrogen inputs for the old German states correspond well.

For the new German states greater variations exist because quantity of surface runoff is estimated to be lower (average for the period 1983-1987 was 3 mm/m²) than the values from WERNER & WODSAK (1994) (10 mm/m²). For phosphorus, the inputs estimated by WERNER ET AL. (1991) attributed to surface runoff are clearly greater than those attributed here. This is based on the fact that WERNER ET AL. (1991) used a dissolved P-concentration of 0.79 mg P/l for the whole surface runoff. However, the surface runoff comes not only from arable areas and other areas with surface runoff mostly show clearly lower soil P-saturation levels. Therefore one must assume, as given in Section 3.1.2.3, that clearly lower P-concentrations are caused from this input pathway.

Table 4.8: Comparison of nutrient inputs via surface runoff ($ERO_{N,P}$) for all of Germany and in the old and new German states for the period 1983-87 with the years 1987 (OGS) and 1988/89 (NGS) according to WERNER & WODSAK (1994) and MONERIS.

Area	ERO_P		ERO_N	
	MONERIS	WERNER & WODSAK (1994)	MONERIS	WERNER & WODSAK (1994)
	[t P/a]		[t N/a]	
Germany	2,520	7,960	13,350	17,980
Old German states	2,360	7,100	12,580	15,400
New German states	160	860	770	2,580

Maps 4.6 and 4.7 give an overview of the regional differentiation of the surface runoff-linked dissolved nutrient inputs for the period 1993-1997. These maps reveal the surface specific phosphorus and nitrogen inputs through surface runoff. Accordingly, the basis assumptions show catchments with high surface flow areas or a high proportion of arable land stand out as main areas for phosphorus inputs from surface runoff (e.g. foothills of the Alps, upper Rhine area). On the other hand, the inputs through surface runoff in the catchment areas of the north east German flatlands and the lower Saale are about a magnitude or more lower, which is attributed to the very low calculated surface flows in these areas.

For nitrogen, there is a clearer relationship between the areas with high surface flows and high area-specific surface runoff inputs as a result of the relative low variation in the concentrations in precipitation. Accordingly, high inputs stand out only for the catchment areas of the Alpine foothills, in the upper Rhine and in the lower East Rhine. In the Elbe catchment area, only for the upper Unstrut and the upper Bode were similarly high specific N-inputs estimated. For most catchment areas of the north east German flatlands, low nitrogen inputs from surface runoff have been quantified. In Table 4.9, nutrient inputs from surface runoff and their changes are listed.

Table 4.9: Nutrient inputs in German catchment areas via surface runoff ($ERO_{N,P}$) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	ERO_P				ERO_N			
		1983-87	1993-97	Change	Discharge corrected change	1983-87	1993-97	Change	Discharge corrected change
		[t P/a]		*[%]*		[t N/a]		*[%]*	
14902	Naab	18	22	*+18.9*	*0.0*	150	100	*-29.3*	*-39.0*
16902	Isar	120	150	*+29.8*	*0.0*	770	810	*+4.6*	*-11.7*
18902	Inn	140	190	*+35.5*	*0.0*	980	1,150	*+17.6*	*-7.1*
19101	Danube	620	810	*+30.8*	*0.0*	4,090	4,190	*+2.3*	*-16.5*
23704	Upper Rhine	360	370	*+1.2*	*0.0*	1,590	1,460	*-8.0*	*-11.2*
23801	Neckar	180	210	*+16.2*	*0.0*	590	650	*+9.6*	*-3.9*
24901	Main	150	160	*+7.3*	*0.0*	680	530	*-21.9*	*-27.5*
26901	Mosel	110	130	*+13.7*	*0.0*	480	500	*+4.3*	*-8.6*
27601	Ruhr	120	140	*+17.5*	*0.0*	730	590	*-18.8*	*-28.8*
27801	Lippe	48	70	*+37.9*	*0.0*	260	260	*+1.6*	*-22.7*
27903	Rhine	1,230	1,320	*+6.9*	*0.0*	5,660	5,110	*-9.7*	*-15.3*
37602	Ems	70	110	*+74.7*	*0.0*	370	460	*+22.6*	*-23.4*
41002	Werra	34	60	*+70.5*	*0.0*	170	170	*-0.2*	*-36.1*
42001	Fulda	70	70	*+0.1*	*0.0*	360	270	*-25.0*	*-25.1*
48901	Aller	100	160	*+65.2*	*0.0*	400	490	*+23.1*	*-20.6*
49103	Weser	280	410	*+46.5*	*0.0*	1,340	1,380	*+3.1*	*-24.9*
53801	Schwarze Elster	4	16	*+305.7*	*0.0*	19	42	*+118.7*	*-38.9*
54901	Mulde	24	70	*+202.6*	*0.0*	110	180	*+64.1*	*-36.5*
56901	Saale	70	140	*+100.5*	*0.0*	310	390	*+24.3*	*-31.4*
58901	Havel	6	31	*+452.6*	*0.0*	27	100	*+250.9*	*-30.7*
59101	Elbe	120	320	*+159.5*	*0.0*	570	890	*+56.9*	*-32.6*
69001	Odra	3	7	*+123.7*	*0.0*	13	22	*+68.5*	*-22.5*
North Sea coast		160	240	*+46.9*	*0.0*	1,130	1,290	*+14.2*	*-17.6*
Baltic Sea coast		32	70	*+109.8*	*0.0*	140	200	*+40.8*	*-24.7*
North Sea total		**1,870**	**2,400**	***+28.8***	***0.0***	**9,080**	**9,140**	***+0.6***	***-18.4***
Baltic Sea total		**35**	**70**	***+111.0***	***0.0***	**160**	**220**	***+43.0***	***-24.5***
Black Sea		**620**	**810**	***+30.8***	***0.0***	**4,110**	**4,200**	***+2.2***	***-16.6***
Germany		**2,520**	**3,290**	***+30.4***	***0.0***	**13,350**	**13,560**	***+1.6***	***-17.9***

While with phosphorus (see Section 3.1.2.3), according to the model output, the flow-normalised surface runoff inputs have not changed, one finds lower inputs with nitrogen due to the reduction in atmospheric deposition. These reductions are between 4% and 40% for individual catchment areas and 18% for Germany as a whole.

4.1.2.3 Nutrient inputs via erosion

With nutrient inputs through erosion, a comparison with the results of WERNER ET AL. (1991) and WERNER & WODSAK (1994) is also possible. Table 4.10 shows the corresponding results for particulate transported nutrients through erosion for the old and new German states and for Germany as a whole for the period up to 1990. For this, values determined by WERNER ET AL. (1991) and WERNER & WODSAK (1994) are used for catchment areas of 1,000 km². From Table 4.10, it can be seen that with the help of the first steps described here, P-inputs through erosion in all three areas are about 30% greater than previously estimated. On the other hand, with nitrogen, the estimated erosion inputs of MONERIS are about 10% lower in comparison with earlier values for the old German states and about 20% higher for the new German states.

Table 4.10: Comparison of nutrient inputs via erosion ($EER_{N,P}$) for all of Germany and in the old and new German states for the period 1983-87 with the years 1987 (OGS) and 1988/89 (NGS) according to WERNER & WODSAK (1994) and MONERIS.

Area	EER_P		EER_N	
	MONERIS	WERNER & WODSAK (1994)	MONERIS	WERNER & WODSAK (1994)
	[t P/a]		[t N/a]	
Germany	7,490	5,390	12,200	12,350
Old German states	5,460	3,900	8,750	9,600
New German states	2,040	1,490	3,450	2,750

Since for the new German states a nearly identical database for soil erosion (see Map 3.4) is used and also the used soil P-contents are similar, the cause for the differences must be seen in the different approaches for the estimation of the sediment delivery ratio (SDR-model) and the enrichment ratio.

For testing the information on the erosion inputs in the covered catchment areas, the information of WERNER & WODSAK (1994) for 17 different catchment areas in the unconsolidated rock region in the new German states will be directly compared with the MONERIS results. This comparison is shown in Figure 4.3. It is clear that the model for particulate nutrients inputs through erosion for 16 of the 17 catchment areas delivers very similar results. Only for the Havel catchment excluding the Spree, the results of MONERIS are clearly lower than given by WERNER & WODSAK (1994). This difference is presumably due to the consideration of slope reductions with the previous calculation of the SDR-relationship. In the Havel area, the average slopes and therefore the SDR are comparatively low.

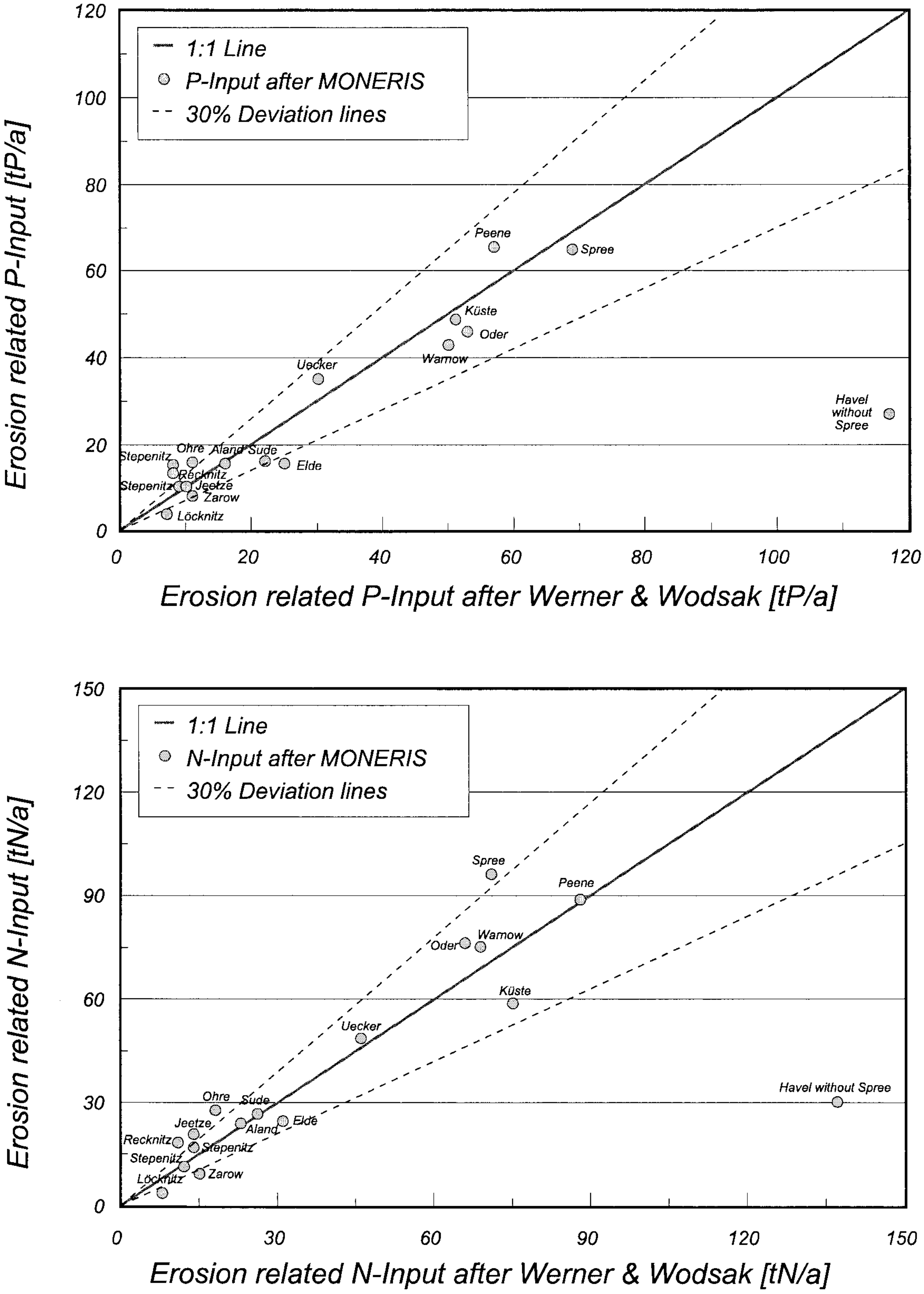


Figure 4.3: Comparison of the estimated erosion derived nutrient inputs for catchment areas of unconsolidated rock regions according to WERNER & WODSAK (1994) and MONERIS.

A further cause of the underestimates of erosion related nutrient inputs in the Havel appears to lie in the various solutions of the database for soil erosion. So WERNER & WODSAK (1994) used the aggregated district data, while the calculations of MONERIS where carried out on a database for municipalities (see Map 3.4). The community based estimates for the Havel basin without the Spree give a third lower figures for soil erosion than those given by WERNER & WODSAK (1994). Overall we cannot decide however from only the model results which value is better.

Table 4.11: Nutrient inputs in German catchment areas via erosion ($EER_{N,P}$) for the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	EER_P				EER_N			
		1983-87	1993-97	Change	Discharge corrected change	1983-87	1993-97	Change	Discharge corrected change
		[t P/a]		[%]		[t N/a]		[%]	
14902	Naab	120	150	*+20.5*	*+9.2*	300	330	*+10.1*	*0.0*
16902	Isar	230	260	*+11.9*	*+7.6*	210	220	*+4.0*	*0.0*
18902	Inn	250	300	*+20.4*	*+7.0*	240	270	*+13.8*	*0.0*
19101	Danube	1,660	1,910	*+14.8*	*+7.9*	2,340	2,490	*+6.2*	*0.0*
23704	Upper Rhine	320	350	*+8.1*	*+6.0*	500	510	*+2.5*	*0.0*
23801	Neckar	410	450	*+8.8*	*+7.2*	700	710	*+1.9*	*0.0*
24901	Main	1,060	1,190	*+12.5*	*+7.5*	1,990	2,100	*+5.7*	*0.0*
26901	Mosel	120	120	*+5.2*	*+7.3*	290	290	*-2.5*	*0.0*
27601	Ruhr	24	22	*-11.1*	*+9.8*	32	25	*-20.9*	*0.0*
27801	Lippe	110	120	*+7.1*	*+10.5*	150	140	*-2.8*	*0.0*
27903	Rhine	2,560	2,770	*+7.8*	*+7.4*	4,570	4,610	*+1.0*	*0.0*
37602	Ems	100	110	*+10.3*	*+12.1*	210	210	*-1.4*	*0.0*
41002	Werra	150	150	*-3.1*	*+4.9*	340	320	*-8.0*	*-0.3*
42001	Fulda	120	120	*+0.5*	*+7.1*	200	190	*-6.1*	*0.0*
48901	Aller	420	450	*+7.1*	*+9.2*	570	560	*-2.1*	*0.0*
49103	Weser	960	1,000	*+4.0*	*+8.4*	1,460	1,400	*-4.3*	*-0.1*
53801	Schwarze Elster	50	50	*+0.8*	*+6.5*	70	60	*-5.5*	*0.0*
54901	Mulde	260	260	*-0.6*	*+5.7*	520	490	*-6.1*	*0.0*
56901	Saale	960	1,000	*+3.9*	*+4.4*	1,620	1,610	*-0.5*	*0.0*
58901	Havel	90	100	*+11.1*	*+7.2*	120	130	*+5.1*	*0.0*
59101	Elbe	1,680	1,740	*+3.6*	*+5.2*	2,880	2,830	*-1.6*	*0.0*
69001	Odra	60	70	*+12.8*	*+7.8*	100	100	*+4.4*	*0.0*
North Sea coast		140	160	*+14.8*	*+11.4*	210	210	*+3.0*	*0.0*
Baltic Sea coast		330	350	*+6.5*	*+7.2*	430	430	*-0.4*	*0.0*
North Sea total		**5,440**	**5,770**	***+6.1***	***+7.1***	**9,330**	**9,270**	***-0.6***	***0.0***
Baltic Sea total		**390**	**420**	***+7.5***	***+7.3***	**530**	**530**	***+0.5***	***0.0***
Black Sea		**1,660**	**1,910**	***+14.9***	***+7.9***	**2,340**	**2,490**	***+6.4***	***0.0***
Germany		**7,490**	**8,100**	***+8.1***	***+7.3***	**12,200**	**12,290**	***+0.8***	***0.0***

Since nutrient inputs caused by erosion for the unconsolidated rock region correspond relatively well with the previously given model results, one can assume that with MONERIS estimated higher nutrient inputs through the erosion pathway for the whole new German states area are caused by the comparatively higher inputs in the catchment areas of the consolidated rock region which show a higher proportion of areas favourably disposed for erosion.

An overview of nutrient inputs through erosion and their changes since the mid-eighties in the large German catchments is given in Table 4.11. From this, the highest specific P-inputs from erosion are in the Saale, Main, Mulde and Inn catchments with more than 35 kg P/(km²· a). The lowest specific inputs are in the Havel, Ruhr and North Sea coast catchments with less than 5 kg P/(km²· a). While the low values in the Havel and North Sea coast areas are attributable to the lack of slopes in the catchment area, it can be concluded for the Ruhr that these contents are influenced by the comparatively low proportion of arable land.

The regional distribution of nutrient inputs caused by erosion is shown in Maps 4.8 and 4.9. From this, the hot-spots of nutrient inputs through the erosion pathway are the lower Danube, the upper and middle Main, the upper reaches of the Mulde and Saale as well as the middle Weser and Leine. In all these catchment areas, the proportion of arable land is well above average and are classified as areas of intermediate rather than high elevations. Low nutrient inputs through erosion are presently found in the catchments of the lower Ems and Weser, the North Sea coastal region and the middle part of the north east German flatlands with the Havel and Schwarze Elster.

4.1.2.4 Nutrient inputs via tile drainage

The comparison of the model-derived estimated nutrient inputs for the period 1983-1987 with the results from WERNER ET AL. (1991) and WERNER & WODSAK (1994) shows a relatively good correspondence for phosphorus for Germany as a whole (see Table 4.12). However, there is a clear divergence between estimates for the old and new German states. In comparison to the published information, the P-inputs from tile drainage in the old German states is overestimated and in the new German states underestimated. As already ascertained by WERNER ET AL. (1991), drained bog soil areas with about 2.930 t P/a have far and away the greatest P-input through drainage. The cause of the higher P-inputs from MONERIS is based on the acceptance of a higher P-concentration in the drainage from bog soils.

For nitrogen, Table 4.12 shows both for the whole of Germany and for the old and new German states, a very large difference between the estimates of 200% to 800%. The cause of these differences lies on the one hand in the different methods for estimation of N-inputs from tile drainage. On the other hand, new studies show that some of the basic assumptions of WERNER ET AL. (1991) and WERNER & WODSAK (1994) do not correspond with reality. This is related to the considered drain flow for the old German states with 30% and especially with the new German states with 50% which clearly lie below the information from other studies (BRAUN ET AL., 1991; SCHOLZ, 1997). Further the assumptions of the division of drained areas into arable land and grassland were questionable. While WERNER & WODSAK (1994) give a figure of 60% for the proportion of grassland with tile drainage, the overlapping of the digitised areas with the CORINE-landcover map gives an average of 85% drained areas for arable land (SCHOLZ, 1997). One can conclude that with the earlier estimations, the nitrogen inputs through tile drainage was greatly underestimated.

Table 4.12: Comparison of nutrient inputs via tile drainage ($EDR_{N,P}$) for all of Germany and in the old and new German states for the period 1983-87 with the years 1987 (OGS) and 1988/89 (NGS) according to WERNER & WODSAK (1994) and MONERIS.

Area	EDR_P		EDR_N	
	MONERIS	WERNER & WODSAK (1994)	MONERIS	WERNER & WODSAK (1994)
	[t P/a]		[t N/a]	
Germany	3,510	2,730	168,290	53,900
Old German states	3,300	2,400	98,490	45,000
New German states	200	330	69,800	8,900

BEHRENDT (1996a) determined N-inputs through tile drainage for Mecklenburg-Western Pomerania catchment areas for the period 1992-1994 from an improved database as well as with the methods of WERNER ET AL. (1991). The comparison of these results with N-inputs estimated with MONERIS is shown in Figure 4.4.

For most of these catchment areas, the difference between the estimates is under 30%. The differences are mainly due to the aggregated values for tile drainage being based on information from the districts of former GDR while for the drained area estimated here the regional distribution of these areas corresponding to the water saturation grade of the individual soil type is considered (see Section 3.1.2.5 and SCHOLZ, 1997).

Drainage water concentrations calculated with Equations 3.37 and 3.42 for phosphorus and nitrogen correspond well with literature information (see Section 3.1.2.5). For example, for the area of the north east German flatlands for the period 1993-1997 an average nitrogen concentration of 20 mg N/l was calculated. The measurement results for 1995 given in Table 3.21 show for nitrogen values between 1.9 and 5.4 mg N/l in grassland areas and between 24.2 and 36.3 mg N/l in arable areas. The calculated value of 20 mg N/l refers to the whole catchment area and contains both grassland and arable areas. One sets for grassland an average value of 3 mg N/l and for arable land, 30 mg/l for the area of the north east German flatlands shown in Table 3.21. This gives an overall drainage water concentration of 22.4 mg N/l.

The quantities of phosphorus and nitrogen emitted by the tile drainage pathway for the periods 1983-87 and 1993-1997 are shown in Tables 4.13 and 4.14. In addition to the emission information for the studied time periods, area-specific emissions (covered in the agricultural areas) for the period 1993-1997, size of the drained area and changes since the mid-eighties under consideration of the different hydrological situations and flow normalised are given. An overview of tile drainage in 1993-1997 in the German catchment area is given in Maps 4.10 and 4.11.

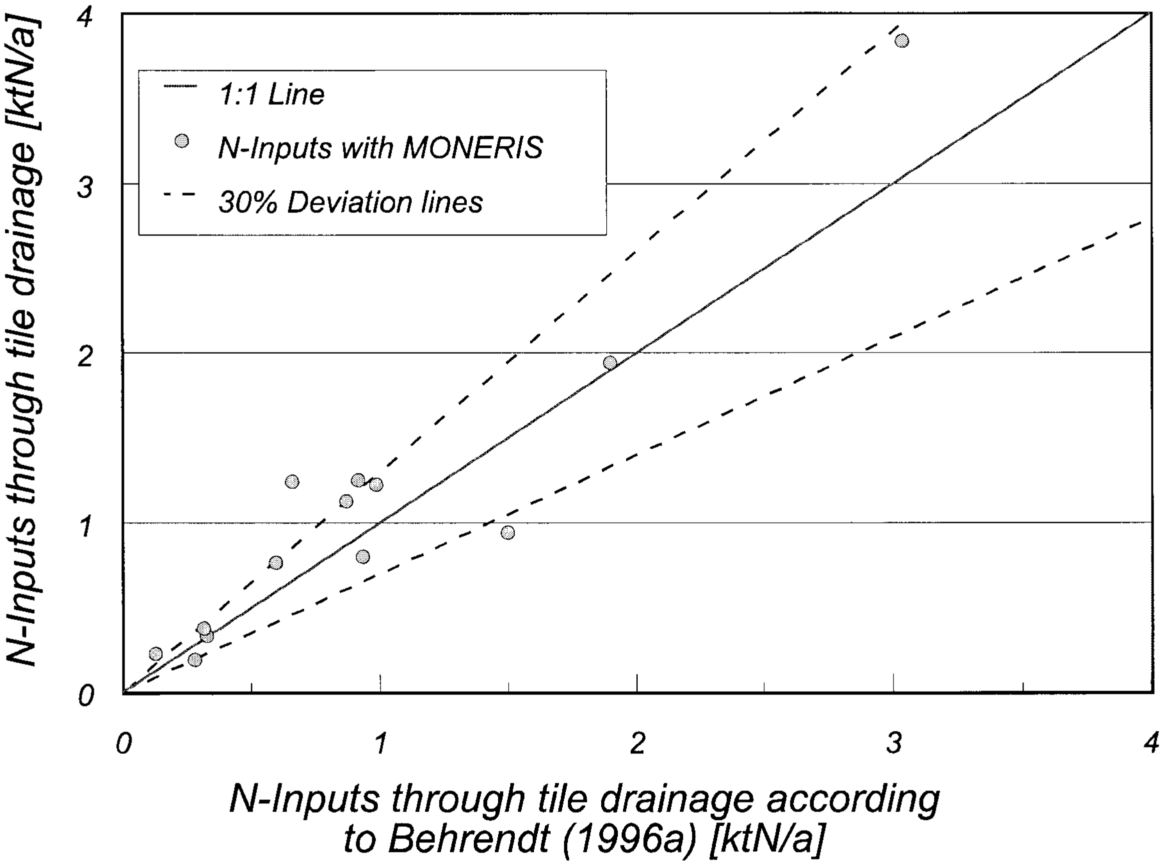


Figure 4.4: Comparison of the estimated nitrogen inputs via tile drainage according to BEHRENDT (1996a) and MONERIS for Mecklenburg-Western Pomeranian catchment areas.

Regarding the input changes in the studied periods it must be taken into account that the estimation of basic inputs could only be determined on the basis of an incomplete existing database for both time periods. Since no information on changes in drained areas is available for the last 15 years, estimates were based on the same size of drained areas for both time periods. Furthermore, with phosphorus, uniform concentrations for the flow of installed drains were used for both time periods. Therefore, the changes in phosphorus inputs are based alone on changes in the size of drain flow. Contrary, the changes with nitrogen are attributed to changed nitrogen concentrations and different quantities of drain flow. Therefore, these factors have been enlisted to calculate the contribution of drains.

For phosphorus with specific emissions between 0.1 and 6.2 kg P/($km^2 \cdot$ a) per agricultural area, it is clear that the input through drainage in the most studied catchment areas more likely occupies a subordinate role. Loading hot-spots occur if a number of significant factors for phosphorus output over tile drainage come together in a catchment area. To know are the use-intensity, the amount of the drainage flow, which is controlled by the amount of precipitation and the proportion of drained bog soils in the catchment area. The highest phosphorus emissions between 11.7 and 28.55 kg P/(km²· a) are shown by the Ems, Aller and Weser catchment areas. In all three areas one finds 1% to 6% bog soils, intensive usage with 51% to 76% arable land in the agricultural areas and high drain flow.

Table 4.13: Phosphorus inputs in German catchment areas via tile drainage (EDR_P) in the periods 1983-87 and 1993-97 and their changes, specific emissions in 1993-97 (EDR_{SP_P}) and drained areas (A_{DR}) covered in agricultural areas.

ADDR.	River/Basin	A_{DR}/A_{LN}	EDR_P		EDR_{SP_P}	Change	Discharge corrected change
			1983-87	1993-97	1993-97		
		[%]	[t/a]		[kg/(km² AL·a)]	*[%]*	
14902	Naab	*0.3*	0.2	0.2	0.1	*-4.5*	*0.0*
16902	Isar	*12.2*	24	21	5.7	*-14.0*	*0.0*
18902	Inn	*7.2*	15	14	5.3	*-6.2*	*0.0*
19101	Danube	*9.8*	100	90	3.3	*-9.2*	*0.0*
23704	Upper Rhine	*6.5*	11	9	2.0	*-23.6*	*0.0*
23801	Neckar	*13.6*	17	17	2.2	*0.0*	*0.0*
24901	Main	*4.0*	13	13	0.9	*+1.0*	*0.0*
26901	Mosel	*4.6*	13	13	2.5	*+5.3*	*0.0*
27601	Ruhr	*1.7*	0.9	1	0.6	*+10.1*	*0.0*
27801	Lippe	*21.2*	18	20	6.2	*+12.8*	*0.0*
27903	Rhine	*8.3*	100	100	2.0	*+0.9*	*0.0*
37602	Ems	*7.4*	80	90	11.7	*+2.5*	*0.0*
41002	Werra	*6.4*	4	5	1.7	*+10.5*	*0.0*
42001	Fulda	*5.1*	5	5	1.6	*+4.9*	*0.0*
48901	Aller	*16.5*	270	260	28.5	*-3.4*	*0.0*
49103	Weser	*10.7*	380	360	16.0	*-4.9*	*0.0*
53801	Schwarze Elster	*16.9*	13	15	5.0	*+15.2*	*0.0*
54901	Mulde	*27.6*	14	17	4.0	*+16.6*	*0.0*
56901	Saale	*14.1*	29	32	2.0	*+11.3*	*0.0*
58901	Havel	*9.9*	30	34	3.0	*+13.4*	*0.0*
59311	Elbe	*14.9*	140	160	3.2	*+13.3*	*0.0*
59311	Odra	*10.7*	7	7	2.5	*+8.4*	*0.0*
North Sea coast		*14.9*	2,610	2,370	87.9	*-9.5*	*0.0*
Baltic Sea coast		*21.0*	80	90	5.0	*+5.5*	*0.0*
North Sea total		***11.9***	**3,320**	**3,070**	**19.6**	***-7.4***	***0.0***
Baltic Sea total		***19.6***	**90**	**100**	**4.7**	***+5.7***	***0.0***
Black Sea		***9.7***	**100**	**90**	**3.3**	***-9.2***	***0.0***
Germany		***12.4***	**3,510**	**3,260**	**15.9**	***-7.1***	***0.0***

The output of nitrogen, especially the flushable nitrates, occurs at higher rates in drained areas than from non-drained areas (SCHEFFER & BARTELS, 1980). With the results in Table 4.14, it is clear that in the studied catchment area with specific nitrogen emissions between 20 and 1,588 kg N/(km² AL· a) for the period 1993-97, considerable quantities come through drainage in the surface waters. The smallest quantity of nitrogen is found in the Naab catchment which has only 0.3% of agricultural land with drainage. This is the lowest proportion of the 22 catchment areas.

The highest nitrogen input through drainage (1,588 kg N/(km²· a) has been calculated for the Lippe catchment area. Second highest is for the Mulde with 940 kg N/(km²· a). In hindsight, the change in nitrogen emissions through drainage shows with all catchment areas a clear and nearly uniform decrease with a mean for Germany of about 28%. This decrease comes from the decline in soil nitrogen surpluses which is the input for the calculation of nitrogen in drainage water.

Table 4.14: Nitrogen inputs in German catchment areas via tile drainage (EDR_P) in the periods 1983-87 and 1993-97 and their changes, specific emissions in 1993-97 (EDR_{SP_P}) and drained areas (A_{DR}) covered in agricultural areas.

ADDR.	River/Basin	A_{DR}/A_{LN}	EDR_N		EDR_{SP_N}	Change	Discharge corrected change
			1983-87	1993-97	1993-97		
		[%]	[t/a]		[kg/(km² AL·a)]	*[%]*	
14902	Naab	*0.3*	60	50	20.4	*-21.9*	*-25.7*
16902	Isar	*12.2*	3,360	2,650	731.2	*-21.1*	*-25.7*
18902	Inn	*7.2*	2,060	1,570	610.6	*-23.6*	*-25.7*
19101	Danube	*9.8*	21,110	16,600	621.4	*-21.4*	*-25.7*
23704	Upper Rhine	*6.5*	2,100	1,480	341.4	*-29.2*	*-25.7*
23801	Neckar	*13.6*	7,150	5,610	753.4	*-21.5*	*-25.7*
24901	Main	*4.0*	3,880	3,070	207.8	*-21.0*	*-25.7*
26901	Mosel	*4.6*	1,190	950	179.6	*-19.6*	*-25.7*
27601	Ruhr	*1.7*	210	170	94.4	*-21.4*	*-25.7*
27801	Lippe	*21.2*	6,680	5,180	1,587.9	*-22.4*	*-25.7*
27903	Rhine	*8.3*	28,690	22,340	450.0	*-22.1*	*-25.7*
37602	Ems	*7.4*	5,690	4,530	609.0	*-20.5*	*-25.7*
41002	Werra	*6.4*	1,270	810	291.7	*-36.4*	*-38.5*
42001	Fulda	*5.1*	1,200	950	274.0	*-21.0*	*-25.7*
48901	Aller	*16.5*	10,750	8,560	927.1	*-20.4*	*-25.7*
49103	Weser	*10.7*	17,740	13,910	618.2	*-21.6*	*-26.6*
53801	Schwarze Elster	*16.9*	3,010	1,930	640.6	*-36.0*	*-38.5*
54901	Mulde	*27.6*	6,170	3,920	940.2	*-36.4*	*-38.5*
56901	Saale	*14.1*	16,630	10,560	657.1	*-36.5*	*-38.5*
58901	Havel	*9.9*	6,030	3,830	337.0	*-36.5*	*-38.5*
59311	Elbe	*14.9*	47,460	30,340	601.8	*-36.1*	*-38.2*
69001	Odra	*10.7*	1,740	1,100	385.0	*-37.0*	*-38.5*
North Sea coast		*14.9*	20,810	16,160	599.9	*-22.4*	*-25.7*
Baltic Sea coast		*21.0*	25,030	16,410	921.0	*-34.4*	*-37.0*
North Sea total		***11.9***	**120,400**	**87,280**	**556.1**	***-27.5***	***-30.7***
Baltic Sea total		***19.6***	**26,780**	**17,510**	**847.0**	***-34.6***	***-37.1***
Black Sea		***9.7***	**21,110**	**16,600**	**618.7**	***-21.4***	***-25.7***
Germany		***12.4***	**168,290**	**121,390**	**593.8**	***-27.9***	***-31.1***

4.1.2.5 Nutrient inputs via groundwater

The nutrient inputs via the groundwater pathway were determined with the methods described in Section 3.1.2.6 based on regionally differentiated surpluses. It should be noted that natural interflow is included in this pathway. This has not been separately considered up to now.

As already shown in Section 3.1.2.6, the model performance for N-inputs through groundwater has been carried out based on measured groundwater concentrations. The relationship between calculated and measured groundwater concentrations of the investigated river basins has a correlation of 48%.

Table 3.23 shows the changes of average nitrate concentration in Bavaria and Baden-Württemberg. From this can be concluded that the mean nitrate concentrations in Bavaria increased a little and in Baden Württemberg decreased a little. One gets similar results if the standardised hydrological changes of N-inputs for the Danube, the upper Rhine and the Neckar are considered. The N-inputs through groundwater in the Danube increased by around 4% while in the upper Rhine and Neckar decreased by about 3%.

From the monitoring programme of Saxony, we have at our disposal values for the nitrate concentrations in groundwater from 7 monitoring points for the period 1983 to 1997. From these data a mean increase of the nitrate concentration of 5% can be estimated. With the hydrologically standardised N-inputs through groundwater we can determine an increase of 7% to 9% for the Saale and Mulde catchment areas. Also here the tendency of increased N-inputs is validated through changes in the measured groundwater concentrations.

Table 4.15 shows a comparison of estimated groundwater nutrient inputs with MONERIS and estimates according to WERNER ET AL. (1991) and WERNER & WODSAK (1994) for the period prior to 1990. For the whole area of Germany, the estimated results are in good agreement. The difference is less than 10%. On a regional scale however, larger differences are ascertainable. The MONERIS values for groundwater N-inputs for the old German states are about 20% greater than the values given by WERNER ET AL. (1991). On the other hand, the estimated N-input through this pathway for the new German states is almost 30% less than the value given by WERNER & WODSAK (1994). It should be taken into account that the MONERIS groundwater N-input estimates for 1983-1987 are simply back-calculated with consideration of the long-term changes in nitrogen surpluses and the various hydrological conditions from the 1993-1997 inputs. WERNER ET AL. (1991) and WERNER & WODSAK (1994) have used long term means for groundwater flow.

For phosphorus, there are very large differences between MONERIS and earlier estimates (WERNER ET AL., 1991; WERNER & WODSAK, 1994) of groundwater inputs. While average estimates for the new German states with MONERIS gave "only" a double so large input, estimates for the old German states are nearly an order of magnitude different. One of the causes of these differences is that separate estimates were made for groundwater phosphorus inputs from agriculturally used peaty soils with MONERIS, especially in the Weser and Ems areas. Alone, these soils cause a P-input of about 2,700 t P/a with the accepted P-concentration in near-surface groundwater and interflow of 2.5 mg P/l. The consideration of the differences between the dissolved inorganic phosphorus and the total phosphorus concentrations for anoxic groundwater (see Section 3.1.2.6) causes a P-input of 1,700 t P/a. Alone, these two differences in the databases or methods explain two thirds of the discrepancy with the estimates of WERNER ET AL. (1991) and WERNER & WODSAK (1994). In the future it is necessary that the monitoring of groundwater should be changed to a measurement of total phosphorus. Only on this base possible large underestimations can be excluded in particular for areas with anoxic groundwater.

Table 4.15: Comparison of nutrient inputs via groundwater ($EGW_{N,P}$) for all of Germany and in the old and new German states for the period 1983-87 with the years 1987 (OGS) and 1988/89 (NGS) according to WERNER & WODSAK (1994) and MONERIS.

Area	EGW_P		EGW_N	
	MONERIS	WERNER & WODSAK (1994)	MONERIS	WERNER & WODSAK (1994)
	[t P/a]		[t N/a]	
Germany	6,580	1,210	401,430	372,500
Old German states	5,370	600	334,400	280,000
New German states	1,210	610	67,030	92,500

Map 4.12 gives an overview of regional distribution of groundwater nitrogen emissions. Especially high specific inputs can be determined where high nitrogen surpluses (see Map 3.1) are combined with a high proportion of agricultural land (see Map 2.1) and a low nitrogen retention (low denitrification potential) in the unsaturated zone and in groundwater. According to Map 4.13, this denitrification potential is especially high (more than 90%) for most catchment areas of the north east German flatlands. Nitrogen concentrations in seepage water of 60 mg N/l and more are reduced to less than 2 mg N/l due to extensive denitrification. N-retention or loss of less than 40% can only be ascertained in a few catchment areas of the consolidated rock region and in the middle Ems.

For the catchment areas considered in Table 4.16, the highest specific groundwater N-emissions are found in the Ems and Lippe areas with 24 and 19 kg N/(ha· a) respectively. On the other hand, the values for the Havel and the German catchment of the Odra are under 4 kg N/(ha· a) and for the Schwarze Elster and Baltic Sea coast only 5 kg N/(ha· a). Flow-normalisation gives for all catchments with the exception of the Rhine yet higher groundwater N-inputs and is to be attributed to the long-term averages of previous years of N-surpluses of 20 or 30 years. Accordingly, the increases in the new German states were highest with 8% to 9% because the mean N-surpluses of the previous 30 years were considered.

For Germany as a whole, an increase of groundwater N-inputs of 2.4% is estimated in comparison to 1983-1987. The calculated reductions in the N-surpluses are 27% and 45%

respectively for the old and new German states. Eventually, in the years after 2000, the groundwater N-inputs are expected to sink when the water residence time in the saturated and unsaturated zones is considered.

Table 4.16: Nutrient inputs in German catchment areas via groundwater and natural interflow ($EGW_{N,P}$) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	EGW_P				EGW_N			
		1983-87	1993-97	Change	Discharge corrected change	1983-87	1993-97	Change	Discharge corrected change
		[t P/a]		[%]		[t N/a]		[%]	
14902	Naab	60	47	*-15.8*	*+0.1*	8,230	6,990	*-15.1*	*+2.7*
16902	Isar	100	110	*+6.1*	*-0.1*	11,370	12,780	*+12.4*	*+3.9*
18902	Inn	140	130	*-10.2*	*-0.1*	13,120	12,980	*-1.0*	*+4.9*
19101	Danube	670	590	*-12.1*	*0.0*	79,400	78,090	*-1.6*	*+4.2*
23704	Upper Rhine	130	130	*-4.7*	*0.0*	14,160	12,890	*-9.0*	*-3.2*
23801	Neckar	90	90	*-3.9*	*+0.1*	20,520	18,960	*-7.6*	*-2.8*
24901	Main	200	200	*+1.4*	*+0.3*	34,870	32,980	*-5.4*	*-3.8*
26901	Mosel	110	100	*-8.0*	*+0.2*	13,310	11,670	*-12.3*	*-3.0*
27601	Ruhr	60	60	*+1.4*	*+0.4*	5,010	4,810	*-4.0*	*-4.7*
27801	Lippe	45	50	*+9.3*	*+0.5*	8,240	8,620	*+4.6*	*-3.2*
27903	Rhine	880	850	*-2.7*	*+0.2*	132,580	122,750	*-7.4*	*-3.3*
37602	Ems	840	670	*-20.3*	*-0.1*	19,080	21,850	*+14.5*	*+5.1*
41002	Werra	50	49	*-8.2*	*+0.1*	7,600	7,550	*-0.7*	*+7.1*
42001	Fulda	80	70	*-12.7*	*+0.1*	9,680	8,680	*-10.3*	*+3.4*
48901	Aller	200	130	*-35.1*	*-0.1*	16,400	14,800	*-9.7*	*+3.8*
49103	Weser	710	530	*-25.6*	*0.0*	50,060	45,820	*-8.5*	*+4.4*
53801	Schwarze Elster	60	50	*-8.6*	*-0.1*	3,270	2,860	*-12.6*	*+7.3*
54901	Mulde	40	39	*-1.6*	*0.0*	6,710	6,840	*+1.9*	*+7.6*
56901	Saale	110	110	*-0.8*	*0.0*	21,990	23,360	*+6.3*	*+9.1*
58901	Havel	390	380	*-3.3*	*0.0*	9,270	9,000	*-3.0*	*+7.3*
59101	Elbe	950	1,000	*+5.3*	*-0.1*	53,760	57,270	*+6.5*	*+8.4*
69001	Odra	50	50	*+5.4*	*0.0*	1,670	1,740	*+4.2*	*+8.4*
North Sea coast		2,180	1,770	*-19.0*	*-0.1*	52,770	54,000	*+2.3*	*+3.7*
Baltic Sea coast		290	270	*-5.7*	*0.0*	11,840	12,600	*+6.4*	*+8.1*
North Sea total		**5,560**	**4,820**	***-13.3***	***0.0***	**308,240**	**301,690**	***-2.1***	***+1.7***
Baltic Sea total		**340**	**330**	***-4.0***	***0.0***	**13,510**	**14,340**	***+6.1***	***+8.1***
Black Sea		**680**	**590**	***-12.1***	***0.0***	**79,680**	**78,390**	***-1.6***	***+4.2***
Germany		**6,580**	**5,740**	***-12.7***	***0.0***	**401,430**	**394,430**	***-1.7***	***+2.4***

Map 4.14 gives an overview of the regional distribution of groundwater P-inputs. The loading hot-spots are undoubtedly in the Ems and lower Weser catchments which again is attributable to the high proportion of bog soils in the agricultural areas. Such areas also occur in some Danube and Rhine catchment areas according to the BÜK. In these areas, individual catchments can be identified with relatively high groundwater P-inputs. Also in the Elbe basin, there are areas with high specific groundwater P-inputs. This is caused by a relatively high proportion of areas with anoxic groundwater which results in the clearly higher

groundwater P-concentrations. In accordance with the model assumptions, after which the P-concentrations in groundwater in both considered time periods did not change, according to Table 4.16 also with consideration of the same hydrological conditions no changes in groundwater P-inputs were determined.

4.1.2.6 Nutrient inputs via urban areas

A comparison of estimated nutrient inputs via the various pathways in urban areas is possible with other research projects as well as the literature. BROMBACH & MICHELBACH (1998) quantified the nutrient input through sewer systems in the catchment area of Lake Constance. FUCHS & HAHN (1999) and BORCHARDT & GEFFERS (1999) estimated in the framework of the joined research project "Precipitation" nutrient inputs from separate and mixed sewer system overflows and from the inhabitants and inhabited areas which either only or not at all are connected to a sewer system, for the Necker and Lahn catchments. For the Ruhr upstream Villigst and upstream Essen there are also results published for nutrient inputs from the separate and mixed sewer systems (RUHRVERBAND, 1998). Consideration of nutrient inputs from separate and mixed sewer systems in Berlin has been carried out by the Senate for *City Development, Environment and Technology* which have been published by BEHRENDT & OPITZ (1996). HAMM ET AL. (1991) and WERNER & WODSAK (1994) present the nutrient emissions from paved urban areas via the different sewer systems for the years 1987 and the period 1985 to 1989.

Table 4.17 shows the comparison of the results of these authors with nutrient inputs estimated according to MONERIS from the separated sewer system and the combined sewer overflows. Overall, it shows both for phosphorus and nitrogen an acceptable correspondence with the results of other authors. The difference is between 1% and 122%. It should be noted however that the values given by BROMBACH & MICHELBACH (1998) in a capacity of the combined sewer system received 50% while with our considerations for 1995 the value of 77% for Baden-Württemberg was used.

With a 50% removal-grade, MONERIS yields discharges of 65 t P/a or 355 t N/a for the Lake Constance catchment and for the 7 t P/a or 40 t N/a Schussen catchment area. With this, the difference in estimates for these two catchments, particularly for phosphorus, is less than 10%, however for nitrogen it is around 30%. With the consideration of the Ruhr, information comes from the *Ruhr Organisation* for the Villigst and Essen monitoring stations. For the Ruhr catchment upstream Essen, no nutrient inputs were estimated with MONERIS. The difference in the size of the catchments between the Duisburg and Essen monitoring stations is about 7% so that one can conclude that the MONERIS results for the Essen monitoring station must probably be 5% to 10% underestimated. If these differences in the catchment areas are taken into account the difference between the two estimates does not increase essential and remains under 30% for nitrogen and phosphorus at the Essen monitoring station.

The relatively large differences in the estimated values for the new German states are attributable to the fact that the estimates for these pathway made by WERNER & WODSAK (1994) were carried out with a substantially smaller database. For phosphate, there is a relatively large difference in the two estimates for the Lahn and Neckar. The cause of these differences probably lies in the different assumptions made for the determination of the number of days with storm water runoff.

Table 4.17: Comparison of nutrient inputs via separated ($EUT_{N,P}$) and combined sewer overflows ($EUM_{N,P}$) according to MONERIS and other authors.

Area	Monitoring station	Period	MONERIS			Other authors			Difference	Source
			EUT_P	EUM_P	Sum	EUT_P	EUM_P	Sum		
			[t P/a]						*[%]*	
Rhine	Oehningen	1993-97	8	46	54			59	*-8.3*	BROMBACH & MICHELBACH (1998)
Schussen	Meckenbeuren	1993-97	1	5	6			7	*-14.3*	
Neckar	Mannheim	1993-97	4	180	184	3	101	104	*+77.5*	FUCHS & HAHN (1999)
Lahn	Limburg-Staffel	1993-97	2	36	38	5	43	48	*-20,0*	BORCHARDT & GEFFERS (1999)
Ruhr	Villigst	1993-97	2	14	16	6	24	29	*-45.6*	RUHRVERBAND (1998)
Ruhr	Duisburg	1993-97	10	64	74	19	73	92	*-19.4*	
Spree	City of Berlin	1993-97	16	22	38	23	15	38	*+0.3*	BEHRENDT & OPITZ (1996)
OGS		1983-87	521	2,870	3,391	1,000	4,800	5,800	*-41.5*	HAMM ET AL. (1991)
NGS		1983-87	142	634	776	130	1,300	1,430	*-45.8*	WERNER & WODSAK (1994)
			EUT_N	EUM_N	Sum	EUT_N	EUM_N	Sum	Difference	
			[t N/a]						*[%]*	
Rhine	Oehningen	1993-97	79	225	303			276	*+9.9*	BROMBACH & MICHELBACH (1998)
Schussen	Meckenbeuren	1993-97	11	23	34			30	*+13.5*	
Neckar	Mannheim	1993-97	39	895	934	28	618	646	*+44.6*	FUCHS & HAHN (1999)
Lahn	Limburg-Staffel	1993-97	26	171	197	39	273	312	*-36.8*	BORCHARDT & GEFFERS (1999)
Ruhr	Villigst	1993-97	31	65	96	30	160	190	*-49.5*	RUHRVERBAND (1998)
Ruhr	Duisburg	1993-97	134	316	450	100	496	596	*-24.5*	
Spree	City of Berlin	1993-97	289	217	506	138	90	228	*+121.9*	BEHRENDT & OPITZ (1996)
OGS		1983-87	6,471	9,680	16,151	3,000	17,000	20,000	*-19.2*	HAMM ET AL. (1991)
NGS		1983-87	1,352	1,531	2,883	840	6,500	7,340	*-60.7*	WERNER & WODSAK (1994)

Overall, the comparison shows that the performance of the used model is adequate for a calculation of nutrient inputs through separated sewers and combined sewer overflows for the various considered basins.

A comparison of the results of nutrient inputs from urban areas and inhabitants which have a sewer system but no connection with a wastewater treatment plant or without a connection to sewer systems, is only possible, according to Table 4.18, with four areas (Neckar, Lahn, total old and new German states in the years 1987 and 1985-1989 respectively) (see FUCHS & HAHN, 1999; BORCHARDT & GEFFERS, 1999; HAMM ET AL. 1991; WERNER & WODSAK, 1994). The difference in estimates ranges between 2% and 50% for the individual catchment areas. For phosphorus, the Lahn area and the new German states clearly show higher differences in the period 1985-1989 than for the Neckar and the old German states prior to

1990. The large difference for the new German states can probably once more be attributed to the coarse data base used for the studies of WERNER & WODSAK (1994). The cause for the Lahn area is not yet clear.

Table 4.18: Comparison of nutrient inputs via inhabitants and paved urban areas not connected to sewerage ($EUN_{N,P}$) or neither sewer nor WWTP connection ($EUK_{N,P}$) according to MONERIS and other authors.

Area	Monitoring station	Period	MONERIS			Other authors			Difference	Source
			EUK_P	EUN_P	Sum	EUK_P	EUN_P	Sum		
			[t P/a]						*[%]*	
Neckar	Mannheim	1993-97	9	1	10	12		12	*-14.4*	FUCHS & HAHN (1999)
Lahn	Limburg-Staffel	1993-97	11	1	11	18		18	*-36.8*	BORCHARDT & GEFFERS (1999)
OGS		1983-87	1,754	388	2,142	2,000		2,000	*+7.1*	HAMM ET AL. (1991)
NGS		1983-87	2,157	724	2,881	2,010	350	2,360	*+22.1*	WERNER & WODSAK (1994)
			EUK_N	EUN_N	Sum	EUK_N	EUN_N	Sum	Difference	
			[t N/a]						*[%]*	
Neckar	Mannheim	1993-97	73	25	98	65		65	*+50.4*	FUCHS & HAHN (1999)
Lahn	Limburg-Staffel	1993-97	91	17	108	104		104	*+3.8*	BORCHARDT & GEFFERS (1999)
OGS		1983-87	6,640	4,410	11,049	17,200		17,200	*-35.8*	HAMM ET AL. (1991)
NGS		1983-87	8,079	5,485	13,564	12,260	1,570	13,830	*-1.9*	WERNER & WODSAK (1994)

Maps 4.15 and 4.16 show the summarised results of the calculations of N- and P- inputs from paved urban areas and from inhabitants via separated sewers, combined sewer overflows and without any sewer connection for the period 1993-1997. The specific emissions shown in the Maps refer to the whole urban area in the particular catchment area.

The highest emissions are found in the catchment areas of Thuringia and Saxony and in the lower and upper reaches of the Rhine. The cause of the high specific nutrient emissions lies, particularly for the Rhine area, on the one hand in the high proportion of combined sewer systems and in the general very high population density. On the other hand, the high emissions from urban areas in the Saxony and Thuringia regions are due to the high proportion of the population which is connected to sewers but not to a wastewater treatment plant.

Tables 4.19 to 4.22 present the results for the individual considered input paths from urban areas for the 25 principal catchment areas in the period 1983-1987 and 1993-1997 and the changes occurring over time. With the changes over time values are presented for the differentiated rainfall in the two study periods and for the flow normalised situation regarding the period 1983 to 1987.

Overall, one can conclude from this that P-inputs from the separate sewer system and combined sewer overflows have been reduced by about 41% since 1985. This is related to the reduction of specific P-emission of inhabitants of 3.3 (old German states) or 4.0 P/(E· a) (new German states) in 1985 to a uniform 1.8 g P/(E· a) in 1995. This can be attributed to the almost total substitution of phosphorus in washing detergents. A smaller factor is the reduction in

Table 4.20: Nitrogen inputs in German catchment areas via separate sewer systems (EUT_N) and combined sewer overflows (EUM_N) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	1983-1987			1993-97			Change	Discharge corrected change
		EUT_N	EUM_N	Sum	EUT_N	EUM_N	Sum		
		[t N/a]						[%]	
14902	Naab	8	80	90	11	60	70	*-14.8*	*-15.7*
16902	Isar	300	400	700	410	250	660	*-6.3*	*-7.6*
18902	Inn	90	110	190	140	80	220	*+15.5*	*+14.0*
19101	Danube	570	1,360	1,930	810	1,040	1,850	*-4.0*	*-5.7*
23704	Upper Rhine	210	380	590	270	300	570	*-3.6*	*-4.0*
23801	Neckar	40	1,120	1,160	39	890	930	*-19.2*	*-21.1*
24901	Main	130	1,450	1,580	140	1,020	1,170	*-26.3*	*-25.6*
26901	Mosel	37	280	320	49	260	310	*-2.8*	*-2.7*
27601	Ruhr	80	540	620	130	320	450	*-26.8*	*-27.0*
27801	Lippe	180	240	420	200	150	350	*-15.3*	*-16.7*
27903	Rhine	1,400	6,990	8,390	1,640	4,940	6,590	*-21.4*	*-21.4*
37602	Ems	440	100	540	490	70	560	*+2.5*	*+1.9*
41002	Werra	12	70	80	15	70	80	*-1.5*	*-4.1*
42001	Fulda	45	210	260	50	160	210	*-16.3*	*-16.3*
48901	Aller	870	190	1,050	960	110	1,070	*+2.0*	*+1.1*
49103	Weser	1,300	640	1,940	1,480	460	1,940	*0.0*	*-0.9*
53801	Schwarze Elster	45	26	70	80	20	100	*+34.3*	*+32.8*
54901	Mulde	12	180	190	60	190	250	*+27.6*	*+22.0*
56901	Saale	180	480	660	220	490	710	*+7.9*	*+4.8*
58901	Havel	680	420	1,100	750	450	1,190	*+8.9*	*+7.1*
59101	Elbe	1,100	1,400	2,500	1,420	1,360	2,790	*+11.4*	*+9.0*
69001	Odra	100	26	130	110	27	140	*+10.5*	*+9.9*
North Sea coast		2,550	580	3,140	2,910	370	3,290	*+4.8*	*+4.6*
Baltic Sea coast		370	90	470	650	80	730	*+57.0*	*+56.3*
North Sea total		**6,780**	**9,720**	**16,510**	**7,950**	**7,210**	**15,160**	***-8.2***	***-8.7***
Baltic Sea total		**470**	**120**	**590**	**760**	**110**	**870**	***+47.2***	***+46.5***
Black Sea		**570**	**1,370**	**1,930**	**810**	**1,040**	**1,860**	***-4.0***	***-5.7***
Germany		**7,820**	**11,210**	**19,030**	**9,530**	**8,360**	**17,890**	***-6.0***	***-6.7***

This is clearly shown with the nitrogen inputs through these pathways. As Table 4.20 shows, one can ascertain for the catchments of the old German states in which combined sewer systems predominate, a clear reduction in N-inputs of up to 35%. This is due to the increase in retention volumes in the combined sewers. On the other hand, in areas where separate sewer systems predominate, the reductions in nitrogen inputs are less than 10%. The size of the reductions is dependent on the changes in atmospheric N-deposition (see Section 4.1.2.1), so that in individual catchment areas such as the German part of the Inn, where in recent years an extensive increase in separate sewer systems is combined with a small increase in atmospheric N-deposition, an increase in N-inputs from both types of sewer system is determined.

inputs through the increase of retention volume in combined sewer systems and an increasing proportion of separate sewer systems.

Table 4.19: Phosphorus inputs in German catchment areas via separate sewer systems (EUT_P) and combined sewer overflows (EUM_P) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	1983-1987			1993-97			Change	Discharge corrected change
		EUT_P	EUM_P	Sum	EUT_P	EUM_P	Sum		
		[t P/a]						[%]	
14902	Naab	0.8	24	25	1	13	15	*-41.3*	*-42.0*
16902	Isar	25	120	140	35	50	90	*-40.5*	*-41.8*
18902	Inn	7	33	41	12	18	30	*-25.9*	*-27.4*
19101	Danube	49	410	460	70	220	290	*-36.9*	*-38.4*
23704	Upper Rhine	22	110	130	27	60	90	*-32.6*	*-32.9*
23801	Neckar	4	320	330	4	180	180	*-43.8*	*-45.1*
24901	Main	14	430	440	15	210	220	*-49.0*	*-48.5*
26901	Mosel	4	90	90	5	60	60	*-32.5*	*-32.4*
27601	Ruhr	6	160	160	10	60	70	*-54.2*	*-54.3*
27801	Lippe	13	70	80	15	30	45	*-46.0*	*-47.4*
27903	Rhine	120	2,050	2,170	140	1,010	1,150	*-47.0*	*-47.0*
37602	Ems	33	31	60	37	14	50	*-20.6*	*-21.7*
41002	Werra	1	30	31	1	16	17	*-43.9*	*-45.6*
42001	Fulda	4	60	70	4	35	39	*-42.4*	*-42.4*
48901	Aller	80	60	130	90	23	110	*-17.7*	*-19.1*
49103	Weser	110	200	310	130	100	230	*-27.8*	*-28.9*
53801	Schwarze Elster	5	12	16	8	5	13	*-20.8*	*-22.4*
54901	Mulde	1	80	80	6	43	49	*-36.9*	*-40.2*
56901	Saale	18	200	220	22	110	130	*-39.1*	*-41.2*
58901	Havel	70	170	240	80	90	170	*-27.5*	*-29.3*
59101	Elbe	110	580	690	150	300	450	*-34.9*	*-36.9*
69001	Odra	10	11	21	11	6	17	*-16.8*	*-17.7*
North Sea coast		190	180	370	220	80	300	*-18.8*	*-19.3*
Baltic Sea coast		38	39	80	60	18	80	*+5.7*	*+4.7*
North Sea total		**570**	**3,040**	**3,610**	**670**	**1,510**	**2,180**	***-39.6***	***-40.2***
Baltic Sea total		**48**	**50**	**100**	**70**	**24**	**100**	***+0.9***	***0.0***
Black Sea		**49**	**410**	**460**	**70**	**220**	**290**	***-36.9***	***-38.4***
Germany		**660**	**3,500**	**4,170**	**820**	**1,750**	**2,570**	***-38.4***	***-39.0***

For the catchment areas of the old German states with a very high proportion of separate sewer systems (Aller, Ems, North Sea coast), the reductions are naturally lower than for the areas with a very high proportion of combined sewers (Danube, Neckar, Main, Ruhr and Lippe). In comparison with the catchment areas in the old German states, the reductions in the inputs from these sources are low for catchments in the new German states with the exception of the Mulde and Saale. This is valid in particular for the Baltic Sea coast and Havel catchments. The comparatively small reductions of P-inputs are in large part due to the extension of sewer systems in the new German states.

For the catchments of the new German states, a general increase in N-inputs from sewer systems has been ascertained. This is attributable in all areas to an increase in connection grade to sewer systems in urban areas and their inhabitants. With exception of the Havel basin, the separate sewer system is preferred, so that in particular the N-inputs over this pathway increased despite clearly reduced atmospheric N-deposition. For the Havel, one must conclude that combined sewer systems have also increased so that here the N-inputs by both types of sewer system have increased. The greatest increase in N-inputs through sewer systems was about 50% for the Baltic Sea coast. This is due to a substantial increase in separate sewer systems.

For the whole of Germany there was a reduction of 41% for phosphorus and 8% for nitrogen for the sum of separate sewers and combined sewer overflows. For areas draining into the North Sea and Black Sea, the reductions for phosphorus (40% to 42%) and nitrogen (85% to 10%) were typical. For areas draining into the Baltic Sea the reductions in phosphorus inputs are 2% and for nitrogen there was an increase in input of more than 46%

The changes in nutrient inputs from inhabitants and paved urban areas with no sewer connection are shown in Tables 4.21 and 4.22.

For phosphorus emissions, there was a large decrease of 45% to 81%. This is once more the consequence of the reduction in inhabitant specific P-emissions and a further reduction in the areas and the number of inhabitants connected only to a sewer without wastewater treatment plant or neither sewer nor wastewater treatment plant.

As no change in specific emissions from inhabitants was considered for nitrogen, the reductions were often smaller and lie in the range from 8% to 86%. The hot-spots of emissions have hardly changed at all. The nutrient inputs over these pathways in the Saale also yet in the period 1993-1997 are about a quarter and in the Elbe more than half of the total German inputs.

For Saxony and Thuringia the cause for this is the high proportion of people still connected to a sewer but not to a wastewater treatment plant.

Table 4.21: Phosphorus inputs in German catchment areas via inhabitants and paved urban areas not connected to sewerage (EUN_P) or neither sewer nor WWTP connection (EUK_P) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	1983-1987			1993-97			Change	Discharge corrected change
		EUK_P	EUN_P	Sum	EUK_P	EUN_P	Sum		
		[t P/a]						[%]	
14902	Naab	33	5	37	11	1	12	*-67.5*	*-66.6*
16902	Isar	13	18	31	2	4	6	*-82.1*	*-77.9*
18902	Inn	20	16	36	2	5	6	*-83.2*	*-78.9*
19101	Danube	290	80	360	60	19	80	*-77.9*	*-76.1*
23704	Upper Rhine	34	10	44	8	3	11	*-74.6*	*-72.9*
23801	Neckar	31	3	34	9	1	10	*-69.9*	*-68.7*
24901	Main	280	9	290	60	3	60	*-78.2*	*-77.9*
26901	Mosel	370	5	380	90	3	100	*-74.7*	*-74.3*
27601	Ruhr	35	8	43	6	2	8	*-81.5*	*-79.5*
27801	Lippe	5	7	12	1	2	3	*-70.7*	*-64.4*
27903	Rhine	1,140	80	1,220	200	23	230	*-81.4*	*-80.7*
37602	Ems	0.9	20	21	0.6	6	6	*-68.9*	*-58.5*
41002	Werra	280	12	290	100	5	100	*-64.4*	*-64.0*
42001	Fulda	110	2	110	23	0.5	24	*-78.6*	*-78.5*
48901	Aller	90	8	100	16	2	18	*-81.0*	*-80.2*
49103	Weser	510	39	550	140	11	160	*-71.8*	*-71.2*
53801	Schwarze Elster	70	60	130	30	13	43	*-65.7*	*-62.7*
54901	Mulde	410	80	490	130	20	150	*-69.3*	*-68.2*
56901	Saale	1,040	150	1,190	430	31	460	*-61.0*	*-60.3*
58901	Havel	39	210	250	13	48	60	*-75.3*	*-69.7*
59101	Elbe	1,870	640	2,510	720	150	870	*-65.4*	*-63.7*
69001	Odra	18	46	60	10	23	33	*-48.3*	*-45.1*
North Sea coast		49	80	130	8	19	26	*-79.0*	*-74.0*
Baltic Sea coast		33	130	170	34	22	60	*-66.6*	*-62.8*
North Sea total		**3,570**	**860**	**4,430**	**1,080**	**210**	**1,280**	***-71.0***	***-69.6***
Baltic Sea total		**50**	**180**	**230**	**43**	**45**	**90**	***-61.5***	***-57.9***
Black Sea		**290**	**80**	**360**	**60**	**19**	**80**	***-77.9***	***-76.0***
Germany		**3,910**	**1,110**	**5,020**	**1,180**	**270**	**1,450**	***-71.1***	***-69.5***

Table 4.22: Nitrogen inputs in German catchment areas via inhabitants and paved urban areas not connected to sewerage (EUN_N) or neither sewer nor WWTP connection (EUK_N) in the periods 1983-1987 and 1993-1997 and their changes.

ADDR.	River/Basin	1983-1987			1993-97			Change	Discharge corrected change
		EUK_N	EUN_N	Sum	EUK_N	EUN_N	Sum		
		[t N/a]						[%]	
14902	Naab	120	49	170	100	23	120	*-31.0*	*-26.5*
16902	Isar	49	190	240	14	80	100	*-59.9*	*-48.4*
18902	Inn	80	180	260	11	110	120	*-54.2*	*-41.2*
19101	Danube	1,090	800	1,890	520	430	950	*-49.8*	*-42.3*
23704	Upper Rhine	130	130	260	50	80	130	*-48.5*	*-42.0*
23801	Neckar	120	27	150	70	25	100	*-33.1*	*-26.9*
24901	Main	1,040	100	1,140	510	60	570	*-49.8*	*-48.0*
26901	Mosel	1,400	60	1,460	790	70	870	*-40.4*	*-38.9*
27601	Ruhr	130	90	220	47	60	100	*-53.4*	*-45.0*
27801	Lippe	20	70	90	11	50	60	*-36.3*	*-19.6*
27903	Rhine	4,310	890	5,190	1,720	550	2,260	*-56.4*	*-53.1*
37602	Ems	4	220	220	2	140	140	*-35.1*	*-14.3*
41002	Werra	1,060	90	1,150	870	100	970	*-15.2*	*-12.6*
42001	Fulda	410	25	440	200	11	210	*-51.2*	*-50.4*
48901	Aller	330	90	420	140	45	180	*-56.7*	*-53.3*
49103	Weser	1,930	390	2,320	1,250	240	1,500	*-35.6*	*-32.3*
53801	Schwarze Elster	250	440	690	260	280	540	*-22.1*	*-10.5*
54901	Mulde	1,530	610	2,130	1,130	430	1,560	*-26.9*	*-21.1*
56901	Saale	3,880	1,130	5,010	3,740	670	4,420	*-11.9*	*-8.0*
58901	Havel	150	1,600	1,750	110	1,060	1,170	*-33.2*	*-16.1*
59101	Elbe	6,990	4,940	11,930	6,210	3,250	9,460	*-20.7*	*-13.1*
69001	Odra	70	560	640	60	540	600	*-6.0*	*+0.8*
North Sea coast		200	910	1,110	50	480	530	*-52.4*	*-40.3*
Baltic Sea coast		120	1,170	1,290	290	470	760	*-41.2*	*-30.8*
North Sea total		**13,430**	**7,350**	**20,780**	**9,240**	**4,660**	**13,900**	***-33.1***	***-26.7***
Baltic Sea total		**200**	**1,730**	**1,930**	**350**	**1,010**	**1,360**	***-29.6***	***-20.4***
Black Sea		**1,090**	**810**	**1,900**	**530**	**430**	**960**	***-49.7***	***-42.1***
Germany		**14,720**	**9,890**	**24,610**	**10,120**	**6,100**	**16,210**	***-34.1***	***-27.4***

4.1.2.7 Total nutrient inputs via diffuse sources

In Sections 4.1.2.1 to 4.1.2.6, the results of the estimation of nutrient emissions by the individual diffuse pathways were given. In the following, an overview of the total diffuse nutrient inputs and their changes will be presented. A comparison with the results of other authors regarding these inputs is given in Section 4.1.5.

Nitrogen

The results for the diffuse nitrogen inputs are shown in Tables 4.23 to 4.25, Figures 4.5 and 4.6 and Maps 4.17 and 4.18.

For the diffuse nitrogen emissions the main part of the inputs will be caused only through the groundwater and tile drainage pathways in all catchment areas and both considered time periods. For the whole of Germany, these pathways contribute 67% and 21% respectively to the total diffuse N-inputs into the surface water. The groundwater contribution ranges from 39% (Baltic Sea coast) to 90% (Naab). Accordingly, the lowest and highest N-emissions from tile drainage are in the Naab and Baltic Sea coast area with 0% and 50% respectively. Of the remaining diffuse input pathways, a figure of more than 10% (11% to 20%) is found for urban area emissions in the new German states. On the basis of the high proportion of lakes in the Baltic Sea coast and Havel catchments, inputs through atmospheric deposition are high in comparison to other catchments with 4.5% and 6.7% respectively.

In the period 1993 to 1997 the highest specific diffuse nitrogen inputs were found in the Lippe and Ems catchments with more than 30 kg N/(ha· a). For the Isar, Inn and North Sea coast catchments, specific diffuse N-inputs between 20 and 22 kg N/(ha· a) were estimated. For the Danube, Neckar, Werra, Mulde and Saale the values were between 18 and 20 kg N/(ha· a). The lowest values for Germany were estimated for the Havel and Odra catchments with 7 and 8 kg N/(ha· a) respectively.

The total diffuse nitrogen input for German catchments is 586,000 t N/a for the period 1993 to 1997. For the 1983 to 1987 period, a figure of 653,000 t N/a was estimated. This represents a reduction of 10% between the two considered periods. Using the same hydrological conditions, as for the 1983-1987 period, the reduction in diffuse nitrogen inputs would be 9%. The greatest reduction (22%) was determined for the Baltic Sea coast area.

With the exception of the Werra catchment, a reduction of diffuse N-inputs of 10% to 15% was determined for all catchments in the new German states as well as the Lippe and Ruhr. On the other hand, flow-normalised reductions in the Danube, Ems, Weser and North Sea coast catchment areas were the lowest at less than 5%. If one calculates separately the changes in emission pathways dominated by agriculture (groundwater, tile drainage, erosion and surface runoff), one can discern on average smaller decreases than for the total diffuse N-inputs. In the Naab, the catchment with the highest proportion of groundwater N-input, a smaller increase in the agricultural influenced diffuse N-inputs was estimated.

Table 4.23: Diffuse nitrogen inputs in German catchment areas in the period 1993-1997.

ADDR.	River/Basin	EGW_N	EDR_N	EAD_N	EER_N	ERO_N	EUR_N	ED_N
		[t N/a]						
14902	Naab	6,990	50	100	330	100	190	7,770
16902	Isar	12,780	2,650	360	220	810	750	17,560
18902	Inn	12,980	1,570	330	270	1,150	340	16,650
19101	Danube	78,090	16,600	1,440	2,490	4,190	2,800	105,610
23704	Upper Rhine	12,890	1,480	420	510	1,460	700	17,470
23801	Neckar	18,960	5,610	140	710	650	1,030	27,100
24901	Main	32,980	3,070	340	2,100	530	1,740	40,760
26901	Mosel	11,670	950	120	290	500	1,180	14,710
27601	Ruhr	4,810	170	140	25	590	550	6,280
27801	Lippe	8,620	5,180	130	140	260	410	14,750
27903	Rhine	122,750	22,340	2,300	4,610	5,110	8,850	165,970
37602	Ems	21,850	4,530	250	210	460	700	28,000
41002	Werra	7,550	810	60	320	170	1,050	9,960
42001	Fulda	8,680	950	110	190	270	430	10,630
48901	Aller	14,800	8,560	310	560	490	1,260	25,980
49103	Weser	45,820	13,910	740	1,400	1,380	3,440	66,690
53801	Schwarze Elster	2,860	1,930	140	60	42	630	5,670
54901	Mulde	6,840	3,920	100	490	180	1,810	13,340
56901	Saale	23,360	10,560	380	1,610	390	5,130	41,430
58901	Havel	9,000	3,830	1,110	130	100	2,360	16,520
59311	Elbe	57,270	30,340	2,700	2,830	890	12,250	106,290
69001	Odra	1,740	1,100	90	100	22	740	3,800
North Sea coast		54,000	16,160	1,510	210	1,290	3,820	77,000
Baltic Sea coast		12,600	16,410	1,470	430	200	1,490	32,600
North Sea total		**301,690**	**87,280**	**7,510**	**9,270**	**9,140**	**29,060**	**443,940**
Baltic Sea total		**14,340**	**17,510**	**1,560**	**530**	**220**	**2,230**	**36,390**
Black Sea		**78,390**	**16,600**	**1,440**	**2,490**	**4,200**	**2,810**	**105,940**
Germany		**394,430**	**121,390**	**10,510**	**12,290**	**13,560**	**34,100**	**586,280**

The reduction of agriculturally influenced N-inputs is attributed in all areas to a strong reduction in drainage inputs. Again, these are the result of reduced N-surpluses in agricultural land. In contrast to the groundwater pathway, tile drainage N-inputs show the effects of lower N-surpluses very quickly. Regarding the groundwater N-inputs, in the next decade, according to the performance of the model, clear reductions due to lower N-surpluses are to be expected.

The emissions from all diffuse pathways presented in map 4.17 and 4.18 clearly show a tendency towards a reduction for nitrogen for both 1983-1987 and 1993-1997, in particular a decrease in the proportion of catchment areas with specific N-inputs of more than 30 kg N/(ha· a). In relation to that, the Maps show also that inside the catchments considered in the Tables, there are clear differences regarding diffuse N-inputs. These are often caused by the dominance of individual input pathways in some sub-areas. Only for the north west German area of the Ems, Vechte and Lippe catchment areas, the high to very high N-inputs over the individual pathways give an almost isolated area with the highest specific N-inputs into the rivers.

Table 4.24: Diffuse nitrogen inputs in German catchment areas in the period 1983-1987.

ADDR.	River/Basin	EGW_N	EDR_N	EAD_N	EER_N	ERO_N	EUR_N	ED_N
		[t N/a]						
14902	Naab	8,230	60	160	300	150	260	9,170
16902	Isar	11,370	3,360	420	210	770	940	17,070
18902	Inn	13,120	2,060	330	240	980	450	17,170
19101	Danube	79,400	21,110	1,790	2,340	4,090	3,830	112,560
23704	Upper Rhine	14,160	2,100	520	500	1,590	840	19,710
23801	Neckar	20,520	7,150	130	700	590	1,300	30,390
24901	Main	34,870	3,880	470	1,990	680	2,720	44,610
26901	Mosel	13,310	1,190	130	290	480	1,780	17,170
27601	Ruhr	5,010	210	200	32	730	830	7,010
27801	Lippe	8,240	6,680	170	150	260	510	16,010
27903	Rhine	132,580	28,690	2,760	4,570	5,660	13,580	187,840
37602	Ems	19,080	5,690	310	210	370	770	26,430
41002	Werra	7,600	1,270	90	340	170	1,230	10,720
42001	Fulda	9,680	1,200	150	200	360	700	12,280
48901	Aller	16,400	10,750	380	570	400	1,480	29,980
49103	Weser	50,060	17,740	960	1,460	1,340	4,270	75,820
53801	Schwarze Elster	3,270	3,010	240	70	19	760	7,380
54901	Mulde	6,710	6,170	170	520	110	2,330	16,010
56901	Saale	21,990	16,630	600	1,620	310	5,670	46,820
58901	Havel	9,270	6,030	1,610	120	27	2,840	19,910
59311	Elbe	53,760	47,460	4,060	2,880	570	14,430	123,160
69001	Odra	1,670	1,740	130	100	13	760	4,420
North Sea coast		52,770	20,810	1,960	210	1,130	4,250	81,130
Baltic Sea coast		11,840	25,030	2,080	430	140	1,760	41,280
North Sea total		**308,240**	**120,400**	**10,040**	**9,330**	**9,080**	**37,290**	**494,380**
Baltic Sea total		**13,510**	**26,780**	**2,210**	**530**	**160**	**2,520**	**45,700**
Black Sea		**79,680**	**21,110**	**1,790**	**2,340**	**4,110**	**3,830**	**112,880**
Germany		**401,430**	**168,290**	**14,050**	**12,200**	**13,350**	**43,650**	**652,970**

Table 4.25: Changes in diffuse nitrogen inputs in German catchment areas between 1983-1987 and 1993-1997.

ADDR.	River/Basin	$EGW_N+EDR_N+EER_N+ERO_N$		EAD_N+EUR_N		ED_N	
		Change	Discharge corrected change	Change	Discharge corrected change	Change	Discharge corrected change
		[%]					
14902	Naab	*-14.5*	*+1.7*	*-31.0*	*-29.7*	*-15.2*	*+0.3*
16902	Isar	*+4.7*	*-3.3*	*-18.4*	*-17.1*	*+2.9*	*-4.4*
18902	Inn	*-2.5*	*+0.3*	*-14.1*	*-10.1*	*-3.0*	*-0.2*
19101	Danube	*-5.2*	*-2.6*	*-24.5*	*-23.0*	*-6.2*	*-3.6*
23704	Upper Rhine	*-10.9*	*-6.4*	*-17.7*	*-16.8*	*-11.3*	*-7.1*
23801	Neckar	*-10.5*	*-8.4*	*-18.6*	*-19.9*	*-10.8*	*-8.9*
24901	Main	*-6.6*	*-6.1*	*-34.9*	*-34.2*	*-8.6*	*-8.1*
26901	Mosel	*-12.1*	*-4.9*	*-31.9*	*-30.9*	*-14.3*	*-7.7*
27601	Ruhr	*-6.5*	*-8.3*	*-33.0*	*-31.5*	*-10.4*	*-11.8*
27801	Lippe	*-7.3*	*-13.3*	*-20.3*	*-18.9*	*-7.8*	*-13.5*
27903	Rhine	*-9.7*	*-7.4*	*-31.7*	*-31.0*	*-11.6*	*-9.4*
37602	Ems	*+6.7*	*-2.3*	*-11.4*	*-9.6*	*+5.9*	*-2.6*
41002	Werra	*-5.8*	*-0.2*	*-15.9*	*-13.9*	*-7.0*	*-1.9*
42001	Fulda	*-11.8*	*-0.6*	*-35.8*	*-35.7*	*-13.5*	*-3.0*
48901	Aller	*-13.2*	*-7.9*	*-15.7*	*-16.5*	*-13.3*	*-8.4*
49103	Weser	*-11.5*	*-4.0*	*-20.0*	*-19.5*	*-12.0*	*-5.1*
53801	Schwarze Elster	*-23.2*	*-14.6*	*-22.7*	*-14.8*	*-23.1*	*-14.6*
54901	Mulde	*-15.4*	*-14.1*	*-23.5*	*-19.0*	*-16.7*	*-14.9*
56901	Saale	*-11.4*	*-11.1*	*-12.1*	*-9.4*	*-11.5*	*-10.9*
58901	Havel	*-15.5*	*-10.7*	*-22.1*	*-16.2*	*-17.0*	*-11.9*
59311	Elbe	*-12.7*	*-13.2*	*-19.1*	*-14.7*	*-13.7*	*-13.4*
69001	Odra	*-15.9*	*-15.1*	*-7.0*	*-2.3*	*-14.1*	*-12.5*
North Sea coast		*-4.3*	*-4.8*	*-14.2*	*-11.5*	*-5.1*	*-5.3*
Baltic Sea coast		*-20.8*	*-22.3*	*-22.9*	*-19.6*	*-21.0*	*-22.0*
North Sea total		***-8.9***	***-7.5***	***-22.8***	***-20.3***	***-10.2***	***-8.7***
Baltic Sea total		***-20.4***	***-21.6***	***-19.9***	***-16.4***	***-20.4***	***-21.1***
Black Sea		***-5.2***	***-2.6***	***-24.5***	***-23.0***	***-6.1***	***-3.6***
Germany		***-9.0***	***-7.6***	***-22.7***	***-20.2***	***-10.2***	***-8.7***

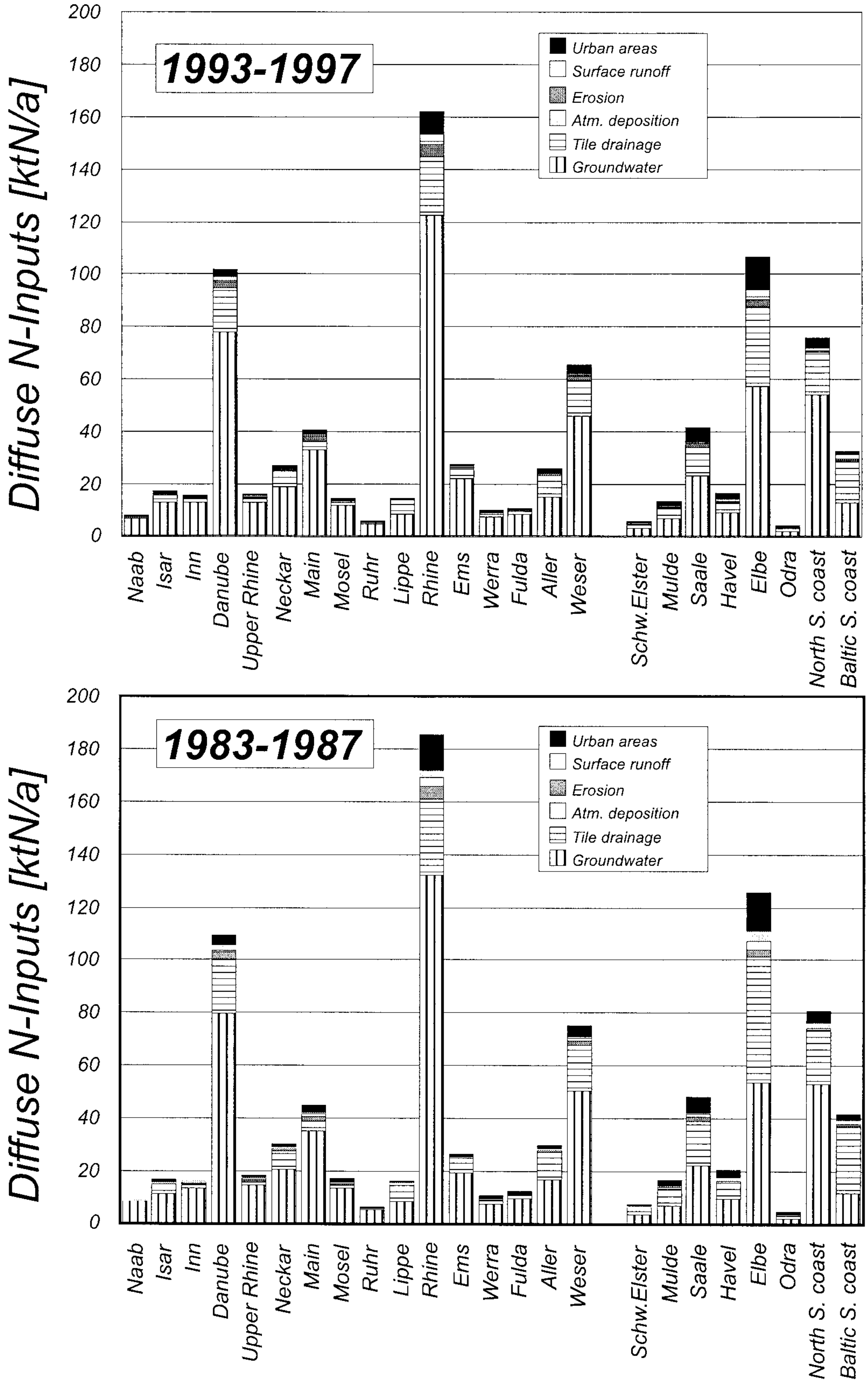


Figure 4.5: Nitrogen inputs in German catchment areas via diffuse pathways for the periods 1983-1987 and 1993-1997.

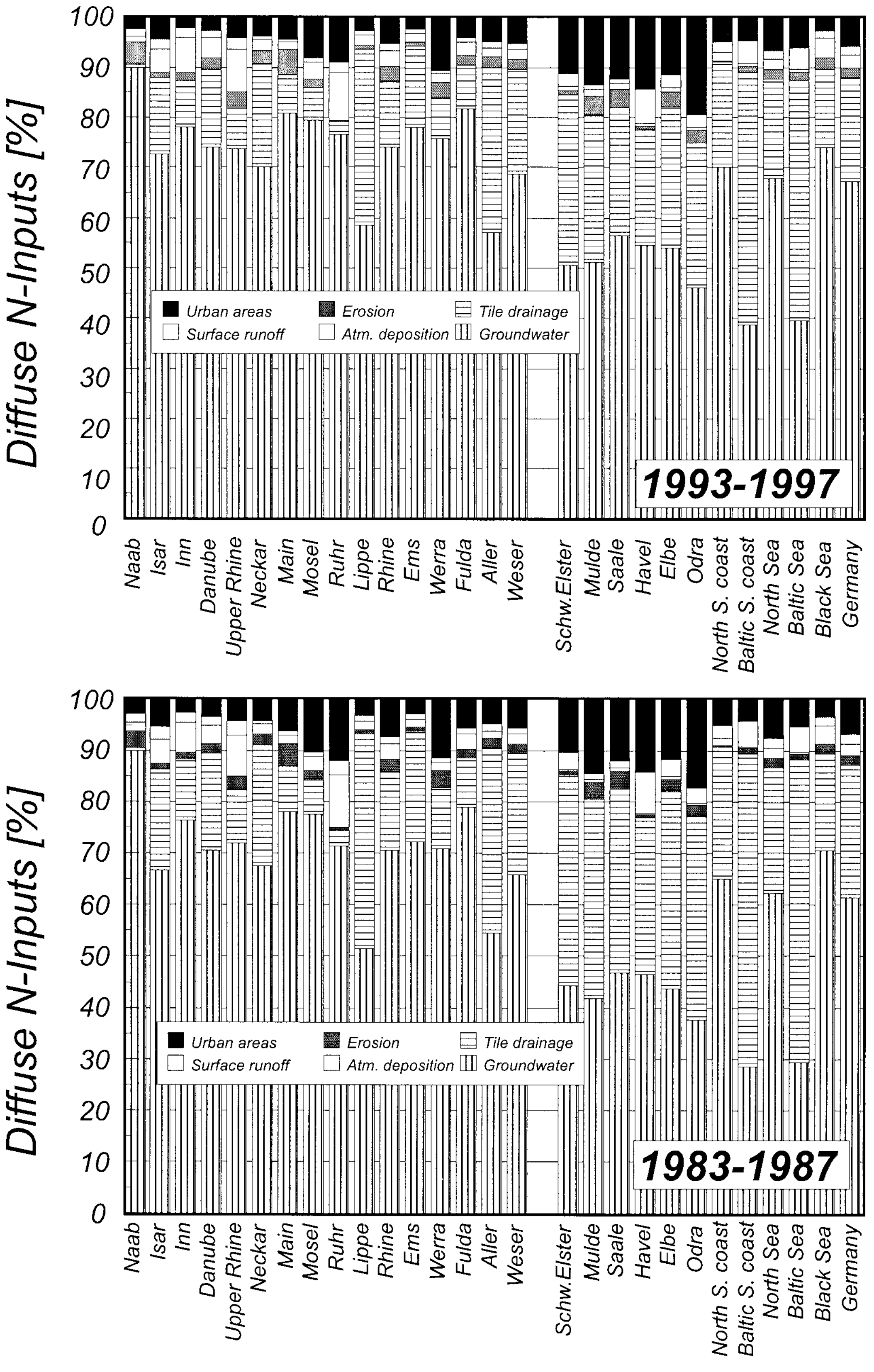


Figure 4.6: Proportion of the various diffuse pathways to the total nitrogen inputs in German catchment areas for the periods 1983-1987 and 1993-1997.

Phosphorus

The results for diffuse phosphorus inputs are shown in Tables 4.26 to 4.28, Figures 4.7 and 4.8 as well as Maps 4.19 and 4.20.

Diffuse phosphorus inputs show a different picture to that for nitrogen. With an average of 33%, erosion was the dominant diffuse pathway. The percentage input from this pathway ranged from 3% (North Sea coast area) to 64% (Main). Groundwater was the second most important pathway with a German average of 23%. This figure showed much variation between individual catchment areas ranging from low figures of 6% for the Saale and 7% for the Mulde to 64% for the Ems. The total P-emissions through tile drainage, surface runoff and urban areas lie between 13% and 16% of the total. The roles of the individual pathways show much variation from catchment to catchment.

In the 1993 to 1997 period, the highest specific diffuse P-inputs were found in the Ems and North Sea coast catchment areas with more than 1 kg P/(ha· a). In the Isar, Inn, upper Rhine, Mulde and Saale, specific diffuse P-inputs of 0.8 to 0.9 kg P/(ha· a) were determined. On the other hand, values of under 0.4 kg P/(ha· a) were found for the Schwarze Elster, Havel and North Sea coast catchments and a little under 0.4 kg P/(ha· a) for the German area of the Odra.

The calculations give a figure of 24,600 t P/a for the total diffuse phosphorus inputs in German catchment areas in the period 1993 to 1997 and 29,600 t P/a for 1983 to 1987. This represents a reduction of 17% between the two periods. Assuming the same hydrological conditions, as found in the 1983-1987 period, this reduction would be 16%. Reductions of more than 30% were determined in the Mosel, Mulde and Werra catchment areas. In the Danube, Ems, Aller and North Sea coast catchments, the reduction in diffuse P-inputs was less than 10%.

If the changes of the mainly agriculture-influenced pathways of diffuse P-emissions (groundwater, tile drainage, erosion and surface runoff) were calculated separately, an overall increase in these inputs of 0.3% to 6% can be determined under the assumption of the same flow conditions in all catchment areas. This increase is largely attributable to the increased P-emissions by erosion resulting from an further increase in P-content of top-soils in arable land.

Since the other agriculture-influenced flow-normalised diffuse P-inputs have not changed, the overall reduction in diffuse P-inputs is almost certainly attributable to reduced inputs from urban areas.

In the 1983 to 1987 period, P-inputs from urban areas were the most important pathway with 9,200 t P/a or 33% of the total German diffuse emissions. In the catchments of the new German states as well as the Mosel and Ruhr, 50% or even more of the diffuse P-inputs are estimated to enter by this pathway.

Table 4.26: Diffuse phosphorus inputs in German catchment areas in the period 1993-1997.

ADDR.	River/Basin	EGW_P	EDR_P	EAD_P	EER_P	ERO_P	EUR_P	ED_P
		[t P/a]						
14902	Naab	47	0	2	150	22	27	240
16902	Isar	110	21	6	260	150	90	640
18902	Inn	130	14	6	300	190	36	670
19101	Danube	590	90	29	1,910	810	370	3,790
23704	Upper Rhine	130	9	11	350	370	100	960
23801	Neckar	90	17	3	450	210	190	960
24901	Main	200	13	8	1,190	160	290	1,860
26901	Mosel	100	13	3	120	130	160	530
27601	Ruhr	60	1	2	22	140	80	310
27801	Lippe	50	20	2	120	70	48	310
27903	Rhine	850	100	46	2,770	1,320	1,380	6,460
37602	Ems	670	90	4	110	110	60	1,040
41002	Werra	49	5	1	150	60	120	380
42001	Fulda	70	5	2	120	70	60	330
48901	Aller	130	260	6	450	160	130	1,130
49103	Weser	530	360	14	1,000	410	380	2,690
53801	Schwarze Elster	50	15	4	50	16	60	200
54901	Mulde	39	17	2	260	70	200	590
56901	Saale	110	32	9	1,000	140	600	1,890
58901	Havel	380	34	29	100	31	230	810
59311	Elbe	1,000	160	70	1,740	320	1,320	4,620
69001	Odra	50	7	3	70	7	50	190
North Sea coast		1,770	2,370	26	160	240	330	4,880
Baltic Sea coast		270	90	39	350	70	140	950
North Sea total		**4,820**	**3,070**	**160**	**5,770**	**2,400**	**3,460**	**19,700**
Baltic Sea total		**330**	**100**	**41**	**420**	**70**	**190**	**1,150**
Black Sea		**590**	**90**	**29**	**1,910**	**810**	**370**	**3,800**
Germany		**5,740**	**3,260**	**230**	**8,100**	**3,290**	**4,020**	**24,640**

On the other hand, these P-inputs were reduced by about 55% to 4,000 t P/a by the mid-nineties. This is a consequence of the extensive elimination of phosphorus as a component of washing detergents. Without the P-free washing detergents, the P-inputs from urban areas, considering the P-inputs from combined sewer overflows and people with only or no sewer connection, would have been 6,800 t P/a by 1995. This means that 54% or 2,800 t P/a of the reduction in P-inputs from urban areas is due to the lack of phosphorus in washing detergents. The remaining 46% or 2,400 t P/a is from the increase in retention volumes of mixed sewer systems or the improvement of removal grade of municipal wastewater treatment plants.

Table 4.27: Diffuse phosphorus inputs in German catchment areas in the period 1983-1987.

ADDR.	River/Basin	EGW_P	EDR_P	EAD_P	EER_P	ERO_P	EUR_P	ED_P
		[t P/a]						
14902	Naab	60	0	3	120	18	60	260
16902	Isar	100	24	7	230	120	180	660
18902	Inn	140	15	6	250	140	80	630
19101	Danube	670	100	30	1,660	620	820	3,900
23704	Upper Rhine	130	11	11	320	360	180	1,010
23801	Neckar	90	17	3	410	180	360	1,070
24901	Main	200	13	9	1,060	150	730	2,150
26901	Mosel	110	13	3	120	110	470	830
27601	Ruhr	60	0,9	2	24	120	200	410
27801	Lippe	45	18	2	110	48	90	320
27903	Rhine	880	100	48	2,560	1,230	3,390	8,210
37602	Ems	840	80	4	100	70	80	1,180
41002	Werra	50	4	3	150	34	330	570
42001	Fulda	80	5	2	120	70	180	460
48901	Aller	200	270	6	420	100	230	1,220
49103	Weser	710	380	16	960	280	860	3,210
53801	Schwarze Elster	60	13	7	50	4	140	280
54901	Mulde	40	14	5	260	24	570	910
56901	Saale	110	29	17	960	70	1,410	2,600
58901	Havel	390	30	50	90	6	490	1,070
59311	Elbe	950	140	130	1,680	120	3,200	6,230
69001	Odra	50	7	5	60	3	80	210
North Sea coast		2,180	2,610	29	140	160	500	5,620
Baltic Sea coast		290	80	60	330	32	240	1,040
North Sea total		**5,560**	**3,320**	**230**	**5,440**	**1,870**	**8,040**	**24,450**
Baltic Sea total		**340**	**90**	**70**	**390**	**35**	**330**	**1,250**
Black Sea		**680**	**100**	**30**	**1,660**	**620**	**830**	**3,910**
Germany		**6,580**	**3,510**	**330**	**7,490**	**2,520**	**9,190**	**29,620**

Maps 4.19 and 4.20 give an overview of the regional differentiation of diffuse P-inputs and their change since the mid-eighties. The number of catchment areas with more than 2 kg P/(ha· a) from these inputs has clearly declined. These high specific diffuse P-inputs are found, with the exception of the central part of Berlin, only in the catchments in which bog soils are intensively used for agriculture.

Table 4.28: Changes in diffuse phosphorus inputs in German catchment areas between 1983-1987 and 1993-1997.

ADDR.	River/Basin	$EGW_N+EDR_N+EER_N+ERO_N$		EAD_N+EUR_N		ED_N	
		Change	Discharge corrected change	Change	Discharge corrected change	Change	Discharge corrected change
		[%]					
14902	Naab	*+9.9*	*+5.7*	*-55.0*	*-54.7*	*-6.2*	*-9.3*
16902	Isar	*+13.8*	*+3.7*	*-46.3*	*-46.6*	*-2.8*	*-10.1*
18902	Inn	*+15.7*	*+3.1*	*-49.5*	*-48.4*	*+7.0*	*-3.7*
19101	Danube	*+11.3*	*+4.3*	*-53.3*	*-53.3*	*-2.8*	*-8.3*
23704	Upper Rhine	*+2.6*	*+2.3*	*-40.9*	*-40.8*	*-5.5*	*-5.7*
23801	Neckar	*+8.8*	*+4.2*	*-45.9*	*-47.0*	*-9.9*	*-13.3*
24901	Main	*+10.3*	*+5.6*	*-59.9*	*-59.5*	*-13.7*	*-16.7*
26901	Mosel	*+3.8*	*+2.5*	*-66.1*	*-65.8*	*-36.0*	*-36.4*
27601	Ruhr	*+9.2*	*+1.3*	*-59.3*	*-59.0*	*-24.9*	*-28.8*
27801	Lippe	*+14.7*	*+5.3*	*-48.2*	*-48.6*	*-4.3*	*-11.0*
27903	Rhine	*+5.5*	*+4.0*	*-58.6*	*-58.4*	*-21.3*	*-22.1*
37602	Ems	*-10.0*	*+1.0*	*-31.1*	*-29.8*	*-11.6*	*-1.3*
41002	Werra	*+6.2*	*+3.1*	*-62.4*	*-62.1*	*-33.1*	*-34.3*
42001	Fulda	*-3.2*	*+3.3*	*-64.1*	*-64.1*	*-27.5*	*-23.6*
48901	Aller	*+1.2*	*+3.9*	*-43.3*	*-44.0*	*-7.3*	*-5.3*
49103	Weser	*-1.3*	*+3.4*	*-55.1*	*-55.1*	*-16.1*	*-12.7*
53801	Schwarze Elster	*+7.1*	*+2.6*	*-59.9*	*-57.6*	*-28.9*	*-29.7*
54901	Mulde	*+14.3*	*+4.4*	*-64.7*	*-64.2*	*-35.5*	*-38.9*
56901	Saale	*+9.4*	*+3.6*	*-57.5*	*-57.2*	*-27.3*	*-29.7*
58901	Havel	*+5.1*	*+1.2*	*-51.4*	*-49.7*	*-23.7*	*-24.7*
59311	Elbe	*+11.2*	*+3.0*	*-58.3*	*-57.5*	*-25.9*	*-29.3*
69001	Odra	*+12.1*	*+3.9*	*-40.9*	*-38.8*	*-9.9*	*-13.8*
North Sea coast		*-11.1*	*+0.3*	*-32.8*	*-31.7*	*-13.2*	*-2.7*
Baltic Sea coast		*+6.1*	*+3.2*	*-42.6*	*-40.8*	*-8.2*	*-9.8*
North Sea total		***-0.7***	***+2.4***	***-56.2***	***-55.7***	***-19.5***	***-17.2***
Baltic Sea total		***+7.0***	***+3.3***	***-42.2***	***-40.4***	***-8.5***	***-10.5***
Black Sea		***+11.4***	***+4.3***	***-53.2***	***-53.3***	***-2.8***	***-8.3***
Germany		***+1.4***	***+2.7***	***-55.3***	***-54.8***	***-16.8***	***-15.8***

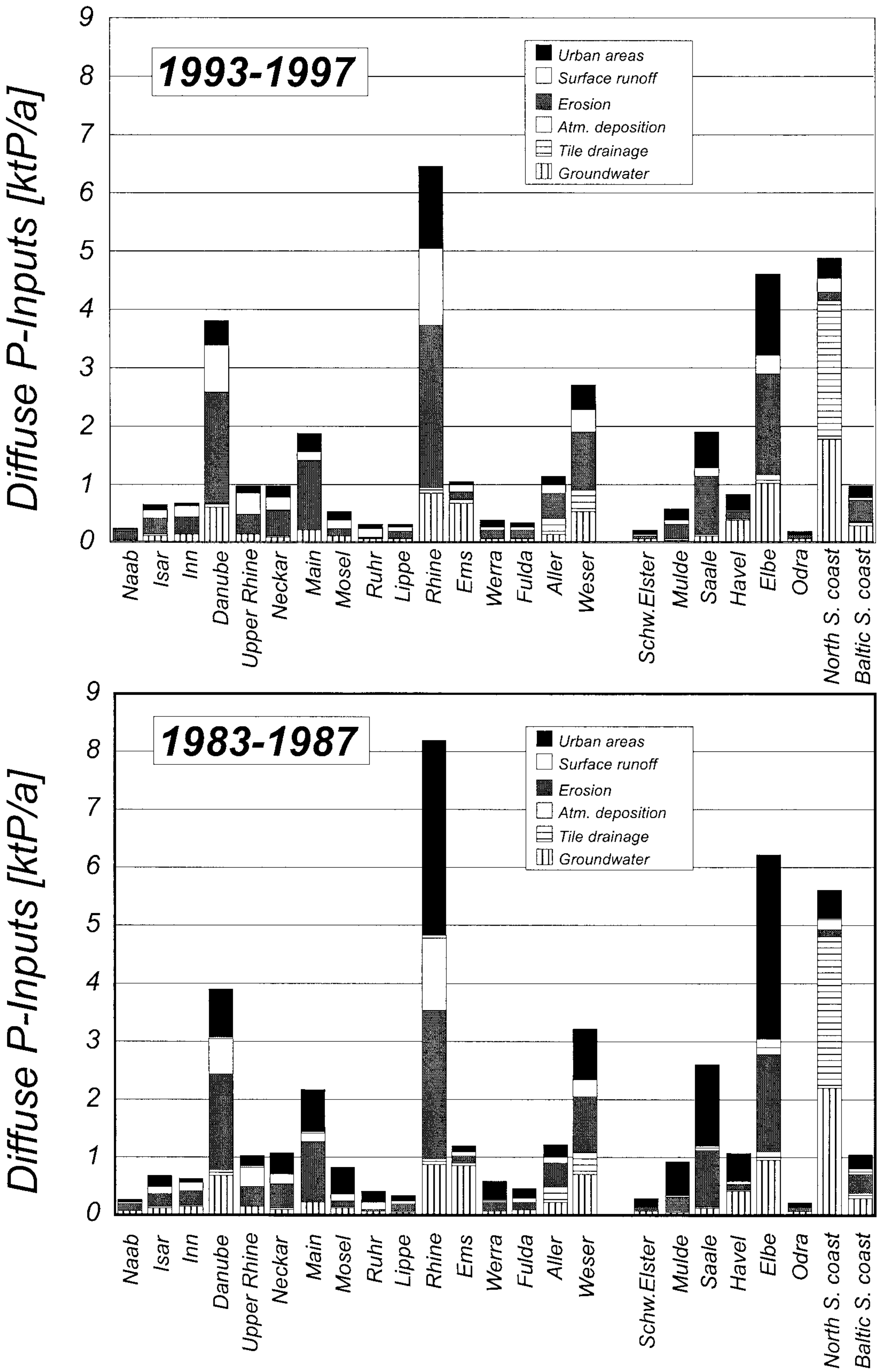


Figure 4.7: Phosphorus inputs in German catchment areas via diffuse pathways for the periods 1983-1987 and 1993-1997.

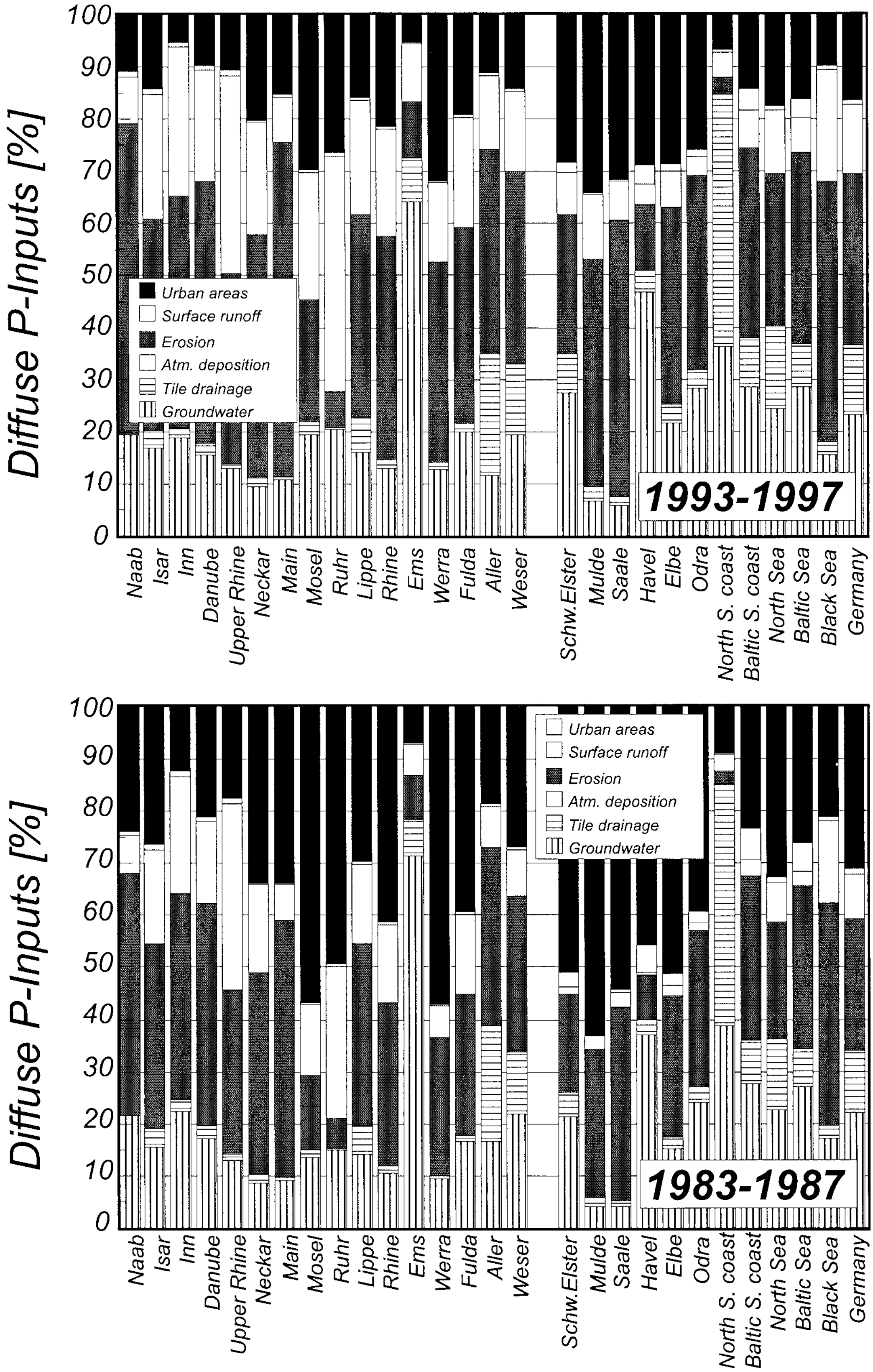


Figure 4.8: Proportion of the various diffuse pathways to the total phosphorus inputs in German catchment areas for the periods 1983-1987 and 1993-1997.

4.1.3 Total nutrient inputs via diffuse and point sources

The results for individual emission pathways were given in Sections 4.1.1.1 to 4.1.2.7. In the following, an overview will be given of nutrient inputs and their changes in German catchment areas since the mid-eighties.

Nitrogen

N-inputs in German catchment areas for the periods 1983-1987 and 1993-1997 are shown in Table 4.29, Figures 4.9 and 4.10 as well as Maps 4.21 and 4.22.

Table 4.29: Diffuse (ED_N) and total (EG_N) nitrogen inputs in German catchment areas in the periods 1983-1987 and 1993-1997 and changes in total nitrogen inputs.

ADDR.	River/Basin	1983-1987			1993-1997			Change in EG_N	Discharge corrected change in EG_N
		ED_N	EG_N	Portion ED_N	ED_N	EG_N	Portion ED_N		
		[t N/a]		[%]	[t N/a]		[%]	[%]	
14902	Naab	9,170	10,820	*84.7*	7,770	9,000	*86.3*	*-16.8*	*-3.7*
16902	Isar	17,070	26,600	*64.2*	17,560	25,600	*68.6*	*-3.8*	*-8.4*
18902	Inn	17,170	24,360	*70.5*	16,650	19,940	*83.5*	*-18.1*	*-16.1*
19101	Danube	112,560	150,090	*75.0*	105,610	131,300	*80.4*	*-12.5*	*-10.6*
23704	Upper Rhine	19,710	34,670	*56.9*	17,470	25,440	*68.7*	*-26.6*	*-24.2*
23801	Neckar	30,390	61,040	*49.8*	27,100	44,230	*61.3*	*-27.5*	*-26.6*
24901	Main	44,610	80,680	*55.3*	40,760	63,160	*64.5*	*-21.7*	*-21.4*
26901	Mosel	17,170	26,560	*64.7*	14,710	19,730	*74.6*	*-25.7*	*-21.5*
27601	Ruhr	7,010	13,180	*53.2*	6,280	12,300	*51.1*	*-6.7*	*-7.5*
27801	Lippe	16,010	22,800	*70.2*	14,750	20,060	*73.5*	*-12.0*	*-16.0*
27903	Rhine	187,840	395,550	*47.5*	165,970	277,720	*59.8*	*-29.8*	*-28.7*
37602	Ems	26,430	35,210	*75.1*	28,000	33,270	*84.1*	*-5.5*	*-11.9*
41002	Werra	10,720	12,460	*86.0*	9,960	11,000	*90.6*	*-11.7*	*-7.3*
42001	Fulda	12,280	15,520	*79.2*	10,630	13,960	*76.1*	*-10.0*	*-1.8*
48901	Aller	29,980	42,910	*69.9*	25,980	33,110	*78.5*	*-22.8*	*-19.4*
49103	Weser	75,820	107,020	*70.8*	66,690	85,050	*78.4*	*-20.5*	*-15.6*
53801	Schw. Elster	7,380	9,650	*76.5*	5,670	7,240	*78.3*	*-24.9*	*-18.4*
54901	Mulde	16,010	28,280	*56.6*	13,340	18,410	*72.5*	*-34.9*	*-33.9*
56901	Saale	46,820	84,850	*55.2*	41,430	58,680	*70.6*	*-30.8*	*-30.5*
58901	Havel	19,910	42,850	*46.5*	16,520	26,830	*61.6*	*-37.4*	*-35.0*
59311	Elbe	123,160	219,250	*56.2*	106,290	147,520	*72.0*	*-32.7*	*-32.6*
69001	Odra	4,420	7,890	*56.1*	3,800	6,440	*58.9*	*-18.3*	*-17.4*
North Sea coast		81,130	116,040	*69.9*	77,000	98,560	*78.1*	*-15.1*	*-15.2*
Baltic Sea coast		41,280	53,190	*77.6*	32,600	38,410	*84.9*	*-27.8*	*-28.5*
North Sea total		**494,380**	**873,070**	***56.6***	**443,940**	**642,120**	***69.1***	**-26.5**	**-25.6**
Baltic Sea total		**45,700**	**61,070**	***74.8***	**36,390**	**44,850**	***81.1***	**-26.6**	***-27.1***
Black Sea		**112,880**	**150,430**	***75.0***	**105,940**	**131,650**	***80.5***	**-12.5**	**-10.6**
Germany		**652,970**	**1,084,580**	***60.2***	**586,280**	**818,630**	***71.6***	**-24.5**	**-23.6**

The total nitrogen input into the German parts of all river basins was 819 kt N/a for the 1993-1997 period. Of this total, 71.6% came from diffuse sources. In comparison with the earlier study period, this proportion represents an increase of more than 10%, although the diffuse nitrogen inputs have decreased. In the period 1983-1987, total nitrogen inputs were 1,085 kt N/a or about 266 kt N/a higher. That means that total nitrogen inputs decreased 25% between the two studied periods. Assuming the same hydrological conditions as for the 1983-1987 period, this decrease would be 24%. The greatest decreases of 30% to 35% were estimated for the Mulde, Saale and Havel catchments as well the German part of the Elbe river basin. Overall one must conclude that for nitrogen, the goal of an overall 50% reduction in inputs from 1985 or 1987 was not achieved for any German catchment area.

As shown in Figure 4.10 and Table 4.29, the proportion of total nitrogen emissions from point source nitrogen inputs was comparatively high at 30% to 40% in catchments with urban agglomerations (Isar, Neckar, Main, Ruhr, Rhine, Saale und Havel). For the Ruhr, Rhine, Havel and Odra, these point source emissions were greater than from groundwater, the dominant diffuse input pathway. On the other hand the proportion of point source N-inputs in the Naab, Inn, Danube, Ems, Werra catchments and the Baltic Sea coast area was low at 10% to 20%.

The highest area-specific N-inputs were calculated for the Lippe and Ems catchments with 44 and 36 kg N/(ha· a) respectively. The reason is the very high diffuse N-inputs. Specific inputs of over 30 kg N/(ha· a) were also determined for the Neckar and Isar. However, in these catchments, the high proportion of point source discharges is an important component of total emissions. The lowest area-specific N-inputs, 11-14 kg N/(ha· a) were determined for the Schwarze Elster and Havel catchments as well as the German part of the Odra basin. As shown in Maps 4.21 and 4.22 the low values for the Schwarze Elster and Havel are the results of different input sources coming together. The N-inputs in the parts of the Schwarze Elster (Große Elster, upper Schwarze Elster) and Spree with consolidated rocks are fairly high. In addition, the Berlin agglomeration is clearly shown as a loading hot-spot. Also for most of the larger German catchment areas, a differentiation of areas in terms of the size of area-specific N-inputs is shown in Table 4.29. Catchment areas in north-western Germany along the Netherlands border have the highest nitrogen inputs and north-eastern flatlands, the lowest.

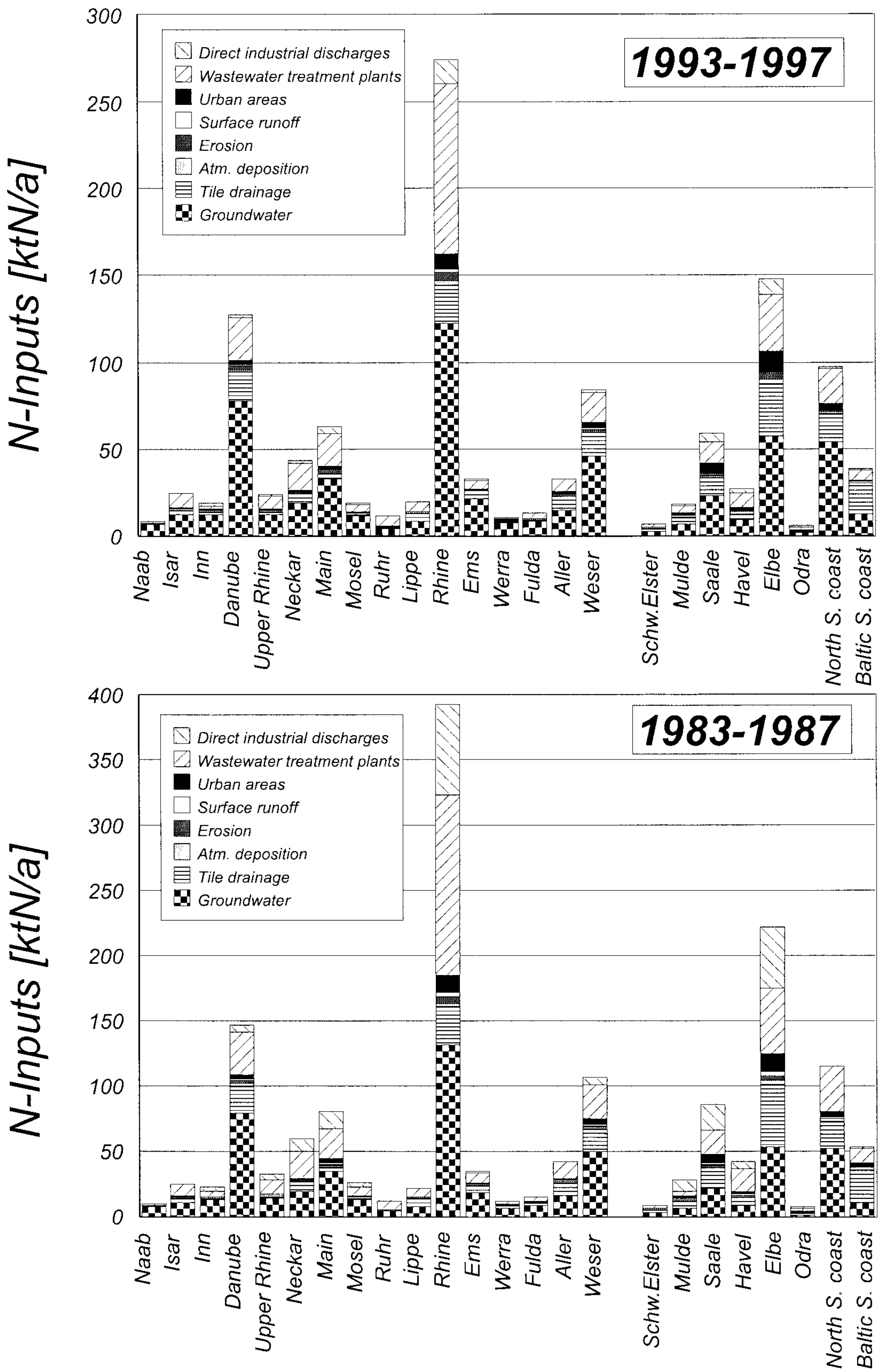


Figure 4.9: Nitrogen inputs in German catchment areas via point and diffuse inputs in the periods 1983-1987 and 1993-1997.

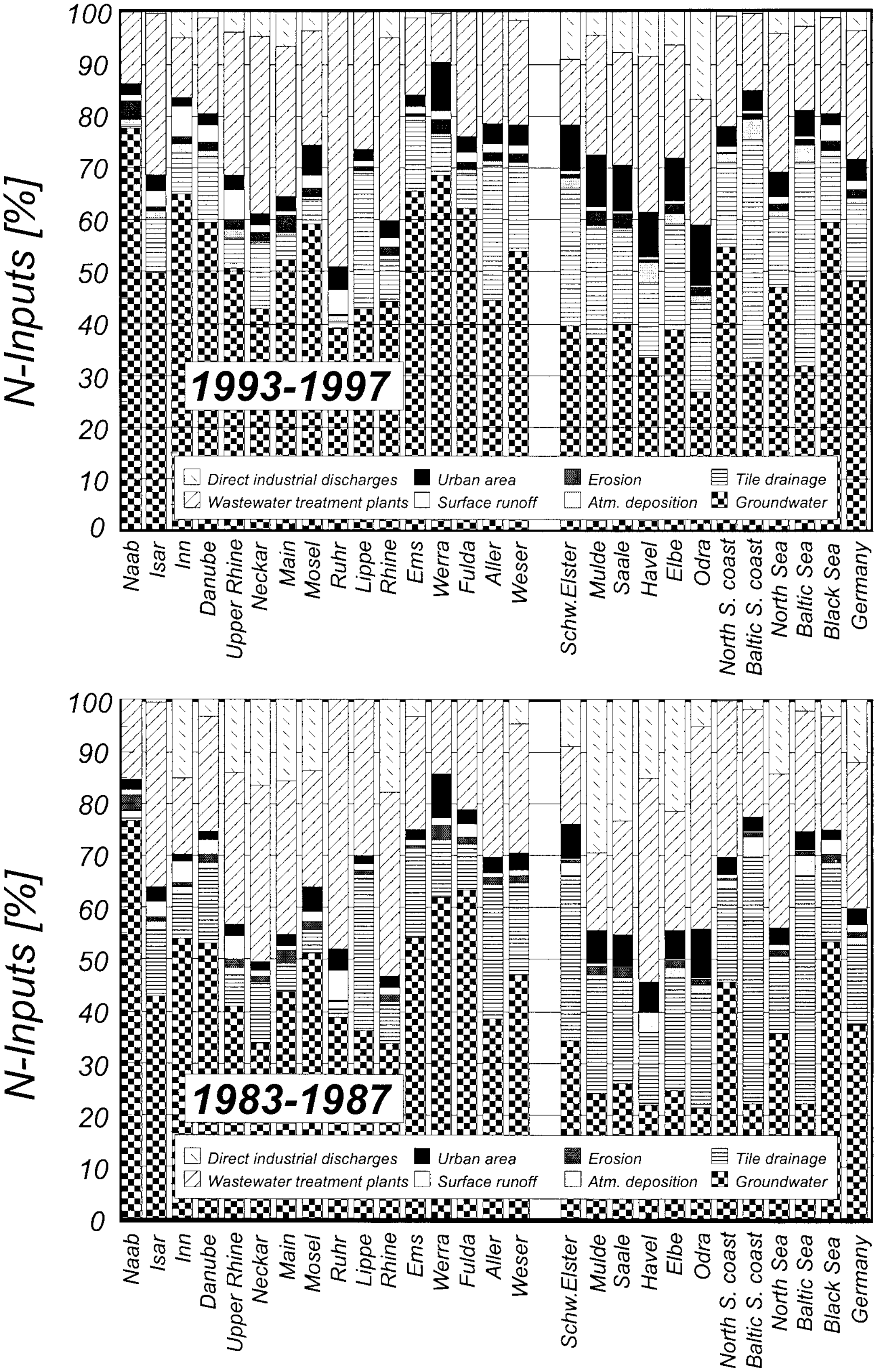


Figure 4.10: Proportions of different pathways to the total nitrogen inputs in German catchment areas in the periods 1983-1987 and 1993-1997.

Phosphorus

Phosphorus emissions in the German parts of the river basins are shown in Table 4.30, Figures 4.11 and 4.12 as well as Maps 4.23 and 4.24 for the period 1983-1987 and 1993-1997.

A total phosphorus input for German catchment areas of 37.25 kt P/a was determined for the period 1983-1987 and 1993-1997. Of this total, 66.1% came from diffuse sources. The diffuse P-inputs more than doubled since the 1983-1987 period.

Table 4.30: Diffuse (ED_P) and total (EG_P) phosphorus inputs in German catchment areas in the periods 1983-1987 and 1993-1997 and changes in total nitrogen inputs.

ADDR.	River/Basin	1983-1987			1993-1997			Change in EG_P	Discharge corrected change in EG_P
		ED_P	EG_P	Portion ED_P	ED_P	EG_P	Portion ED_P		
		[t P/a]		*[%]*	[t P/a]		*[%]*	*[%]*	
14902	Naab	260	610	*42.9*	240	350	*70.2*	*-42.7*	*-44.0*
16902	Isar	660	2,540	*26.1*	640	940	*68.7*	*-63.1*	*-65.0*
18902	Inn	630	1,660	*37.7*	670	890	*75.6*	*-46.6*	*-50.7*
19101	Danube	3,900	10,630	*36.7*	3,790	5,300	*71.5*	*-50.1*	*-52.1*
23704	Upper Rhine	1,010	2,670	*38.0*	960	1,400	*68.4*	*-47.5*	*-47.5*
23801	Neckar	1,070	5,550	*19.3*	960	1,840	*52.4*	*-66.9*	*-67.6*
24901	Main	2,150	7,340	*29.3*	1,860	2,970	*62.5*	*-59.5*	*-60.4*
26901	Mosel	830	2,250	*36.7*	530	990	*53.5*	*-56.2*	*-56.3*
27601	Ruhr	410	1,550	*26.7*	310	570	*54.1*	*-63.0*	*-64.0*
27801	Lippe	320	1,530	*21.0*	310	520	*59.0*	*-66.0*	*-67.4*
27903	Rhine	8,210	37,550	*21.9*	6,460	12,040	*53.7*	*-67.9*	*-68.1*
37602	Ems	1,180	2,600	*45.3*	1,040	1,300	*80.4*	*-50.1*	*-45.4*
41002	Werra	570	1,090	*52.5*	380	470	*81.3*	*-56.8*	*-57.4*
42001	Fulda	460	1,060	*43.1*	330	520	*63.2*	*-50.6*	*-49.0*
48901	Aller	1,220	3,620	*33.7*	1,130	1,610	*70.1*	*-55.4*	*-54.7*
49103	Weser	3,210	8,510	*37.7*	2,690	3,810	*70.6*	*-55.2*	*-53.9*
53801	Schw. Elster	280	790	*35.3*	200	300	*65.5*	*-61.7*	*-62.0*
54901	Mulde	910	2,370	*38.4*	590	1,160	*50.5*	*-51.0*	*-52.3*
56901	Saale	2,600	7,460	*34.8*	1,890	2,790	*67.6*	*-62.6*	*-63.4*
58901	Havel	1,070	4,000	*26.6*	810	1,260	*64.4*	*-68.4*	*-68.7*
59311	Elbe	6,230	18,800	*33.2*	4,620	7,160	*64.5*	*-61.9*	*-63.0*
69001	Odra	210	750	*28.5*	190	410	*47.5*	*-46.0*	*-47.1*
North Sea coast		5,620	11,300	*49.7*	4,880	6,000	*81.3*	*-46.9*	*-41.7*
Baltic Sea coast		1,040	3,380	*30.8*	950	1,220	*78.5*	*-64.0*	*-64.5*
North Sea total		**24,450**	**78,770**	***31.0***	**19,700**	**30,320**	***65.0***	***-61.5***	***-60.8***
Baltic Sea total		**1,250**	**4,130**	***30.4***	**1,150**	**1,620**	***70.7***	***-60.7***	***-61.3***
Black Sea		**3,910**	**10,640**	***36.7***	**3,800**	**5,310**	***71.5***	***-50.1***	***-52.1***
Germany		**29,620**	**93,540**	***31.7***	**24,640**	**37,250**	***66.2***	***-60.2***	***-59.9***

However, as already shown in the previous section, diffuse P-inputs have been reduced by about 10%. Overall, phosphorus inputs were reduced by 56.3kt P/a or about 60%. Assuming the same hydrological conditions as found in 1983-1987, this decline remains at 60%. The greatest reductions of 65% to 70% were reached in the catchments of the Isar, Neckar, Lippe, the German part of the Rhine as well as the Havel and the Baltic Sea coast area. Overall, one can conclude that the goal of a 50% reduction in total phosphorus inputs of 50% from 1985 or 1987 levels was achieved for most of the large catchment areas. This goal was only barely achieved in the Naab, the German part of the Rhine above Karlsruhe, the Ems, the German part of the Odra and the North Sea coast area.

As shown in Figure 4.12 and Table 4.30, the proportion of point source P-discharges in the total is comparatively high at 45% to 50% in a few catchment areas (Neckar, Mosel, Ruhr, Rhine, Mulde). In most catchments and Germany as a whole, point sources, particularly wastewater treatment plants, are the dominant pathway of P-emissions. The proportion from point sources is less than 25% only in the Inn, Ems ans Werra catchments and the North Sea and Baltic Sea areas.

The largest area-specific P-inputs of 1.5 and 1.7 kg P/(ha· a) respectively were calculated for the North Sea coast and Mulde catchments. The causes are different for these two areas. The high value for the North Sea coast is caused by the particularly high proportion of agricultural areas on drained bog soils. In the Mulde catchment on the other hand, the large discharges from municipal wastewater treatment plants and urban areas leads to the highest area-specific P-inputs. Specific P-inputs in the Neckar and Ems catchments are also high at over 1.3 kg P/(ha· a). For the Ems this is attributed to groundwater inputs from agricultural land on bog soils and for the Neckar to inputs from municipal wastewater treatment plants. The lowest area-specific P-inputs of 0.5 to 0.6 kg P/(ha· a) were determined for the catchments of the Schwarze Elster and Havel as well as the Baltic Sea coast area. In the Havel and Baltic Sea catchments this is in apparent contradiction with the very high eutrophication in these areas. This contradiction is resolved if one considers flow conditions in addition to the P-inputs. An average annual P-concentration can be calculated from the average specific P-inputs and the average flow contributions. This gives values of 0.27 mg P/l for the Baltic Sea coast and 0.37 mg P/l for the Havel. This is only in the mid-zone of possible P-concentrations which range from 0.13 mg P/l for the Inn to 0.73 mg/l for the Saale.

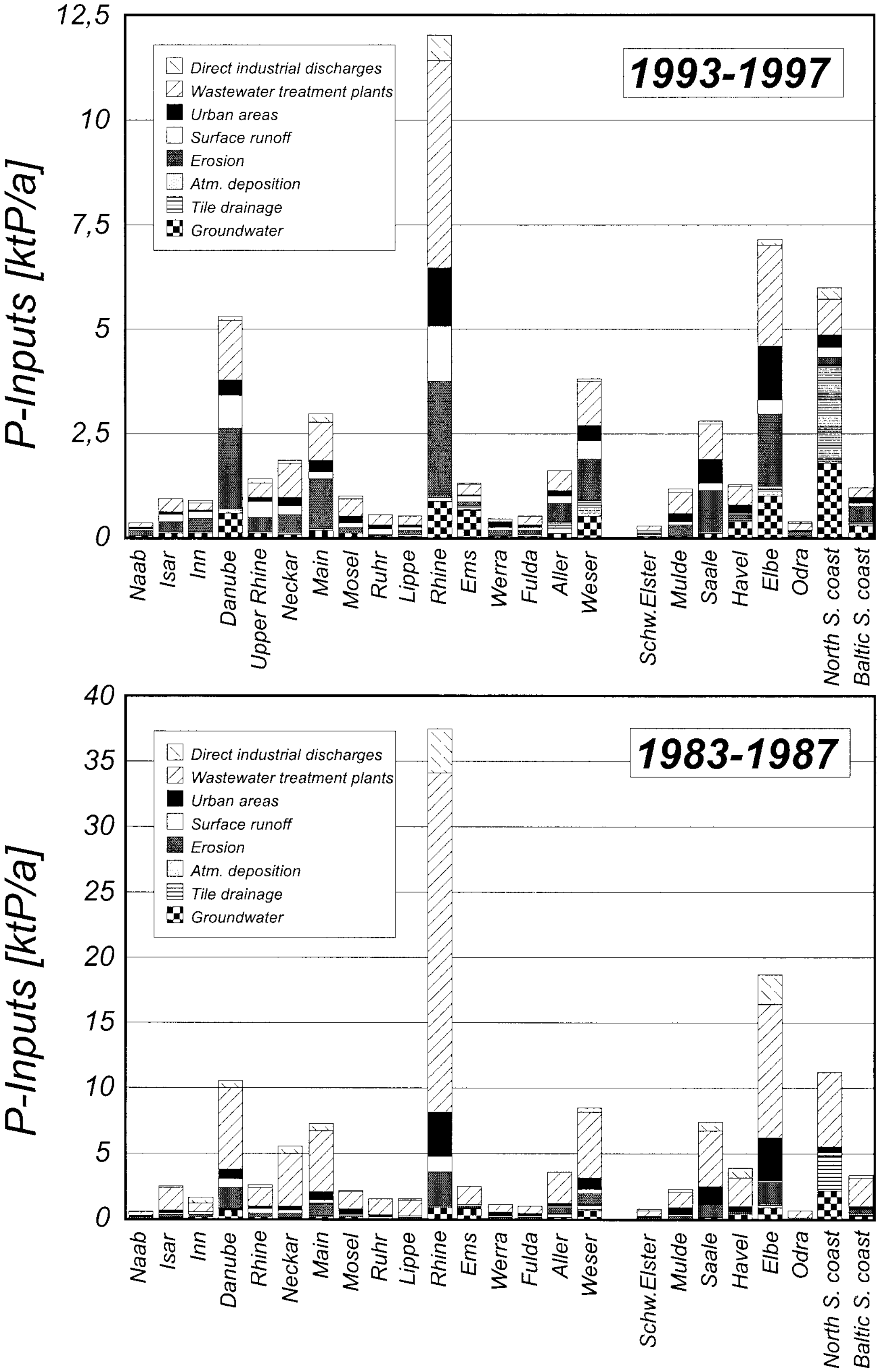
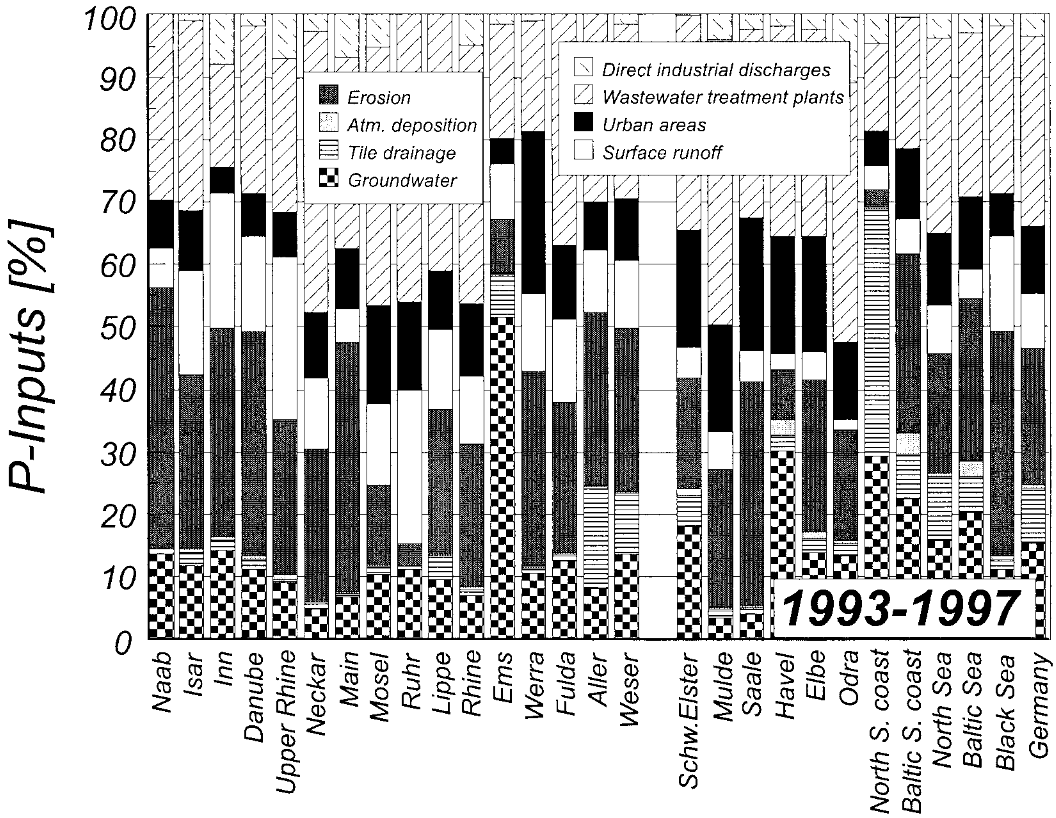


Figure 4.11: Phosphorus inputs in German catchment areas via point and diffuse inputs in the periods 1983-1987 and 1993-1997.



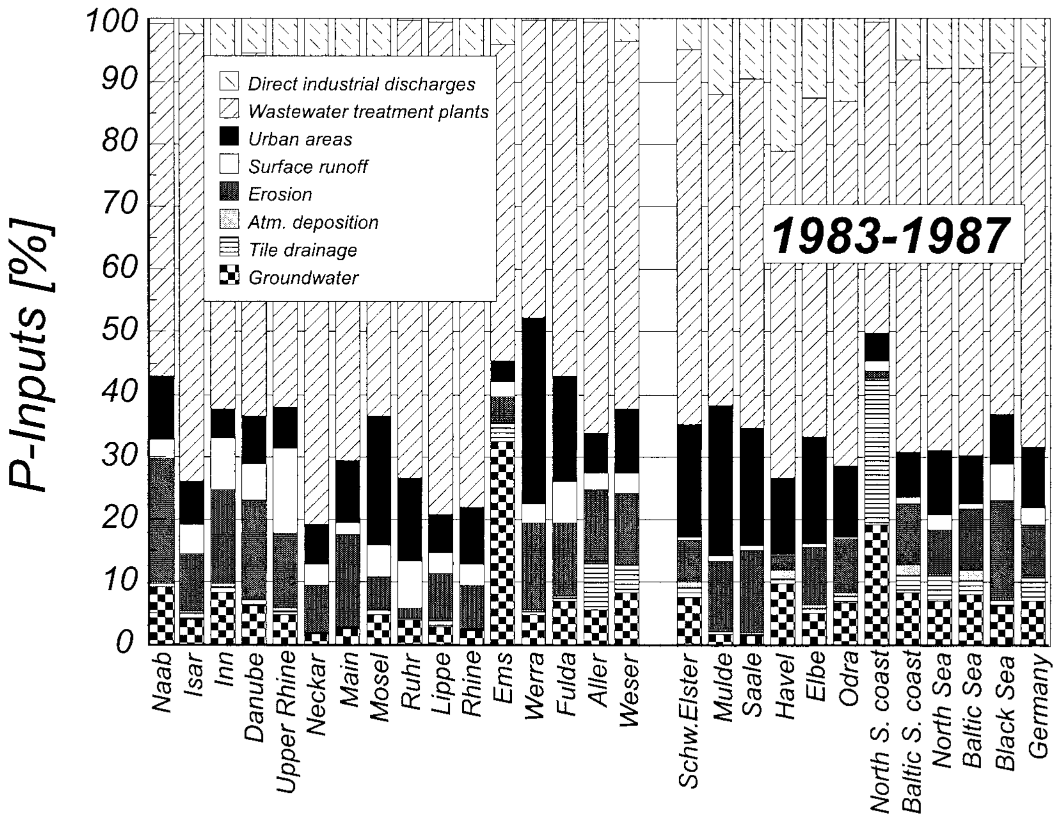


Figure 4.12: Proportions of different pathways to the total phosphorus inputs in German catchment areas in the periods 1983-1987 and 1993-1997.

It should be noted that these annual P-concentrations do not represent measured P-concentrations at a monitoring station since the internal retention processes of a water-body are not yet included. Further one should consider that with low flows and the large numbers of lakes water residence times are relatively large which results in conditions particularly favourable for growth of phytoplankton.

As shown in Maps 4.23 and 4.24, the phosphorus emissions of the larger catchment areas are the result of the coming together of very different inputs in parts of the catchments. So as shown in Map 4.24, the specific P-emissions for the 1993-1997 period, areas which stand out have very high point source P-loadings as a result of greater populations (Isar, Neckar around Stuttgart, lower Main, Berlin) or comparatively poor waste-water treatment (Mulde, Saale around Halle and Leipzig and Saar) and also areas with high diffuse P-inputs (Ems, North Sea coast between the Ems and Weser, rivers in the Alps).

4.1.4 Nutrient inputs under consideration of sources in other countries

Up to now, only the nutrient inputs in the German parts of the river basins have been presented. A proportion of the catchments have sources in other countries. It is therefore necessary to estimate the inputs in these foreign areas for a comparison of nutrient loadings and their changes (see Section 4.2). For this, the same approaches will be used as for the German areas. In cases where the data base for the areas in other countries is not available, the basic data from the German areas is used. For nutrient surpluses in these foreign areas, it can be concluded that in Austria, Switzerland and France, similarly high surpluses and changes occurred as in the German states. On the other hand, for the part of the Elbe catchment in the Czech Republic, an analogous development to that of the new German states is considered.

The results on point source discharges and diffuse nutrient inputs in the German part and in the total basins are presented in Tables 4.31 and 4.32 for catchments with more than 10% in other countries. No estimates for the entire Odra area are given since studies on diffuse and point source nutrient inputs in the Polish and Czech parts of the catchment have not yet been completed. Figures 4.13 to 4.15 give an overview regarding the total nutrient inputs through individual nutrient pathways in the entire catchments of the Danube, Rhine and Elbe and also their changes since the mid-eighties. Figures 4.14 and 4.16 show the point source and diffuse inputs for the German and foreign parts of these catchment areas as well as their changes.

Nitrogen

Total nitrogen emission in the Danube basin in the period 1993-1997 was 153.7 ktN/a. In comparison with the period 1983 to 1987 the decrease of nitrogen emissions was about 26 kt N/a or 16.4% (flow normalised). The point discharges from Austria are small with only 3% (4.3 kt N/a) of inputs to the whole catchment. A total of 11.8% (18.2 kt N/a) of all diffuse

N-inputs in the Danube upstream Jochenstein come from the Austrian, Swiss and Italian parts of the catchment area. This is less than the proportion of the catchment lying within these countries. This is due to the clearly lower proportion of agricultural land in these areas.

Table 4.31: Point source (EP_N) and diffuse (ED_N) nitrogen inputs in 1983-1987 and 1993-1997 in catchment areas with more than 10% outside Germany and changes in total inputs (EG_N) based on hydrological conditions found in 1983-1987.

ADDR.	River/Basin	1983-97				1993-97				Change	
		ED_N		EP_N		ED_N		EP_N		EG_N	
		Germany	Other countries	Germany	Other countries	Germany	Other countries	Germany	Other countries	Germany	Other countries
		[t N/a]								*[%]*	
16902	Isar	17,070	1,140	9,530	120	17,560	1,160	8,040	110	*-8.4*	*-11.5*
18902	Inn	17,170	19,680	7,190	6,210	16,650	14,990	3,290	3,910	*-16.1*	*-16.9*
19101	Danube	112,560	22,790	37,530	6,570	105,610	18,190	25,690	4,250	*-10.6*	*-16.4*
23704	Upper Rhine	19,710	62,840	14,960	41,180	17,470	55,250	7,960	24,120	*-24.2*	*-20.7*
26901	Mosel	17,170	35,170	9,390	33,860	14,710	30,460	5,020	12,000	*-21.5*	*-34.5*
27903	Rhine	187,840	98,380	207,700	75,030	165,970	86,050	111,750	36,120	*-28.7*	*-27.1*
59311	Elbe	123,160	76,720	96,090	32,580	106,290	64,060	41,230	22,210	*-32.6*	*-13.9*

Total nitrogen emissions in the Rhine basin in the period 1993-1997 was 400 kt N/a. This represents a reduction of 169 kt N/a or 28% since the mid-eighties. In the Swiss and French parts of the catchment, reductions are attributed to a decrease in inputs from point discharges. In the 1993-1997 period, 9% (36.1 kt N/a) of all point source N-emissions were caused in parts of the basins outside Germany. For diffuse N-inputs, the figure is 21.5% (86.9 kt N/a) for these areas which is only a little less than the proportion of the catchment in these areas. This is, as for phosphorus, attributed to the higher proportion of agricultural land in the Swiss part of the Rhine catchment. For the Mosel, the specific N-emissions in the French part are about the same as in the German part.

For the Elbe basin, total nitrogen emissions of 233.8 kt N/a are estimated for the period 1993 to 1997. This is a decrease of 95 kt N/a or 29% since the mid-eighties. About 9.5 % (22.2 kt N/a) of total point source discharges and 27.5% of diffuse N-inputs came from the Czech part of the basin. Area-specific diffuse N-inputs are almost identical in the Czech and German parts of the catchment.

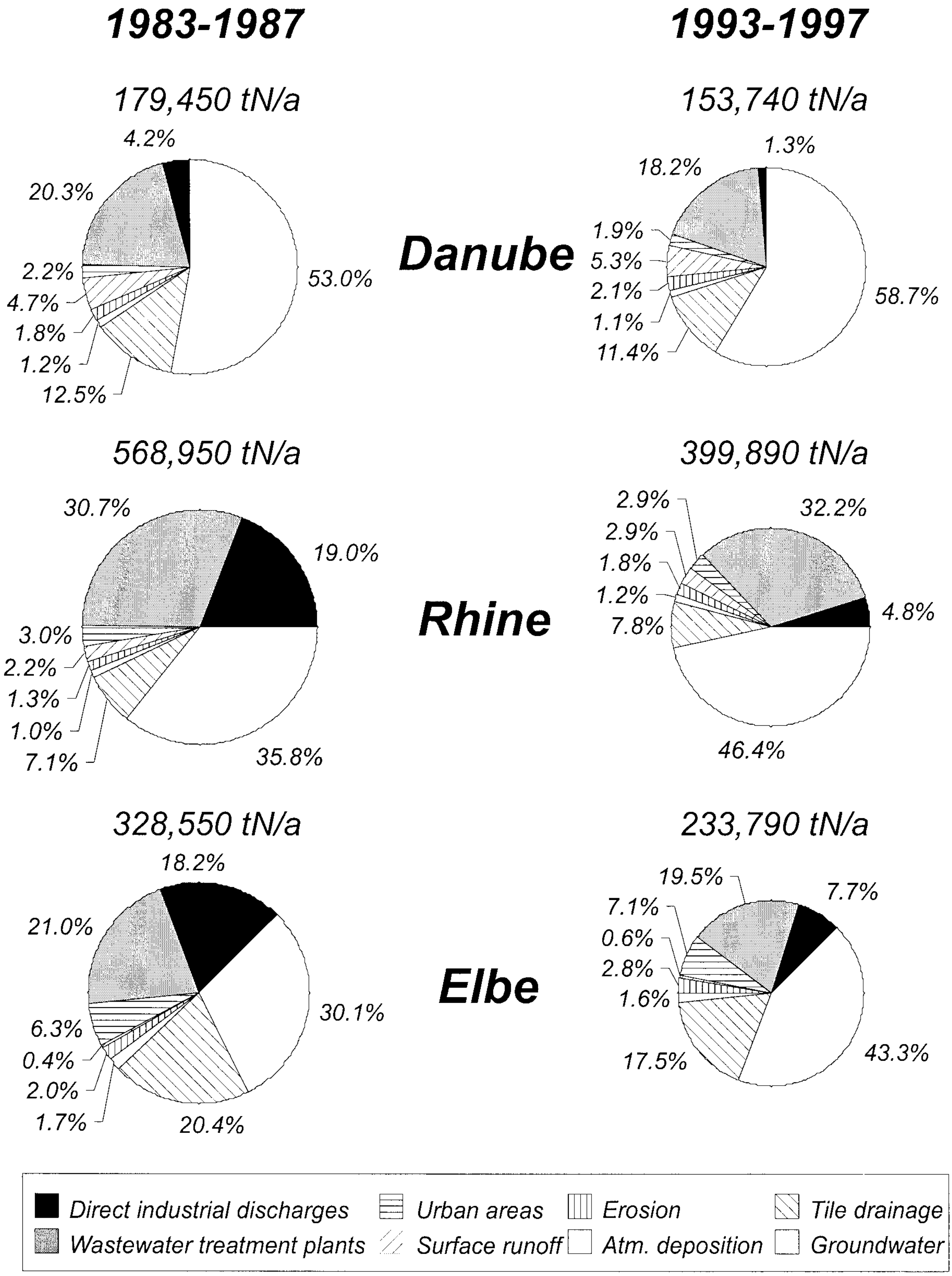


Figure 4.13: Nitrogen inputs in the Danube, Rhine and Elbe catchment areas in the periods 1983-1987 and 1993-1997 under consideration of catchment parts in other countries.

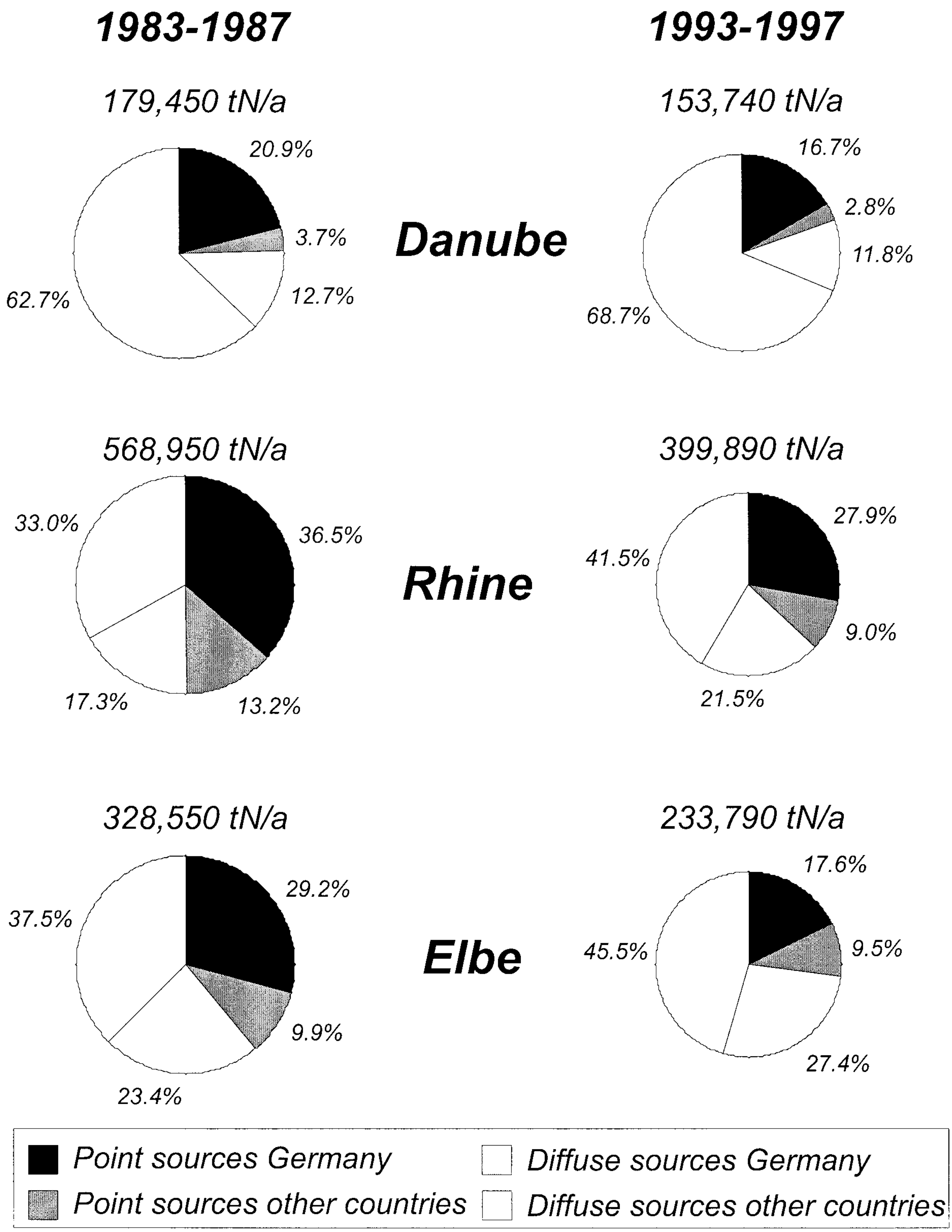


Figure 4.14: Proportion of point and diffuse nitrogen inputs in the Danube, Rhine and Elbe catchment areas in Germany and other countries in the periods 1983-1987 and 1993-1997.

Phosphorus

A total phosphorus input of 7,500 t P/a is estimated for the area of the Danube catchment upstream Jochenstein for the period 1993-1997. The reduction amounts about 6,000 t P/a or 44.4% since the mid-eighties. The proportion of total P-inputs in the foreign part (Austria, Switzerland and Italy) of the catchment is 29.3 %. From this a proportion of about 6.3% (470 t P/a) is caused by point sources and 23% (1,720 t P/a) by diffuse inputs. Reduction of inputs in the Austrian part of the Danube catchment are overall less than in the German part.

For the Rhine, a total P-input of 20,500 t P/a is estimated for the period 1993-1997. Related to the mid-eighties this is a reduction of 30.600 t P/a or 60%. For the Rhine, can be concluded that the decrease in P-inputs in the Swiss and French parts of the catchment are smaller than in the German part, attributable to a smaller reduction in point source discharges of phosphorus. The proportion of total P-inputs in the Rhine basin in the Swiss and French parts upstream Lobith is 41.3%. Point sources discharge an emission of about 21.3% (4.370 t P/a) and diffuse source emissions of about 20% (4.100 t P/a).

For the Elbe basin upstream Zollenspieker, a total P-input of 12,500 t P/a is estimated for the 1993-1997 period. The reduction amounts about 52% (13,300 t P/a) since the 1983-1987 period. It can also be seen that the reduction in P-inputs in the Czech part of the catchment is lower than in the German part. From the total P-input, 42.5% are caused by emissions in the Czech part. Point source discharges and diffuse inputs in this area represent 18.8% (2,350 t P/a) and 23.7% (2,950 t P/a) respectively of the totals for the whole catchment area.

Table 4.32: Point source (EP_P) and diffuse (ED_P) phosphorus inputs in 1983-1987 and 1993-1997 in catchment areas with more than 10% outside Germany and changes in total inputs (EG_N) based on hydrological conditions found in 1983-1987.

ADDR.	River/Basin	1983-97				1993-97				Change	
		ED_P		EP_P		ED_P		EP_P		EG_P	
		Germany	Other countries	Germany	Other countries	Germany	Other countries	Germany	Other countries	Germany	Other countries
		[t P/a]								[%]	
16902	Isar	660	60	1,870	38	640	60	290	15	-65.0	-40.0
18902	Inn	630	1,570	1,030	1,070	670	1,560	220	430	-50.7	-29.2
19101	Danube	3,900	1,730	6,720	1,190	3,790	1,720	1,510	470	-52.1	-30.5
23704	Upper Rhine	1,010	3,400	1,650	5,290	960	3,230	440	2,440	-47.5	-36.9
26901	Mosel	830	990	1,430	3,840	530	860	460	1,940	-56.3	-40.0
27903	Rhine	8,210	4,400	29,340	9,130	6,460	4,100	5,580	4,370	-68.1	-38.1
59311	Elbe	6,230	4,210	12,560	2,850	4,620	2,950	2,540	2,340	-63.0	-24.4

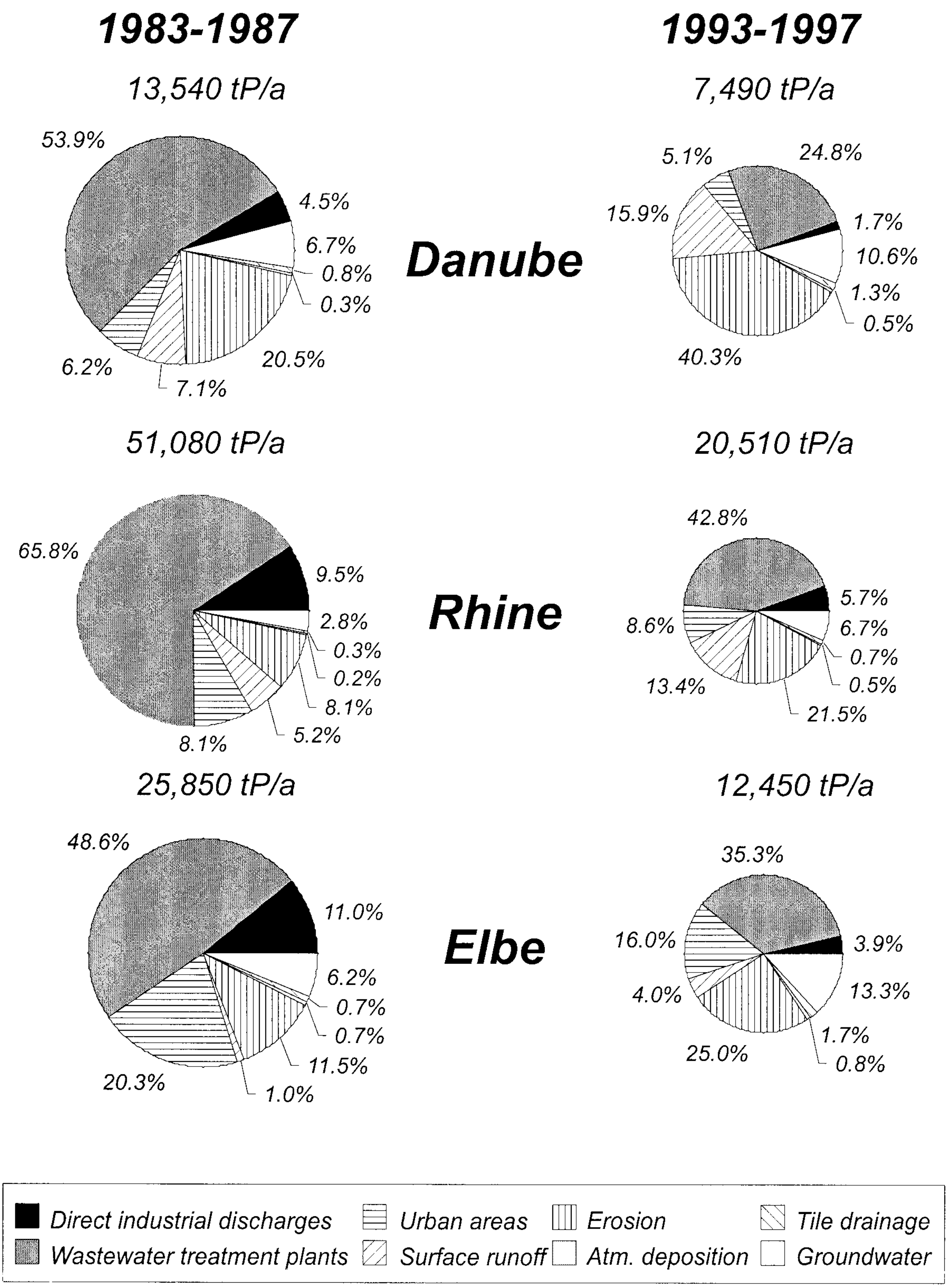


Figure 4.15: Phosphorus inputs in the Danube, Rhine and Elbe catchment areas in the periods 1983-1987 and 1993-1997 under consideration of catchment parts in other countries.

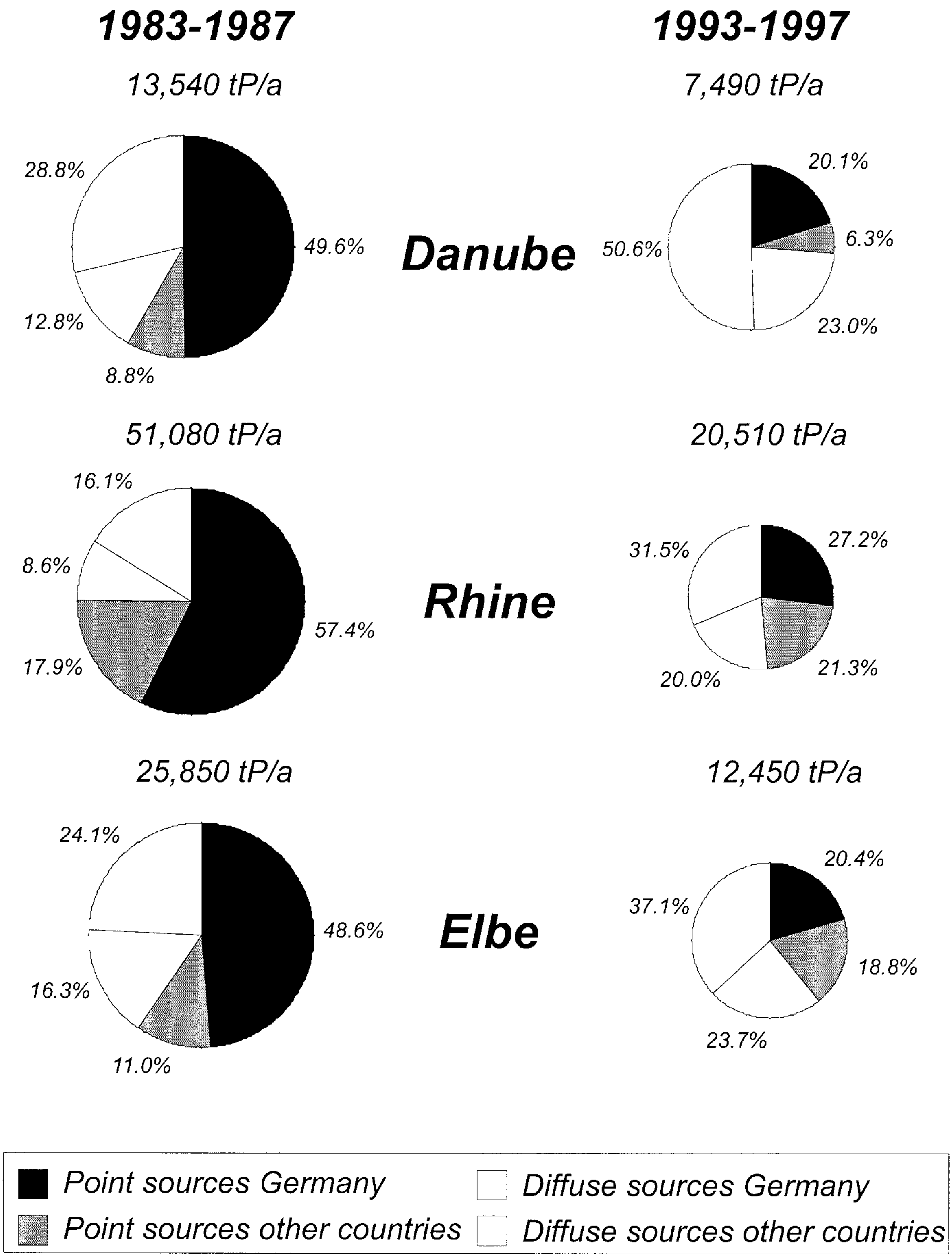


Figure 4.16: Proportion of point and diffuse phosphorus inputs in the Danube, Rhine and Elbe catchment areas in Germany and other countries in the periods 1983-1987 and 1993-1997.

4.1.5 Comparison of nutrient inputs according to MONERIS with other estimates

Results on nutrient inputs in catchment areas can be compared, in some cases, with results of previous studies. It is to be noted that one can not really conclude the quality of present or former input estimates from such comparisons. Tables 4.33 and 4.34 and also Figures 4.17 and 4.18 give an overview of the comparison for a total of 29 catchment areas. For the period around 1985, a comparison for the Rhine and its main tributaries is contained in Tables 4.33 and 4.34. Information on the nutrient inputs is based on the results of *ICPR* (IKSR, 1989) and published in BEHRENDT (1996b). For the Lake Constance catchment area, which almost completely matches with the Rhine catchment at the Öhningen monitoring station, the nutrient inputs of PRASUHN ET AL. (1996) for the years 1985 and 1986 have been estimated. In RUHRVERBAND (1998) results are published on nutrient inputs in the Ruhr river system for the Villigst and Essen monitoring stations for 1990 and 1997. For these two years, the 1997 information can be used for a near comparison with the results for the period 1993 to 1997.

For the Elbe and its main tributaries, values for nutrient inputs for the period around 1985 from WERNER & WODSAK (1994) are available. NESMERÁK ET AL. (1994) carried out an analysis of nutrient inputs in the Czech part of the Elbe for the period 1992 to 1993. This data are not comparable with the inputs estimated here for 1993 to 1997 since the time periods differ.

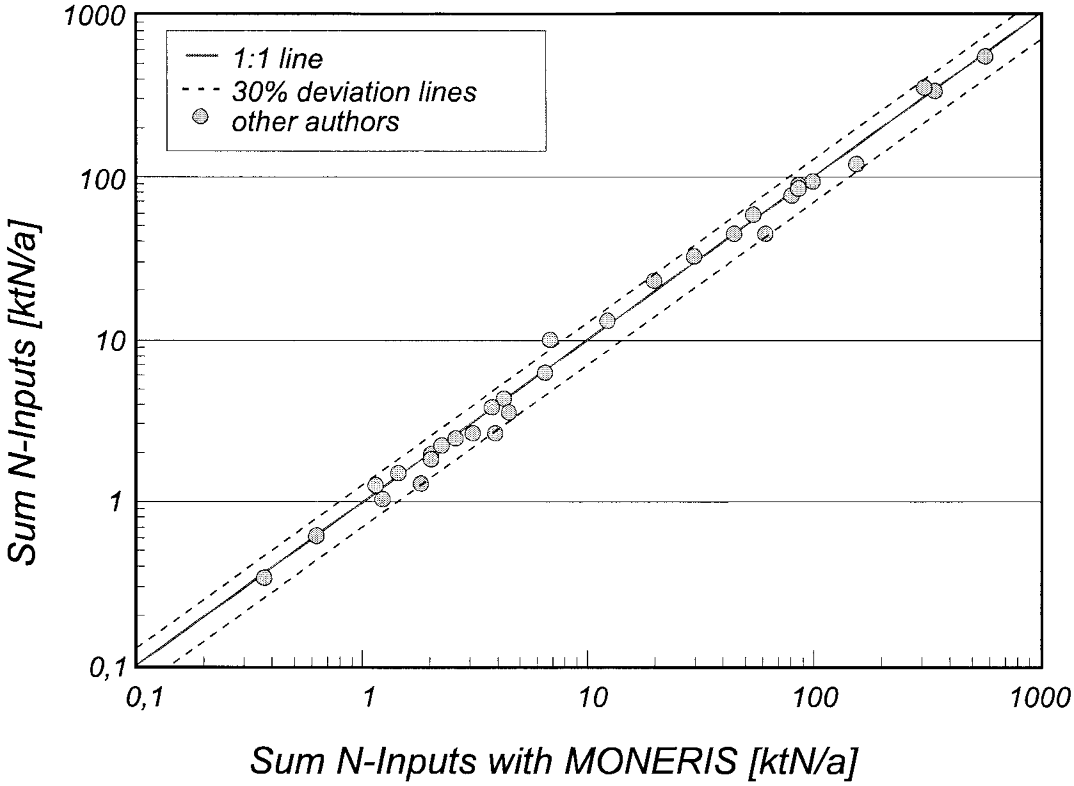
BEHRENDT (1996a) estimated nutrient inputs in catchment areas in Mecklenburg-Western Pomerania for the period 1992 to 1994. Data for catchments of more than 500 km² are used here for the comparison, although the studied time periods are not identical. In addition to these catchment areas, one can also use for the comparison the estimates of ISERMANN (1997) for the Danube at Jochenstein, of KROIß ET AL. (1997) for the Inn at Kirchdorf, of RADERSCHALL (1996) for the Hunte at Tungeln and of FEHR & FÖHSE (1998) for the Böhme and Ilmenau. It should also be borne in mind that the studied time periods are not identical with the 1993-1997 period used in our study.

For nitrogen, Figure 4.17 shows that there are only small differences between the estimates for all catchment areas except the Inn at Kirchdorf and the Rhine at Öhningen. These differences are under 30% for both the sum of nitrogen inputs and also the diffuse sources. On average, the difference for total N-inputs is 11% and 16% for diffuse inputs. This shows that the presented model can describe both the spatial differences occurring in Germany and the changes in nitrogen loading over time in the 1985-1995 period. The comparison shows that the estimates published by KROIß ET AL. (1997) for the Inn upstream Kirchdorf are about 50% higher as the results of MONERIS.

Table 4.33: Comparison of estimated sums of total and diffuse N-inputs for various catchment areas according to MONERIS and other authors.

River/Basin	Monitoring station	MONERIS results		Results of other authors		Source
		Sum	Diffuse sources	Sum	Diffuse sources	
		[t N/a]				
Inn	Kirchdorf	6,830	4,420	10,330	8,060	KROIß ET AL. (1997)
Danube	Jochenstein	153,690	123,750	123,000	102,500	ISERMANN (1997)
Rhine	Oehningen	19,900	14,540	23,830	18,270	PRASUHN ET AL. (1996)
Schussen	Meckenbeuren	2,580	1,610	2,500	1,900	PRASUHN ET AL. (1996)
Neckar	Mannheim	60,920	30,270	46,310	24,180	IKSR (1989)
Main	Kahl am Main	54,740	38,480	59,630	40,450	IKSR (1989)
Main	Bischofsheim	80,680	44,610	78,230	47,010	IKSR (1989)
Mosel	Koblenz	99,150	55,900	96,400	45,880	IKSR (1989)
Rhine	Koblenz	343,630	187,590	346,910	188,620	IKSR (1989)
Rhine	Kleve-Bimmen	573,460	290,720	562,300	258,700	IKSR (1989)
Ruhr	Villigst	4,240	2,750	4,420	2,580	RUHRVERBAND (1998)
Ruhr	Essen	12,320	6,300	13,330	8,130	RUHRVERBAND (1998)
Hunte	Tungeln	4,480	4,110	3,650	3,270	RADERSCHALL (1996)
Mulde	Dessau	29,470	16,660	33,000	16,000	WERNER & WODSAK (1994)
Saale	Gross Rosenburg	85,270	47,040	92,000	51,000	WERNER & WODSAK (1994)
Havel	Toppel (Havelberg)	44,920	21,940	46,000	20,000	WERNER & WODSAK (1994)
Elbe	Schnackenburg	307,400	191,730	365,000	230,000	WERNER & WODSAK (1994)
Elbe	Schmilka	86,610	64,180	87,380	56,170	NESMERÁK ET AL. (1994)
Elde	Doemitz	3,060	2,570	2,750	2,210	BEHRENDT (1996a)
Stepenitz	Dassow	2,010	1,970	2,050	1,950	BEHRENDT (1996a)
Warnow	Kessin	3,710	3,530	3,980	3,660	BEHRENDT (1996a)
Recknitz	Ribnitz	1,230	1,210	1,070	950	BEHRENDT (1996a)
Peene	Downstream Anklam	6,520	5,900	6,410	5,740	BEHRENDT (1996a)
Trebel	Downstream Wotenick	1,440	1,380	1,550	1,470	BEHRENDT (1996a)
Tollense	Demmin	2,230	1,990	2,310	1,920	BEHRENDT (1996a)
Zarow	Grambin	620	610	650	590	BEHRENDT (1996a)
Randow	Eggesin	370	350	350	330	BEHRENDT (1996a)
Sude	Bandekow	3,870	3,810	2,710	2,580	BEHRENDT (1996a)
Uecker	Ueckermuende	2,010	1,860	1,870	1,570	BEHRENDT (1996a)
Böhme	Boehme	1,140	850	1,290	1,110	FEHR & FÖHSE (1998)
Illmenau	Rote Schleuse	1,820	1,510	1,340	1,120	FEHR & FÖHSE (1998)

The causes can only be partly explained by the 15% higher loading of inorganic dissolved nitrogen calculated by KROIß ET AL. (1997). For the Lake Constance catchment area, which is almost identical with the Rhine catchment upstream the Öhningen monitoring station, the results of PRASUHN ET AL. (1996) for 1985/86 show a 70% difference from the estimates made here. The differences for the German part of the Schussen catchment, likewise studied by these authors, are clearly smaller (see Table 4.33). It can be concluded that the MONERIS estimated diffuse N-inputs - at least for the catchments in other countries - for catchments with a very high proportion of grassland the values are clearly smaller than estimates of other authors.



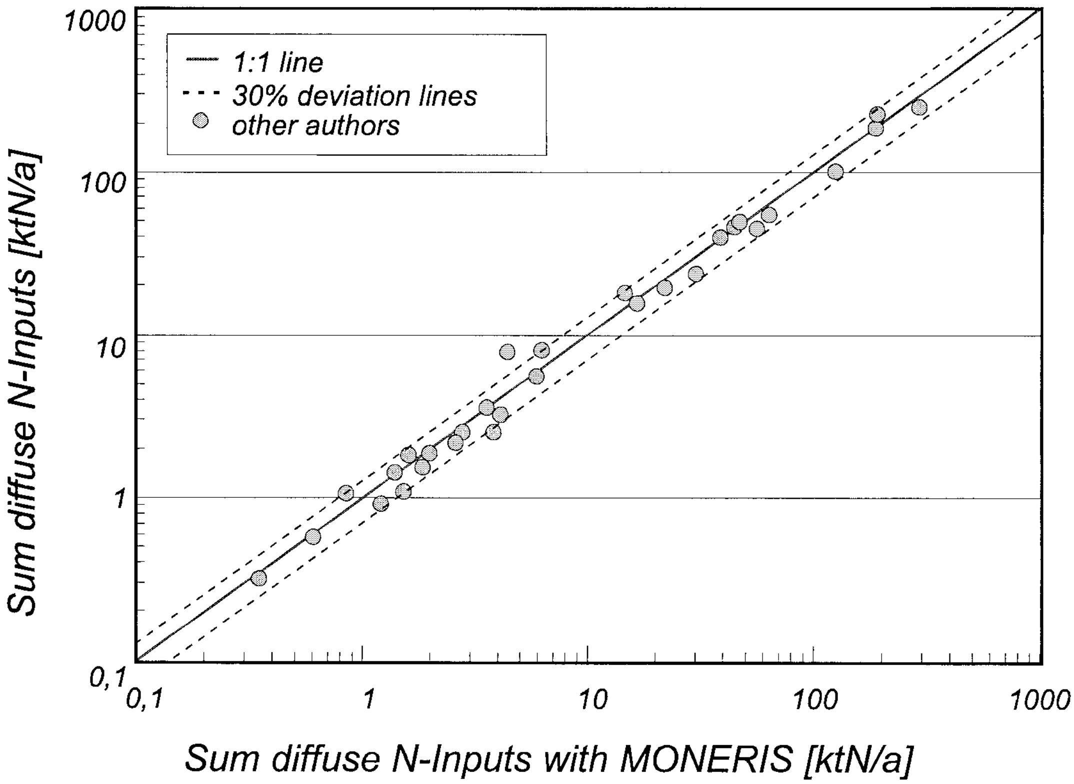


Figure 4.17: Comparison of estimated N-inputs according to MONERIS and other authors.

For phosphorus, the differences between MONERIS values and literature results are on average 33% for total P-inputs and 35% for diffuse P-inputs. These differences are clearly higher than those for nitrogen. In comparison with the estimates of the *ICPR* (IKSR, 1989) for 1985 and of WERNER & WODSAK (1994) for 1985 to 1989 the total phosphorus emissions, as for total nitrogen, show only small differences of 11% and 19% respectively. However, the differences are also large for the catchment areas in Mecklenburg-Western Pomerania studied by BEHRENDT (1996a). The differences for these rivers for total P-inputs are greater than for the sum of all diffuse P-inputs in contrast to all other catchment areas. The cause of these differences is based on the fact that BEHRENDT (1996a) used the values of HAMM ET AL. (1991) or the inhabitant specific phosphate output of 2.8 g P/(E· d) for the estimation of point source P-inputs. However, as the studies of SCHMOLL (1998) show, this value should be 1.8 g P/(E· d). On top of that, BEHRENDT (1996a) considered explicitly also the inputs of agricultural direct inputs so that also the diffuse inputs were probably overestimated. Taking both these factors into account, the differences for these catchments sink to less than 30%.

Apart from the Inn, differences of more than 40% are only found with the estimates for the Danube at Jochenstein, the Lake Constance catchment and the Schussen river. The differences are however not the same. For the Inn at Kirchdorf, the MONERIS values for diffuse emissions are 65% higher. This is also the case for the comparison of P-loads which according to the values of the Bavarian Agency for Water Management are about 48% over those given by KROIß ET AL. (1997).

In a difference to the Inn, ISERMANN (1997) and PRASUHN ET AL. (1996) determined clearly higher diffuse P-inputs for the Danube catchment at Jochenstein and the Lake Constance catchment. For the Danube, one can probably conclude that the differences are in large part attributable to the different time periods covered since the P-loadings given by ISERMANN (1997), like the diffuse inputs, are about 70% higher than the MONERIS estimated load for the 1993 to 1997 period. For the Lake Constance catchment, such a direct loading comparison is not possible since the measured P-loading at Öhningen is not only caused by inputs but is also influenced by the very high P-retention of Lake Constance itself.

If the Vollenweider-Model for the relationship between lake and inflow phosphorus concentration is assumed to be valid for Lake Constance, from the average P-loading of 479 t P/a for the 1993 to 1997 period a P-input to Lake Constance of about 1,480 t P/a can be expected. The high specific outflow of 30 l/(km· s) leaves only a very low P-retention in the river system upstream Lake Constance (BEHRENDT & OPITZ, 1999). From that one can conclude that the inputs into rivers upstream of the Lake Constance catchment (1,550-1,600 t P/a) are only 5% to 10% higher than for Lake Constance itself. Comparison of these P-inputs with the values given in Table 4.34 show that PRASUHN ET AL. (1996) give a 50% overestimate and MONERIS a 14% underestimates of P-emissions.

For the individual input pathways, inputs through erosion show particularly large differences (PRASUHN ET AL., 1996: 1.145 t P/a; MONERIS: 311 t P/a). The values of PRASUHN ET AL. (1996) for erosion from arable land are about 50% higher than those of the modified soil erosion map for Europe (see Section 3.1.2.4). The large difference however comes from the top soil P-content. PRASUHN ET AL. (1996) use a figure for arable soils twice as high and for „natural" soils almost three times as high as those formulated here.

The comparison with results of other authors shows that with the estimates for nitrogen, the differences are relatively low. For phosphorus the differences are particularly large for the areas of the Alps and Alpine foothills for the period after 1990. This is indicative of the uncertainties with the quantification of diffuse P-inputs and particularly the inputs by erosion.

Table 4.34: Comparison of estimated sums of total and diffuse P-inputs for various catchment areas according to MONERIS and other authors.

River/Basin	Monitoring station	MONERIS results		Results of other authors		Source
		Sum	Diffuse sources	Sum	Diffuse sources	
		[t P/a]				
Inn	Kirchdorf	1,290	1,060	710	350	KROIß ET AL. (1997)
Danube	Jochenstein	7,490	5,500	10,900	8,940	ISERMANN (1997)
Rhine	Oehningen	1,360	880	2,370	1,790	PRASUHN ET AL. (1996)
Schussen	Meckenbeuren	110	100	190	100	PRASUHN ET AL. (1996)
Neckar	Mannheim	5,510	1,030	4,790	1,410	IKSR (1989)
Main	Kahl am Main	4,840	1,760	4,940	2,360	IKSR (1989)
Main	Bischofsheim	7,340	2,150	7,370	2,750	IKSR (1989)
Mosel	Koblenz	7,100	1,840	6,400	2,110	IKSR (1989)
Rhine	Koblenz	30,440	8,850	28,160	8,830	IKSR (1989)
Rhine	Kleve-Bimmen	51,150	12,680	45,560	12,890	IKSR (1989)
Ruhr	Villigst	190	120	180	90	RUHRVERBAND (1998)
Ruhr	Essen	580	320	480	270	RUHRVERBAND (1998)
Hunte	Tungeln	210	200	260	200	RADERSCHALL (1996)
Mulde	Dessau	2,390	930	3,000	800	WERNER & WODSAK (1994)
Saale	Gross Rosenburg	7,480	2,610	7,700	2,400	WERNER & WODSAK (1994)
Havel	Toppel (Havelberg)	4,250	1,300	5,100	1,700	WERNER & WODSAK (1994)
Elbe	Schnackenburg	25,340	10,280	29,600	12,000	WERNER & WODSAK (1994)
Elbe	Schmilka	5,300	2,960	5,250	2,110	NESMERÁK ET AL. (1994)
Elde	Doemitz	120	90	190	140	BEHRENDT (1996a)
Stepenitz	Dassow	42	38	66	54	BEHRENDT (1996a)
Warnow	Kessin	130	120	250	210	BEHRENDT (1996a)
Recknitz	Ribnitz	37	34	50	39	BEHRENDT (1996a)
Peene	Upstream Anklam	200	170	370	300	BEHRENDT (1996a)
Trebel	Upstream Wotenick	31	28	71	55	BEHRENDT (1996a)
Tollense	Demmin	81	70	133	106	BEHRENDT (1996a)
Zarow	Grambin	27	25	56	47	BEHRENDT (1996a)
Randow	Eggesin	20	19	42	38	BEHRENDT (1996a)
Sude	Bandekow	120	120	160	140	BEHRENDT (1996a)
Uecker	Ueckermuende	80	70	160	100	BEHRENDT (1996a)
Böhme	Boehme	39	20	39	28	FEHR & FÖHSE (1998)
Illmenau	Rote Schleuse	66	55	90	67	FEHR & FÖHSE (1998)

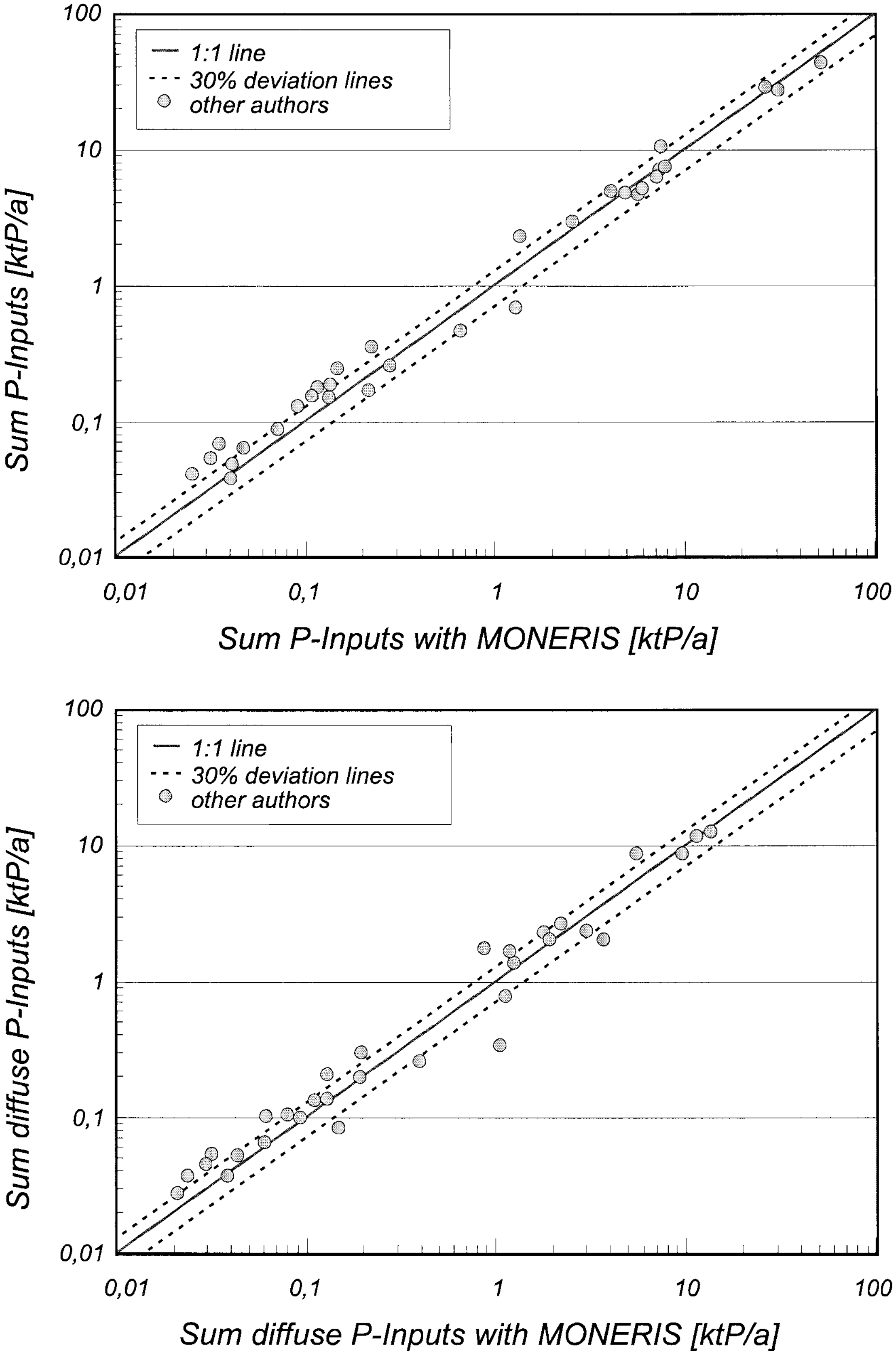


Figure 4.18: Comparison of estimated P-inputs according to MONERIS and other authors.

4.2 Nutrient load of the rivers

Calculated average flows and loads were compared with each other for the periods 1983-1987 (see Table 4.35) and 1993-1997 (see Table 4.36) to determine changes within the studied time periods. As not all parameters were neither measured in the whole period nor at every measurement station, only a partial comparison is possible. Percentage changes of all components are shown in Table 4.37 and DIN-, TN- and TP-loadings in Figure 4.19.

Table 4.35: Discharges and nutrient loadings for the period 1983-1987.

ADDR.	River/Basin	Discharge	Loading					
			NH_4-N	NO_3-N	DIN	TN	PO_4-P	TP
		[m³/s]	[t/a]					
14902	Naab	54	530	7,100	7,600		250	500
16902	Isar	167	2,060	17,500	21,100		1,440	1,890
18902	Inn	732	3,110	26,500	29,600		1,440	2,690
19101	Danube	1,420	7,510	100,500	108,100		4,780	8,520
23704	Upper Rhine	1,330	7,350	70,600	81,200		2,420	
23801	Neckar	172	1,540	32,600	34,200		2,140	3,110
24901	Main	232	4,730	46,700	51,300		3,020	5,870
26901	Mosel	394	3,850	54,300	58,100		2,860	6,130
27601	Ruhr	75	1,580	10,400	12,200			1,020
27801	Lippe	49	2,260	10,900	13,800			1,250
27903	Rhine	2,491	39,280	316,300	355,200	449,400	22,410	35,330
37602	Ems	95	2,400	17,700	20,600		130	970
41002	Werra	58	890	8,200	9,100		680	1,070
42001	Fulda	75	430	11,600	12,100		830	1,300
48901	Aller	153	2,900	25,900	30,700		1,160	1,980
49103	Weser	359	4,430	65,600	70,000		2,880	7,140
53801	Schwarze Elster	30	2,000	1,500	3,500		70	
54901	Mulde							
56901	Saale	133	28,680	17,600	47,900	52,700	1,660	3,960
58901	Havel	113	4,710	4,600	9,400	12,100	1,580	1,900
59311	Elbe	709	48,610	94,600	145,100	163,500		
69001	Odra	510	12,390	46,100	58,800		2,730	6,520

For the large river basins, flow remained about the same for two time periods with the exception of the Ems. Differences of more than 15% were found for the Ems, Ruhr, Lippe and Schwarze Elster. For the Ems, daily flows are not available up to now for use in the calculations. The average yearly flows for the measurement days show fluctuations of up to 60%. One can conclude from this that the increase in flow after 1983-1987 is based in all cases on sampling times. For the Ruhr and the Lippe, not all years within the study period are used in the calculations. The calculation of flow for the Schwarze Elster could only be carried out for 1985-1986 within the 1983-1987 study period. The considerable decline in flow in subsequent years is based on the above-average flow measured in 1986.

The loads of individual nutrient components show clear differences in their changes. Loadings of ammonia and soluble reactive phosphorus (SRP) have clearly decreased at all monitoring stations, in most cases by more than 50%. The extremely low SRP loads in the Schwarze Elster are caused by the high iron-content in water discharged by mining activities (BEHRENDT ET AL., 1998).

Table 4.36: Discharges and nutrient loadings for the 1993-1997 period.

ADDR.	River/Basin	Discharge	Loading					
			NH_4-N	NO_3-N	DIN	TN	PO_4-P	TP
		[m³/s]	[t/a]					
14902	Naab	47	230	6,700	6,900		90	260
16902	Isar	175	390	16,300	16,700		210	440
18902	Inn	744	2,080	27,600	29,700		500	2,420
19101	Danube	1,407	3,900	99,400	103,300		1,440	5,040
23704	Upper Rhine	1,284	2,450	68,600	74,500		1,460	
23801	Neckar	160	630	25,200	25,700		620	1,010
24901	Main	237	1,240	44,600	50,400			2,520
26901	Mosel	366	1,770	59,700	72,900		2,150	3,980
27601	Ruhr	98	1,240	13,500	15,000	16,900	250	300
27801	Lippe	40	370	11,700	12,300	15,500		190
27903	Rhine	2,455	15,510	277,000	292,500	361,000	7,720	14,510
37602	Ems	117	1,460	21,300	25,100	26,300	80	870
41002	Werra	50	360	6,700	7,200		130	350
42001	Fulda	65	390	8,100	8,800		120	390
48901	Aller	130	1,050	19,600	20,500	24,900	220	940
49103	Weser	346	2,710	54,900	54,100		720	2,350
53801	Schwarze Elster	23	290	2,300	2,600		10	70
54901	Mulde	78	1,010	11,900	13,200		50	240
56901	Saale	127	3,340	24,300	28,300	26,500	260	1,110
58901	Havel	104	880	4,600	5,500		300	700
59311	Elbe	723	5,560	105,300	111,700	109,700	1,280	4,550
69001	Odra	470	3,800	44,300	48,300	61,300	1,280	3,050

Loads of nitrate and dissolved inorganic nitrogen (DIN) show no clear picture. However, they do show a decline in the majority of rivers. Only in the Ruhr and Ems DIN-loads increased by 25%. In these rivers, nitrate loads also increased. The increase in loads is really due to increase in flows. Particularly high increases in nitrate loads are also found in the Elbe tributaries Schwarze Elster and Saale. Above all in these rivers, the decrease in ammonia loads is linked to the increase in nitrate loads due to the improvement in oxygenation and consequently improved conditions for nitrification. The three monitoring stations where total nitrogen was measured in the whole period show a clear decrease in the load.

In the Elbe upstream Zollenspieker and the Saale, the load calculation give higher DIN- than TN- loadings in 1993-1997 and in the Weser at Hemelingen, higher nitrate than DIN-loads. This is attributable to the different numbers of measurements for the individual parameters.

For example, TN-measurements were only available for the last two years of the 1993-1997 period for the Elbe at Zollenspieker and the Saale. For the Weser at Hemelingen, no DIN-loading was calculated for 1994 since no ammonia measurements were available.

Table 4.37: Changes in discharges and nutrient loadings between 1983-1987 and 1993-1997.

ADDR.	River/Basin	Change between 1983-87 and 1993-97						
		Discharge	Loading					
			NH_4-N	NO_3-N	DIN	TN	PO_4-P	TP
		[%]						
14902	Naab	*-13*	*-57*	*-6*	*-9*		*-64*	*-48*
16902	Isar	*+5*	*-81*	*-7*	*-21*		*-85*	*-77*
18902	Inn	*+2*	*-33*	*+4*	*0*		*-65*	*-10*
19101	Danube	*-1*	*-48*	*-1*	*-4*		*-70*	*-41*
23704	Upper Rhine	*-3*	*-67*	*-3*	*-8*		*-40*	
23801	Neckar	*-7*	*-59*	*-23*	*-25*		*-71*	*-68*
24901	Main	*+2*	*-74*	*-4*	*-2*			*-57*
26901	Mosel	*-7*	*-54*	*+10*	*+25*		*-25*	*-35*
27601	Ruhr	*+31*	*-22*	*+30*	*+23*			*-71*
27801	Lippe	*-18*	*-84*	*+7*	*-11*			*-85*
27903	Rhine	*-1*	*-61*	*-12*	*-18*	*-20*	*-66*	*-59*
37602	Ems	*+23*	*-39*	*+20*	*22*		*-38*	*-10*
41002	Werra	*-14*	*-60*	*-18*	*-21*		*-81*	*-67*
42001	Fulda	*-13*	*-9*	*-30*	*-27*		*-86*	*-70*
48901	Aller	*-15*	*-64*	*-24*	*-33*		*-81*	*-53*
49103	Weser	*-4*	*-39*	*-16*	*-23*		*-75*	*-67*
53801	Schwarze Elster	*-23*	*-86*	*+53*	*-26*		*-86*	
54901	Mulde							
56901	Saale	*-5*	*-88*	*+38*	*-41*	*-50*	*-84*	*-72*
58901	Havel	*-8*	*-81*	*0*	*-41*		*-81*	*-63*
59311	Elbe	*+2*	*-89*	*+11*	*-23*	*-33*		
69001	Odra	*-8*	*-69*	*-4*	*-18*		*-53*	*-53*

The goal of a 50-percent reduction of nutrient loadings has been achieved for phosphorus in all of the large river basins except the Ems and the Danube (see Figure 4.19). For the Ems, the low reduction is attributable to the high groundwater input and the increase in flows. In the Danube, the main cause is the small reduction in the Inn catchment area. Total phosphorus inputs into both the North Sea and Baltic Sea were reduced by about 50%.

For nitrogen, the reductions are substantially smaller than for phosphorus in all large river basins (see Figure 4.19).

For the direct comparison of river nutrient loads with each other, specific nutrient loadings are considered (see Figures 4.20 and 4.21).

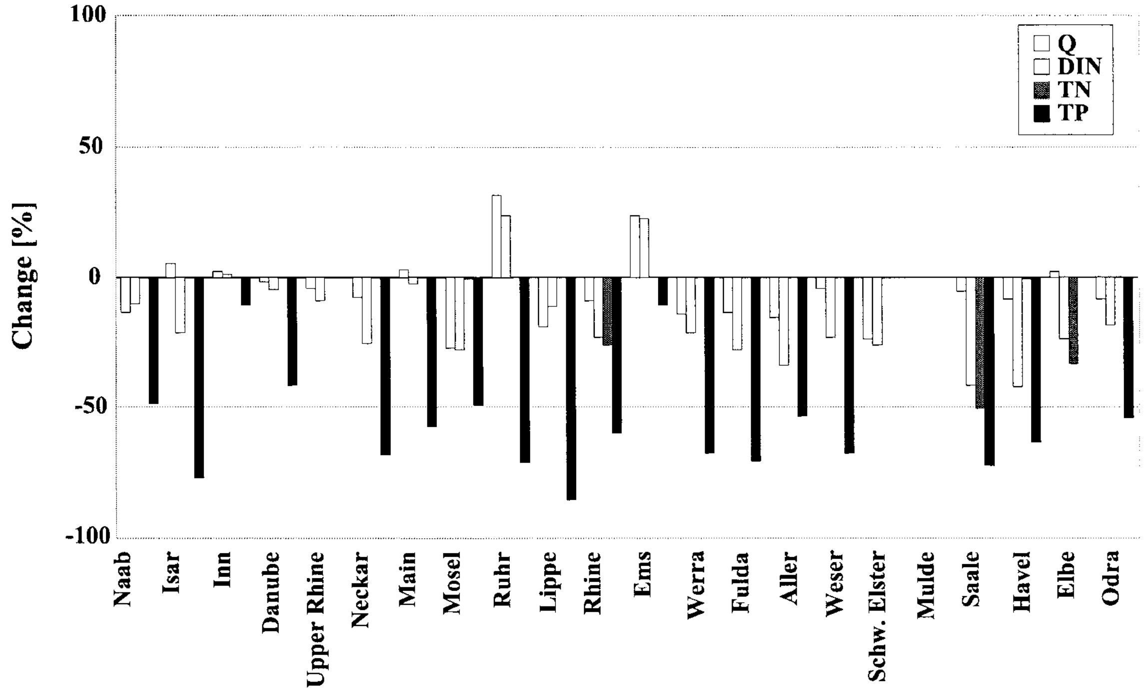


Figure 4.19: Change in flows and DIN-, TN- and TP-loadings between 1983-87 and 1993-97.

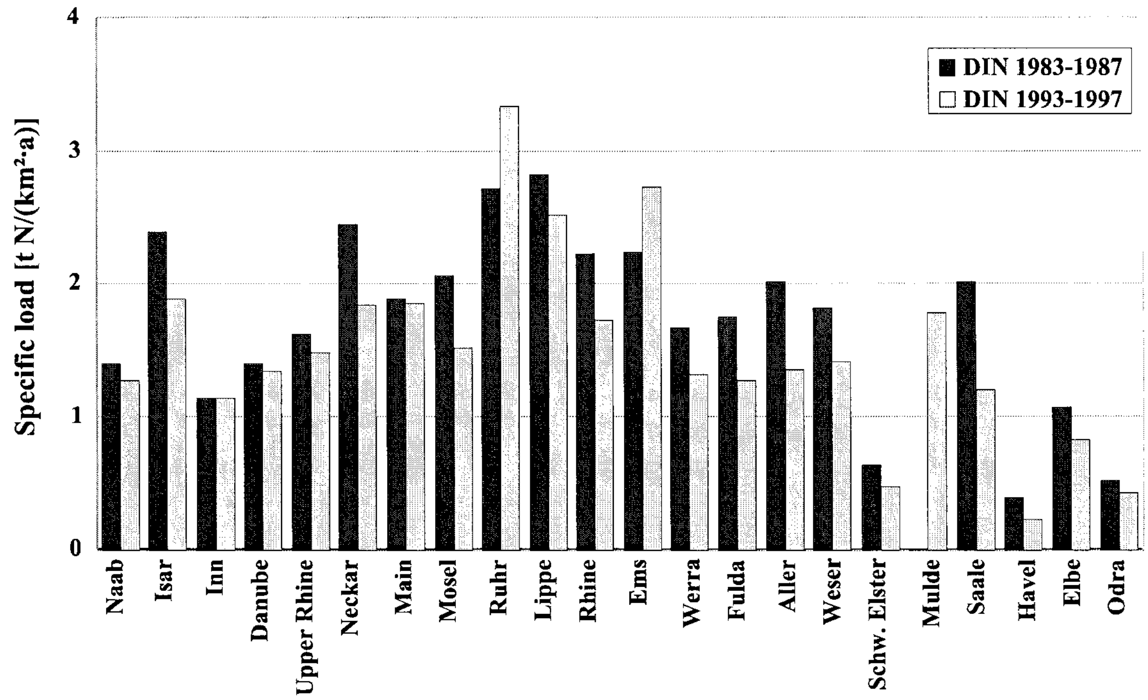


Figure 4.20: Specific DIN-loadings 1983-1987 and 1993-1997.

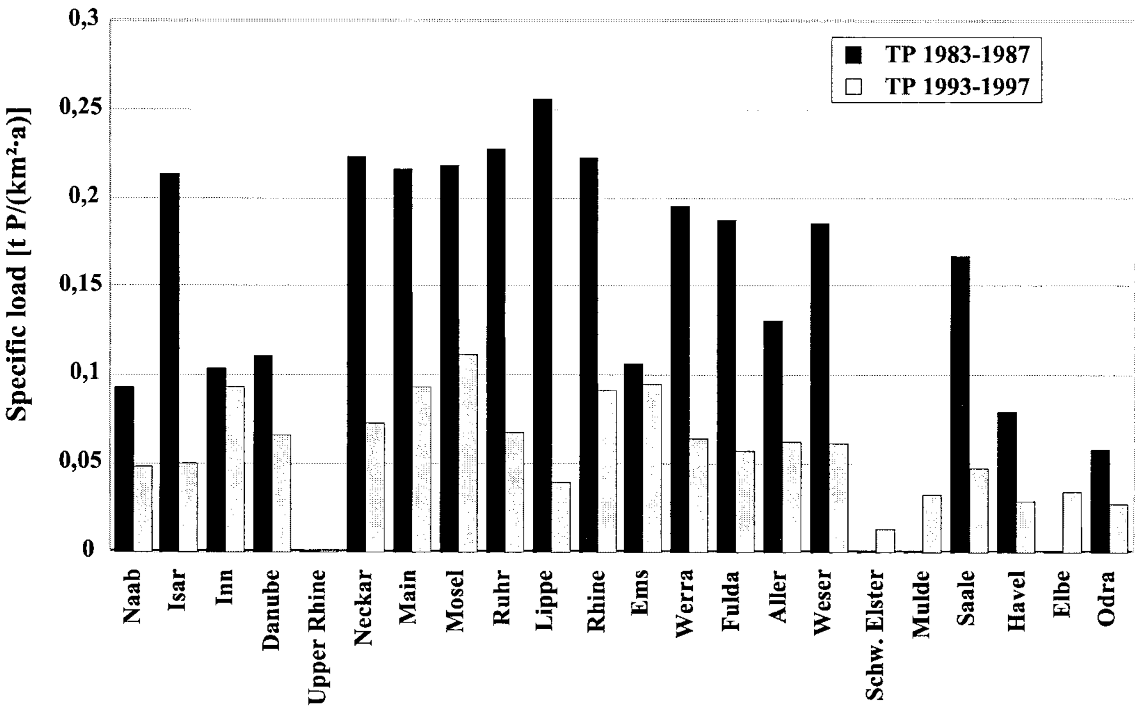
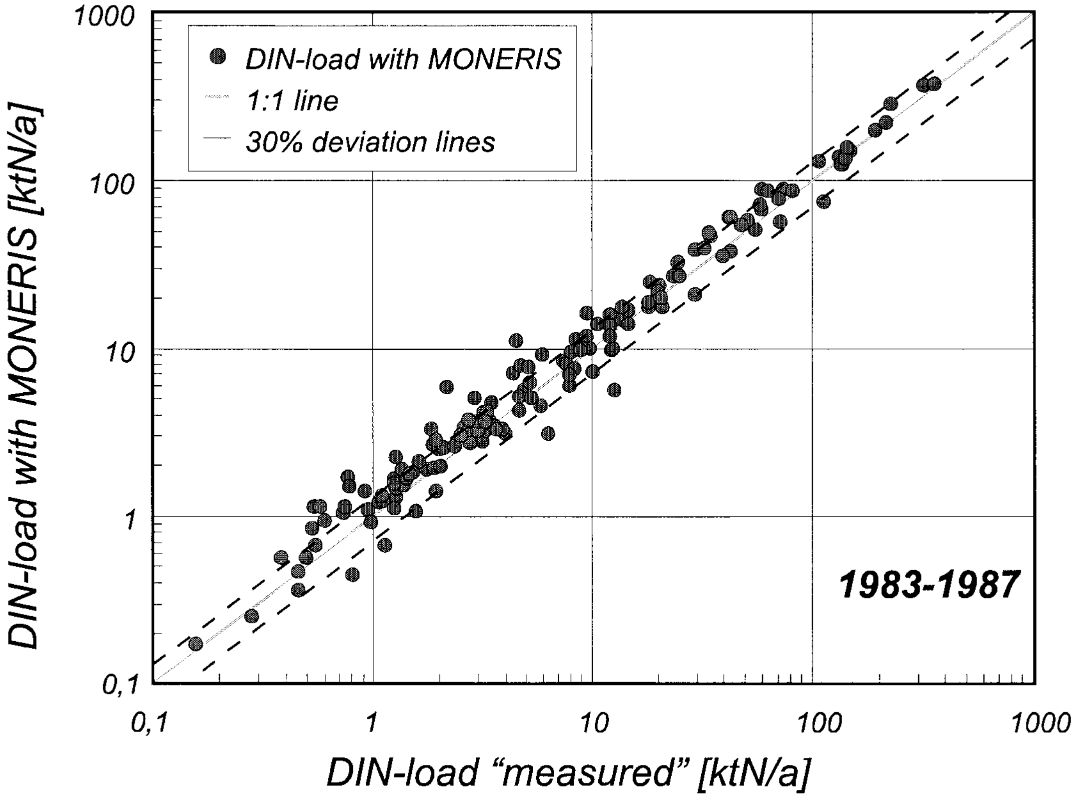


Figure 4.21: Specific TP-loadings 1983-1987 and 1993-1997.

The highest DIN-loads are shown in the Rhine and Ems catchment areas. For the Rhine, it is attributable to the high specific loadings found in the Lippe and Ruhr catchments related to the high population density and intensity of industry in the area. For the Ems it is attributed to the especially intensive agricultural landuse. The Mulde catchment stands out from the otherwise low specific DIN-loads in the Elbe basin despite a great reduction since 1983-1987. The very low DIN- and TP-loadings in the Havel particularly stand out. These are caused by the high specific retention capacity and denitrification potential of the lakes within the catchment. The Mosel stands out from the other catchments which have specific TP loadings of less than 0.1 t P/($km^2\cdot$ a). This is attributed to the high proportion of point source inputs.

4.3 Comparison of nutrient loadings according to MONERIS with loadings calculated from measurements

Since the calculations of nutrient emissions have been carried out for individual catchments, a comparison with the loads calculated from measurements ("measured loadings") is possible if the nutrient retention in the river systems is taken into account for the emissions of the MONERIS model. Nutrient retention in river systems is calculated according to the method presented in Section 3.3. Figures 4.22 and 4.23 show the relationship between the loads of dissolved inorganic nitrogen and total phosphorus calculated according to MONERIS with the retention sub-model for the period 1993-1997 and 1983-1987. The comparison was only carried out for catchment areas with more than 12 measurements per year.



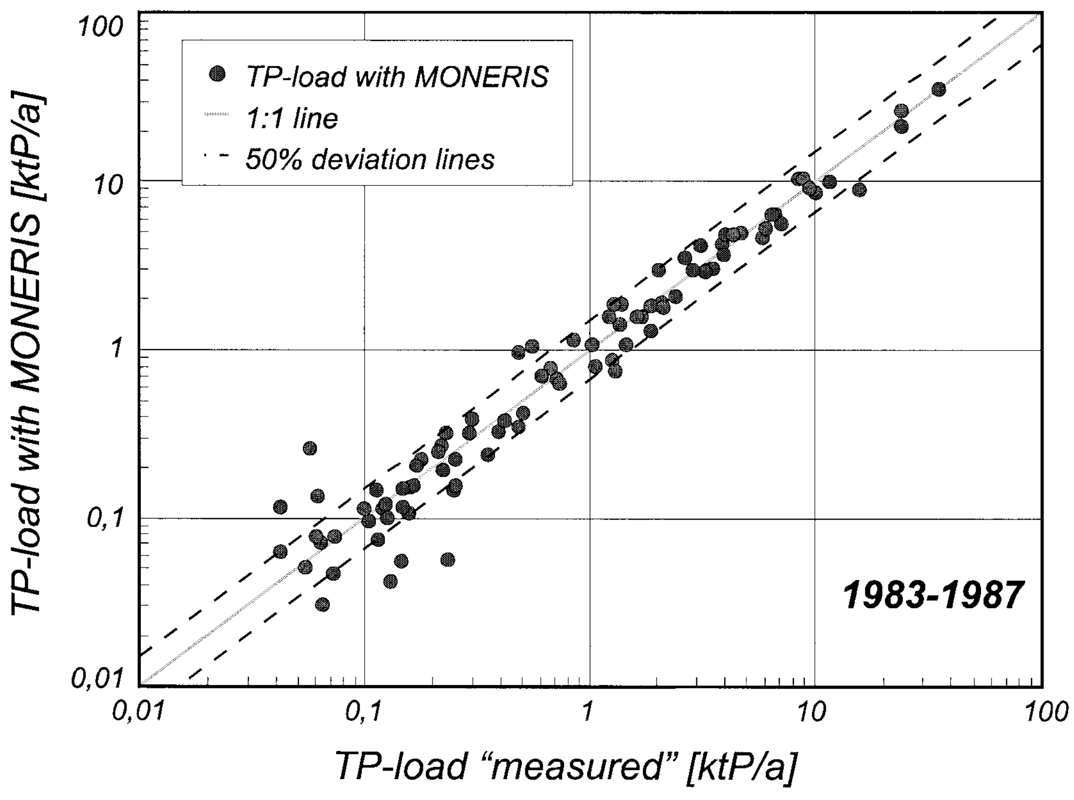


Figure 4.22: Comparison of MONERIS and „measured" estimates of DIN- and TP-loadings for the studied rivers in the period 1983-1987.

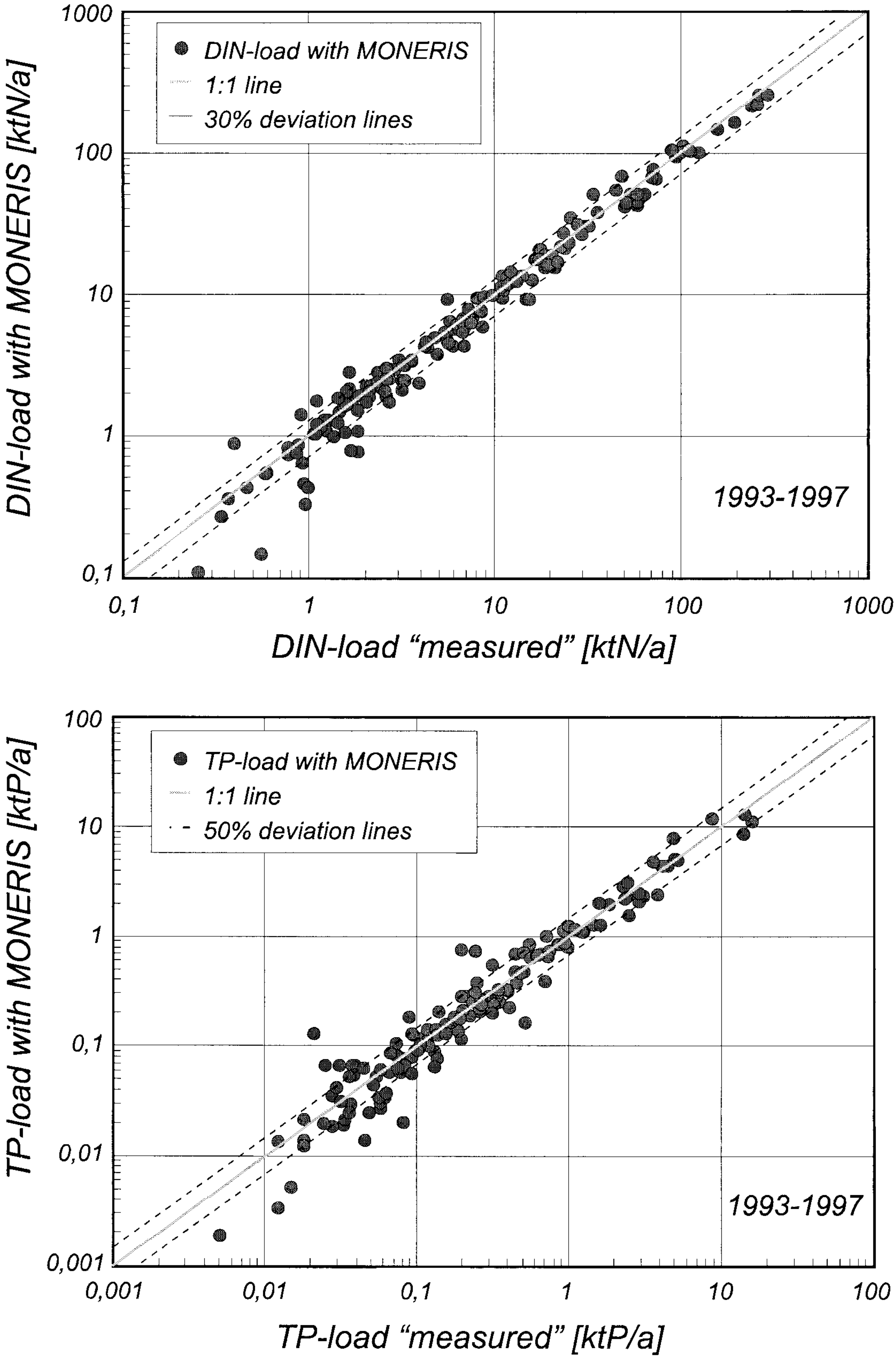


Figure 4.23: Comparison of MONERIS and „measured" estimates of DIN- and TP-loadings for the studied rivers in the period 1993-1997.

For DIN-loads, there was less than 30% difference between the estimated and „measured“ values for 148 out of 168 catchments for the 1993-1997 period. The difference was greater than 40% in only 13 catchment areas. It can be seen in Figure 4.23 that these are mostly small catchments with low DIN-loads.

An analysis of catchment areas with greater difference shows that the probable reason is the calculation of flow rates since the sizes of catchments of the monitoring and flow monitoring stations are very different. Furthermore, this applies particularly to small lowland river systems where above ground and underground catchment areas can be characterised by different size.

The difference between estimated and „measured“ DIN-loadings was greater in the period 1983-1987 and shows a tendency for the MONERIS values to be the higher. One can conclude from this that for this period, either the nitrogen inputs were a little overestimated or the nitrogen retention or losses under the particular conditions (higher organic loading and lower oxygen content; higher nitrogen input, particularly from point sources) were greater in the 1983-1987 period than with the retention formula calculated in Section 3.3.

A comparison regarding the estimated and „measured“ total nitrogen loadings has not yet been carried out since there is too little data available on total nitrogen loadings and inputs for the derivation of an appropriate retention-relationship. However, it seems possible on the basis of the increasing number of "measured" total nitrogen loadings, to determine an analogous relationship from dissolved inorganic nitrogen as follows.

For phosphorus, the differences between the MONERIS estimated and the „measured“ total phosphorus loads are, overall, greater than with nitrogen. In addition, there is a tendency for the smaller catchment areas with smaller loads to yield greater differences. This can be caused both by the larger errors in input estimates and "measurements". With some catchment areas it shows that the estimated loadings are clearly larger than the "measured" loads. That means that for these catchments, the P-retention is clearly greater than calculated with the retention sub-model. This particularly applies to catchments where the monitoring station lies directly upstream of a lake or a reservoir (Alz upstream Seebruck, Rhine upstream Oehningen, Mulde upstream Dessau, Spree upstream the Spremberg reservoir). On the other hand, catchments occur in which there are large lakes and reservoirs in the upper reaches of a river, a long way from the monitoring station. For these (Elde upstream Doemitz, Uecker upstream Ueckermünde), the loads are underestimated. For these catchments, one can not apply the assumption of a homogeneous distribution of surface water area in a catchment as in the previously developed retention-relationships. Accordingly, in future studies on the retention of a river system, one must consider the distribution of surface water areas within catchment areas. Until this is achieved, the estimated loadings can be corrected with inclusion of the Vollenweider-relationship for P-retention in lakes.

A comparison of Figures 4.22 and 4.23 show for phosphorus that the differences between MONERIS and „calculated“ estimates of phosphorus loads for the 1983-1987 period when phosphorus inputs were much higher are clearly smaller than for the 1993-1997 period. This indicates that in particular greater errors can be expected for the quantification of a greater proportion of diffuse P-inputs.

Bearing in mind the present unsatisfactory position with the data-base and models for the calculation of nutrient inputs and also possible errors in load estimations, one can conclude that with the MONERIS model, calculations of nitrogen loads have an error of less than 30% and phosphorus loads less than 50%. It is generally valid that these errors are reduced for the larger catchment areas.

4.4 Comparison with the results of the immission method

A comparison between the results of the immission method according to BEHRENDT (1993, 1994b) and the emission method estimates (MONERIS) of the proportions of diffuse and point source inputs is possible for a total of 29 catchment areas. Catchments for which analyses have already been carried out with immission methods were consciously chosen. Estimates of the proportions of diffuse inputs have been published in BEHRENDT (1993), BEHRENDT (1994b), BEHRENDT (1996a) and FEA (UBA, 1998). A comparison of these results is shown in Table 4.38 and Figure 4.24. For 18 of these catchment areas, the study period of 1985 to 1990 was used and is compared to the 1983-1987 period of this study. For 26 catchments, results from immission methods are available for the 1992-1995 period.

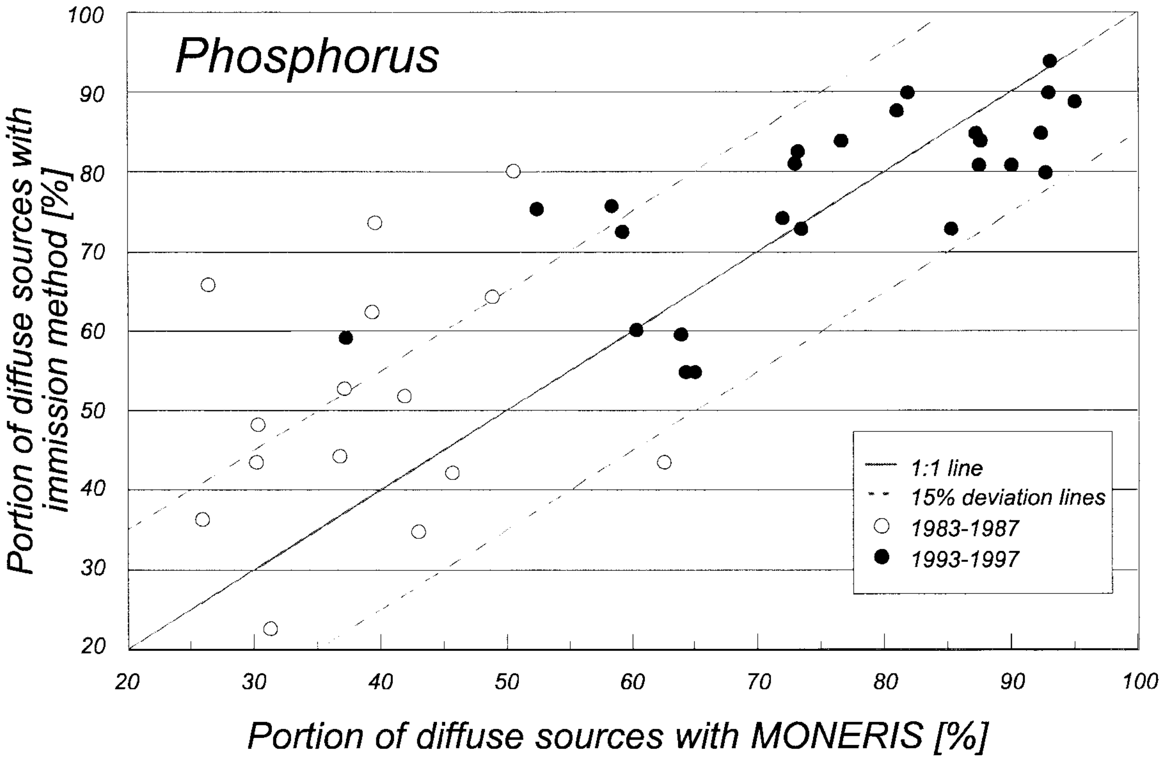
Overall, the estimates of the proportion of nutrient inputs from diffuse sources vary in a range of about 15% from estimates according to MONERIS for the period 1993 to 1997. For nitrogen, with the immission method, there is a tendency for a higher estimated proportion of inputs from these sources where the proportion is small. This also applies for phosphorus if one includes the results for 1983-1987. The reason of this may be in particular related to inputs from municipal wastewater treatment plants which includes a fraction of storm water runoff from paved urban areas. That means that these inputs are not always the same but climb with increasing flows. Through this behaviour, especially where there is a high proportion of point source discharges in the loads, the immission method yields a higher estimated proportion of diffuse inputs than the emission method. This behaviour is particularly applicable to areas with a high proportion of combined sewer systems in urban areas. Figure 4.25 shows for nitrogen the dependence of the difference between estimates with the immission and emission method on the connection of urban areas to combined sewers.

This relationship between the differences in the two estimation methods and the proportion of combined sewers in the urban areas of a catchment explains a large part of the differences shown in Figure 4.24.

Overall, one can conclude that results from the immission method and the emission method used here are in concurrence. Therefore, one should consider that the proportion of diffuse sources estimated with the immission method is more prone to error since errors from individual measurements can influence the estimate.

Table 4.38: Comparison of estimated proportions of diffuse inputs in the nutrient loadings of chosen rivers according to MONERIS and with the immission method for the periods 1983-1987 and 1993-1997.

River/Basin	Monitoring station	Phosphorus				Nitrogen			
		1983-1987		1993-1997		1983-1987		1993-1997	
		Diffuse proportion MONERIS	Diffuse proportion Immission	Diffuse proportion MONERIS	Diffuse proportion Immission	Diffuse proportion MONERIS	Diffuse proportion Immission	Diffuse proportion MONERIS	Diffuse proportion Immission
		[%]							
Rhine	Bimmen	*24.8*	*36.4*	*51.4*	*75.5*	*50.7*	*60.7*	*62.2*	*72.6*
Rhine	Koblenz	*29.1*	*43.7*	*57.6*	*75.8*	*54.6*	*72.7*	*64.8*	*83.1*
Rhine	Mainz	*29.2*	*48.3*	*58.6*	*72.6*	*54.5*	*63.4*	*64.9*	*82.8*
Rhine	Karlsruhe	*38.6*	*62.6*	*59.1*	*0.0*	*59.7*	*72.9*	*69.1*	*84.4*
Mosel	Koblenz	*25.9*	*66.0*	*36.8*	*59.4*	*56.4*	*73.9*	*72.3*	*83.2*
Main	Kahl	*40.9*		*61.5*	*54.9*	*61.3*	*69.2*	*73.1*	*87.9*
Elbe	Zollenspieker	*40.6*	*34.8*	*60.6*	*54.9*	*62.4*	*67.5*	*73.5*	*88.9*
Elbe	Schnackenburg	*43.0*	*42.2*	*59.8*	*59.8*	*64.2*	*60.7*	*74.6*	*89.9*
Elbe	Magdeburg	*59.2*	*43.7*	*55.7*	*60.3*	*70.7*	*89.7*	*74.1*	*91.3*
Elbe	Schmilka	*38.9*				*56.5*	*56.3*		
Mulde	Dessau	*34.8*	*44.4*			*55.2*	*43.2*		
Saale	Groß-Rosenburg	*30.7*	*22.7*			*48.8*	*53.1*		
Havel	Havelberg (Toppel)	*37.7*	*73.7*	*70.7*	*81.2*	*70.9*	*88.0*	*78.9*	*89.6*
Weser	Hemelingen	*47.3*	*64.5*	*71.3*	*73.0*	*82.0*	*86.1*	*82.8*	*83.7*
Weser	Hemeln	*45.4*		*80.4*	*87.8*	*75.1*	*89.0*	*84.3*	*91.1*
Ems	Herbrum	*42.3*	*52.0*	*73.5*	*82.7*	*75.4*	*81.6*	*80.5*	*92.1*
Danube	Jochenstein	*51.3*	*80.1*	*77.5*	*84.0*	*73.3*	*92.8*	*81.4*	*73.0*
Inn	Passau	*36.3*	*53.0*	*72.3*	*74.3*	*70.3*	*86.0*	*77.4*	*86.0*
Stepenitz	Dassow			*91.9*	*80.0*			*97.9*	*95.0*
Warnow	Kessin			*86.5*	*84.0*			*95.1*	*93.0*
Recknitz	Ribnitz			*91.8*	*85.0*			*97.7*	*88.2*
Peene	Downstream Anklam			*86.1*	*85.0*			*90.4*	*90.8*
Tollense	Demmin			*86.5*	*81.0*			*89.1*	*90.0*
Trebel	Downstream Wotenick			*89.0*	*81.0*			*95.8*	*95.0*
Uecker	Ueckermuende			*81.7*	*73.0*			*92.3*	*90.0*
Randow	Eggesin			*91.7*	*94.0*			*96.1*	*95.0*
Zarow	Grambin			*91.9*	*90.0*			*97.4*	*95.0*
Sude	Bandekow			*94.8*	*89.0*			*98.3*	*95.0*
Elde	Doemitz			*80.1*	*90.0*			*84.0*	*93.0*



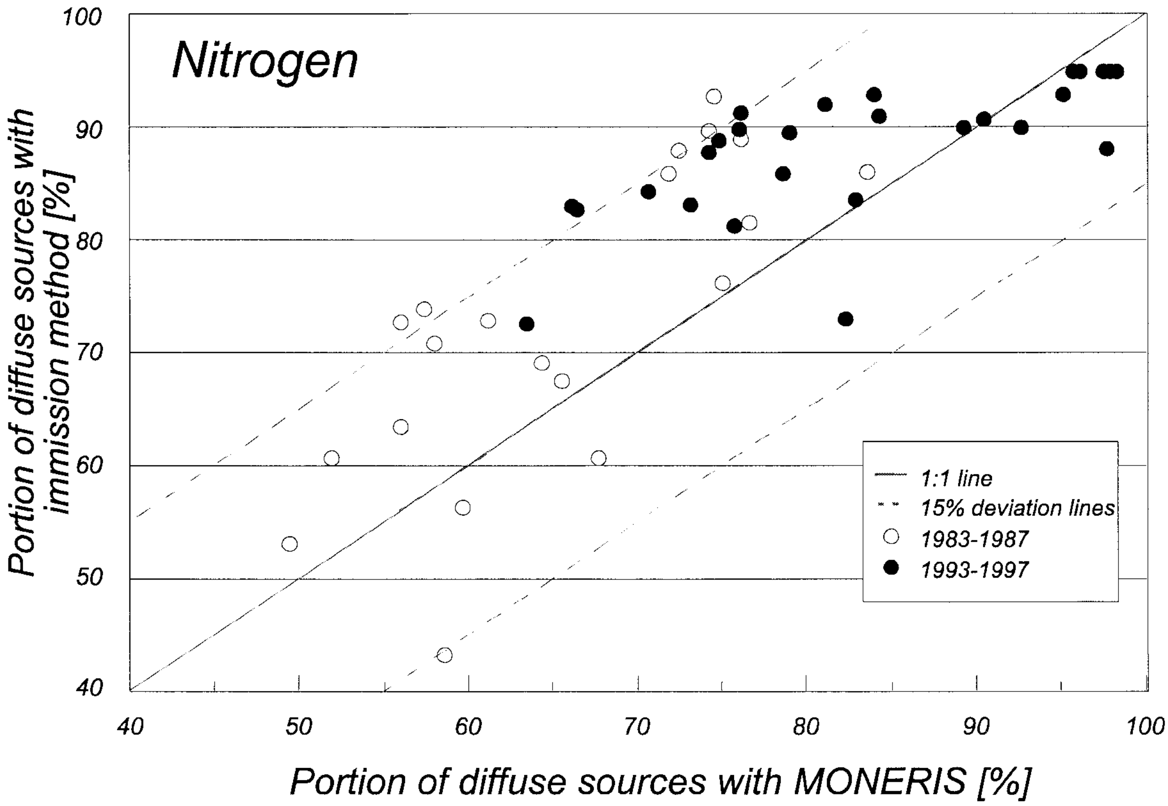


Figure 4.24: Comparison of the proportion of diffuse inputs of phosphorus and nitrogen estimated with the immission method and with MONERIS.

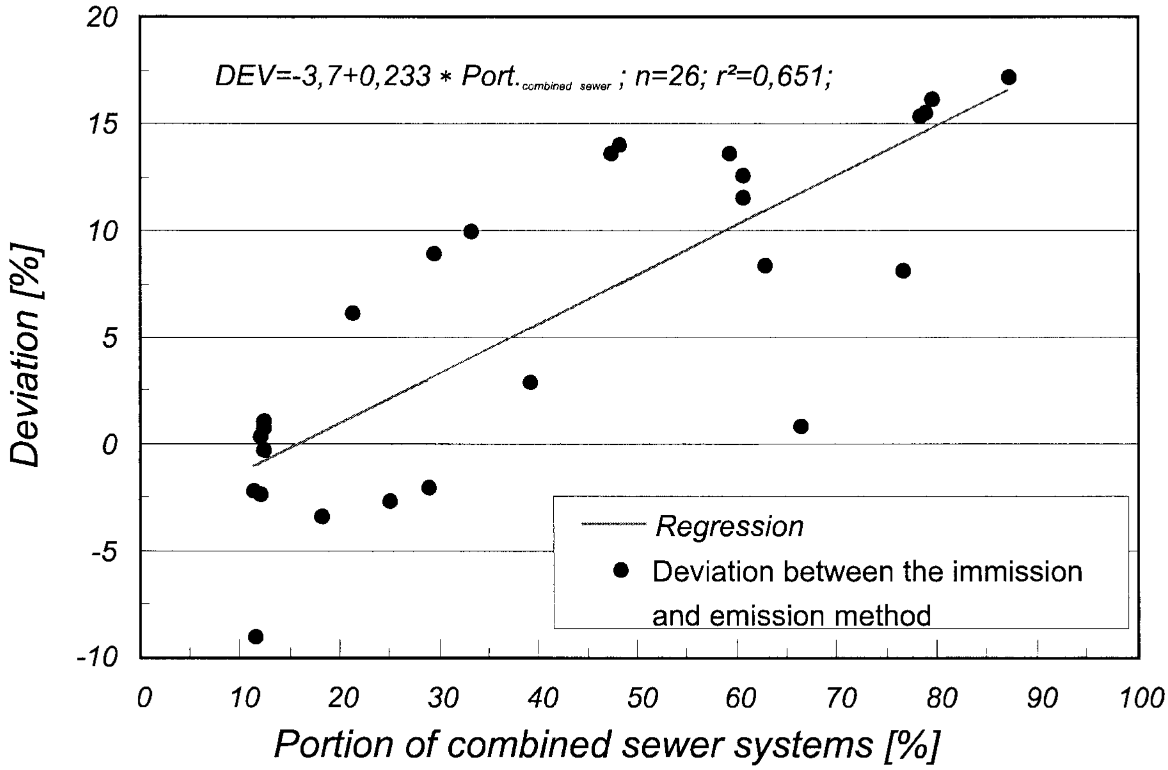
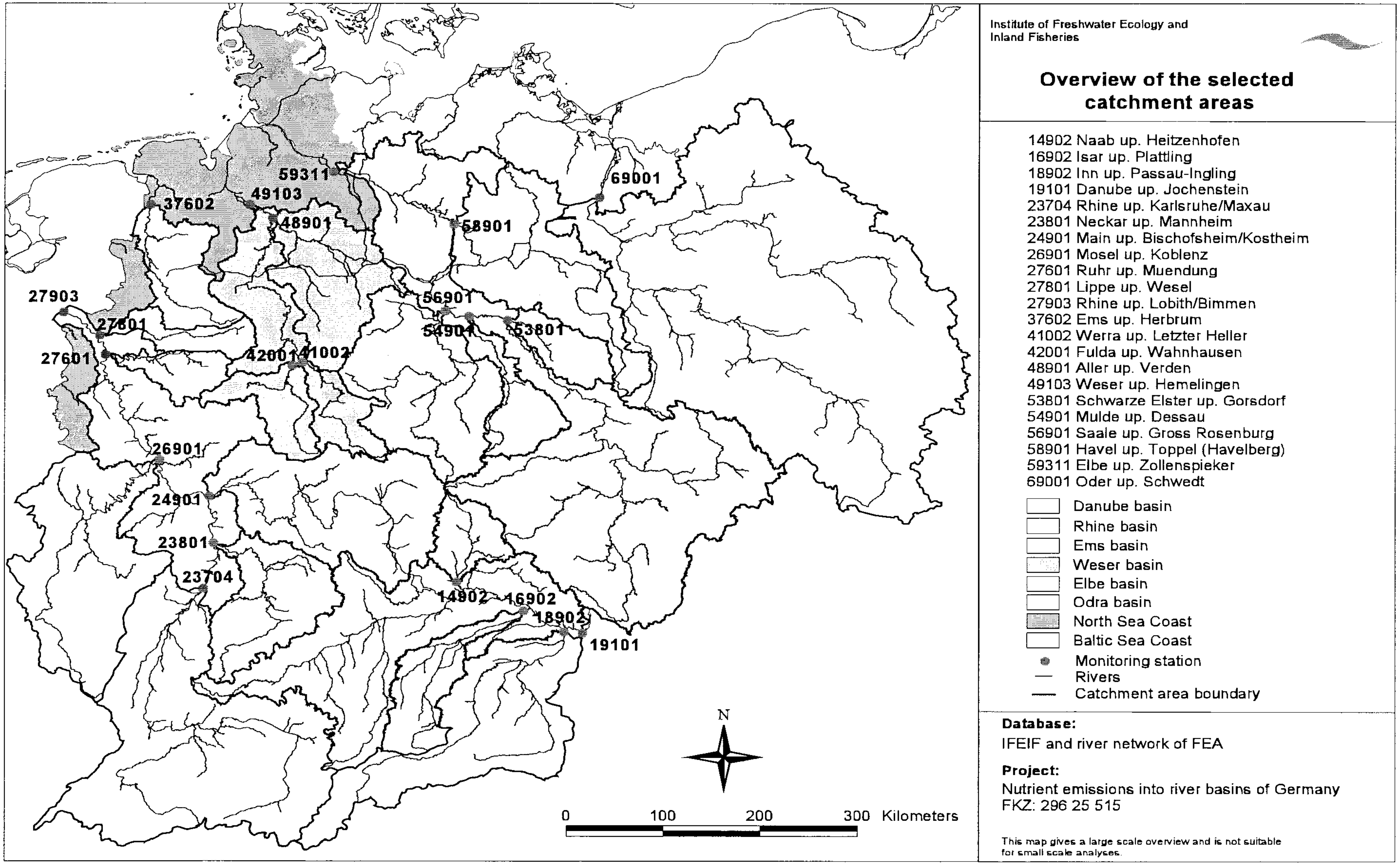
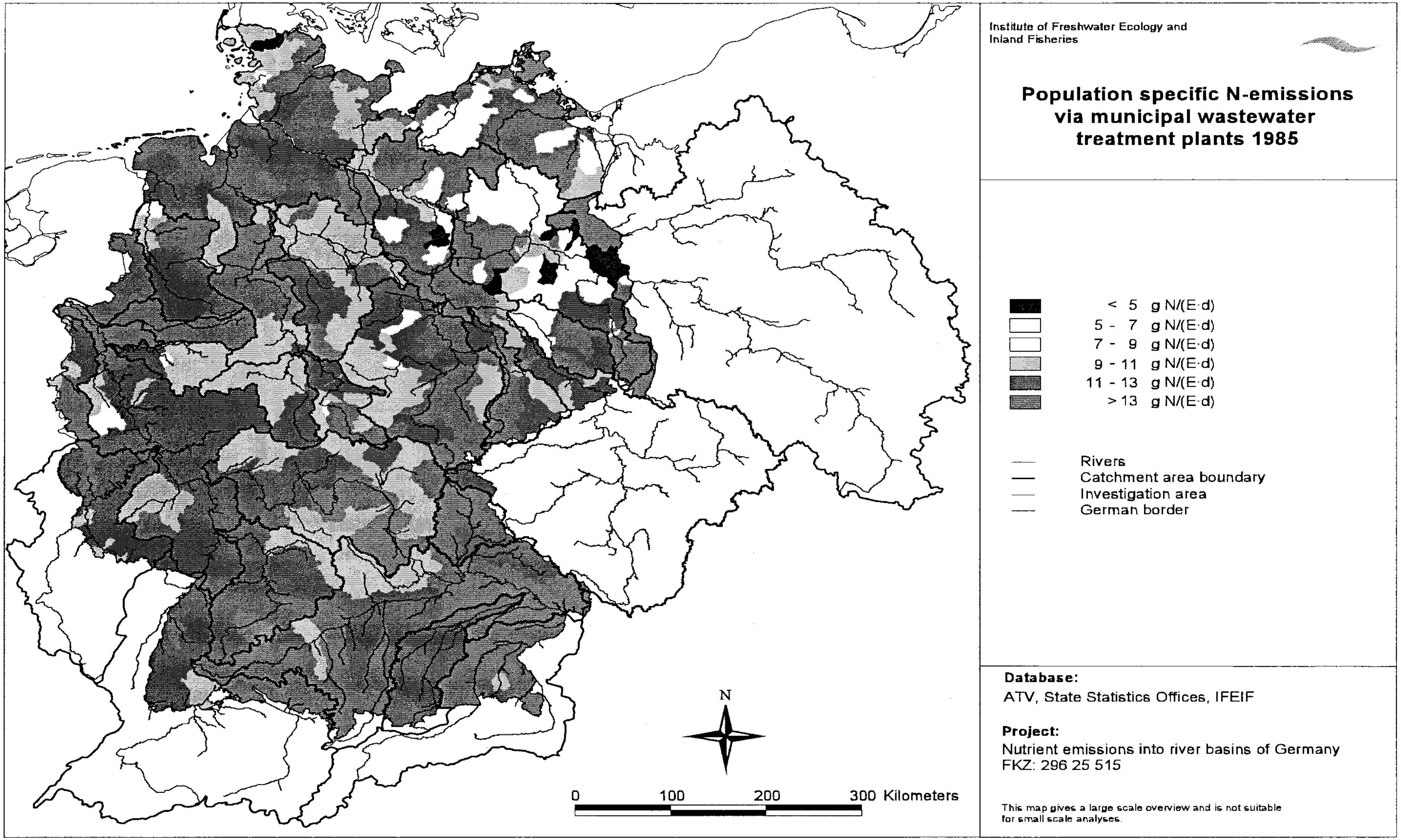


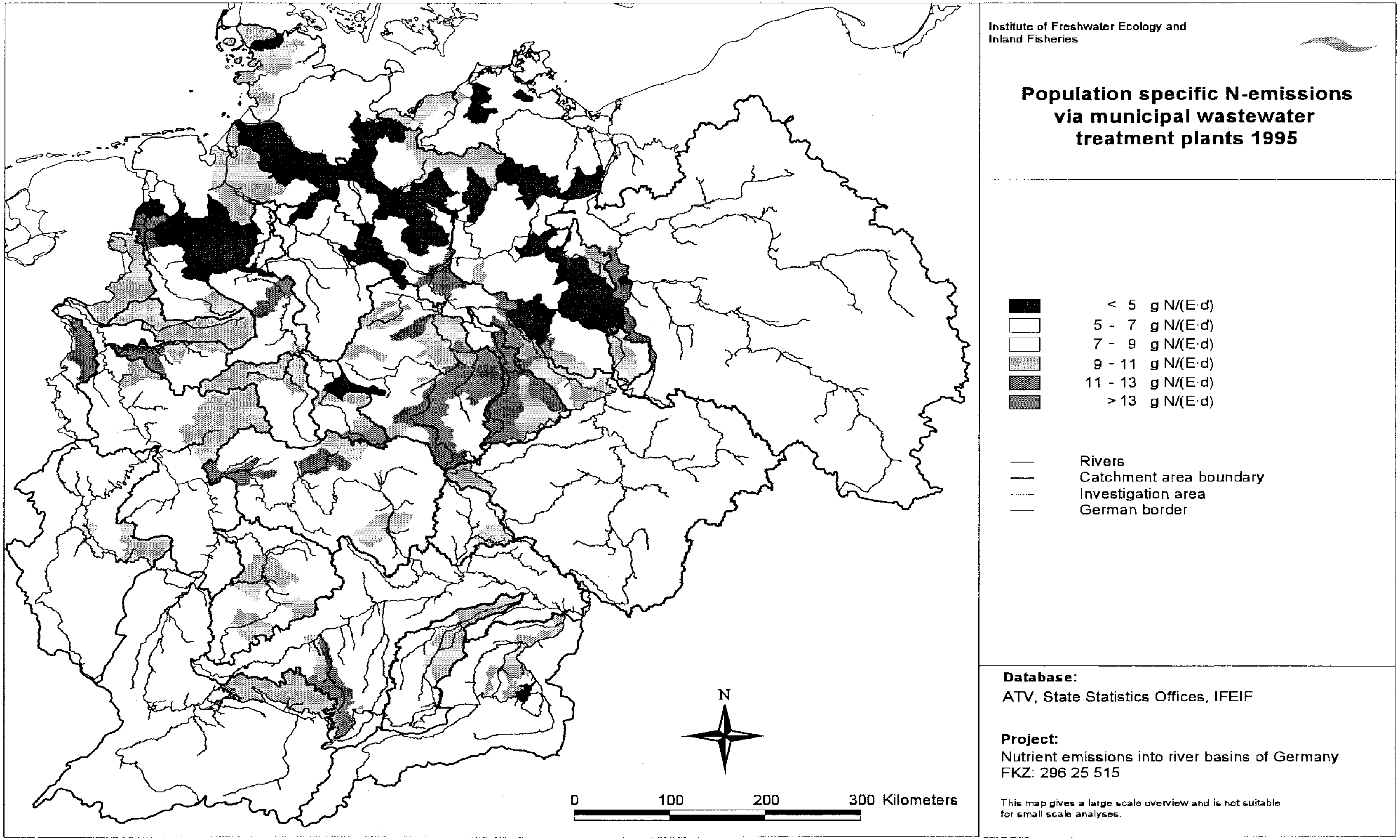
Figure 4.25: Dependence of the deviation between the estimates of the immission and emission method on the connection of paved urban areas to the combined sewers for nitrogen in the period 1993-1997.



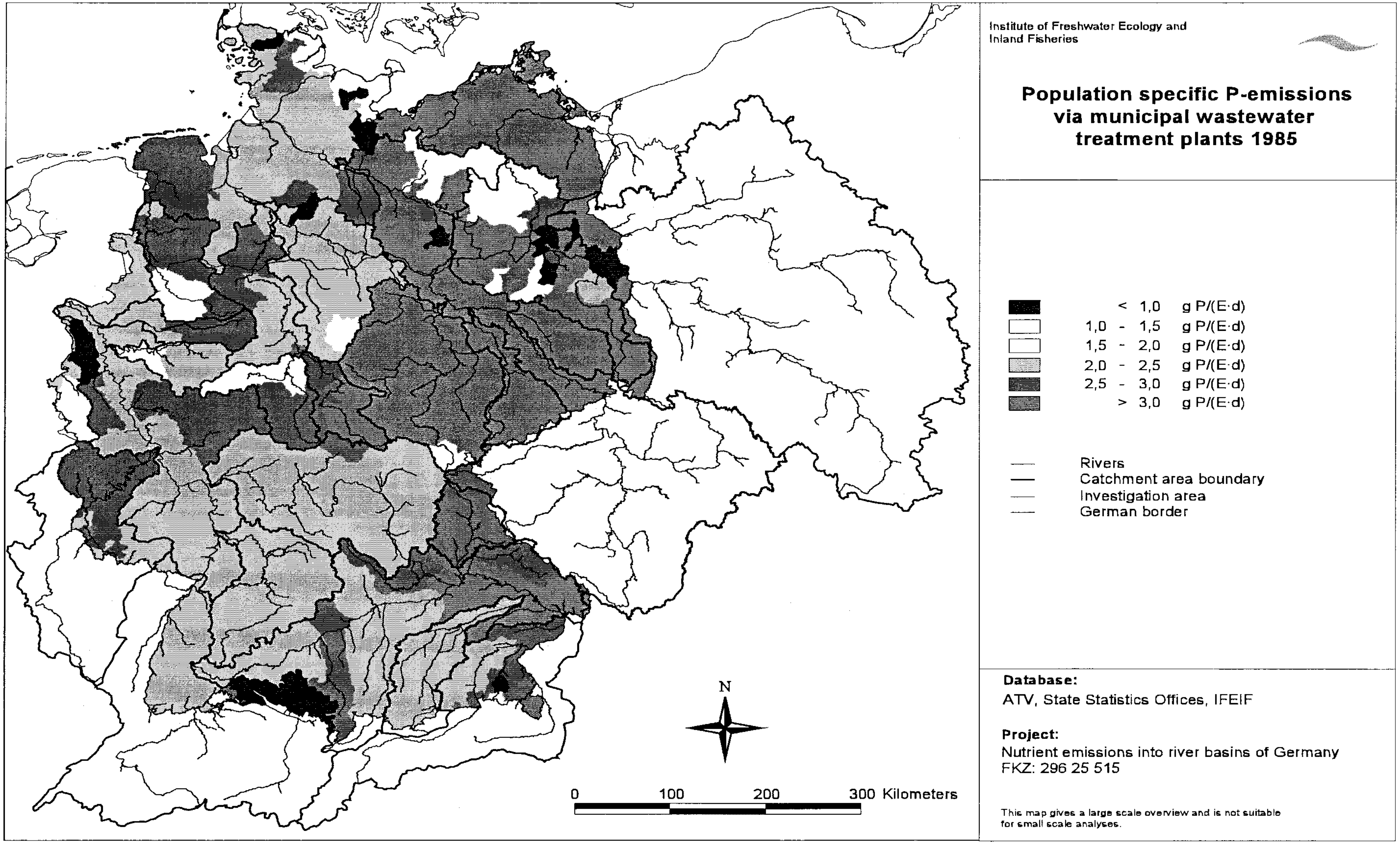
Map 4.1: Overview of the selected catchment areas.



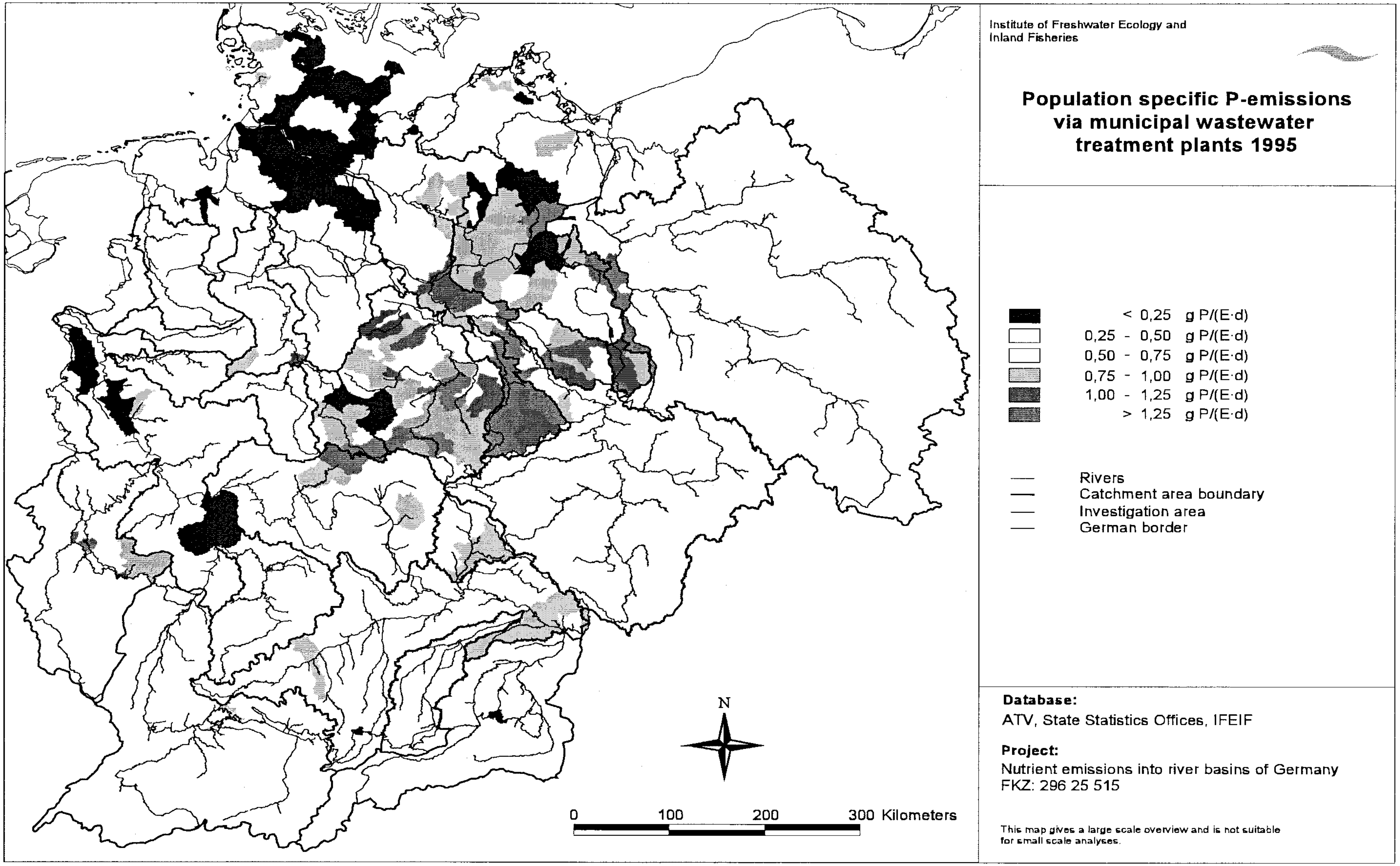
Map 4.2: Population specific N-emissions via municipal wastewater treatment plants 1985.



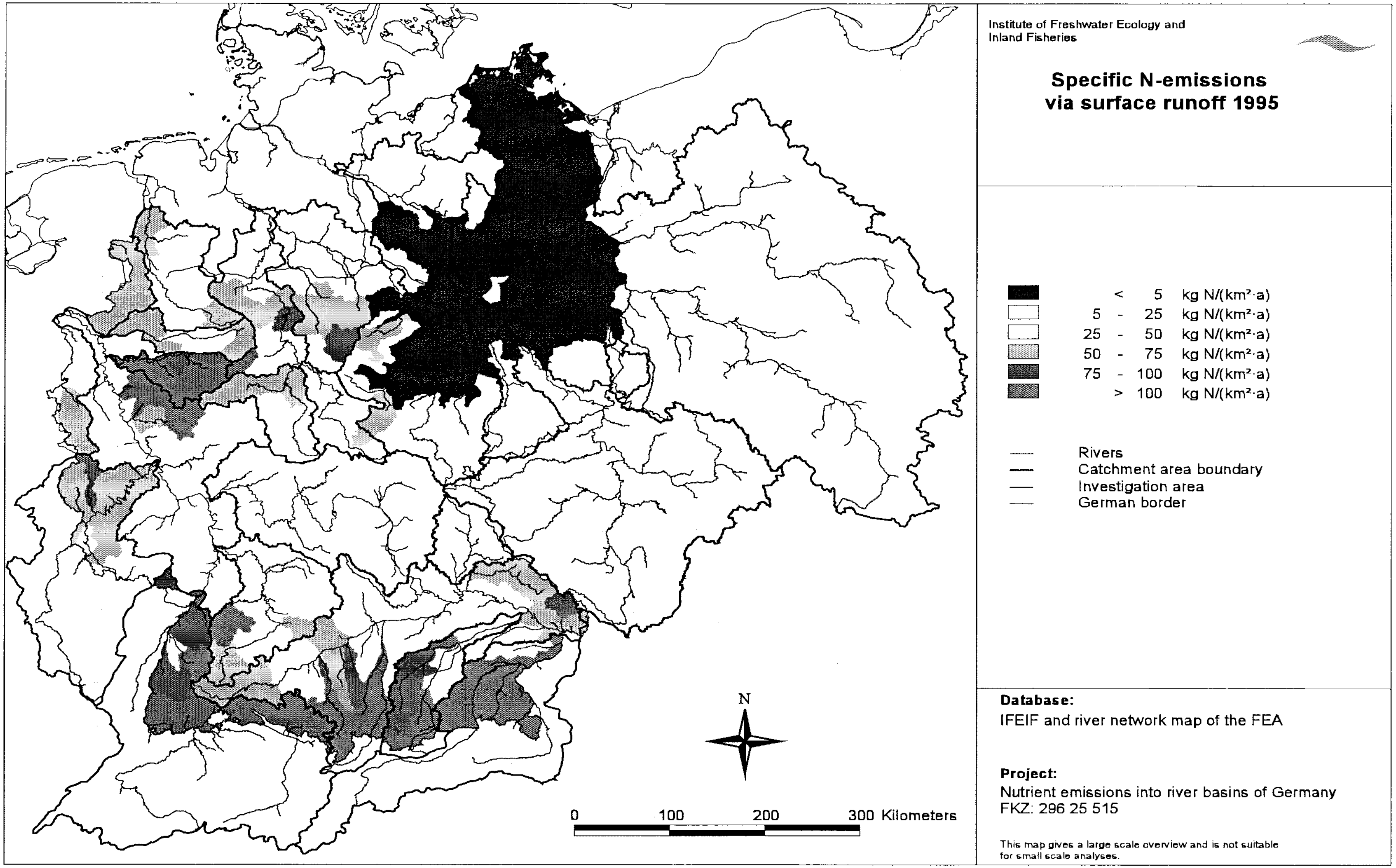
Map 4.3: Population specific N-emissions via municipal wastewater treatment plants 1995.



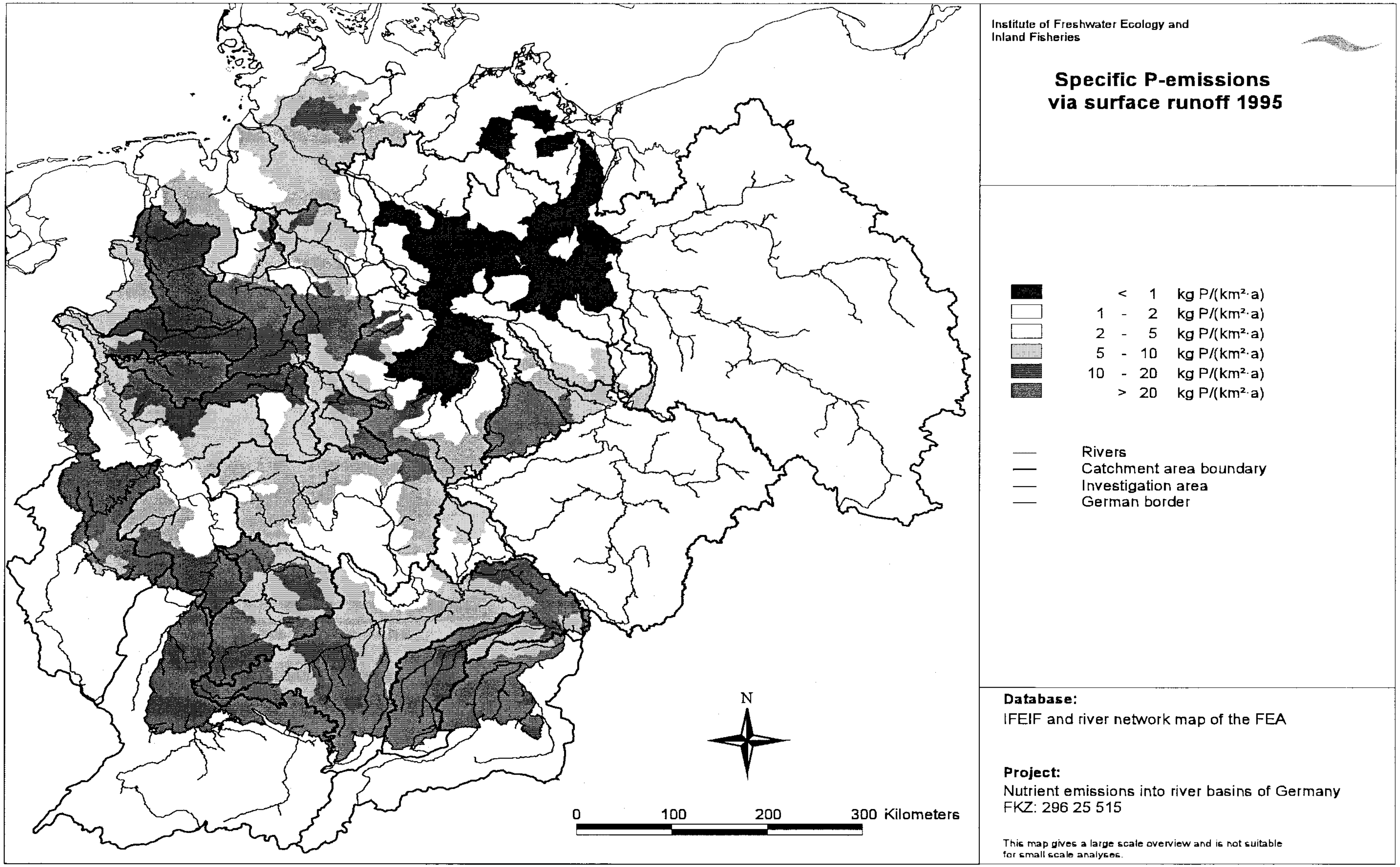
Map 4.4: Population specific P-emissions via municipal wastewater treatment plants 1985.



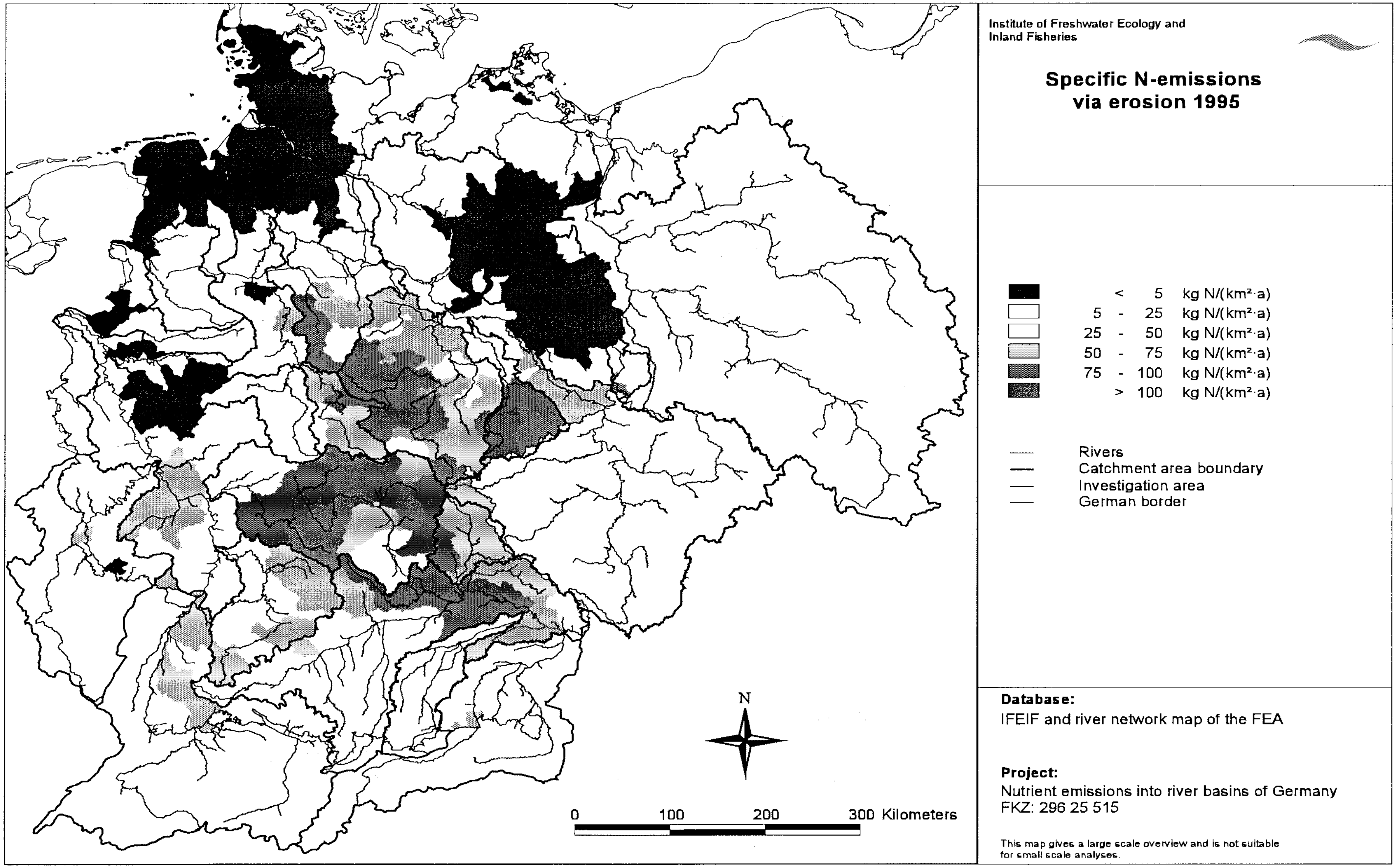
Map 4.5: Population specific P-emissions via municipal wastewater treatment plants 1995.



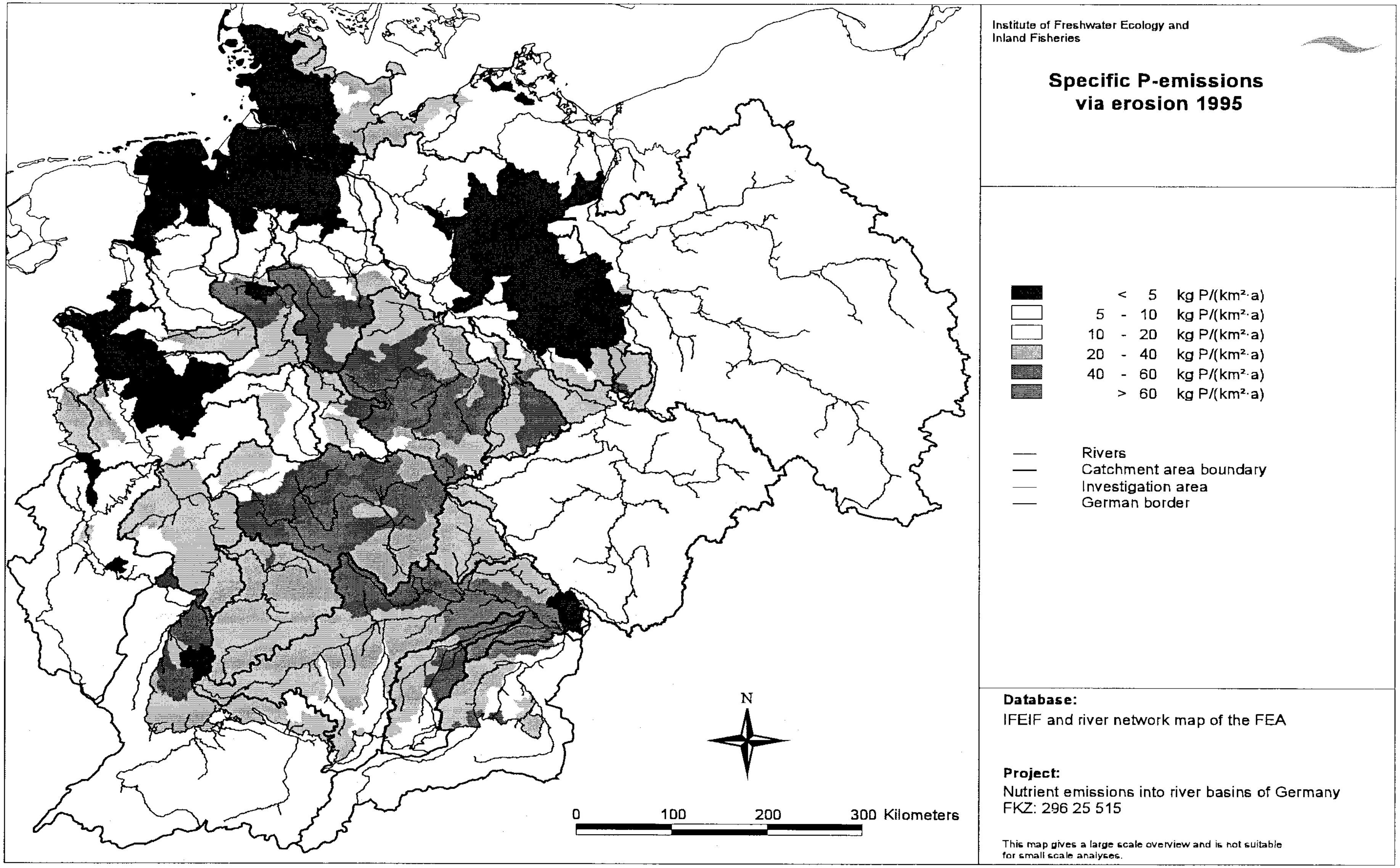
Map 4.6: Specific N-emissions via surface runoff 1995.



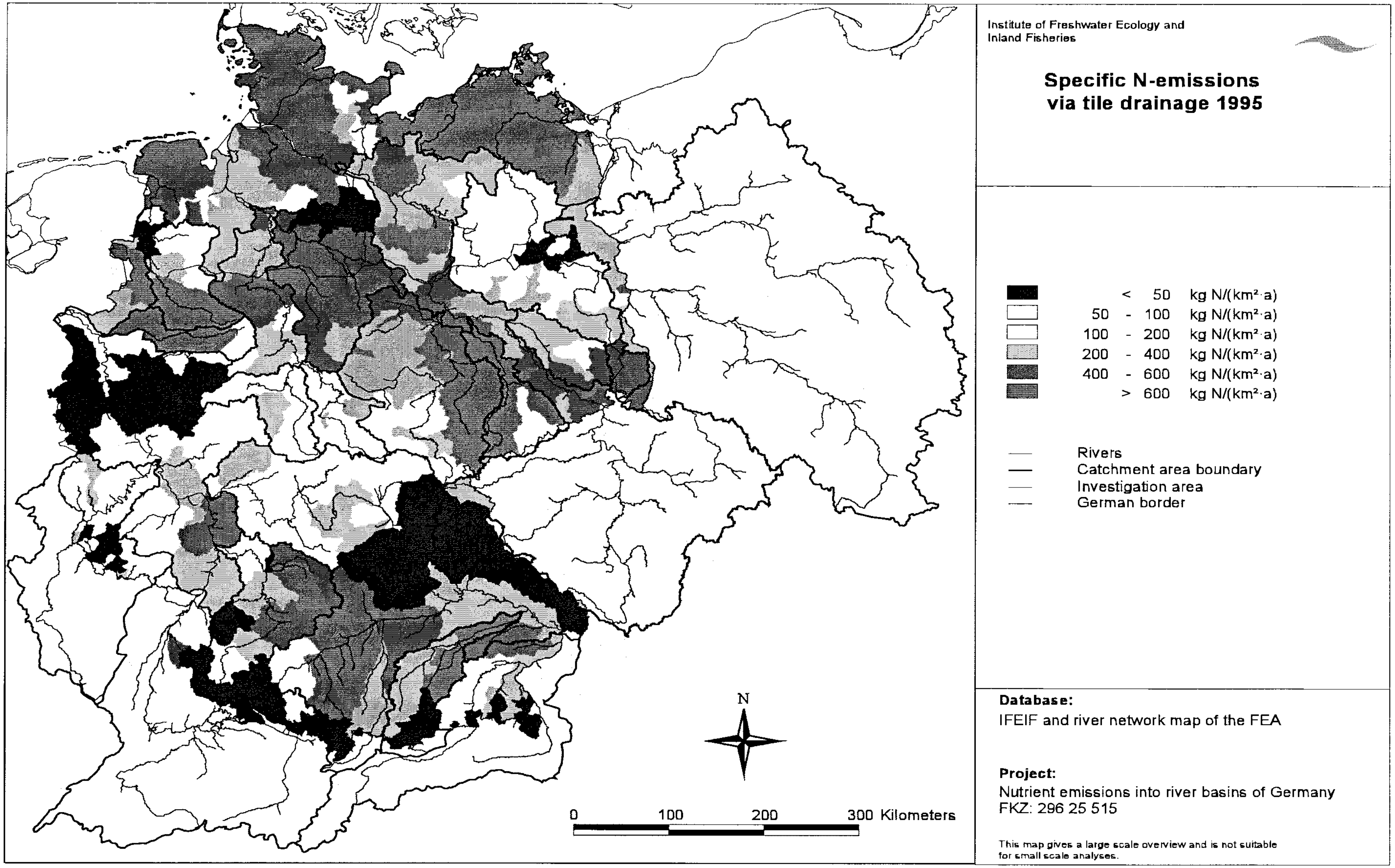
Map 4.7: Specific P-emissions via surface runoff 1995.



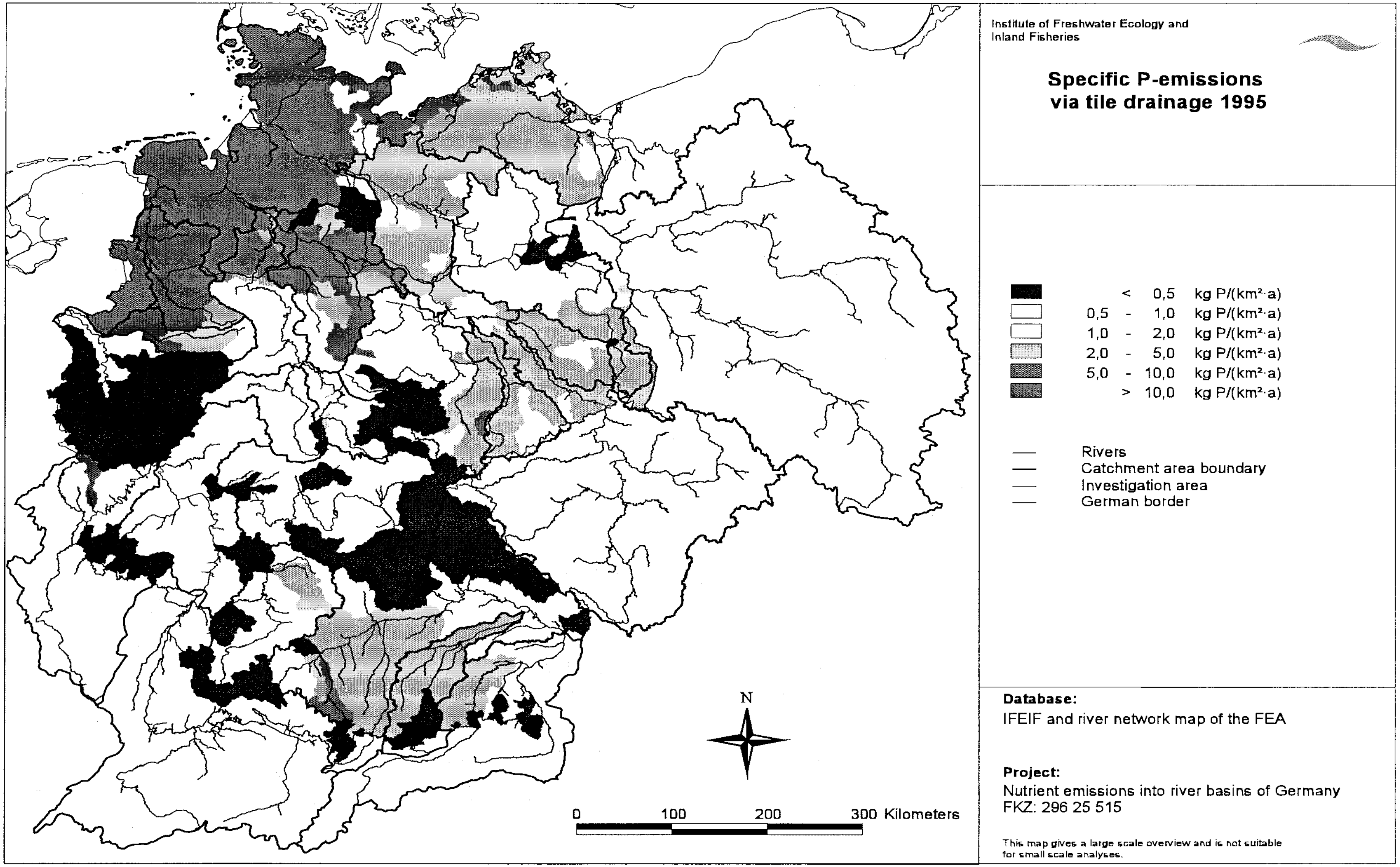
Map 4.8: Specific N-emissions via erosion 1995.



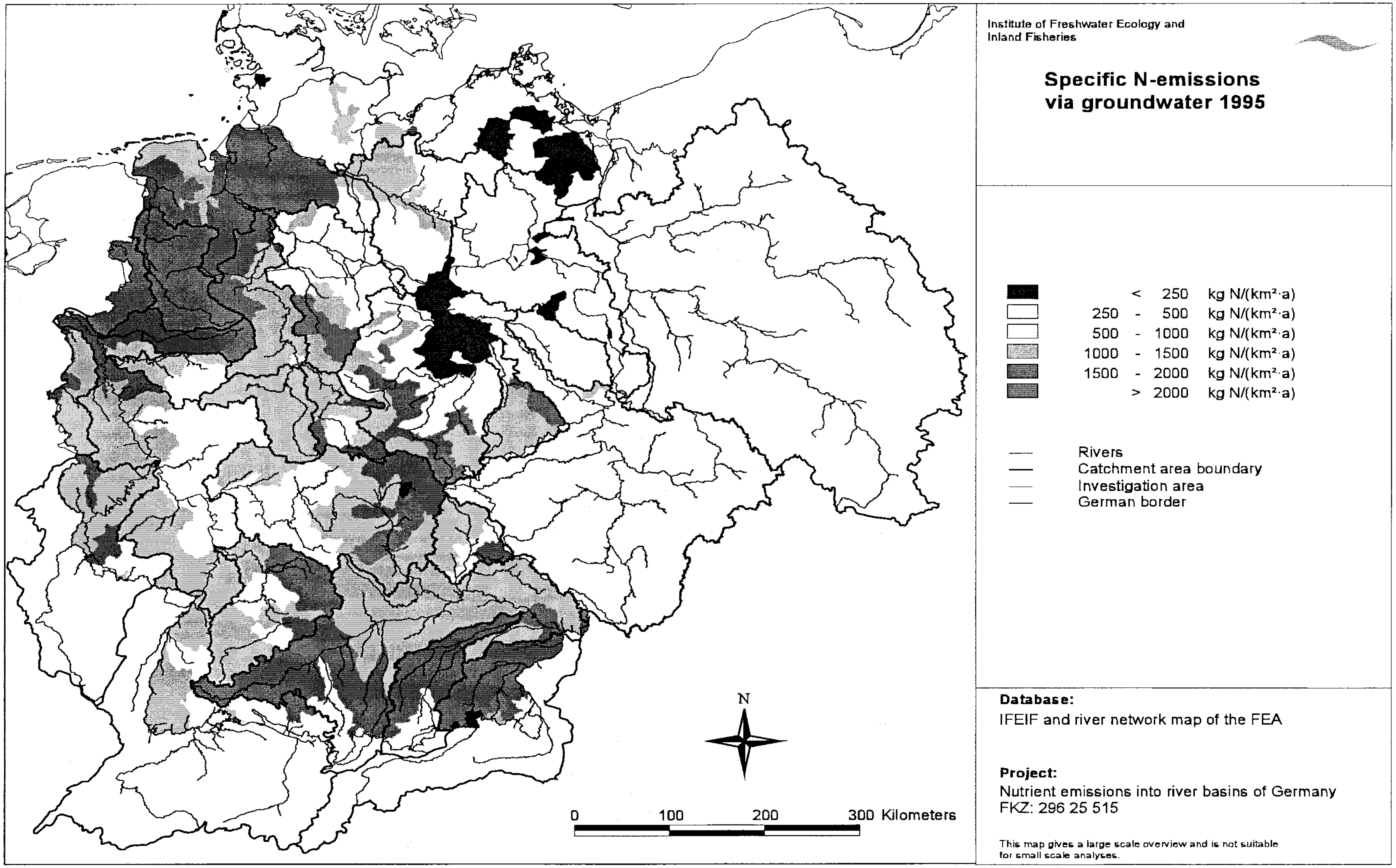
Map 4.9: Specific P-emissions via erosion 1995.



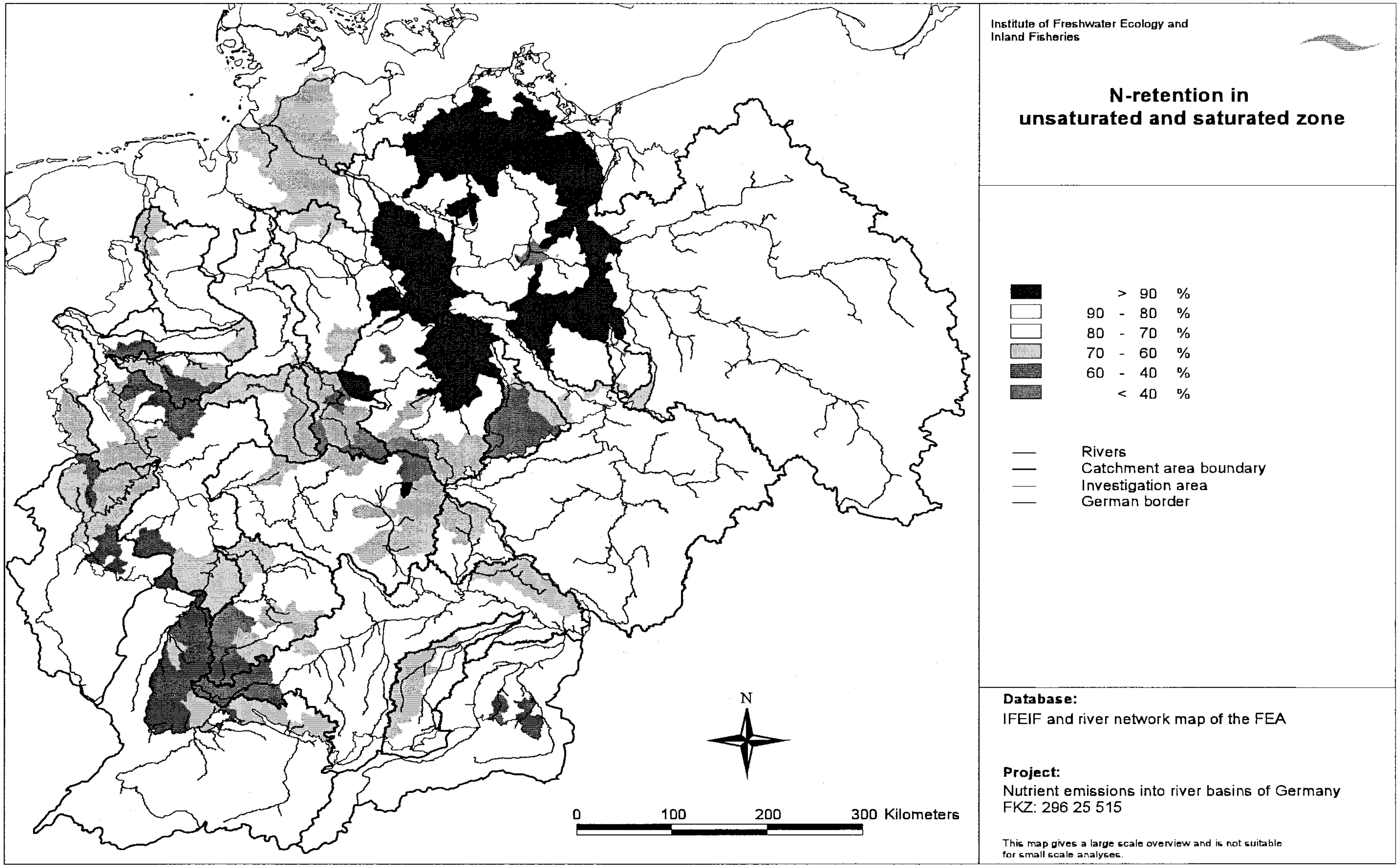
Map 4.10: Specific N-emissions via tile drainage 1995.



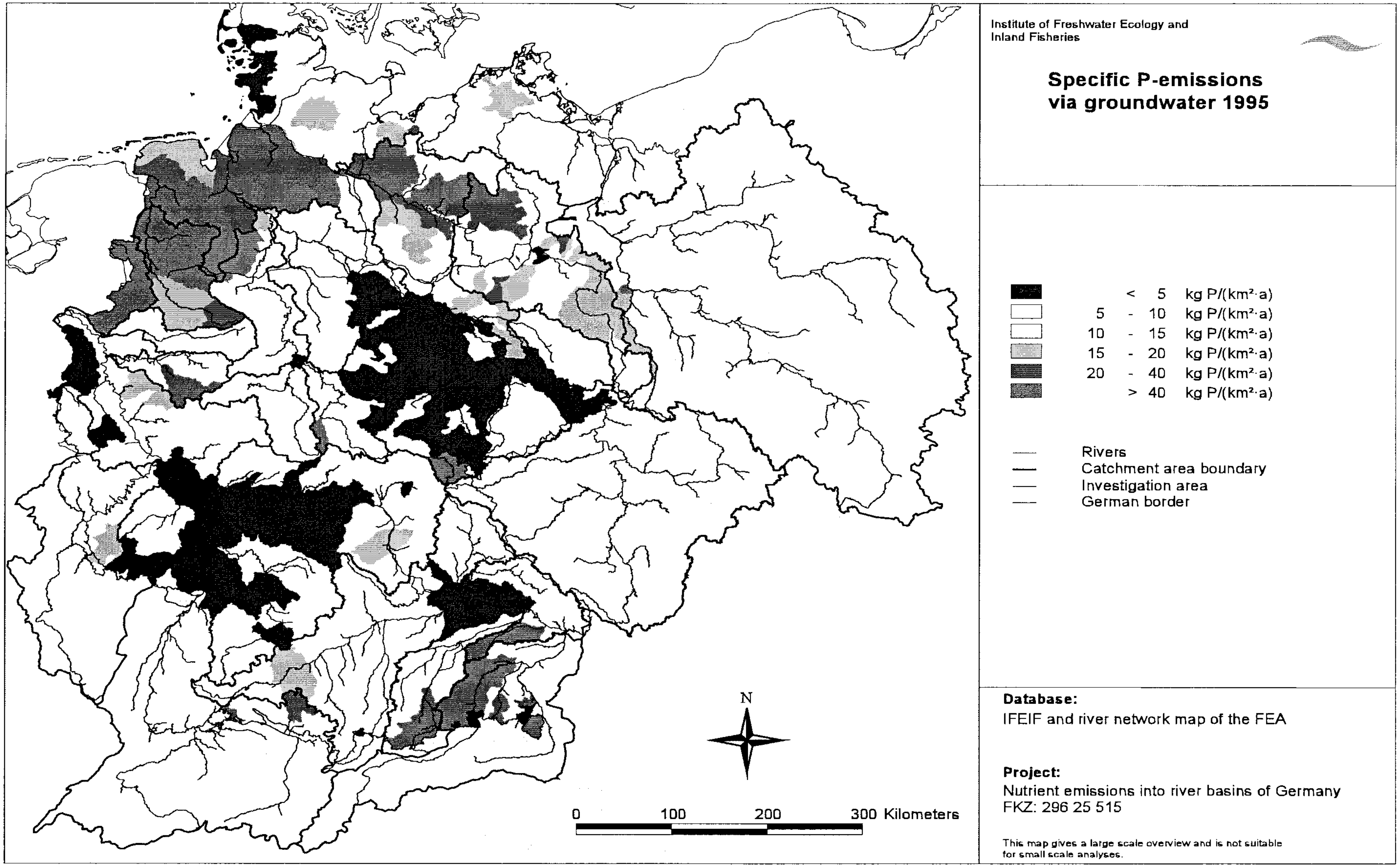
Map 4.11: Specific P-emissions via tile drainage 1995.



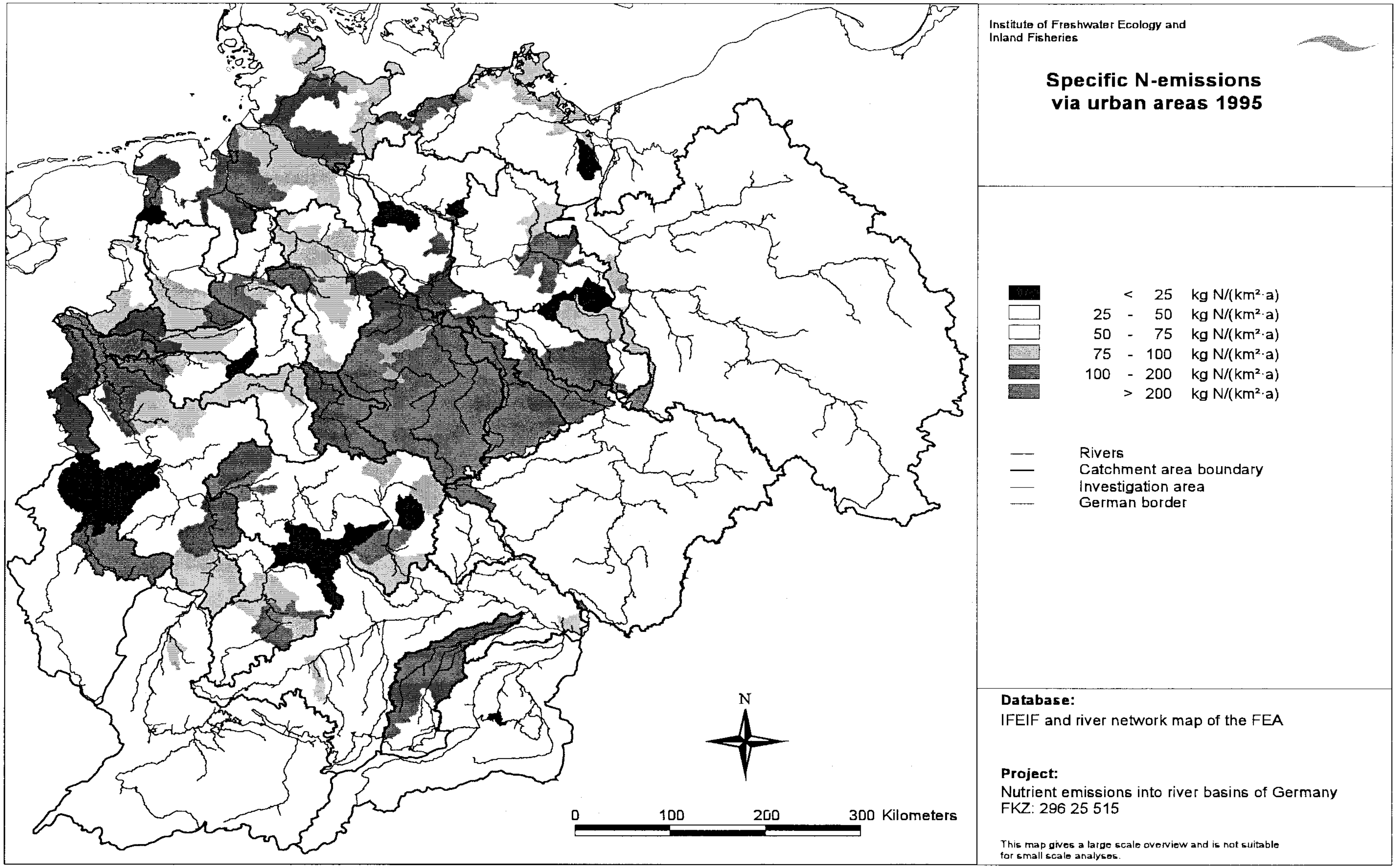
Map 4.12: Specific N-emissions via groundwater 1995.



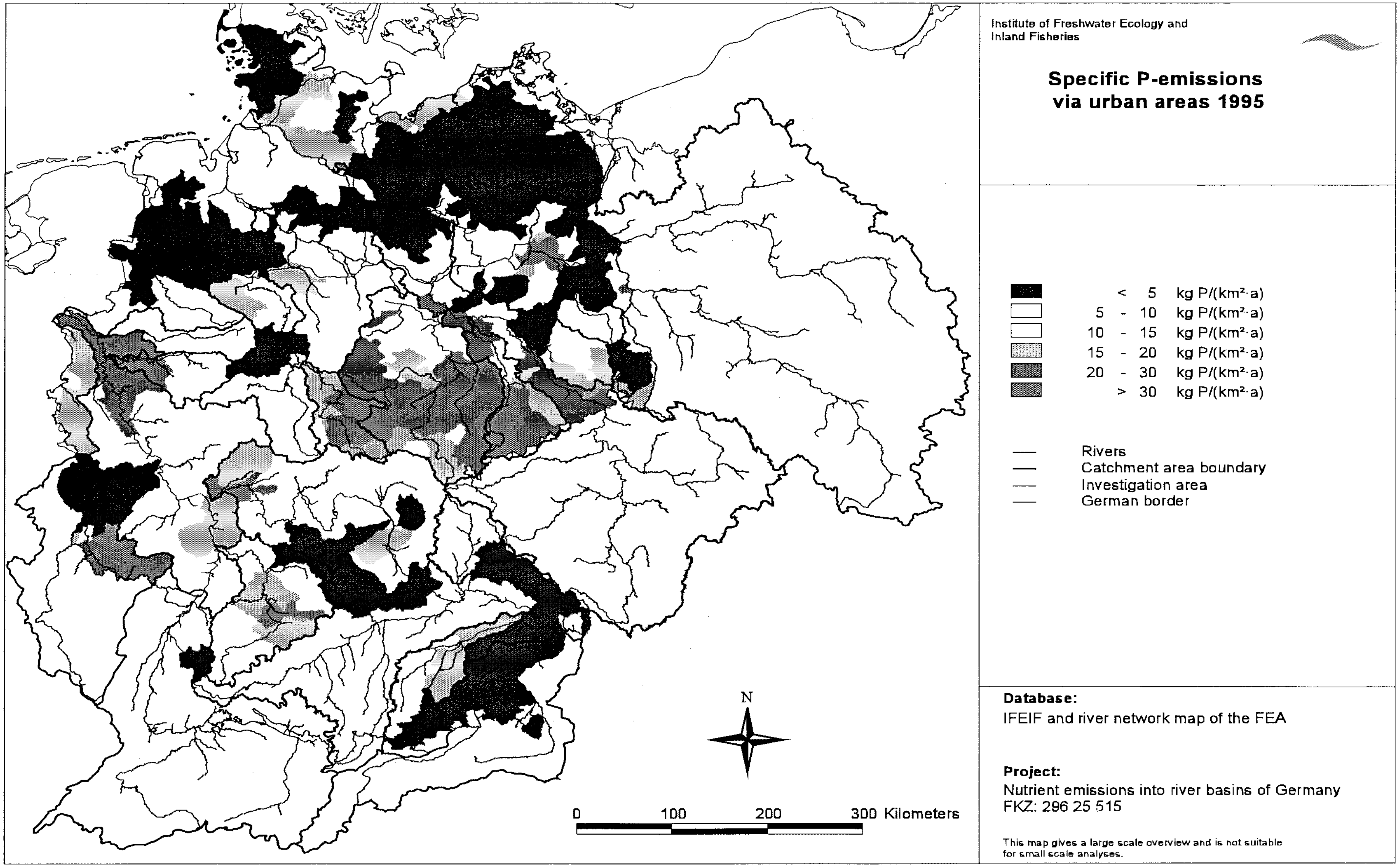
Map 4.13: N-retention in unsaturated and saturated zone.



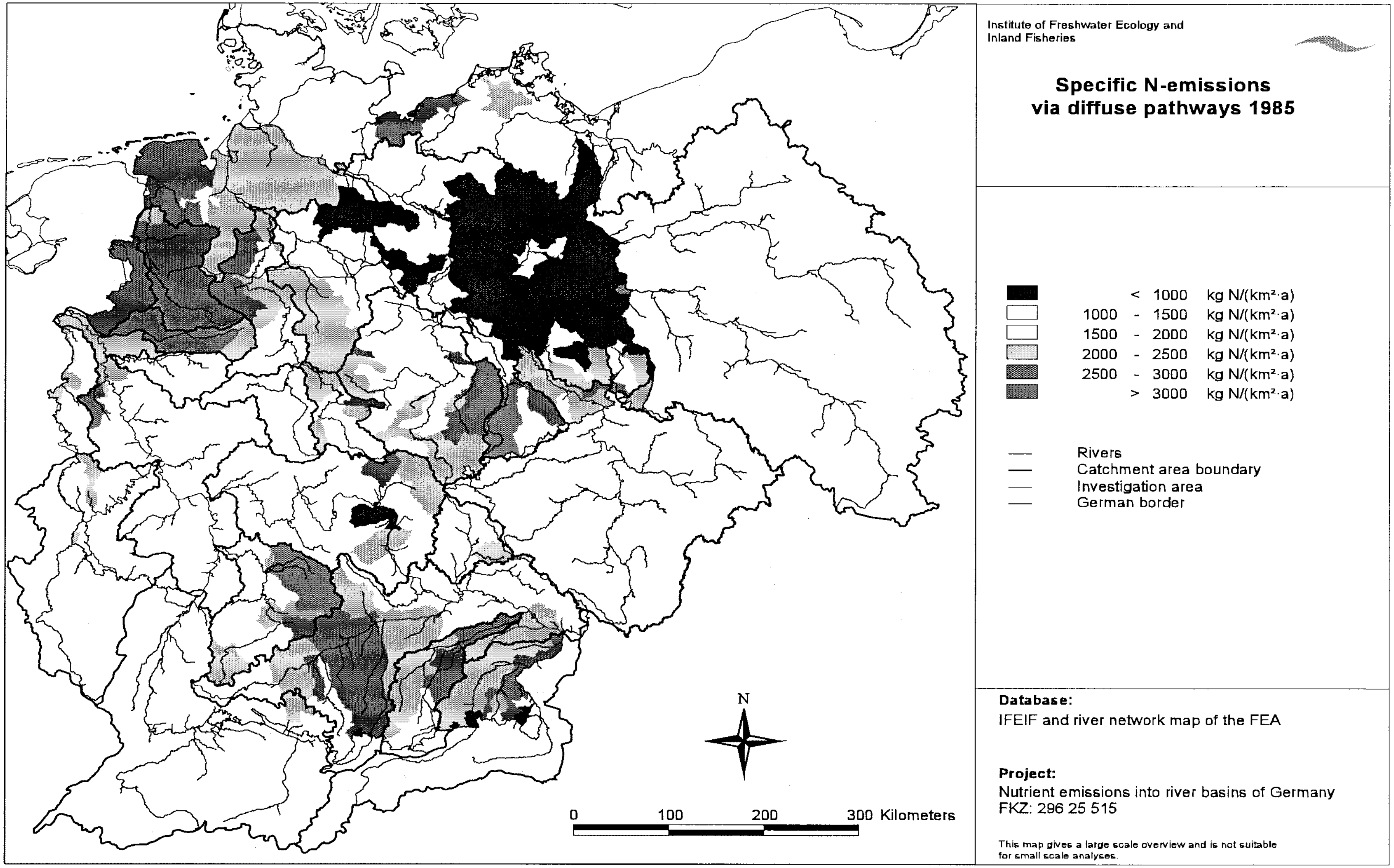
Map 4.14: Specific P-emissions via groundwater 1995.



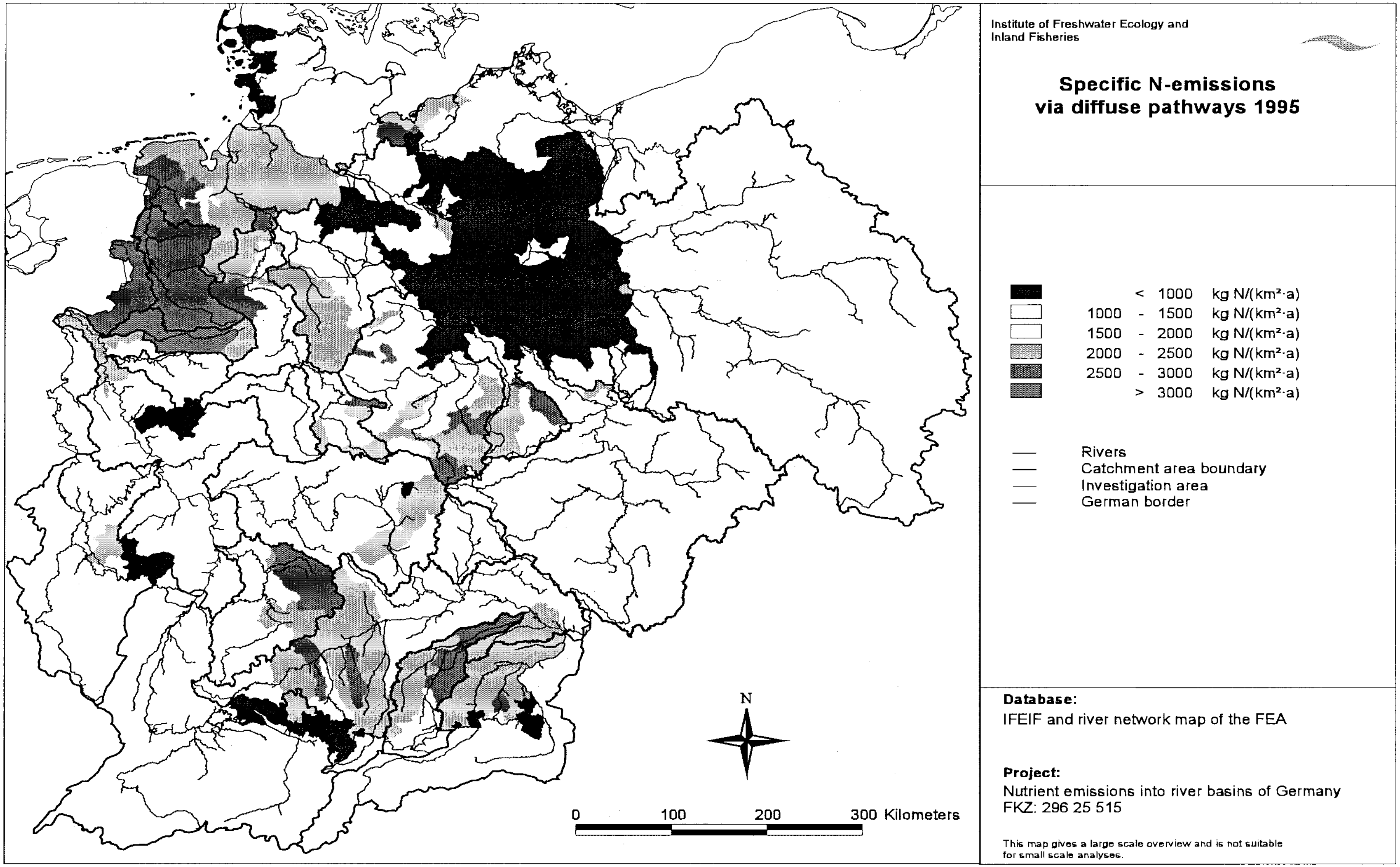
Map 4.15: Specific N-emissions via urban areas 1995.



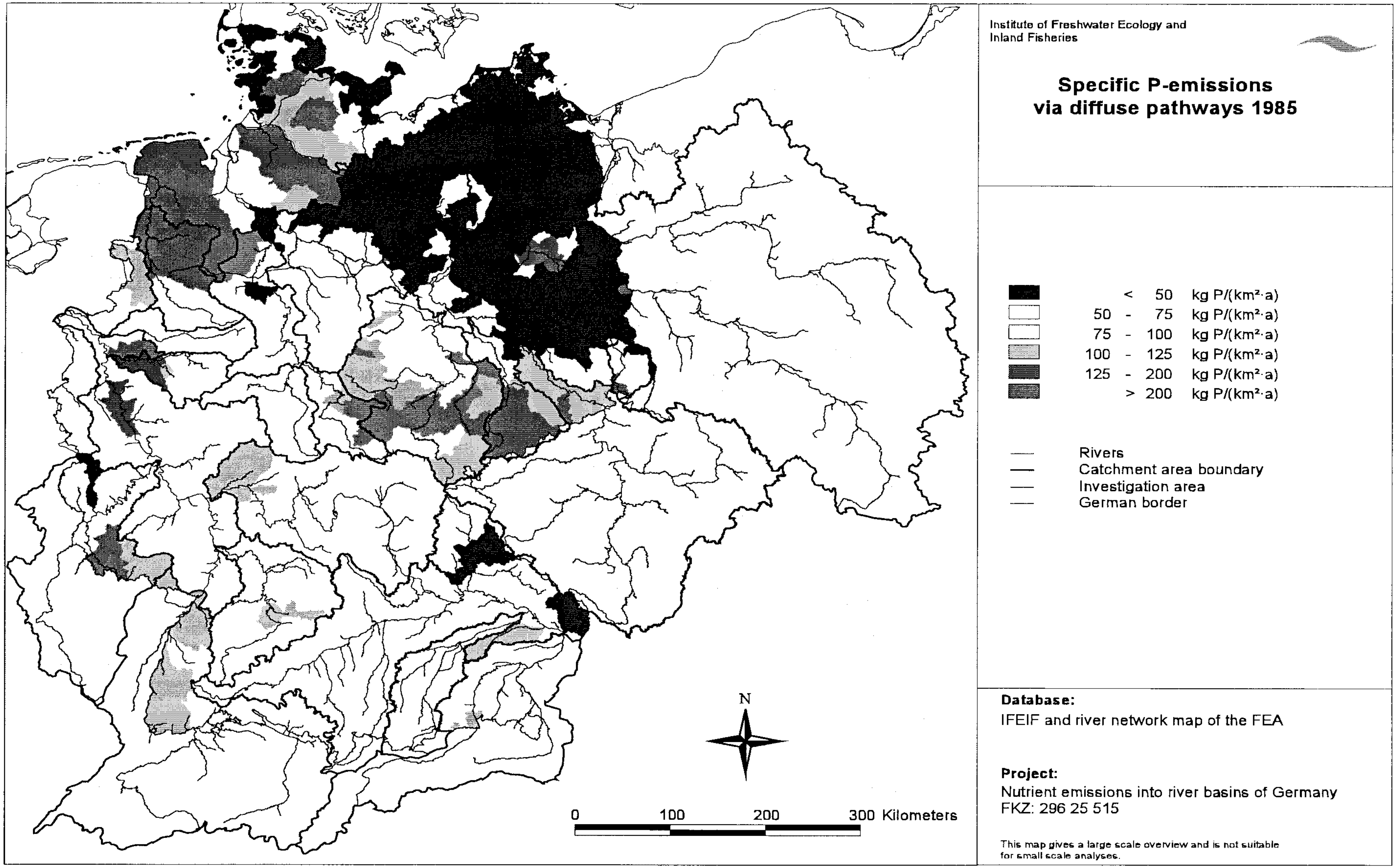
Map 4.16: Specific P-emissions via urban areas 1995.



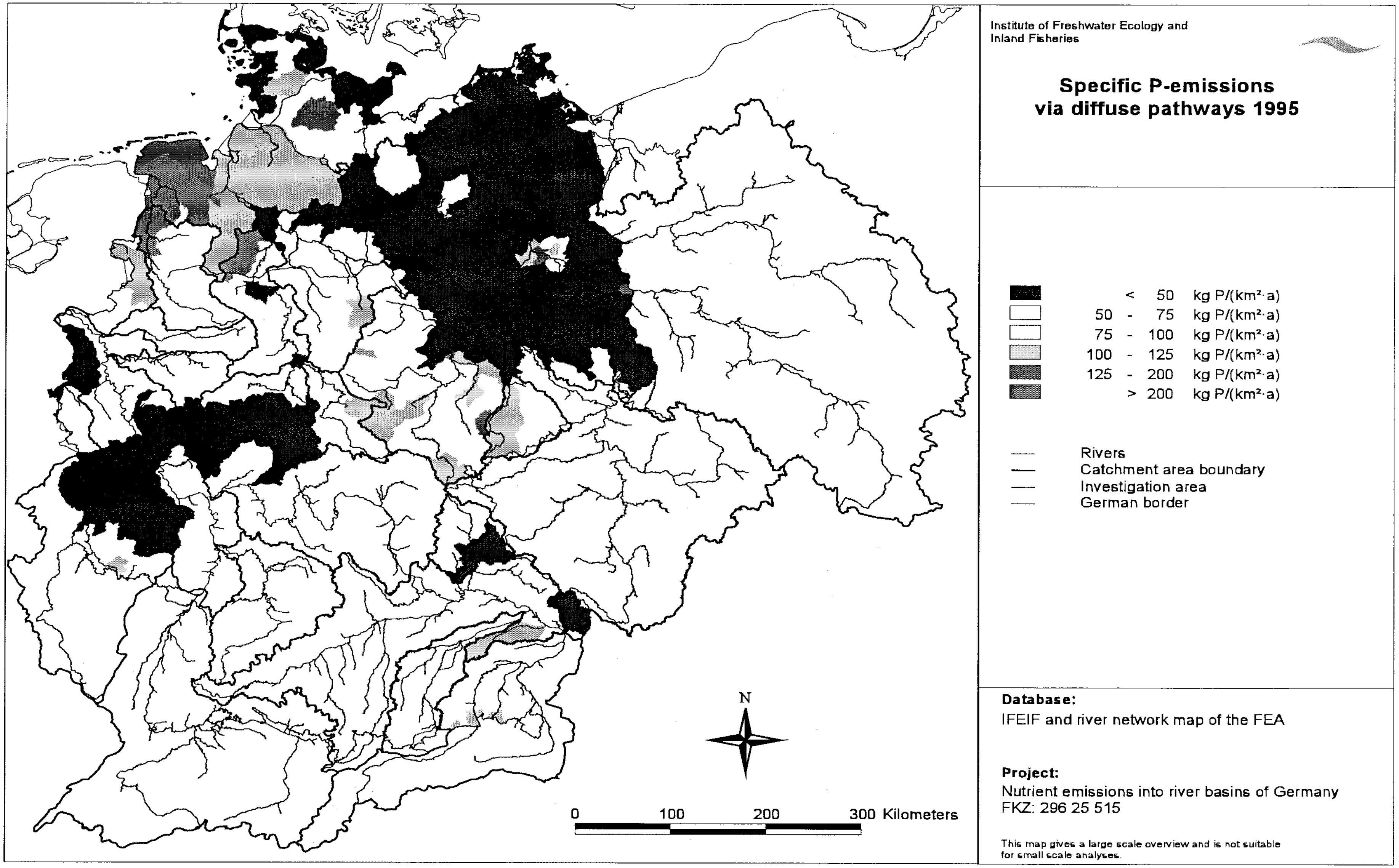
Map 4.17: Specific N-emissions via diffuse pathways 1985.



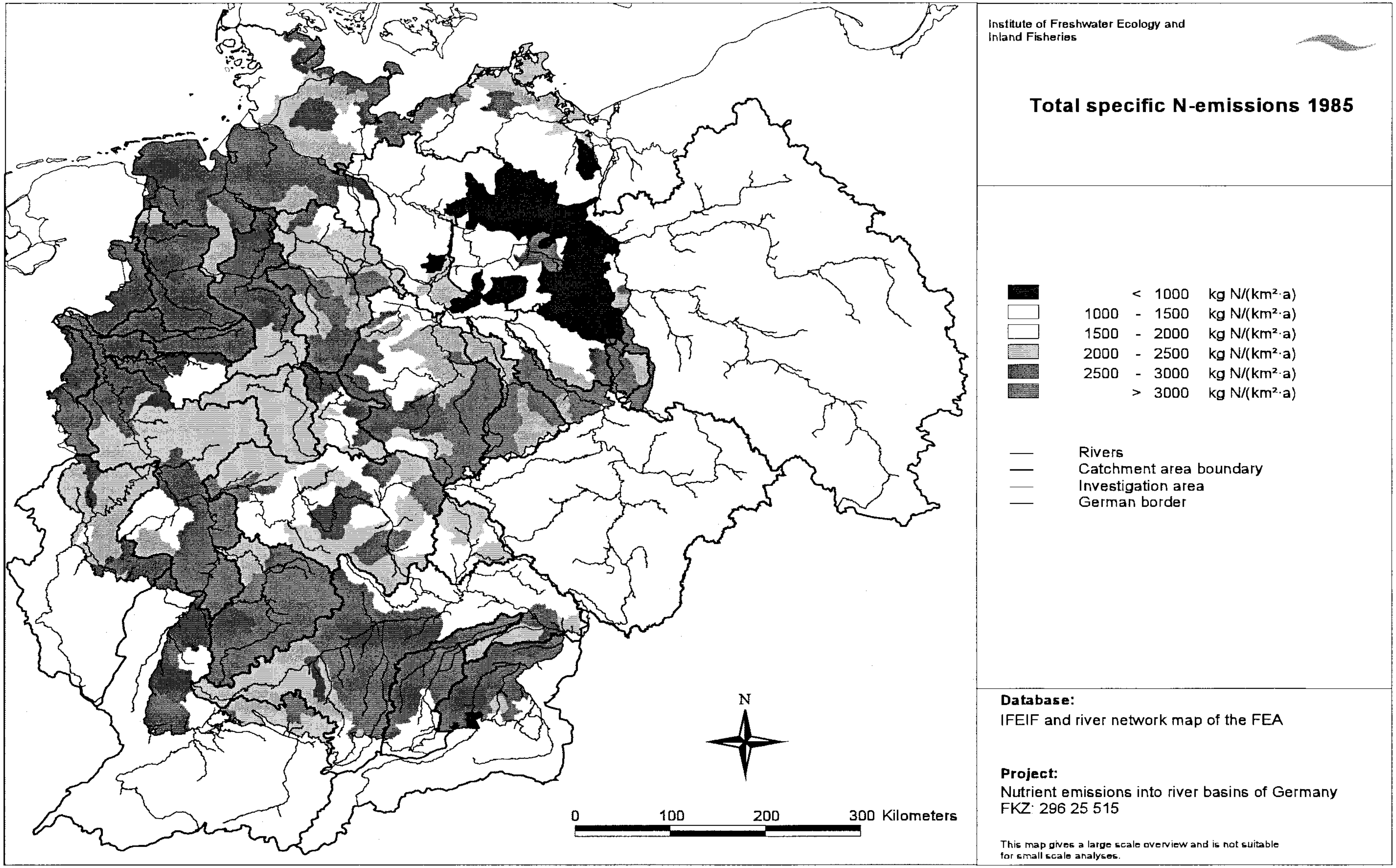
Map 4.18: Specific N-emissions via diffuse pathways 1995.



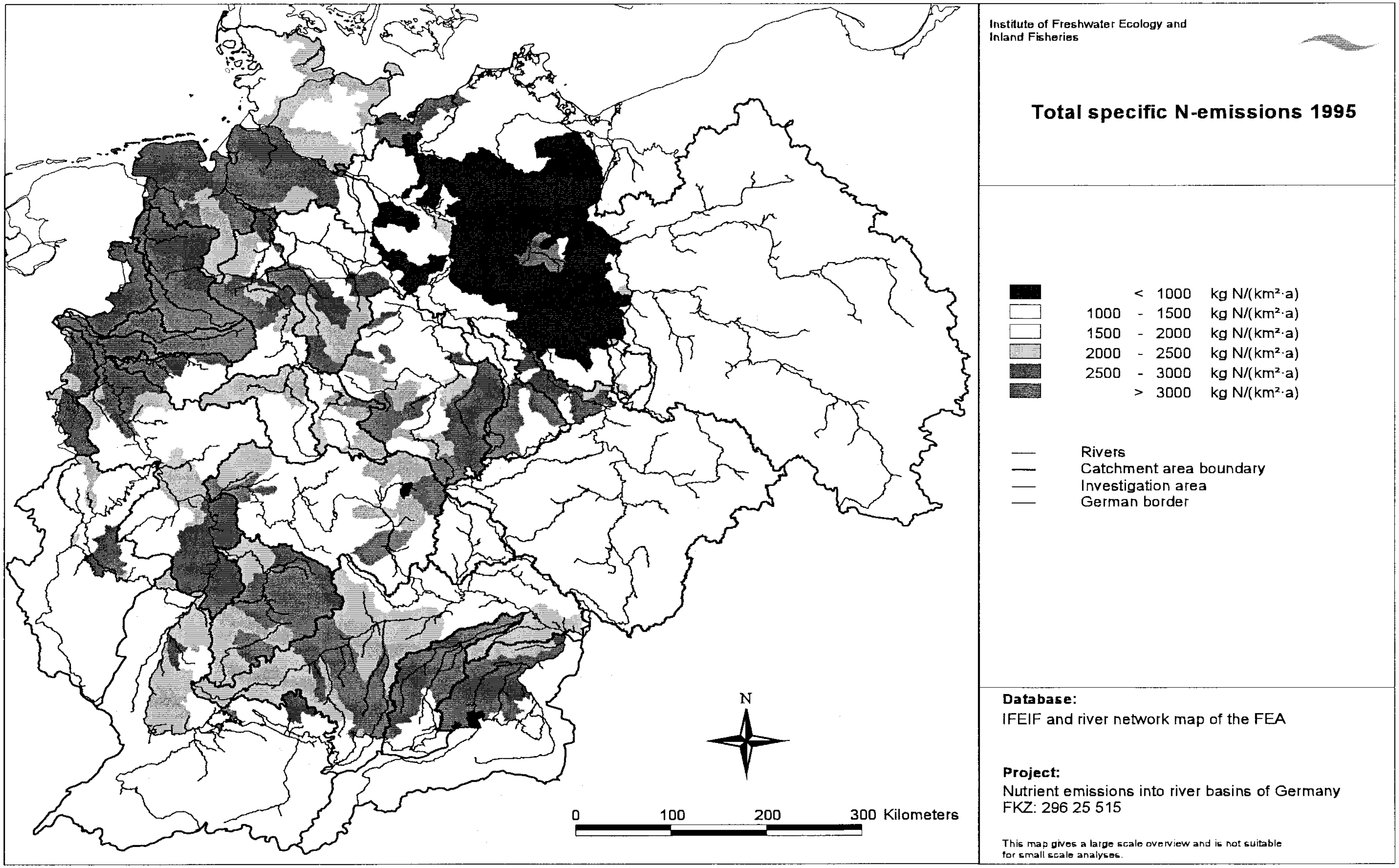
Map 4.19: Specific P-emissions via diffuse pathways 1985.



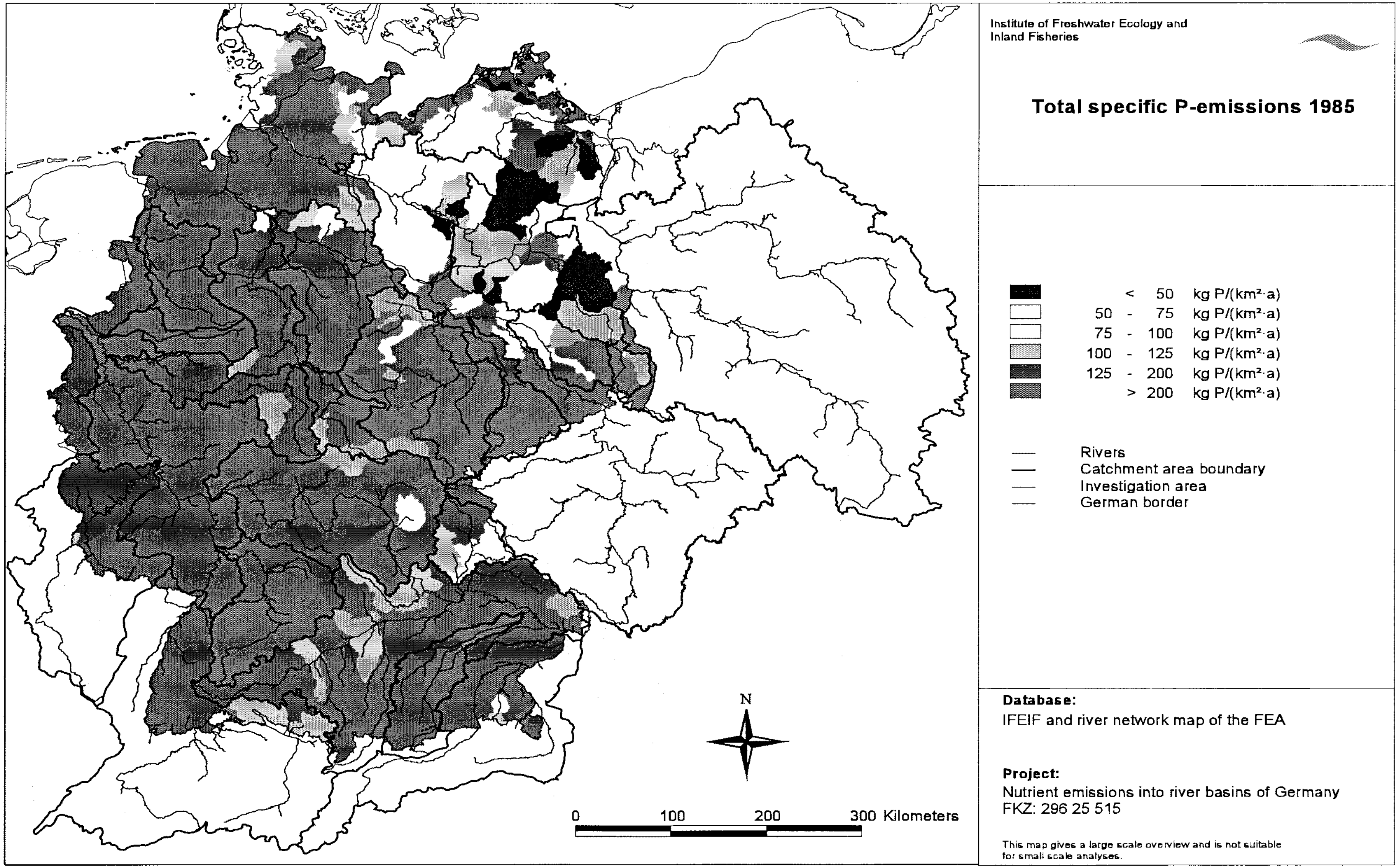
Map 4.20: Specific P-emissions via diffuse pathways 1995.



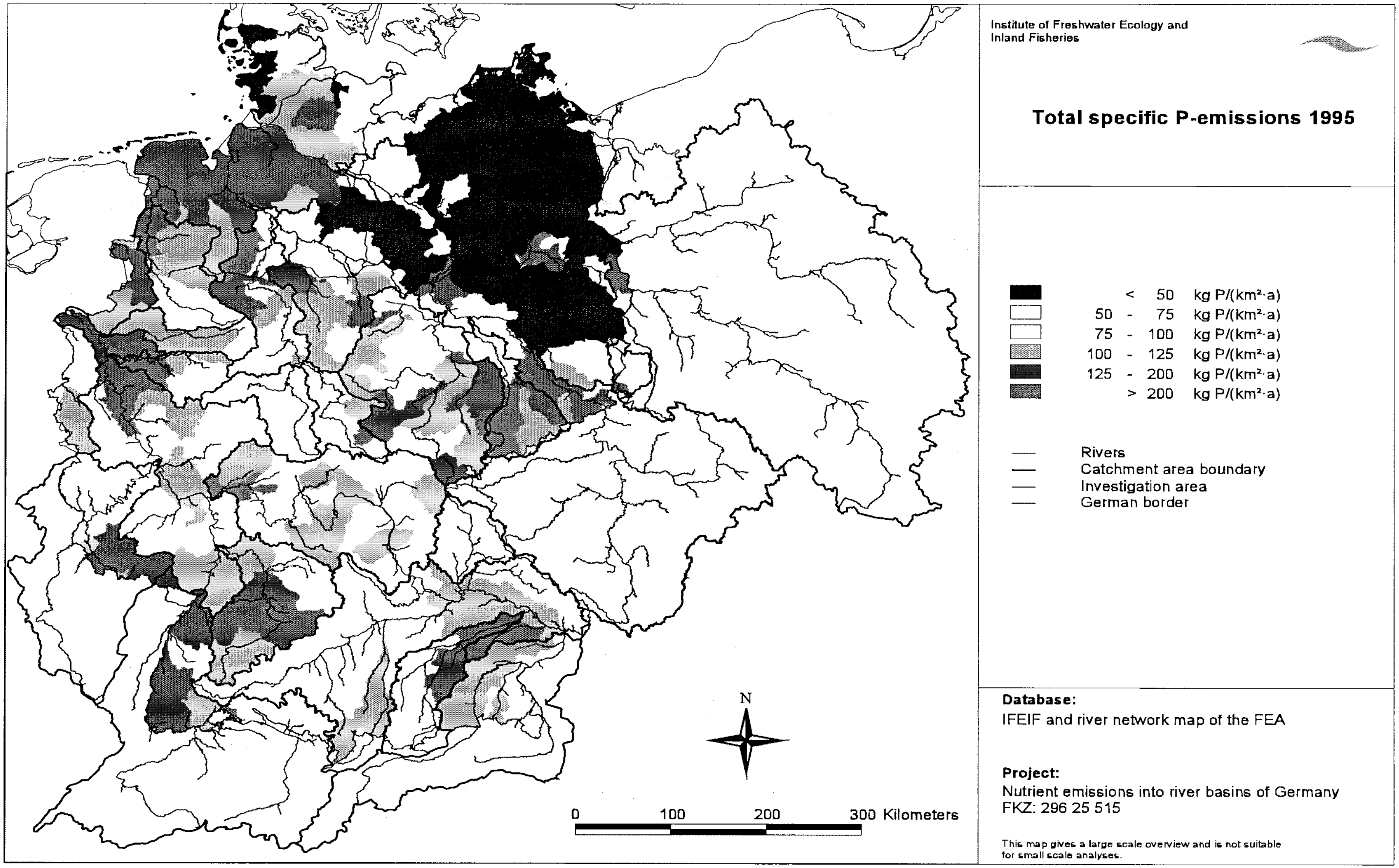
Map 4.21: Total specific N-emissions 1985.



Map 4.22: Total specific N-emissions 1995.



Map 4.23: Total specific P-emissions 1985.



Map 4.24: Total specific P-emissions 1995.

5 Scenarios

5.1 Municipal wastewater treatment plants

For a prediction of the N- and P- emissions from municipal wastewater treatment plants, both medium-term realistic scenarios (Scenarios 1 and 2) and long-term possible scenarios (Scenarios 3 and 4) are considered. The outcome of these scenarios was carried out according to the method described in Section 3.1.1.1.

With all scenarios it was assumed that the number of inhabitant equivalents and also the quantity of water flows were the same as in 1995, the balance year. In addition, the water-purification performance used in Section 3.1.1.1 for the individual processes and the inhabitant- and EGW- specific nitrogen emissions as well as their deployment in the individual procedures were not changed within the framework of the scenarios. Although a further increased proportion of phosphorus in the compact laundry detergents principally from light increased inhabitant-specific P-emissions is anticipated (MOHAUPT, 1998 personal communication), the values for 1995 will be used for the scenarios since the mid term i.e. expected increase in P-emissions lie within the error values of the 1995 values.

For the individual scenarios, the following assumptions were applied:

- **Scenario 1** comes from the fulfilment of the *statutory requirements*, in other words all municipal wastewater treatment plants of size class 3 and above have a denitrification treatment and all of size class 4 and above operate with a specific P-reduction procedure. It is also assumed that the number of inhabitants connected to a municipal wastewater treatment plants remains the same as in 1995.

- **Scenario 2** considers, in addition to Scenario 1, an *increased connection-grade*. It is assumed that all inhabitants connected in 1995 to a sewer but not to a public treatment plant were connected to a treatment plant. In addition, in the catchment areas in which the level of connection to public treatment plants was under 80%, an increase of 3% is assumed; in areas in which the level of connection was between 80% and 90% an increase of 1% was considered.

- **Scenario 3,** in addition to Scenario 2 uses an *expansion of P-elimination* with treatment plants of size class 3 and above.

- **Scenario 4** considers, in addition to Scenario 3, the carrying out of a fourth purification in the form of microfiltration for treatment plants of size-class 5.

The results of these scenario considerations are shown in Table 5.1.

Table 5.1: Changes in nitrogen and phosphorus emissions ($EKK_{N,P}$) of municipal wastewater treatment plants according to the realisation of various scenarios.

ADDR.	River/Basin	EKK_N 1995	Change with Scenario 1	Change with Scenario 2	EKK_P 1995	Change with Scenario 1	Change with Scenario 2	Change with Scenario 3	Change with Scenario 4
		[t N/a]	[%]		[t P/a]	[%]			
14902	Naab	1,200	-32,2	-30,3	100	-20,1	-18,7	-37,4	-45,2
16902	Isar	8,000	-53,9	-53,8	280	-2,2	-2,0	-4,2	-63,2
18902	Inn	2,300	-39,7	-39,2	150	-22,6	-21,6	-28,0	-35,7
19101	Danube	24,400	-42,9	-42,3	1,410	-18,9	-18,0	-27,0	-51,1
23704	Upper Rhine	7,000	-42,6	-42,5	340	-31,7	-31,6	-38,8	-54,6
23801	Neckar	15,100	-42,9	-42,8	820	-34,8	-34,8	-44,3	-59,2
24901	Main	18,300	-47,5	-46,8	910	-32,2	-31,5	-40,0	-56,7
26901	Mosel	4,300	-39,4	-34,2	410	-42,6	-39,4	-47,9	-55,0
27601	Ruhr	6,000	-58,4	-58,3	260	-43,6	-43,6	-49,8	-58,6
27801	Lippe	5,300	-57,7	-57,7	210	-36,5	-36,4	-42,5	-60,3
27903	Rhine	98,000	-43,6	-43,1	4,990	-33,6	-33,1	-39,9	-58,5
37602	Ems	5,000	-30,5	-30,3	240	-27,2	-26,7	-32,6	-49,2
41002	Werra	1,000	-34,1	-15,7	80	-29,8	-16,7	-24,7	-32,2
42001	Fulda	3,300	-48,1	-46,7	190	-22,3	-21,1	-34,9	-45,2
48901	Aller	7,100	-29,7	-29,1	480	-38,8	-38,4	-45,2	-64,6
49103	Weser	17,000	-35,3	-33,4	1,070	-33,0	-31,4	-40,2	-55,7
53801	Schwarze Elster	900	-36,2	-27,3	100	-46,4	-40,6	-47,4	-56,1
54901	Mulde	4,300	-57,2	-49,4	530	-66,8	-62,5	-66,1	-74,8
56901	Saale	12,700	-62,2	-54,6	840	-47,7	-39,6	-44,9	-65,5
58901	Havel	8,100	-31,7	-30,7	430	-35,8	-34,5	-36,6	-64,0
59101	Elbe	32,200	-50,5	-45,1	2,380	-49,2	-43,9	-47,8	-67,6
69001	Odra	1,600	-60,9	-59,3	170	-77,5	-76,7	-76,7	-84,1
	North Sea coast	20,800	-32,7	-32,4	-32,4	-20,1	-19,4	-25,7	-57,5
	Baltic Sea coast	5,800	-38,8	-36,9	-36,9	-17,5	-14,4	-17,7	-49,4
	North Sea total	**173,100**	**-42,4**	**-40,9**	**-40,9**	-36,1	-34,2	-40,5	-60,1
	Baltic Sea total	**7,300**	**-43,5**	**-41,7**	**-41,7**	-41,4	-39,1	-41,1	-63,2
	Black Sea total	**24,400**	**-42,9**	**-42,2**	**-42,2**	-18,9	-18,0	-27,0	-51,0
	Germany	**204,900**	**-42,5**	**-41,1**	**-41,1**	-34,1	-32,4	-38,8	-59,1

The fulfilment of the statutory requirements according to Scenario 1 makes possible an average N-reduction of waste water treatment plants of 42% for Germany as a whole. The reduction potential is 30% for the Aller and Ems catchments and up to 60% for the Odra, Saale and Mulde catchments. The increase in connectivity according to Scenario 2 had hardly any effect for Germany as a whole. Only in the Werra, Schwarze Elster, Mulde and Saale catchments and the area of the new German states with a high proportion of the population not connected to public wastewater treatment plants in 1995 was the reduction potential in N-emissions significantly lower than with Scenario 1 (7% to 18%). For the Ruhr catchment, the RUHRVERBAND (1998) determined a reduction potential of 64% which accords well with the reduction potential of 58% given in Table 5.1 (Scenario 1).

With phosphorus, Scenario 1 gives a possible achievable reduction of only 2% for the Isar catchment, for which in 1995 a good P-removal in municipal wastewater treatment plants was documented, to 62% for the Mulde and 78% for the Odra. With the fulfilment of the statutory requirements for P-removal, a Germany wide reduction of 34% can be achieved. The Danube catchment has a lower reduction potential (19%) with Scenario1 compared to other large river catchments. This can be attributed to the larger proportion of small treatment plants in this catchment. The RUHRVERBAND (1998) gives a P-reduction potential of 37% for the Ruhr catchment, in good agreement with the figure given in Table 5.1.

The extension of the statutory requirements to small treatment plants (Scenario 3) requires a Germany-wide reduction in P-inputs into wastewater treatment plants of 39% compared to 1995. In particular in the Danube and Weser catchments and Mosel and Neckar, Scenario 1 yields a clearly higher reduction potential. Scenario 4, unrealistic in the mid-term gives a picture over the large scale a possible P-reduction on the basis of the current *best available technology*. For example, a Germany-wide deployment of microfiltration in treatment plants of size-class 5 gives a reduction in P-outputs of 60% compared to 1995.

5.2 Diffuse sources

For a prediction of N- and P-emissions from diffuse sources, an extrapolation of the situation during the period 1993-1997 was carried out using various possible scenarios in relation to the nutrient surpluses during that period (Scenario 5), a likely mid-term scenario (Scenario 6) an extreme mid-term scenario (Scenario 7) and an extreme long-term scenario (Scenario 8). The estimates for these scenarios were carried on the basis of the methods used for the various diffuse pathways (see Section 3.1.2). For all scenarios, the hydrological situation for the period 1993-1997 was used. For the individual scenarios, the following assumptions are employed:

- **Scenario 5** comes first from a realisation of Scenario 2 for the municipal wastewater treatment plants with a reduction of nutrient inputs from urban areas. In addition, it is assumed that the nutrient surpluses are the same as in 1995. The calculated changes in the diffuse inputs from non-urban areas are the result of a further increase in P-accumulation in agricultural soils of the old German states or allowing for the long-term changes in nitrogen inputs via groundwater resulting from the already reduced level of the nitrogen surplus of agricultural areas. The period 2005 to 2010 is used as the time frame for this scenario.

- **Scenario 6** considers in addition to scenario 5 an increase of 100% in the retention volume for the mixed and separated sewers in all German states and also that the goal of a 50% reduction in inputs from the separated sewer system would be reached. It is also assumed that the P-surplus of agricultural land in the old German states will be reduced to nothing by 2005 (as has already occurred in the new German states). In addition in this scenario, the nitrogen surplus in the old German states will be reduced to 70 kg N/(ha· a) by 2000 and to 50 kg N/(ha· a) by 2005. With these reductions, the N-surplus of agricultural land the old German states will be 2005 at the same level as in the new German states in 1995. No change in the already very low level of N-surplus in the new German states is assumed. Regarding erosion inputs, a reduction of about 25% in soil erosion through application of specific measures is envisaged. Finally, a reduction of 25% in drained areas/drainage inputs is included in this scenario.

- **Scenario 7** includes, in addition to Scenario 6, a reduction of 50% in drained areas and erosion losses from 1995 levels.

- **Scenario 8,** in addition to Scenario 7, takes into account an extension of the time frame to 2015-2020. Only for nitrogen, this scenario leads to further changes in the input situation.

The results of the calculations for the various scenarios are shown in Table 5.2. The figures show that with maintenance of the nitrogen surplus of agricultural land at 1995 levels (Scenario 5), one can anticipate a further 10 % reduction in diffuse N-inputs in the catchment areas due to the already high quality of sewer systems and wastewater treatment plants. For catchments where a high proportion of the population are connected to sewers but not to treatment plants, Scenario 5 predicts a reduction of 15% in N- and 20% in P-inputs compared to the figures for 1993-1997. For phosphorus, further P-accumulation in agricultural soils in the old German states will lead to a slight increase in diffuse P-inputs in catchments with high levels of sewer connectivity and wastewater treatment plants.

The likely mid-term Scenario 6 with a reduction in soil erosion and drained area in the catchments with an already high quality sewer system leads to a reduction of diffuse inputs of around 5-10%. In the new German states in particular, a further reduction of 10-15% in diffuse P-inputs would be reached through an increase in storage capacity. Overall, the realisation of this scenario, results in a 7% reduction in diffuse P-inputs in German catchment areas. For nitrogen, the assumed gradual reduction in the N-surplus of agricultural land in the old German states would reduce diffuse N-inputs by about 10% by the end of the next decade. In contrast, the effects of an increase in the quality of the sewage system in the new German states would yield a reduction of only 1-2% in diffuse N-inputs. For Germany as a whole, it can be concludes that realisation of Scenario 6 would result in a reduction of around 20% in diffuse N-inputs in comparison with present conditions by the end of the next decade.

The assumption of a reduction in soil erosion and the proportion of drained land of 50% and an increase of the storage capacity of 150% (34 m^3/ha of inhabited urban areas) in Scenario 7 is already an extreme situation since a far-reaching adjustment in agriculture and urban water industry is presupposed. Our model calculations show however that at least the change in the targeted storage capacity of the mixed sewer system is necessary since with an increase of

Table 5.2: Changes in nitrogen and phosphorus emissions ($ED_{N,P}$) from diffuse sources according to the realisation of various scenarios.

ADDR.	River/Basin	ED_N 1995	Change with Scenario 5	Change with Scenario 6	Change with Scenario 7	Change with Scenario 8	ED_P 1995	Change with Scenario 5	Change with Scenario 6	Change with Scenario 7
		[t N/a]	*[%]*				[t P/a]	*[%]*		
14902	Naab	7,800	*-10.2*	*-16.1*	*-1.3*	*-31.6*	240	*-0.8*	*-12.6*	*-24.4*
16902	Isar	17,600	*-8.0*	*-18.3*	*-21.2*	*-32.9*	640	*+1.5*	*-9.1*	*-19.3*
18902	Inn	16,600	*-9.0*	*-17.8*	*-19.4*	*-32.9*	670	*+1.5*	*-6.0*	*-14.2*
19101	Danube	105,600	*-9.0*	*-19.9*	*-22.9*	*-35.9*	3.,90	*+0.8*	*-9.4*	*-20.7*
23704	Upper Rhine	17,500	*-9.1*	*-22.0*	*-23.9*	*-31.6*	960	*+0.7*	*-6.3*	*-13.5*
23801	Neckar	27,100	*-9.8*	*-27.8*	*-31.8*	*-40.4*	960	*+1.0*	*-10.1*	*-23.4*
24901	Main	40,800	*-11.3*	*-26.0*	*-27.5*	*-37.5*	1,860	*+0.1*	*-14.5*	*-28.6*
26901	Mosel	14,700	*-14.4*	*-28.2*	*-29.3*	*-37.8*	530	*-12.9*	*-22.8*	*-31.9*
27601	Ruhr	6,300	*-8.6*	*-18.3*	*-18.9*	*-26.0*	310	*-1.4*	*-6.4*	*-14.8*
27801	Lippe	14,800	*-9.5*	*-31.5*	*-37.3*	*-44.6*	310	*+1.8*	*-8.0*	*-20.0*
27903	Rhine	166,000	*-10.3*	*-25.9*	*-28.4*	*-37.1*	6,460	*-0.7*	*-12.1*	*-24.6*
37602	Ems	28,000	*-9.8*	*-21.2*	*-23.7*	*-38.1*	1,040	*+0.6*	*-3.2*	*-9.9*
41002	Werra	10,000	*-14.1*	*-14.8*	*-17.6*	*-27.2*	380	*-19.6*	*-31.2*	*-39.5*
42001	Fulda	10,600	*-10.2*	*-18.9*	*-20.5*	*-33.8*	330	*-4.1*	*-14.7*	*-25.2*
48901	Aller	26,000	*-8.1*	*-24.2*	*-30.9*	*-41.1*	1,130	*+0.8*	*-10.6*	*-30.7*
49103	Weser	66,700	*-9.6*	*-20.9*	*-25.2*	*-36.7*	2,690	*-2.6*	*-13.0*	*-27.7*
53801	Schwarze Elster	5,700	*-9.9*	*-10.1*	*-23.7*	*-30.2*	200	*-13.4*	*-228*	*-30.8*
54901	Mulde	13,300	*-12.7*	*-14.1*	*-23.4*	*-31.2*	590	*-16.3*	*-31.0*	*-41.0*
56901	Saale	41,400	*-13.4*	*-14.4*	*-24.0*	*-32.5*	1,890	*-16.3*	*-31.7*	*-42.9*
58901	Havel	16,500	*-6.1*	*-7.9*	*-17.5*	*-24.2*	810	*-1.3*	*-16.6*	*-25.1*
59101	Elbe	106,300	*-10.8*	*-12.3*	*-23.0*	*-30.8*	4,620	*-11.5*	*-25.3*	*-34.9*
69001	Odra	3,800	*-6.5*	*-7.0*	*-19.3*	*-25.7*	190	*-1.5*	*-13.4*	*-22.8*
North Sea coast		77,000	*-8.7*	*-21.5*	*-24.2*	*-34.9*	4,880	*+0.1*	*-2.6*	*-27..2*
Baltic Sea coast		32,600	*-5.9*	*-9.7*	*-29.4*	*-35.9*	950	*-1.6*	*-6.6*	*-22.3*
North Sea total		**443,900**	***-10.0***	***-20.8***	***-25.6***	***-35.2***	**19,700**	***-3.2***	***-8.2***	***-27.3***
Baltic Sea total		**36,400**	***-6.0***	***-9.4***	***-28.3***	***-34.8***	**1,150**	***-1.5***	***-6.7***	***-22.4***
Black Sea		**105,900**	***-9.1***	***-19.8***	***-22.9***	***-35.9***	**3,800**	***+0.8***	***-2.4***	***-20.7***
Germany		**586,300**	***-9.6***	***-19.9***	***-25.3***	***-35.3***	**24,640**	***-2.5***	***-7.3***	***-26.1***

100% (23 m^3/ha inhabited urban area), an average P-concentration of 1.2 mg P/l in the mixed sewer system would be achieved. A 150% increase in storage capacity would result in 1 mg P/l. In comparison to Scenario 6, additional measures could result in a further reduction of diffuse P-inputs of 10% to 20%. For Germany as a whole, one can predict a reduction of diffuse P-inputs of 26% compared to current levels.

For nitrogen, the assumption of Scenario 7 of a further reduction in drained area would lead to a reduction of diffuse N-inputs of 5% compared to Scenario 6 and 25% compared to the current situation.

If the measures of Scenario 8 were carried out until 2010, a further reduction of 10% in diffuse N-inputs would be achieved within the following decade. Overall, a reduction of around 35% in diffuse N-inputs in the catchments can be expected by 2015-2020.

5.3 Overall results of the scenarios

Overall, the scenarios clearly show that with realistic assumptions for potential reduction in nutrient surpluses and inputs (Scenario 6), only small reductions of around 20% in diffuse inputs are achievable. In addition, considering possible additional reduction in point-source N-inputs according to Scenario 2, one can expect a reduction of 590.000 t N/a or 45% by 2005-2010 compared to the 1983-1987 period. This means however, that with the very ambitious goals of Scenarios 2 and 6 alone, the aim of a reduction in nitrogen loadings of the North Sea and Baltic Sea in the next ten years is not yet achievable. One can only achieve this goal in the mid-term if one can also increase the retention of the total landscape and, in particular the river systems and connected terestical land areas. To that end, with the present approach to retention within river systems, it is concluded that a general increase in water-surface area and the consequent reduction in the hydraulic load, the possible retention is increased. However, such an increase in retention time also increases the probability of increased phytoplankton growth if P-inputs are not reduced at the same time. The complexity of these interactions makes it difficult at present to formulate quantitative scenarios.

With regard to phosphorus, the goal of a reduction in inputs to the North and Baltic Seas of 50% was already achieved in the period 1993-1997. Accordingly there is no immediate necessity for an area-covered implementation of measures for a reduction in point and diffuse inputs. However, since regional impairment of water quality through eutrophication has been established, inputs must be reduced in the future, at least in some catchment areas. Also in this regard, Table 5.2 shows that the reduction potential for diffuse P-inputs bounded without dramatic changes in agricultural practice. For phosphorus, it is clearly imperative for the considered catchments to employ measures in the water bodies or nearby land to increase the retention potential of the river systems and their surrounding areas.

From the calculations carried out for the various scenarios, regionally differentiated appropriate measures can be developed for the individual input pathways providing additional possibilities for reduction in overall nutrient inputs in German catchment areas. Such scenario calculations are possible with MONERIS. However, the limiting conditions for such scenarios should be carried out in every case with the appropriate national and state authorities or the catchment area commissions and organisations.

To allow consideration future estimates of nutrient inputs in relation to already implemented measures, documentation with as large as possible spatial resolution is necessary. Future agricultural statistics of the German states should also document the use of chemical fertilisers, change in land use, area of drainage and areas in which erosion reduction measures have been carried out.

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