ENVIRONMENTAL RESEARCH OF THE
FEDERAL MINISTRY OF THE ENVIRONMENT,
NATURE CONSERVATION AND NUCLEAR SAFETY

Research Report 299 22 285
UBA-FB 000446/E

Texte
82
03

ISSN
0722-186X

Nutrient Emissions into River Basins of Germany on the Basis of a Harmonized Procedure

by

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On behalf of the Federal Environmental Agency

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Publisher: Federal Environmental Agency (Umweltbundesamt)
Postfach 33 00 22
14191 Berlin
Tel.: +49/30/8903-0
Telex: 183 756
Telefax: +49/30/8903 2285
Internet: http://www.umweltbundesamt.de

Edited by: Section II 3.2
Dr. Heike Herata

Berlin, November 2003

Berichts-Kennblatt

1. Berichtsnummer UBA-FB	2.	3.
4. Titel des Berichts Quantifizierung der Nährstoffeinträge in die Oberflächengewässer Deutschlands auf der Grundlage eines harmonisierten Vorgehens		
5. Autoren: Dr. Horst Behrendt Dr. Martin Bach Dr. Ralf Kunkel Dipl. Physiker Dieter Opitz Dr. Wolf-Gunther Pagenkopf Dipl. Geogr. Gaby Scholz Dr. Frank Wendland		8. Abschlußdatum 31.05.2002 9. Veröffentlichungsdatum 30.04.2003 10. UFOPLAN - Nr. 299 222 285
6. Durchführende Institution Leibniz-Institut für Gewässerökologie und Binnenfischerei im Forschungsverbund Berlin e.V. Müggelseedamm 310 12561 Berlin		11. Seitenzahl 201 Seiten 12. Literaturangaben 70 Quellen 13. Tabellen 53 Tabellen
7. Fördernde Institution Umweltbundesamt Bismarckplatz 1 14193 Berlin		14. Abbildungen und Karten 26 Abbildungen 68 Karten
15. Zusätzliche Angaben		
16. Kurzfassung Für 300 deutsche Flussgebiete wurden mit Hilfe des Modellsystems MONERIS die Nährstoffemissionen von punktuellen und diffusen Quellen für die Zeiträume 1998-2000, 1993-1997 und 1983-1987 quantifiziert. Das Modell erlaubt die Abschätzung von 6 verschiedenen diffusen Eintragspfaden und berücksichtigt darüber hinaus die Einträge aus kommunalen Kläranlagen und durch industrielle Direkteinleiter. Für Stickstoff konnten für den Zeitraum 1998-2000 Einträge von insgesamt ca. 688 kt/a für Deutschland ermittelt werden. Diese Einträge haben sich seit 1985 um 400 kt/a vermindert. Für Phosphor beträgt die Reduzierung ca. 59 kt/a. Z. Zt werden noch 33 kt/a Phosphor in die deutschen Flussgebiete eingetragen. Bezogen auf den geogenen Hintergrund liegen die Phosphoreinträge noch um das Zehnfache und die Stickstoffeinträge um das Siebenfache über diesen Werten. Die Anwendung des Modells für das Odereinzugsgebiet und der Vergleich mit anderen Modellen zeigt, dass MONERIS auch für eine Eintragsquantifizierung für Flussgebiete außerhalb Deutschlands geeignet ist.		
17. Schlagwörter Stickstoff- und Phosphoreinträge, Emissionsmethode, MONERIS, Immissionsmethode, Punktquellen, diffuse Quellen, Flußgebiete, Nährstofffrachten, Retention, kommunale Kläranlagen, industrielle Direkteinleiter, atmosphärische Deposition, Abschwemmung, Erosion, Dränage, Grundwasser, urbane Flächen		
18. Preis	19.	20.

<table>
<tr><td>1. Report No.
UBA-FB</td><td>2.</td><td>3.</td></tr>
<tr><td colspan="3">4. Report Title
Nutrient emissions into river basins of Germany on the basis of a harmonised procedure</td></tr>
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30.04.2003</td></tr>
<tr><td>10. UFOPLAN - Ref.No.
299 222 285</td></tr>
<tr><td colspan="2" rowspan="3">6. Performing Organisation

Leibniz-Institute of Freshwater Ecology and Inland Fisheries
Müggelseedamm 310
D-12561 Berlin</td><td>11. No. of Pages
190 pages</td></tr>
<tr><td>12. No. of References
70 references</td></tr>
<tr><td>13. No. of Tables
54 tables</td></tr>
<tr><td colspan="2">7. Sponsoring Agency

Umweltbundesamt
Bismarckplatz 1
14193 Berlin</td><td>14. No. of Figures and Maps
26 figures
68 maps</td></tr>
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The nutrient emissions from point and diffuse sources into about 300 German river basins were estimated for the periods 1998-2000, 1993-1997 and 1983-1987 with the model system MONERIS. The model distinguishes between six diffuse pathways and point source emissions from waste water treatment plants and direct industrial discharges. It was estimated that the total nitrogen emission into the German river systems amounts about 688 kt/a in the period 1998 to 2000. These emissions had been decreasing since the middle of the 1980ies by about 400 kt/a, mainly caused by the reduction of point source discharges. For phosphorus the emissions were reduced by 59 kt/a and amount 33 kt/a in the period 1998-2000. In the period 1998-2000 the sum of the phosphorus emissions was 10 times higher and the total nitrogen emissions was 7 times higher than the background emissions. The application of the model to the Oder basin and the comparison with other methods shows that the model can be applied also for river basins outside of Germany.</td></tr>
<tr><td colspan="3">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</td></tr>
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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
Dev.	deviation
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)
LP_{cal}	calculated load of phosphorus
LP_{meas}	measured load of phosphorus
L_{DINcal}	calculated load of dissolved inorganic nitrogen nitrogen
L_{DINmea}	measured load of dissolved inorganic nitrogen nitrogen
L_{Tncal}	calculated load of total nitrogen
L_{TNmea}	measured load of total nitrogen
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
$NH4_{DEP}$	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 emissions 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 (discharges from municipal waste water treatment plants and direct industrial discharges)
- atmospheric deposition
- erosion
- surface runoff
- groundwater
- tile drainage
- paved urban areas

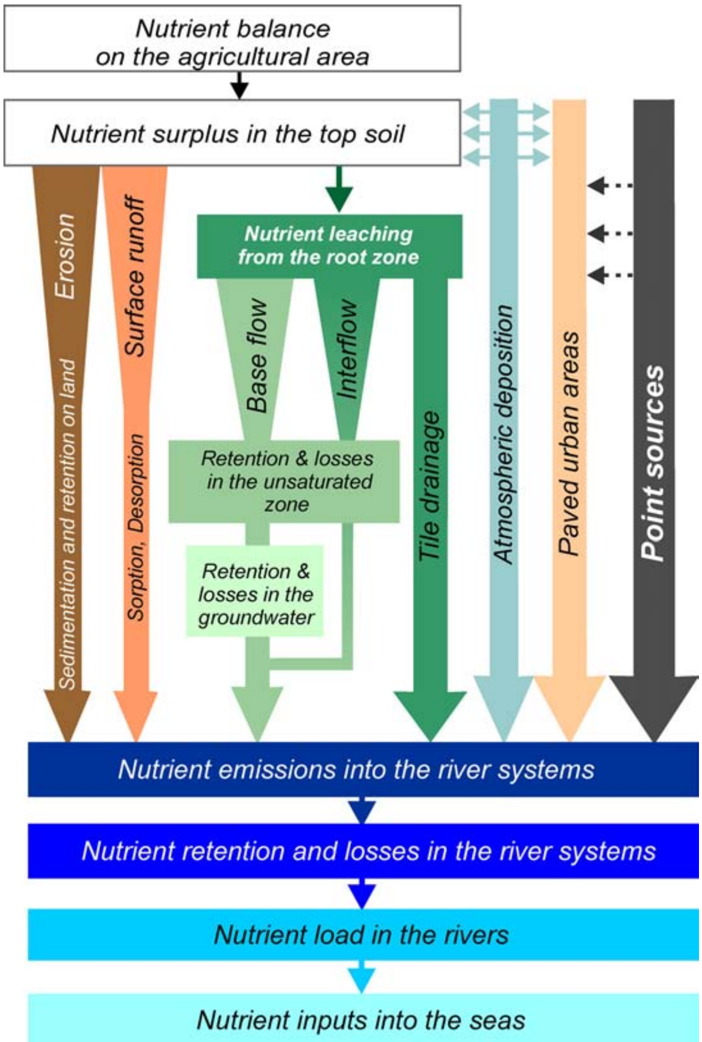


Figure 1: Pathways and processes within MONERIS.

Along the pathway from the source of the emission into the river substances are governed by manifold processes of transformation, retention and loss. Knowledge of these processes of transformation and retention is necessary to quantify and to predict nutrient emissions into the rivers in relation to their sources. The update and evaluation of the description of processes was a main task within this project and focused on the following:

- Testing of the application of the model for catchment areas smaller than 100 km²,
- Calculation of the point source discharges per catchment based on the inventories of the German countries.

- Further development of the module for the calculation of the nitrogen emissions by groundwater by consideration of the median of the residence time of water within the unsaturated zone and in the aquifer of the individual catchments.
- Modification of the approaches for the calculation of the diffuse nutrient emissions from urban areas by calculation of the days of overflow events depending on the precipitation.
- Introduction of a new approach for the calculation of the retention of total nitrogen within the surface waters of a catchment.

The estimation of the nutrient emissions was carried out for about 300 different catchment areas covering the whole of Germany. For all catchments the same method was applied. Because some of the approaches were changed the calculations were done once for the time periods 1983-1987 and 1993-1997. Additionally the nutrient emissions were calculated for the new time period 1998-2000. All calculations were done taking into consideration the different flow conditions within the time periods and for normalized conditions to detect the changes caused by human activities.

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 688 kt/a N in the period 1998-2000 and thus 400 kt/a N, or 37 % lower than in the period 1983-1987. The target of the 50 % reduction of nitrogen loads from Germany into the North Sea and the Baltic Sea was probably achieved only within the catchment area of the Elbe river. 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 70 %. On the other hand the estimated decrease of diffuse emissions was only about 15 %. The input via groundwater is with 56% the dominant pathway in the period 1998-2000. The share of point sources in nitrogen emissions amounts to about 19 %. 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 33 kt/a P in the period 1998-2000. Compared with the period 1983-1987, the phosphorus emissions were reduced by about 59 kt/a P or 64 %. 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 86 % reduction of point sources. The decrease of diffuse phosphorus emissions was larger than for nitrogen, which is caused by a 59 % 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 27 % in the period 1998-2000. Among the diffuse pathways, emissions by erosion dominate and represent 26 % of the total input.

Among the individual river catchments and also the basins of North Sea, Baltic Sea and Black Sea the nutrient emissions 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, Weser and Elbe basin. For the other river basins, one has to assume that nitrogen emissions via this pathway was still increasing during the nineties due to the long residence times of water in the unsaturated zone and in the aquifer or by a too low decrease of the nitrogen surplus in agriculture.

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, 1993-1997 and 1998-2000 for the investigated river basins.

The nutrient emissions estimated with MONERIS can be compared 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 20 to 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 all three time periods. This comparison shows that the deviation between the observed and calculated loads is not changing over the investigated time periods and therefore are not dependent on the level of the nutrient emissions.

For the further development of the model especially the data base for the calculation of the nutrient surplus and the discharges by point sources should be improved.

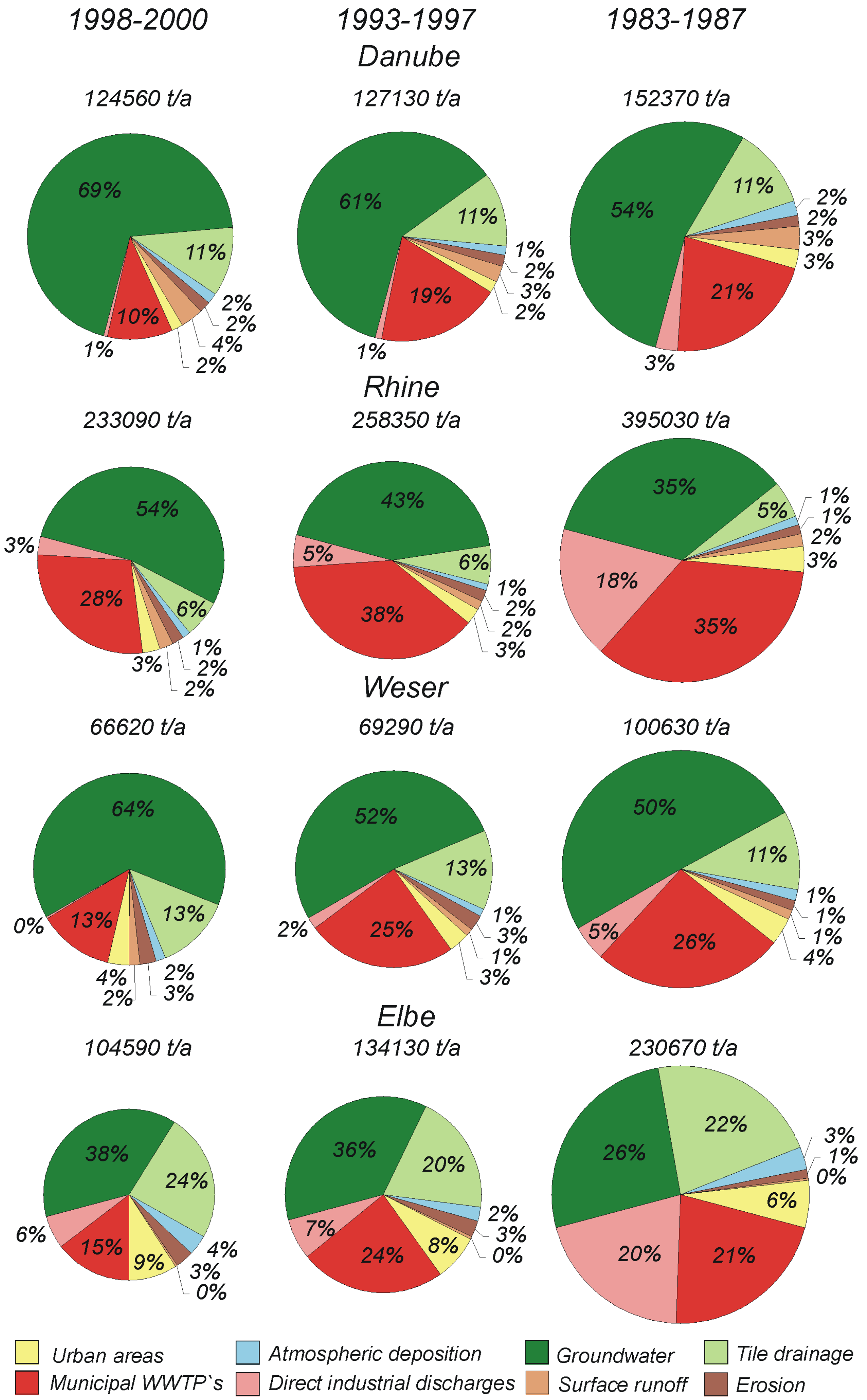


Figure 2: Nitrogen emissions via the various pathways into German river basins in the time periods 1983-1987, 1993-1997 and 1998-2000.

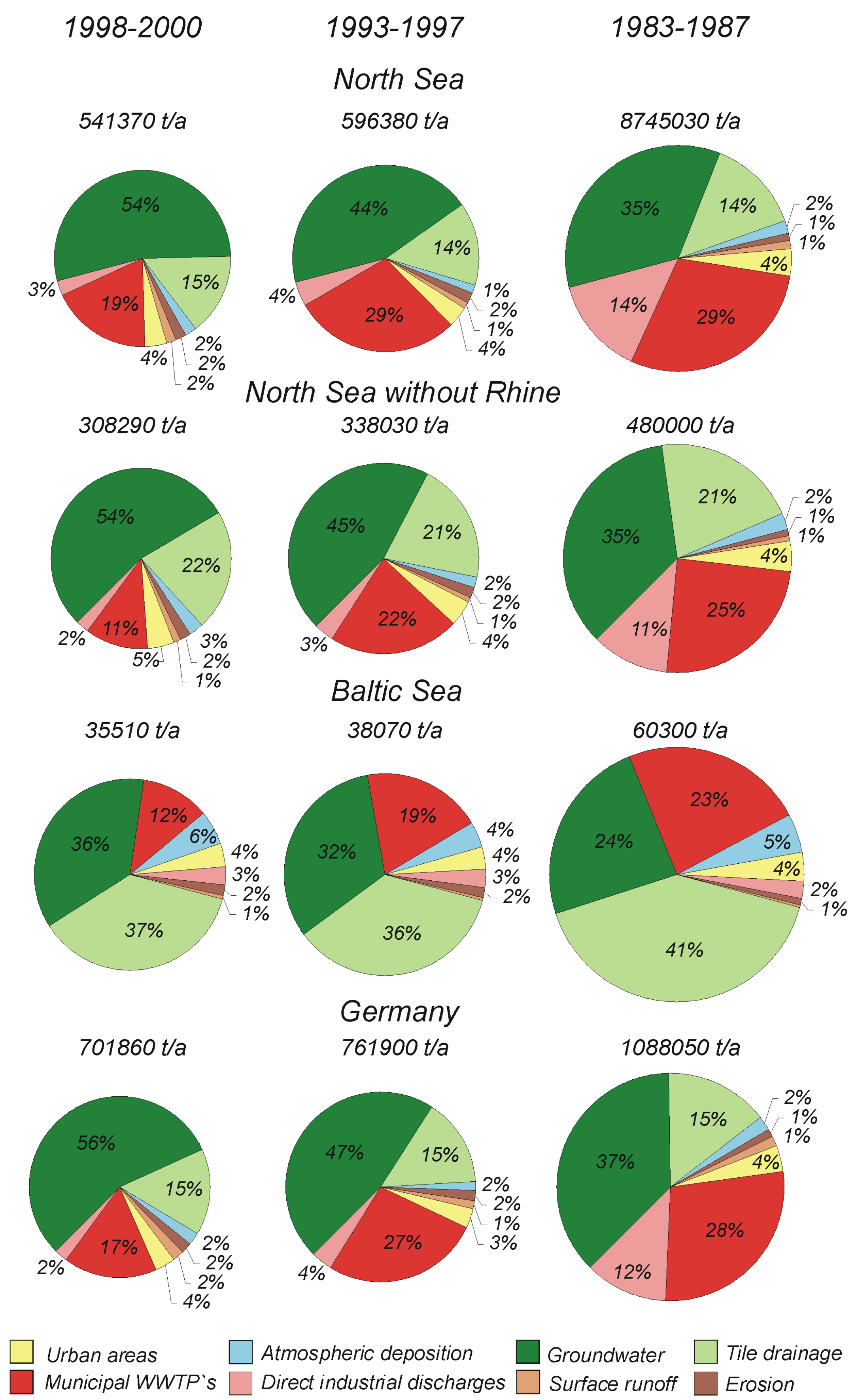


Figure 3: Nitrogen emissions via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987, 1993-1997 and 1998-2000.

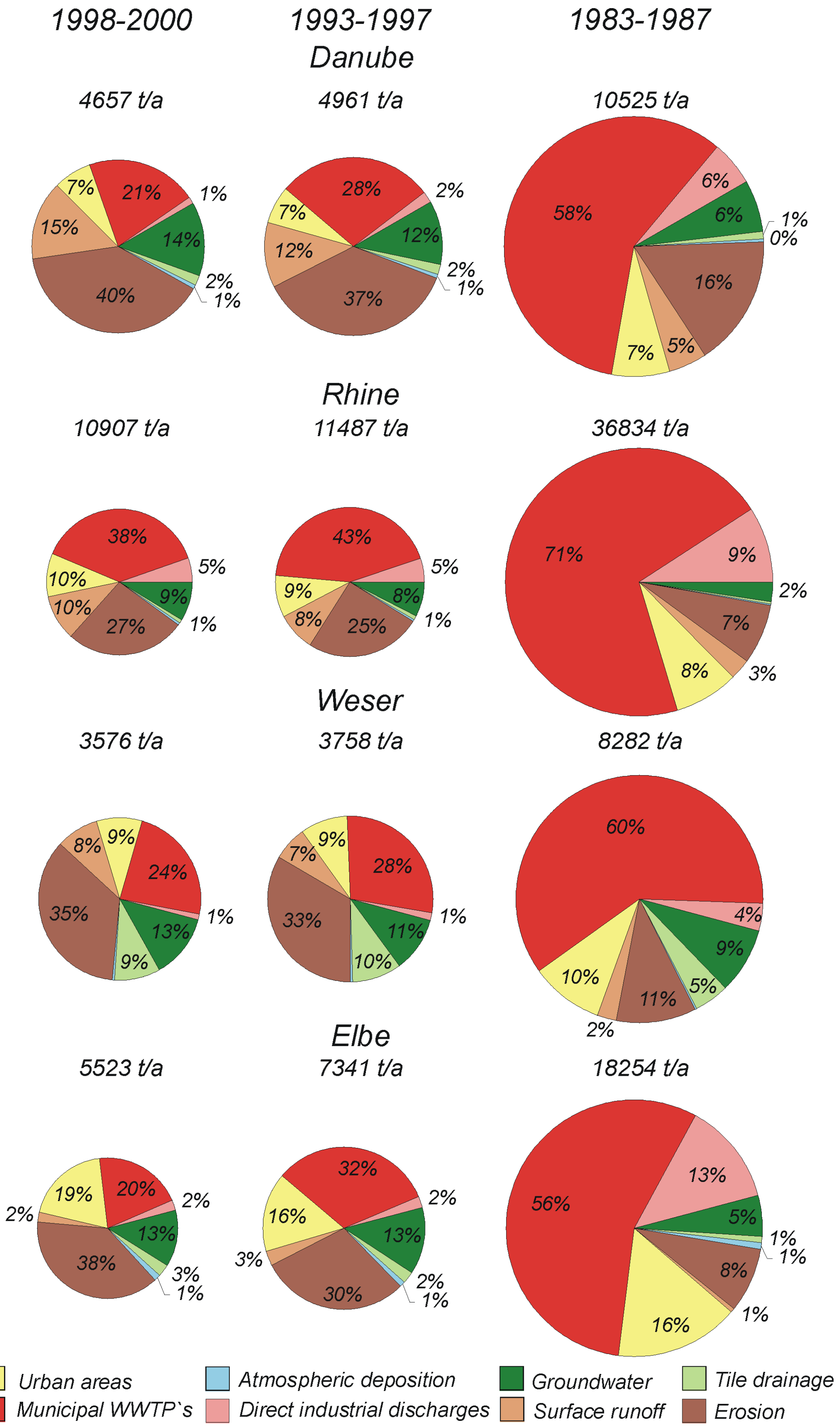


Figure 4: Phosphorus emissions via the various pathways into German river basins in the time periods 1983-1987, 1993-1997 and 1998-2000.

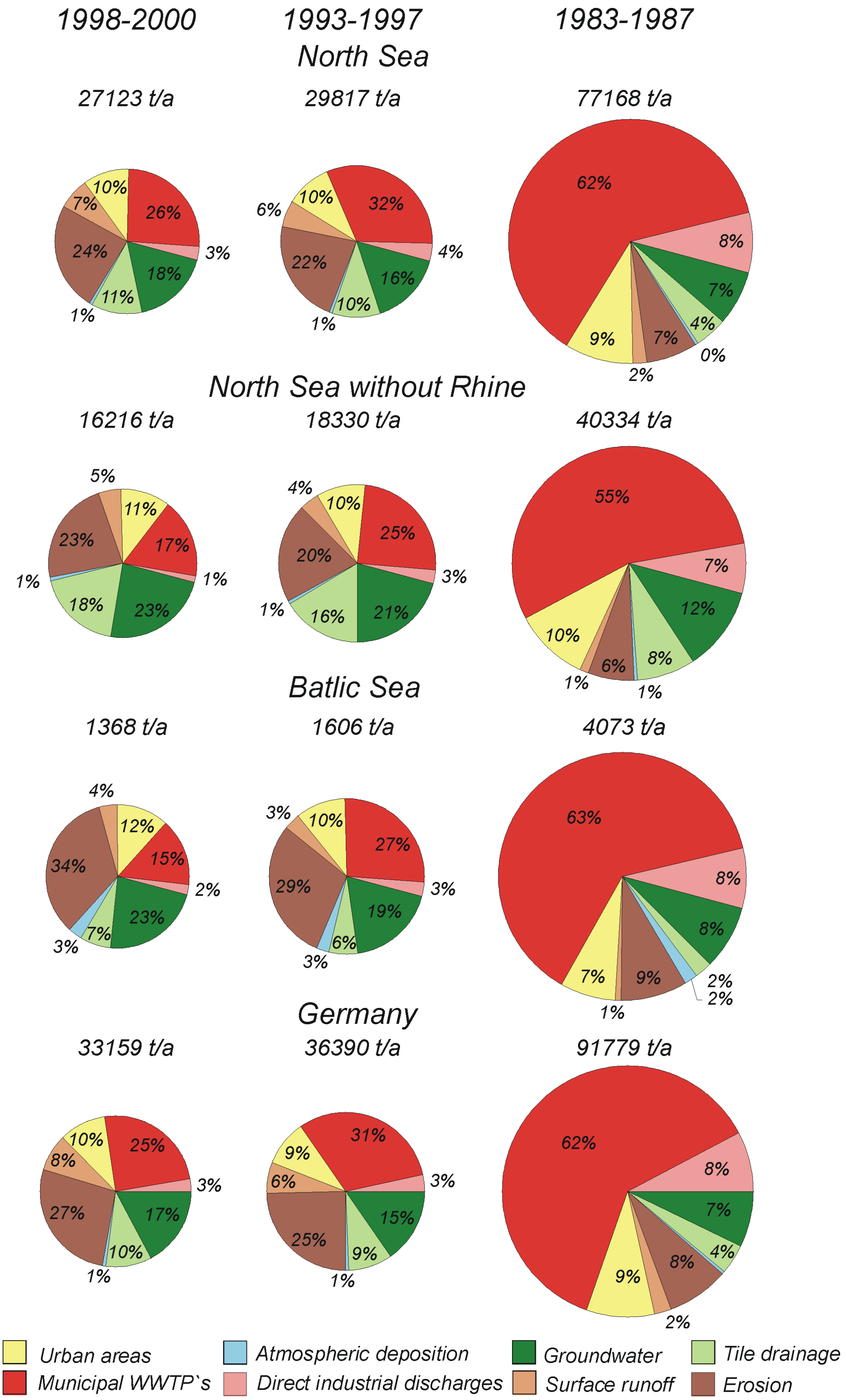


Figure 5: Phosphorus emissions via the various pathways into German catchments of North Sea, Baltic Sea, Black Sea and for all of Germany in the time periods 1983-1987, 1993-1997 and 1998-2000.

Table 1: Nitrogen emissions 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, 1993-1997 and 1998-2000.

Pathway		Danube				Rhine				Weser				Elbe			
		1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change
Groundwater	[t/a]	85120	77370	82770	3	123630	112310	138390	-11	42210	36020	50710	-17	38910	48750	60770	-36
	[%]	*69.4*	*60.9*	*54.3*		*53.5*	*43.5*	*35.0*		*64.4*	*52.0*	*50.4*		*38.0*	*36.3*	*26.3*	
Tile drainage	[t/a]	13380	14590	17470	-23	14890	16320	19440	-23	8350	9070	10820	-23	24840	26700	50300	-51
	[%]	*10.9*	*11.5*	*11.5*		*6.4*	*6.3*	*4.9*		*12.7*	*13.1*	*10.8*		*24.3*	*19.9*	*21.8*	
Erosion	[t/a]	2210	2210	2350	-6	4690	4680	4710	-0	1800	1810	1360	32	3460	3650	2650	31
	[%]	*1.8*	*1.7*	*1.5*		*2.0*	*1.8*	*1.2*		*2.7*	*2.6*	*1.4*		*3.4*	*2.7*	*1.1*	
Surface runoff	[t/a]	4350	3210	5030	-14	5380	3990	6680	-19	1230	830	1310	-6	450	600	630	-29
	[%]	*3.5*	*2.5*	*3.3*		*2.3*	*1.5*	*1.7*		*1.9*	*1.2*	*1.3*		*0.4*	*0.4*	*0.3*	
Atmospheric deposition	[t/a]	2050	1780	3150	-35	3310	2620	4610	-28	1080	840	1500	-28	3970	3060	6550	-39
	[%]	*1.7*	*1.4*	*2.1*		*1.4*	*1.0*	*1.2*		*1.6*	*1.2*	*1.5*		*3.9*	*2.3*	*2.8*	
Urban areas	[t/a]	2230	2280	4070	-45	6960	6680	13500	-48	2320	2360	3720	-38	9370	10130	13680	-32
	[%]	*1.8*	*1.8*	*2.7*		*3.0*	*2.6*	*3.4*		*3.5*	*3.4*	*3.7*		*9.2*	*7.6*	*5.9*	
Sum diffuse sources	**[t/a]**	**109340**	**101440**	**114840**	**-5**	**158860**	**146600**	**187330**	**-15**	**56990**	**50930**	**69420**	**-18**	**81000**	**92890**	**134580**	**-40**
	[%]	***89.2***	***79.8***	***75.4***		***68.8***	***56.7***	***47.4***		***87.0***	***73.5***	***69.0***		***79.2***	***69.3***	***58.3***	
Background	[t/a]	18830	18830	18830	0	32990	32990	32990	0	11100	11100	11100	0	11970	11970	11970	0
	[%]	*15.4*	*14.8*	*12.4*		*14.3*	*12.8*	*8.4*		*16.9*	*16.0*	*11.0*		*11.7*	*8.9*	*5.2*	
Agricultural diffuse sources	[t/a]	86230	78550	88790	-3	115600	104310	136230	-15	42490	36630	53100	-20	55690	67730	102380	-46
	[%]	*70.3*	*61.8*	*58.3*		*50.1*	*40.4*	*34.5*		*64.8*	*52.9*	*52.8*		*54.4*	*50.5*	*44.4*	
Municipal WWTP`s	[t/a]	12610	24420	32750	-61	64670	98010	138250	-53	8330	17050	26310	-68	14980	32230	49340	-70
Direct industrial discharges	[t/a]	690	1270	4780	-86	7440	13740	69450	-89	200	1310	4890	-96	6310	9000	46760	-87
Sum of point sources	**[t/a]**	**13300**	**25690**	**37530**	**-65**	**72100**	**111750**	**207700**	**-65**	**8540**	**18360**	**31210**	**-73**	**21290**	**41240**	**96090**	**-78**
	[%]	***10.8***	***20.2***	***24.6***		***31.2***	***43.3***	***52.6***		***13.0***	***26.5***	***31.0***		***20.8***	***30.7***	***41.7***	
Sum of all sources	**[t/a]**	**122640**	**127130**	**152370**	**-20**	**230960**	**258350**	**395030**	**-42**	**65530**	**69290**	**100630**	**-35**	**102290**	**134130**	**230670**	**-56**
	[%]	***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***	

Table 2: Nitrogen emissions 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, 1993-1997 and 1998-2000.

Pathway		North Sea				Baltic Sea				Black Sea				Germany			
		1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change
Groundwater	[t/a]	285540	264960	307810	-7	12410	12290	14380	-14	85500	77650	83060	3	383450	354900	405250	-5
	[%]	*53.8*	*44.4*	*35.2*		*36.4*	*32.3*	*23.8*		*69.5*	*60.9*	*54.4*		*55.7*	*46.6*	*37.2*	
Tile drainage	[t/a]	79930	85700	118970	-33	12570	13610	24650	-49	13380	14590	17470	-23	105880	113900	161090	-34
	[%]	*15.1*	*14.4*	*13.6*		*36.8*	*35.7*	*40.9*		*10.9*	*11.4*	*11.4*		*15.4*	*14.9*	*14.8*	
Erosion	[t/a]	10490	10650	9120	15	610	630	500	22	2210	2210	2350	-6	13300	13490	11980	11
	[%]	*2.0*	*1.8*	*1.0*		*1.8*	*1.7*	*0.8*		*1.8*	*1.7*	*1.5*		*1.9*	*1.8*	*1.1*	
Surface runoff	[t/a]	9350	6800	10150	-8	200	160	180	11	4380	3220	5050	-13	13930	10180	15380	-9
	[%]	*1.8*	*1.1*	*1.2*		*0.6*	*0.4*	*0.3*		*3.6*	*2.5*	*3.3*		*2.0*	*1.3*	*1.4*	
Atmospheric deposition	[t/a]	11150	8680	15850	-30	1970	1580	2970	-34	2060	1780	3150	-35	15180	12040	21980	-31
	[%]	*2.1*	*1.5*	*1.8*		*5.8*	*4.2*	*4.9*		*1.7*	*1.4*	*2.1*		*2.2*	*1.6*	*2.0*	
Urban areas	[t/a]	21270	21410	34430	-38	1350	1340	2250	-40	2240	2290	4070	-45	24860	25040	40750	-39
	[%]	*4.0*	*3.6*	*3.9*		*4.0*	*3.5*	*3.7*		*1.8*	*1.8*	*2.7*		*3.6*	*3.3*	*3.7*	
Sum diffuse sources	**[t/a]**	**417730**	**398200**	**496330**	**-16**	**29110**	**29610**	**44930**	**-35**	**109770**	**101740**	**115150**	**-5**	**556600**	**529550**	**656430**	**-15**
	[%]	***78.7***	***66.8***	***56.7***		***85.3***	***77.8***	***74.5***		***89.2***	***79.8***	***75.4***		***80.9***	***69.5***	***60.3***	
Background	[t/a]	70920	70920	70920	0	3560	3560	3560	0	18890	18890	18890	0	93370	93370	93370	0
	[%]	*13.4*	*11.9*	*8.1*		*10.4*	*9.4*	*5.9*		*15.3*	*14.8*	*12.4*		*13.6*	*12.3*	*8.6*	
Agricultural diffuse sources	[t/a]	314390	297190	375130	-16	22230	23130	36150	-39	86580	78780	89040	-3	423190	399100	500330	-15
	[%]	*59.2*	*49.8*	*42.9*		*65.2*	*60.8*	*60.0*		*70.3*	*61.8*	*58.3*		*61.5*	*52.4*	*46.0*	
Municipal WWTP`s	[t/a]	98700	173110	256470	-62	3950	7320	14070	-72	12620	24440	32770	-61	115270	204860	303310	-62
Direct industrial discharges	[t/a]	14340	25070	122230	-88	1060	1140	1300	-18	690	1270	4780	-86	16090	27490	128310	-87
Sum of point sources	**[t/a]**	**113040**	**198180**	**378700**	**-70**	**5010**	**8460**	**15370**	**-67**	**13310**	**25710**	**37550**	**-65**	**131360**	**232350**	**431620**	**-70**
	[%]	***21.3***	***33.2***	***43.3***		***14.7***	***22.2***	***25.5***		***10.8***	***20.2***	***24.6***		***19.1***	***30.5***	***39.7***	
Sum of all sources	**[t/a]**	**530770**	**596380**	**875030**	**-39**	**34120**	**38070**	**60300**	**-43**	**123080**	**127450**	**152700**	**-19**	**687960**	**761900**	**1088050**	**-37**
	[%]	***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***	

Table 3: Phosphorus emissions 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, 1993-1997 and 1998-2000.

Pathway		Danube				Rhine				Weser				Elbe			
		1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change
Groundwater	[t/a]	643	578	679	-5	947	869	888	7	456	405	711	-36	720	987	950	-24
	[%]	*13.8*	*11.7*	*6.5*		*8.7*	*7.6*	*2.4*		*12.8*	*10.8*	*8.6*		*13.0*	*13.4*	*5.2*	
Tile drainage	[t/a]	88	89	99	-11	90	98	97	-7	328	361	380	-14	159	170	150	6
	[%]	*1.9*	*1.8*	*0.9*		*0.8*	*0.9*	*0.3*		*9.2*	*9.6*	*4.6*		*2.9*	*2.3*	*0.8*	
Erosion	[t/a]	1835	1822	1719	7	2915	2891	2666	9	1265	1258	870	45	2112	2189	1481	43
	[%]	*39.5*	*36.7*	*16.3*		*26.7*	*25.2*	*7.2*		*35.4*	*33.5*	*10.5*		*38.2*	*29.8*	*8.1*	
Surface runoff	[t/a]	688	587	503	37	1097	953	937	17	301	251	206	46	130	211	100	30
	[%]	*14.8*	*11.8*	*4.8*		*10.0*	*8.3*	*2.5*		*8.4*	*6.7*	*2.5*		*2.4*	*2.9*	*0.5*	
Atmospheric deposition	[t/a]	35	35	38	-8	53	53	57	-7	16	16	19	-16	79	79	147	-46
	[%]	*0.8*	*0.7*	*0.4*		*0.5*	*0.5*	*0.2*		*0.4*	*0.4*	*0.2*		*1.4*	*1.1*	*0.8*	
Urban areas	[t/a]	331	340	764	-57	1057	1044	2845	-63	327	345	791	-59	1068	1161	2863	-63
	[%]	*7.1*	*6.9*	*7.3*		*9.7*	*9.1*	*7.7*		*9.1*	*9.2*	*9.6*		*19.3*	*15.8*	*15.7*	
Sum diffuse sources	**[t/a]**	**3620**	**3451**	**3802**	**-5**	**6159**	**5908**	**7490**	**-18**	**2693**	**2636**	**2977**	**-10**	**4268**	**4797**	**5691**	**-25**
	[%]	***78.0***	***69.6***	***36.1***		***56.4***	***51.4***	***20.3***		***75.3***	***70.1***	***35.9***		***77.3***	***65.3***	***31.2***	
Background	[t/a]	793	793	793	0	1087	1087	1087	0	335	335	335	0	411	411	411	0
	[%]	*17.1*	*16.0*	*7.5*		*9.9*	*9.5*	*3.0*		*9.4*	*8.9*	*4.0*		*7.4*	*5.6*	*2.3*	
Agricultural diffuse sources	[t/a]	2461	2283	2207	12	3962	3724	3501	13	2015	1940	1832	10	2710	3146	2270	19
	[%]	*53.0*	*46.0*	*21.0*		*36.3*	*32.4*	*9.5*		*56.3*	*51.6*	*22.1*		*49.1*	*42.9*	*12.4*	
Municipal WWTP`s	[t/a]	964	1409	6140	-84	4183	4985	25974	-84	842	1067	5007	-83	1123	2383	10214	-89
Direct industrial discharges	[t/a]	59	101	583	-90	584	594	3369	-83	41	55	297	-86	132	162	2349	-94
Sum of point sources	**[t/a]**	**1023**	**1510**	**6723**	**-85**	**4767**	**5579**	**29344**	**-84**	**883**	**1122**	**5305**	**-83**	**1255**	**2544**	**12563**	**-90**
	[%]	***22.0***	***30.4***	***63.9***		***43.6***	***48.6***	***79.7***		***24.7***	***29.9***	***64.1***		***22.7***	***34.7***	***68.8***	
Sum of all sources	**[t/a]**	**4643**	**4961**	**10525**	**-56**	**10926**	**11487**	**36834**	**-70**	**3576**	**3758**	**8282**	**-57**	**5523**	**7341**	**18254**	**-70**
	[%]	***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***	

Table 4: Phosphorus emissions 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, 1993-1997 and 1998-2000.

Pathway		North Sea				Baltic Sea				Black Sea				Germany			
		1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change	1998-00	1993-97	1983-87	Change
Groundwater	[t/a]	4757	4702	5587	-15	308	298	341	-10	646	581	681	-5	5712	5580	6609	-14
	[%]	*17.5*	*15.8*	*7.2*		*22.5*	*18.6*	*8.4*		*13.9*	*11.7*	*6.5*		*17.2*	*15.3*	*7.2*	
Tile drainage	[t/a]	3087	3083	3325	-7	95	97	92	3	88	89	99	-11	3271	3269	3515	-7
	[%]	*11.4*	*10.3*	*4.3*		*6.9*	*6.0*	*2.3*		*1.9*	*1.8*	*0.9*		*9.9*	*9.0*	*3.8*	
Erosion	[t/a]	6597	6634	5235	26	466	473	354	32	1835	1822	1720	7	8898	8929	7310	22
	[%]	*24.3*	*22.2*	*6.8*		*34.1*	*29.5*	*8.7*		*39.4*	*36.7*	*16.3*		*26.8*	*24.5*	*8.0*	
Surface runoff	[t/a]	1896	1690	1438	32	56	54	32	75	692	588	504	37	2644	2332	1974	34
	[%]	*7.0*	*5.7*	*1.9*		*4.1*	*3.4*	*0.8*		*14.9*	*11.8*	*4.8*		*8.0*	*6.4*	*2.2*	
Atmospheric deposition	[t/a]	185	185	263	-30	42	42	70	-40	35	35	38	-8	262	262	371	-29
	[%]	*0.7*	*0.6*	*0.3*		*3.1*	*2.6*	*1.7*		*0.8*	*0.7*	*0.4*		*0.8*	*0.7*	*0.4*	
Urban areas	[t/a]	2816	2903	7004	-60	161	167	293	-45	332	341	766	-57	3309	3411	8063	-59
	[%]	*10.4*	*9.7*	*9.1*		*11.8*	*10.4*	*7.2*		*7.1*	*6.9*	*7.3*		*10.0*	*9.4*	*8.8*	
Sum diffuse sources	**[t/a]**	**19338**	**19197**	**22852**	**-15**	**1128**	**1131**	**1182**	**-5**	**3628**	**3456**	**3808**	**-5**	**24096**	**23783**	**27842**	**-13**
	[%]	***71.2***	***64.4***	***29.6***		***82.5***	***70.4***	***29.0***		***78.0***	***69.6***	***36.1***		***72.7***	***65.4***	***30.3***	
Background	[t/a]	2477	2477	2477	0	169	169	169	0	796	796	796	0	3442	3442	3442	0
	[%]	*9.1*	*8.3*	*3.2*		*12.4*	*10.5*	*4.1*		*17.1*	*16.0*	*7.6*		*10.4*	*9.5*	*3.8*	
Agricultural diffuse sources	[t/a]	13860	13632	13108	6	756	753	650	16	2465	2284	2208	12	17083	16668	15966	7
	[%]	*51.1*	*45.7*	*17.0*		*55.3*	*46.9*	*16.0*		*53.0*	*46.0*	*21.0*		*51.5*	*45.8*	*17.4*	
Municipal WWTP`s	[t/a]	6993	9516	48153	-85	208	427	2570	-92	965	1411	6147	-84	8167	11354	56870	-86
Direct industrial discharges	[t/a]	810	1104	6163	-87	31	48	321	-90	59	101	583	-90	901	1253	7067	-87
Sum of point sources	**[t/a]**	**7804**	**10620**	**54316**	**-86**	**240**	**475**	**2891**	**-92**	**1024**	**1512**	**6730**	**-85**	**9068**	**12607**	**63937**	**-86**
	[%]	***28.8***	***35.6***	***70.4***		***17.5***	***29.6***	***71.0***		***22.0***	***30.4***	***63.9***		***27.3***	***34.6***	***69.7***	
Sum of all sources	**[t/a]**	**27142**	**29817**	**77168**	**-65**	**1368**	**1606**	**4073**	**-66**	**4652**	**4968**	**10538**	**-56**	**33164**	**36390**	**91779**	**-64**
	[%]	***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***		***100.0***	***100.0***	***100.0***	

1 Introduction

The *International Conference on the Protection of the North Sea* (ICN) and the *Helsinki Commission* (HELCOM) agreed on a 50 % reduction in nitrogen and phosphorus inputs to the North Sea and Baltic Sea respectively for the periods 1985/1987 to 1995. The fulfilment of this agreement is a political necessity in relation to sea conservation. In the next two decades, water quality guidelines will be put in place for the reduction of loadings to inland and marine waters to a satisfactory ecological state.

With this in mind, it needs to be tested as to what extent the nutrient loadings of the North and Baltic Seas from German freshwaters have been further reduced since 1995. The basis of this work was the model MONERIS developed by Behrendt et al. (1999). This model provides an overall as well as catchment-differentiated quantification of the input pathways. The catchment-differentiated analysis allows the identification of regional lading hot spots which is important for the implementation of measures for the reduction of nutrient inputs.

The nutrient loading of freshwaters is from both point source and diffuse source input. Since knowledge on the contributions of the individual input pathways in particular catchments is necessary for the determination of further measures for the reduction of nutrient loadings, the emission calculation model was employed based on the studies of HAMM (1991) and WERNER & WODSAK (1994). The comparability of the results of HAMM (1991) for the old German states (former FRG) and of WERNER & WODSAK (1994) for the new German states (former GDR) was, however, hindered by the use of different methods and study periods. The analysis of BEHRENDT ET AL. (1999) unified the various methods, and the results were catchment oriented as the input pathways are related to discharge components.

In the context of previous studies, not all existing problems can be solved relating to estimation of nutrient inputs and loadings to catchments and their changes over time. The aim is to calculate nutrient inputs to German catchments for the time around 2000, to test whether estimates of inputs by various pathways to catchments in neighbouring countries can be applied to Germany and to compare methods. With regard to this, harmonised model parameters should be employed for determination of nutrient inputs within the existing model and through the enlarged database, the model should be improved.

In hindsight, a comparison of model results makes it possible to harmonise inputs as well as to use similar or identical calculation methods, unified databases, definitions and linkages.

The catchment based analyses of nutrient loadings should provide a final picture for all areas, from the causes of the loadings to the realised carriage. In this regard, a catchment based nutrient balance for agricultural land for the period 1985 to 1999 is necessary for it is the relationship between this balance and the various above and below diffuse input pathways in dependence on the geomorphological, soil and hydrological conditions in particular catchments. The methodological work in the present analysis concentrates predominantly on the relationship of the most recent knowledge on regional differences in the underground retention times in the model calculations. However, some important improvements in details of the model were also made to reduce existing discrepancies. As before then, the goal of the study is not only to estimate catchment differentiated nutrient input but also to calculate nutrient loadings so that model results can be directly compared with observations.

The transfer of the pathway-based and catchment-differentiated model results to catchments outside Germany was possible with use of information on the Odra and its sub-catchments (Behrendt et al., 2002). From this, the usability of the model in other catchments (Danube, Vistula, Po, Axios etc) is currently being tested in various national and EU projects.

Since the model inputs of MONERIS were originally designed to be used for catchments of 500 km^2 and larger, the need of an analysis of the loading situation in conjunction with water framework directive (WFD) for catchments of 100 km^2 or less is necessary. It is a goal of this and other studies to test whether the model can be applied for such small catchments. This is being carried out in contracts for the states of Baden-Württemberg and Brandenburg (Behrendt et al., 2000, 2001) as well as four graduate studies (Venohr, 1999; Geisler, 2001; Thomas, 2001; Schmidt 2002).

Without the extensive support of the staff of the German Ministry of the Environment and above all the environmental offices of the sixteen German states, the fulfilment of this contract would not have been possible.

2 Databases

2.1 Area related input data

The following geographical information system (GIS) linked data are used in this project:

- Land use according to CORINE-Landcover (Data on soil cover for Germany, *Federal Statistical Agency* 1997; Corine Land Cover of Europe, *EEA*, Kopenhagen, Dänemark, 2001)
- Land-use from Landsat TM 1989 (*IGB*)
- General soil map (BÜK 1.000 of the *BGR*)
- Mid-scale map of agricultural land use (MMK 100, State geological offices of the NBL)
- Mid-scale map of agricultural land use (MMK 25, *IGB*)
- Hydrological map of Europe from the *National Institute of Public Health and the Environment* (*RIVM*, Netherlands)
- Map of groundwater bearing formations *(Research Center Jülich GmbH, Program group STE)*
- River network and catchment boundaries (*UBA*)
- River network and elevations from TK25AS (*IGB*)
- Digital elevation model after USGS
- Boundaries of administrative units - ArcGemeinde 2000 (ESRI-Germany)
- Statistical data of districts and municipalities (State statistics offices)
- Tile drained areas in selected catchments of eastern Germany (former GDR)
- Soil losses by erosion for selected areas at the district or municipality level (DEUMLICH ET AL., 1997); Bayern, (AUERSWALD, K. & SCHMIDT, F., 1986); Baden-Württemberg (GÜNDRA ET AL., 1995)
- Soil losses by erosion at the municipality level for the Polish part of the Odra catchment (Behrendt et al., 2002)
- Soil loss maps in digital format for Baden-Württemberg, Germany and Western Europe (personal communication KLEIN, 1998)
- Results of atmospheric deposition of nitrogen oxides and ammonium in digital format with 150 km resolution for 1985 and 50 km resolution for 1996 and 1999 after EMEP of the Norwegian Meteorological Institute (*DNMI*, Norway)
- Data on the sewer network and the inhabitants connected to sewers at the state level from state statistics offices
- Map of population density for 2000 from Landscan 1999/2000 (*Oak Ridge National Laboratory* (*ORNL*)) http://sedac.ciesin.org/plue/gpw/landscan/).

All spatial data were transferred in a uniform projection (ARC 500). Through overlay of the catchment boundaries with these data, all values were estimated directly for the catchments. For rivers passing through national borders, attempts were made to extend the digital database to the adjoining areas of the neighbouring countries. For this, representative values are necessary for the entire river catchment. However, this is only possible if the data obtained for these countries are comparable to those for Germany as for example with land-use.

CORINE-Landcover

The available data includes land-use data (CORINE-Landcover) from satellite photographs for the years 1989-1992 for Germany, Austria, France, the Czech Republic, Poland and Switzerland as well as the Benelux countries. This data was obtained from the Federal State Statistics Office, the PHARE-programme of the EU and the *European Topic Centre on Land Cover* (see Map 2.1) and was used for both study periods as no up to date area-based data are available.

Landsat TM 1989

In addition to the CORINE-data, land-use data from Landsat TM 1989 are available for the Spree and Salza catchments. 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 area”, “agricultural areas”, “permanent fallow”, “woodland”, “water-bodies” and “wetlands”.

BÜK and MMK

For the analysis of the soil type in the catchment areas, general soil map for Germany (BÜK 1000) were available with 72 soil classes and a scale of 1:1,000,000 (see Map 2.2). This map is available from the Federal Institute of Geosciences and Natural Resources. In addition to the BÜK maps, for the new German states (former GDR), the mid-scale agricultural site maps (MMK) with a scale of 1:25,000 were used. They are available from state Geology offices. For the Spree catchment there is a 1:25,000 scale MKK map available, too.

Hydrogeology

For the differentiation of areas with consolidated and unconsolidated rocks within catchment areas, a hydrogeological map of Europe from RIVM was used (see Map 2.3).

The starting point for the calculation of retention times for the basic outflow is the map of groundwater bearing formations (see Map 2.4) formed by Wendland & Kunkel, 2000) through the combining of maps of the hydrological atlas for Germany (1979 edition) with the hydrogeological map of the GDR (1985).

River network, catchment boundaries and monitoring stations

The model data for the rivers and also selected shallow water-bodies and also 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 digital river network map D1000 of the German Environment Ministry. In addition, data from the following sources was used:

- ARC/INFO-Cover NETZ of the UBA river network map
- ARC/INFO-Cover of the Polish river network map with a scale of 1:555,000 (*IGB*)
- Digital river network map for Switzerland (Rhine, Danube, Federal Statistics Office, GEOSTAT project)
- Fine scale analogue maps of river networks for sub-catchments of the Danube and Rhine (Austria, France)

Map 2.5 provides a complete overview.

Additionally, the digitised river network from the topographical maps TP25AS of the former GDR were used for the Spree and Salza catchments.

The FEA Cover EZG1000 serves for the initial separation of all catchment areas. In this data, the entire German territory is described according to the 3. LAWA hierarchy. The locations of watersheds were derived according to the *FEA* from the DEM1000. The size of the catchments in Cover EZG1000 do not always correspond with those of the state offices. This initial separation, the catchment boundaries were also determined with the aid of the following data sources:

- EZG-Cover of the FEA database „River network 1:1,000,000“
- EZG-Cover of the IFEIF-database “Polish river network 1:500,000”
- Analogous overview map of the rainfall regions of the Rhine, Danube, and Elbe (especially in their upper reaches and Austrian, French and Swiss areas)
- Analogous watershed maps of the Czech repuplic, scale 1:500,000.

Additional catchment boundaries were constructed during the project from all the monitoring stations used. The basis for the location of the boundaries is a hydrologically rooting through all catchments upstream the generated monitoring stations and between the source locations of all waters in the fine river network.

The geographical location of the monitoring stations within the water network was derived from qualitatively different sources. The primary information comes either as stored location coordinates in various geo-data systems or as verbal descriptions of locations relative to water-bodies and communities. In order to use it in this project, all locations were transferred to a uniform project coordination system.

Following the generation of the additional catchment boundaries in the EZG database of the sub-catchments, a fine-correction was required for many monitoring stations. The corrections were based on the assumption that every monitoring station lies exactly on the cut-off point of the middle of the river and the cachment boundary. In individual cases, existing information on the location on the left or right river bank were ignored because of the small scale of the river network maps.

The catchments used and the measuring stations are shown in Map 2.6.

DHM

For an overview of the relief of the catchments, the digital model GTOPO30 of the US Geological Survey was used (see Map 2.7).

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

ArcGemeinde

The spatial presentation as well as the catchment level analyses of information can be obtained from the ArcGemeinde data bank of coordinates. In this data bank the administrative boundaries for the German states, districts and communities are existing in digital form at a scale of 1:500,000. The coordinate data are already included in the project coordination system.

Statistical data of municipalities and districts

Besides the digital information of the area, there are data in tabular form available on population sizes (see Map 2.8), land-use, cultivation and livestock on a community basis. The data were supplied by the various state statistics offices and transferred to a unified data bank. The data apply to 1999 or 2000. This information was aggregated for each catchment by means of ArcGemeinde.

Since the data on population on the community basis are not always accurate, especially for small catchments and also because of the fact that data for areas outside Germany are only available at a higher administrative level, investigations were made as to whether the population density maps from the Global Population Project of the Oak RIDGE National Laboratory (ORNL) (see http://sedac.ciesin.org/plue/gpw/landscan/) could be used for some catchments.

Tile-drainage areas in selcted catchments

With regards to the extent of tile drainage in agricultural areas of Germany, different data are available for the old (former BRG) and new (former GDR) states. For the new states, information from the GDR statistical yearbooks were used for the drained areas. The information is available at the district level and support the drainage measures carried out between 1960 and 1989. The proportion of agricultural land drained as shown in Map 2.10 were not altered from the analysis for 1995 (Behrendt et al., 1999).

Soil erosion maps

The information of Behrendt et al. (1999) was used for a harmonised soil erosion map (Map 2.11).

Atmospheric deposition

The data from the *Det Norske Meteorologiske Institutt* (*DNMI*) on deposition of nitrogen oxides and ammonium for 1999 with a scale of 50 km were employed. The total nitrogen deposition from 1999 and 1986 are shown in Maps 2.12 and 2.13 respectively.

2.2 Database for the quantification of nutrient inputs via point sources

2.2.1 Municipal wastewater treatment plants in Germany

Statistical information

On the basis of the rules on environmental statistics and the German statistics, information on the public wastewater regulations for 1999 was used . The analysis of the data is carried out by the state statistics offices. The necessary data at the district level were available.

For the period from 1985 to 1995, the results of the analyses of Behrendt et al. (1999) on point-source nutrient inputs were used.

State data tables

For all German states, aggregated data from particular water industry and waste-water treatment plant data banks was used for treatment plants larger than 10000 EW. In addition to the location coordinates of the treatment plants, the following information is available:

- annual waste water quantity
- annual black water quantity
- weighted average of outflow concentrations or loadings for DIN, TN and TP.

For the states of Baden-Württemberg and Bavaria, data for nearly all treatment plants is available. This inventory was united together with treatment plant information from the UBA. Map 2.14 shows the calculated point-sources of used municipal treatment plants in 1999.

2.2.2 Community wastewater treatment plants of countries bordering Germany

An overview of nutrient inputs from municipal wastewater treatment plants for the portions of the Danube, Rhine and Elbe basins lying outside Germany is given in Table 2.7. It should be noted that the determination of nutrient inputs for the Polish and Czech Republic parts of the Oder basin have not yet been completed.

Table 2.1: Nutrient inputs to the Danube, Elbe and Rhine basins form municipal wastewater treatment plants outside Germany

Country	River basin	EKKP 1999	EKKN 1999	Reference
		[t P/a]	[t N/a]	
Switzerland	Rhine	900	14.300	IKSR (2000)
France and Luxemburg	Rhine	2.900	16.400	IKSR (2000)
Austria	Danube	190	1.160	ICPDR (2001)
Czech Rpeublic	Elbe	1.690	16530	ARGE Elbe (2001)

For the Rhine basin, nutrient inputs from municipal wastewater treatment plants for the sections in France and Switzerland for 1996 were assembled through the water protection commissions and the *IKSR* (IKSR, 2000).

For the part of the Danube basin within Austria above Jochenstein, the estimated point-source inputs from the treatment plant inventories of the International Commission for the Protection of the Danube were used (ICPDR, 2002).

For the part of the Elbe basin within the Czech Republic the results of the IKSE for 1999 were used (ARGE Elbe, 2001).

2.2.3 Direct industrial discharges

There are no detailed studies available on determination of direct industrial discharges for the period around 1995. Therefore, data was used for the period around 1995 and changes since then were analysed analogous to those for municipal wastewater treatment plants.

2.3 Monitoring data

2.3.1 Catchments and surface water data

A total of 165 monitoring stations were selected for this study. Every station was given a location based on the 3 digit LAWA number for the catchment and a further 2 digits to locate the position within a catchment. Where the discharge was measured at a different location than the water quality, a correction was made with the multiplication of the discharge station data by a constant for the discharge at the water quality measuring station (see Tables 2.10-2.15). If the correction factor was unavailable, it was estimated from the relationship between the areas of the catchments of the water quality and discharge monitoring stations.

Information on nutrient concentrations and discharges for 1998-2000 were obtained from dependable State Offices and the International Commissions for the protection of the Elbe, Mosel, Rhine and Saar catchments. This data was assembled into a database for a unified utilisation. Maps 2.15 to 2.20 give an overview of the locations of the individual measuring stations selected for this study. The available data are listed by catchment in Tables 2.10 to 2.15. Data for 2001 could not be included as no discharge data for 2000 were available within the time frame of this study.

Table 2.2: Monitoring stations, discharge data and water quality data for the Danube basin.

Loc.	River	Water quality monitoring station	Discharge monitoring station	A_{EZG}	Corr.-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
11304	Danube	Hundersingen	Hundersingen	2,629	1.00				
11301	Danube	Oepfingen	Berg	4,248	1.05				
11404	Iller	Kempten	Kempten	953	1.00	1998	2000	1998	2000
11402	Iller	Wiblingen	Wiblingen	2,115	1.00	1998	2000	1998	2000
11503	Danube	Ulm	Neu-Ulm	7,578	1.00	1998	1998	1998	2000
11501	Danube	Boefinger Halde	Neu-Ulm	8,107	1.00	1998	2000	1998	2000
11602	Mindel	Offingen	Offingen	952	1.00	1998	2000	1998	2000
11702	Danube	Dillingen	Dillingen	11,315	1.00	1998	2000	1998	2000
11802	Woernitz	Ronheim	Harburg	1,566	1.00	1998	200	1998	2000
11901	Danube	Schaefstall	Donauwoerth	15,150	1.00	1998	2000	1998	2000
12303	Lech	Fuessen	Fuessen	1,417	1.00	1998	2000	1998	1999
12901	Lech	Feldheim	Feldheim	3,926	1.00	1998	2000	1998	1999
13302	Danube	Neustadt	Kehlheim	21,792	1.00	1998	2000	1998	2000
13401	Altmuehl	Groegling	Beilngries	2,504	1.00	1998	2000	1998	2000
14302	Naab	Unterkoebelitz	Unterkoebelitz	2,004	1.00	1998	2000	1998	1999
14402	Schwarzach	Warnbach	Warnbach	821	1.00	1998	2000	1998	2000
14601	Vils	Dietldorf	Dietldorf	1,096	1.00	1998	2000	1998	1999
14902	Naab	Heitzenhofen	Heitzenhofen	5,426	1.00	1998	2000	1998	2000
15202	Regen	Regenstauf	Regenstauf	2,658	1.00	1998	2000	1998	2000
15901	Danube	Deggendorf	Pfelling	38,125	1.00	1998	2000	1998	2000
16502	Isar	Baierbrunn	Muenchen	2,803	1.00	1998	2000	1998	2000
16601	Amper	Moosburg	Inkofen	3,088	1.00	1998	2000	1998	2000
16902	Isar	Plattling	Plattling	8,839	1.00	1998	2000	1998	2000
17202	Vils	Grafenmuehle	Grafenmuehle	1,436	1.00	1998	2000	1998	2000
17301	Danube	Passau	Passau	50,586	1.00			1998	2000
17402	Ilz	Kalteneck	Kalteneck	762	1.00	1998	2000	1998	2000
18101	Inn	Kirchdorf	Oberaudorf	9,905	1.00	1998	2000	1998	2000
18302	Inn	Eschelbach	Eschelbach	13,354	1.00				
18402	Alz	Seebruck	Seebruck	1,399	1.00	1998	2000	1998	2000
18404	Tiroler Achen	Staudach	Staudach	944	1.00	1998	2000	1998	2000
18602	Salzach	Laufen	Laufen	6,113	1.00	1998	2000	1998	2000
18603	Saalach	Freilassing	Staufeneck	1,131	1.04	1998	2000	1998	2000
18802	Rott	Ruhstorf	Ruhstorf	1,053	1.00	1998	2000	1998	2000
18902	Inn	Passau-Ingling	Passau-Ingling	26,049	1.00	1998	2000	1998	2000
19101	Danube	Jochenstein	Achleiten	77,086	1.00	1998	2000	1998	2000

Table 2.3: Monitoring stations, discharge data and water quality data for the Rhine basin.

Loc.	River	Water quality monitoring station	Discharge monitoring station	A_{EZG}	Corr.-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
21902	Rhine	Reckingen	Reckingen	14,718	1.00	1998	1998		
23704	Rhine	Karlsruhe	Karlsruhe	50,196	1.00	1998	1999	1998	2000
23806	Neckar	Deizisau	Plochingen	3,995	1.00	1998	1998		
23803	Neckar	Kochendorf	Lauffen	8,510	1.08	1998	1998		
23801	Neckar	Mannheim	Heidelberg	13,957	1.01				
24104	Main	Schwuerbitz	Schwuerbitz	2,420	1.00	1998	2000	1998	2000
24101	Main	Hallstadt	Kemmern	4,399	1.04	1998	2000	1998	2000
24203	Regnitz	Hausen	Huettendorf	4,472	1.20	1998	2000	1998	2000
24202	Regnitz	Pettstadt	Pettstadt	7,005	1.00	1998	2000	1998	2000
24303	Main	Viereth	Trunstadt	11,956	1.00	1998	2000	1998	2000
24401	Fränk. Saale	Gemuenden	Wolfsmuenster	2,141	1.00	1998	2000	1998	2000
24602	Tauber	Waldenhausen	Waldenhausen	1,798	1.00	1998	2000	1998	2000
24702	Main	Kahl a. Main	Kleinheubach	23,152	1.06	1998	2000	1998	2000
24706	Kinzig	Hanau	Hanau	925	1.00	1998	1999	1998	1998
24901	Main	Bischofsheim	Frankfurt	27,140	1.10	1998	1999	1998	2000
25102	Rhine	Mainz	Mainz	98,206	1.00	1998	1999	1998	2000
25802	Lahn	Limburg-Staffel	Kalkofen	4,875	0.92	1998	1999	1998	1999
25901	Rhine	Koblenz	Koblenz	109,806	1.00	1998	2000	1998	2000
26101	Mosel	Palzem	Perl	11,623	1.00	1998	1999	1998	2000
26407	Saar	Saarbruecken	Saarbruecken UP	3,818	0.96	1998	1999	1998	2000
26409	Blies	Reinheim	Reinheim	1,798	1.00			1998	2000
26411	Nied	Niedaltdorf	Niedaltdorf	1,337	1.00			1998	2000
26481	Saar	Kanzem	Fremersdorf	7,490	1.07	1998	1999	1998	2000
26901	Mosel	Koblenz	Cochem	28,100	1.04	1998	2000	1998	2000
27101	Rhine	Bad Honnef	Bonn	140,756	1.00				
27202	Sieg	Menden	Menden	2,862	1.01			1998	2000
27301	Wupper	Opladen	Opladen	827	0.95				
27303	Rhine	Duesseldorf-Flehe	Duesseldorf	145,750	0.99			1998	2000
27401	Erft	Eppinghoven	Neubrueck	1,828	1.15			1998	2000
27605	Ruhr	Villigst	Villigst	1,988	0.99				
27601	Ruhr	Muendung	Hattingen	4,485	1.08			1998	2000
27680	Emscher	Muendung	Muendung	858	1.00				
27801	Lippe	Wesel	Schermbeck 1	4,886	1.02			1998	2000
27903	Rhine	Lobith-Bimmen	Rees	159,127	1.00	1998	1999	1998	2000

Table 2.4: Monitoring stations, discharge data and water quality data for the Weser basin.

Loc.	River	Water quality monitoring station	Discharge monitoring station	A_{EZG}	Corr.-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
41011	Werra	Meiningen	Meiningen	1,170	1.00	1998	2000		
41009	Werra	Dorndorf	Vacha	2,246	1.00				
41007	Werra	Philipsthal	Vacha	2,258	1.03	1999	1999		
41006	Werra	Gerstungen	Gerstungen	3,039	1.00	1998	2000	1998	2000
41080	Werra	Treffurt	Heldra	4,266	0.99			1998	1999
41002	Werra	Letzter Heller	Letzter Heller	5,478	1.00	1998	2000	1998	1999
42004	Fulda	Rotenburg	Rotenburg	2,160	1.00	1999	1999		
42001	Fulda	Wahnhausen	Guntershausen	6,933	1.09	1999	1999	1998	2000
42005	Schwalm	Felsberg-Altenburg	Uttershausen	1,299	1.32	1999	1999	1998	1998
43001	Weser	Hemeln	Wahmbeck	12,550	0.96	1998	2000		
47301	Weser	Porta	Porta	19,162	1.00	1998	2000	1998	2000
47601	Grosse Aue	Steyerberg	Steyerberg	1,446	1.00	1998	2000	1998	2000
48204	Oker	Ohrum	Ohrum	813	1.00	1998	2000	1998	2000
48202	Oker	Gross Schwuelper	Gross Schwuelper	1,734	1.00	1998	2000	1998	2000
48301	Aller	Langlingen	Langlingen	3,288	1.00	1998	2000	1998	2000
48601	Oertze	Stedden	Feuerschuetzenbost.	766	1.04	1998	2000	1998	2000
48808	Leine	Leineturm	Leineturm	990	1.00	1998	2000	1998	2000
48807	Rhume	Elvershausen	Elvershausen	1,115	1.00	1998	2000	1998	2000
48804	Leine	Poppenburg	Poppenburg	3,463	1.00	1998	2000	1998	2000
48805	Innerste	Sarstedt	Heinde	1,263	1.41	1998	2000	1998	2000
48802	Leine	Neustadt	Neustadt	6,043	1.00	1998	2000		
48903	Boehme	Boehme	Hollige	562	1.09	1998	2000	1998	2000
48901	Aller	Verden	Rethem	15,220	1.05	1998	2000		
49103	Weser	Hemelingen	Bremen	38,415	1.00	1998	2000		
49401	Wuemme	Truperdeich	Hellwege-Schleuse	908	1.00	1998	2000	1998	2000
49603	Hunte	Tungeln	Huntlosen	1,878	1.05	1998	2000	1998	2000
49601	Hunte	Reithoerne	Huntlosen	2,344	1.37	1998	2000	1998	2000

Table 2.5: Monitoring stations, discharge data and water quality data for the Elbe basin.

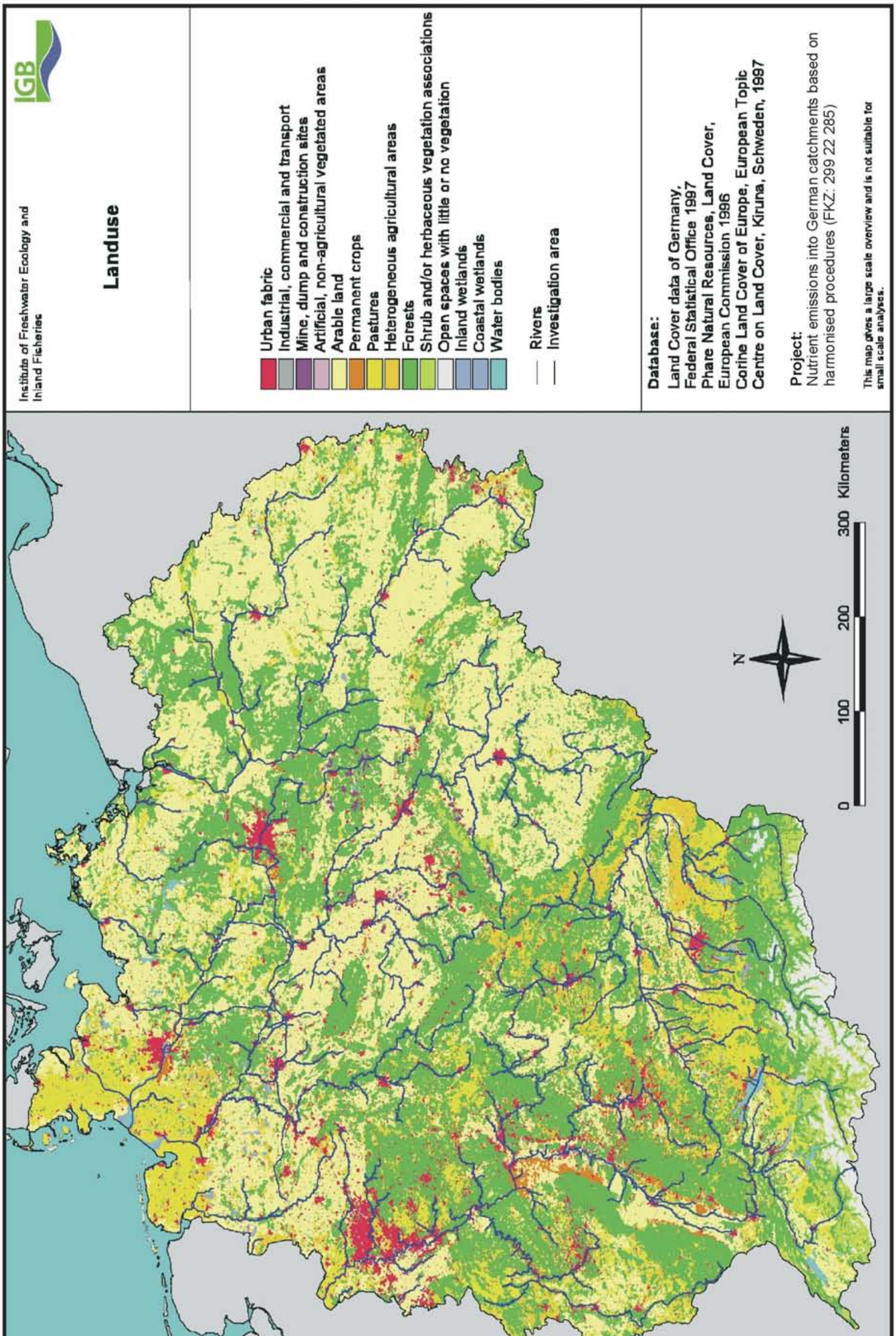
Loc.	River	Water quality monitoring station	Discharge monitoring station	A_{EZG}	Corr-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
53706	Elbe	Schmilka	Schoena	51,391	1.00	1998	2000	1998	2000
53702	Elbe	Torgau	Torgau	55,211	1.00			1998	2000
53801	Schw. Elster	Gorsdorf	Loeben	5,453	1.26	1998	2000	1998	2000
54101	Zwi. Mulde	Sermuth	Wechselburg	2,361	1.12	1998	2000	1998	2000
54205	Zschopau	Muendung	Kriebstein	1,846	1.05	1998	2000	1998	2000
54202	Freib. Mulde	Erlln	Erlln	2,983	1.00	1998	2000	1998	2000
54901	Mulde	Dessau	Bad Dueben	7,399	1.16	1998	2000	1998	2000
56102	Saale	Blankenstein	Blankenstein	1,013	1.00	1998	2000		
56302	Saale	Camburg-Stöben	Camburg-Stöben	3,977	1.00	1998	2000		
56407	Gera	Muendung	Erfurt	1,089	1.29	1998	2000		
56401	Unstrut	Freyburg	Laucha	6,327	1.02	1998	1999	1998	2000
56502	Saale	Naumburg	Naumburg	11,449	1.00	1999	1999	1998	2000
56609	Wei. Elster	Greiz uh	Greiz uh	1,255	1.00	1998	2000		
56604	Wei. Elster	Zeitz	Zeitz	2,479	1.00	1998	1999	1998	2000
56601	Wei. Elster	Ammendorf	Oberthau	5,384	1.09	1998	1999	1998	2000
56704	Saale	Trotha	Trotha	17,979	1.00	1998	1999		
56801	Bode	Neugattersleben	Stassfurt	3,297	1.02	1998	1999	1998	2000
56901	Saale	Gr. Rosenburg	Calbe	23,718	1.00	1998	2000	1998	2000
57302	Elbe	Magdeburg	Magdeburg	94,942	1.00	1998	2000	1998	2000
57602	Ohre	Wolmirstedt	Wolmirstedt	1,503	1.00	1998	1999		
57903	Elbe	Tangermuende	Tangermuende	97,780	1.00	1998	1999	1998	2000
58101	Havel	Hennigsdorf	Borgsdorf	3,108	1.03	1998	2000	1998	2000
58210	Spree	Cottbus	Cottbus	2,269	1.00	1998	1999	1998	2000
58208	Spree	Leibsch	Leibsch	4,529	1.00	1998	1999	1998	2000
58232	Osk	Wernsdorf	Wernsdorf	70	1.00	1998	2000	1998	2000
58214	Dahme	Neue Muehle	Neue Muehle	1,362	1.00	1998	2000	1998	2000
58201	Spree	Neuzittau	Hohenbinde	6,401	1.00	1998	2000	1998	2000
58402	Nuthe	Muendung	Muendung	1,811	1.00	1998	2000	1998	2000
58905	Dosse	Saldernhorst	Wusterhausen	1,099	1.93	1998	2000	1998	2000
58901	Havel	Toppel	Havelberg	24,297	1.01	1998	2000	1998	2000
59101	Elbe	Schnackenburg	Neu-Darchau	125,482	0.93	1998	2000	1998	2000
59108	Biese	Osterburg	Dobbrun	924	0.58	1998	1999		
59201	Elde	Doemitz	Doemitz	2,990	1.02			1998	2000
59302	Jeetzel	Lueggau	Luechow	1,660	1.28	1998	2000	1998	2000
59308	Sude	Bandekow	Garlitz	2,253	3.06	1998	2000	1998	2000
59311	Elbe	Zollenspieker	Neu-Darchau	135,024	1.03	1998	2000	1998	2000
59404	Ilmenau	Rote Schleuse	Bienenbuettel	1,545	1.08			1998	2000

Table 2.6: Monitoring stations, discharge data and water quality data in the Ems area and other North Sea catchments.

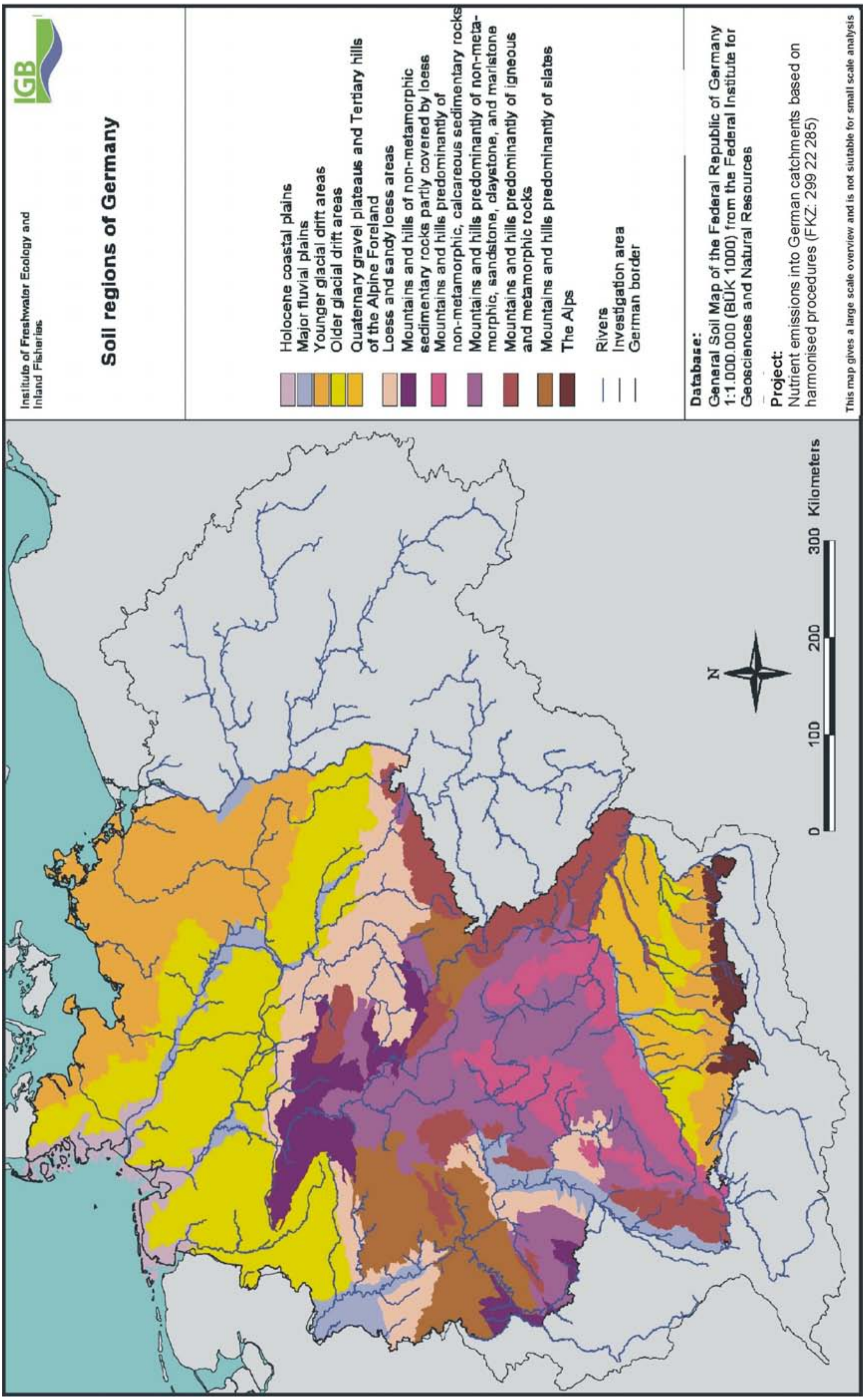
Loc.	Rver	Water quality montoring station	Discharge monitoring station	A_{EZG}	Corr.-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
33001	Ems	Hanekenfaehr	Dalum	4,870	0.98	1998	2000		
36901	Hase	Bokeloh	Bokeloh	2,968	1.00	1998	2000	1998	2000
37302	Ems	Hilter	Herbrum	8,695	0.95	1998	2000		
37602	Ems	Herbrum	Herbrum	9,207	1.00	1998	2000		
38001	Leda	Leer		2,078		1998	2000		
28202	Rur	End-Steinkirchen	Stah	2,300	0.72				
28602	Niers	Pegel Goch	Pegel Goch	1,203	1.00			1998	2000
29001	Vechte	Laar	Emlichheim	1,762	1.20	1998	2000	1998	2000
95202	Eider	Nordfeld		941					
95201	Eider	Toenning		1,918					
95203	Treene	Friedrichstadt	Treia	797	1.68				
95601	Soholmer Au	Schluettsiel	Soholm	468	1.61				

Table 2.7: Monitoring stations, discharge data and water quality data for the Oder and other Baltic Sea catchments.

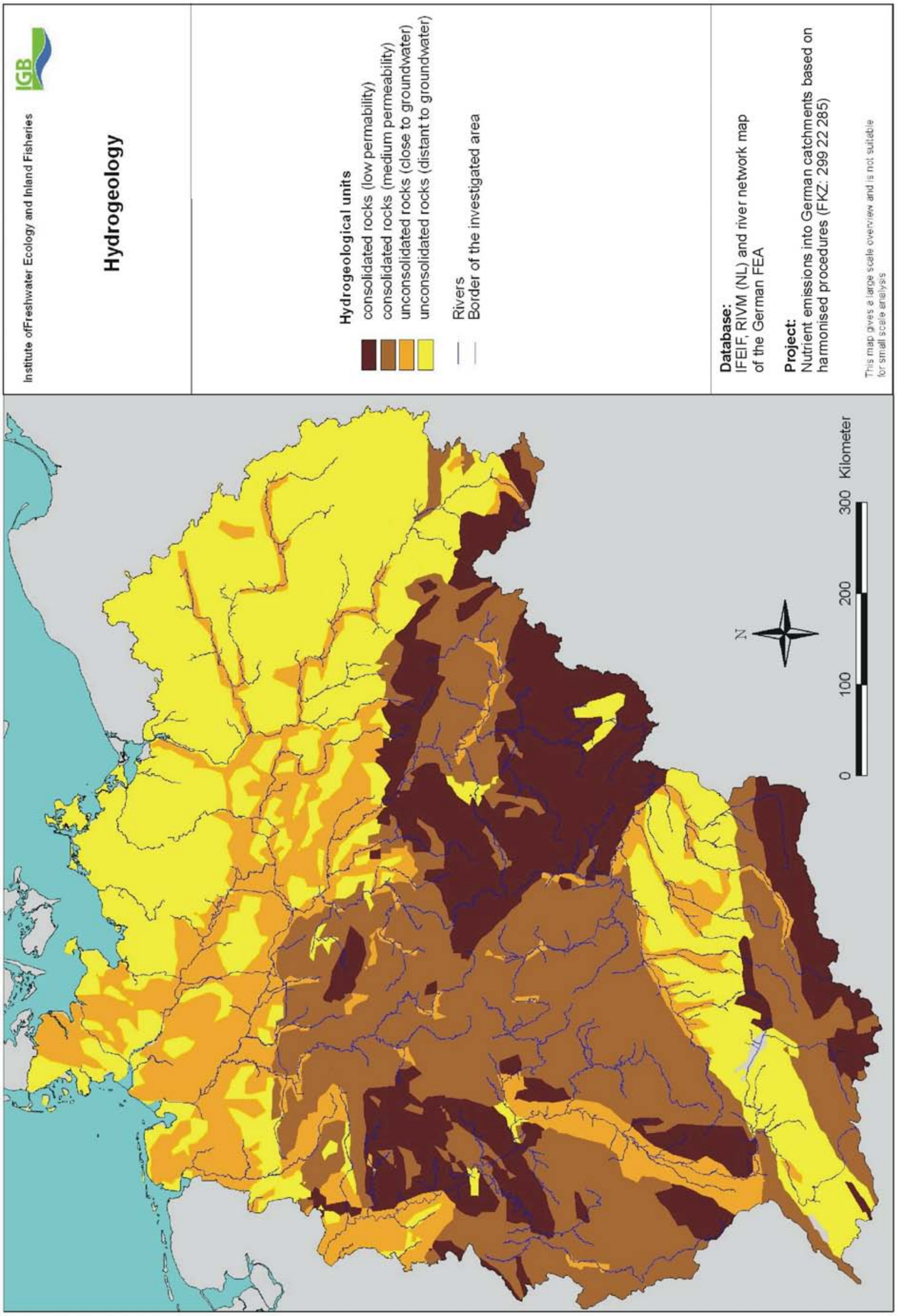
Loc.	River	Water quality monitoring station	Discharge monitoring station	A_{EZG}	Corr.-Factor	Water quality data		Daily discharge	
				[km²]		begin	end	begin	end
66003	Neisse	Goerlitz	Goerlitz	1,621	1.00	1998	2000	1998	2000
66001	Neisse	Muendung	Guben 1	4,579	1.08	1998	2000	1998	2000
67101	Oder	Eisenhuettenstadt	Eisenhuettenstadt	52,033	1.00	1998	2000	1998	2000
67901	Oder	Kietz	Kietz	53,752	1.00	1998	2000		
69003	Oder	Hohenwutzen	Hohensaaten	110,443	1.00	1998	2000	1998	1999
69001	Oder	Schwedt	Hohensaaten	112,950	1.03	1998	2000	1998	1999
96101	Schwentine	Kiel	Preetz	714	1.56			1998	2000
96204	Trave	Sehmsdorf	Sehmsdorf	726	1.00			1998	2000
96205	Stepenitz	Dassow	Boerzow	701	1.59	1998	2000	1998	2000
96301	Wallensteingr.	oh. Wismar	Hohen Viecheln	156	1.48	1998	2000	1998	2000
96401	Warnow	Kessin	Rostock OP	3,140	1.00	1998	2000	1998	2000
96501	Barthe	Barth	Redebas	292	1.36	1998	2000	1998	2000
96502	Recknitz	Ribnitz	Bad Suelze	669	1.50	1998	2000	1998	2000
96503	Ryck	Greifswald	Groß Miltzow	231	7.23	1998	2000	1998	2000
96602	Tollense	Demmin	Klempenow	1,809	1.29	1998	2000	1998	1999
96603	Trebel	Wotenick	Kirch Baggendorf	992	4.96	1998	2000	1998	2000
96601	Peene	Anklam	Klempenow	5,110	3.64	1998	1998	1998	1999
96802	Randow	Eggesin	Loecknitz	668	2.04	1998	2000	1998	2000
96801	Uecker	Ueckermuende	Pasewalk	2,401	1.67	1998	2000	1998	2000
96901	Zarow	Grambin	Brohm	748	7.38	1998	2000	1998	1999



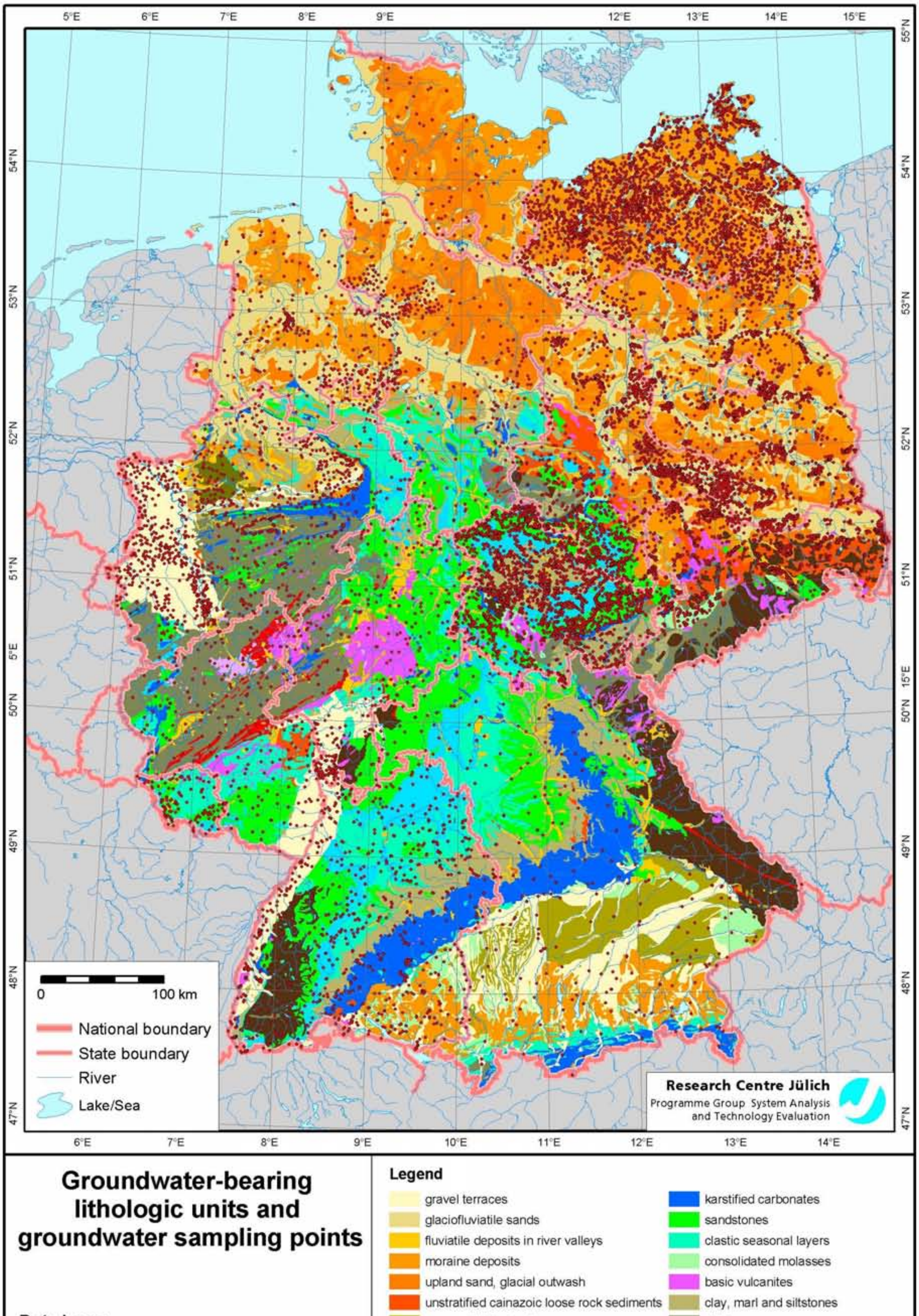
Map 2.1: Land use from CORINE



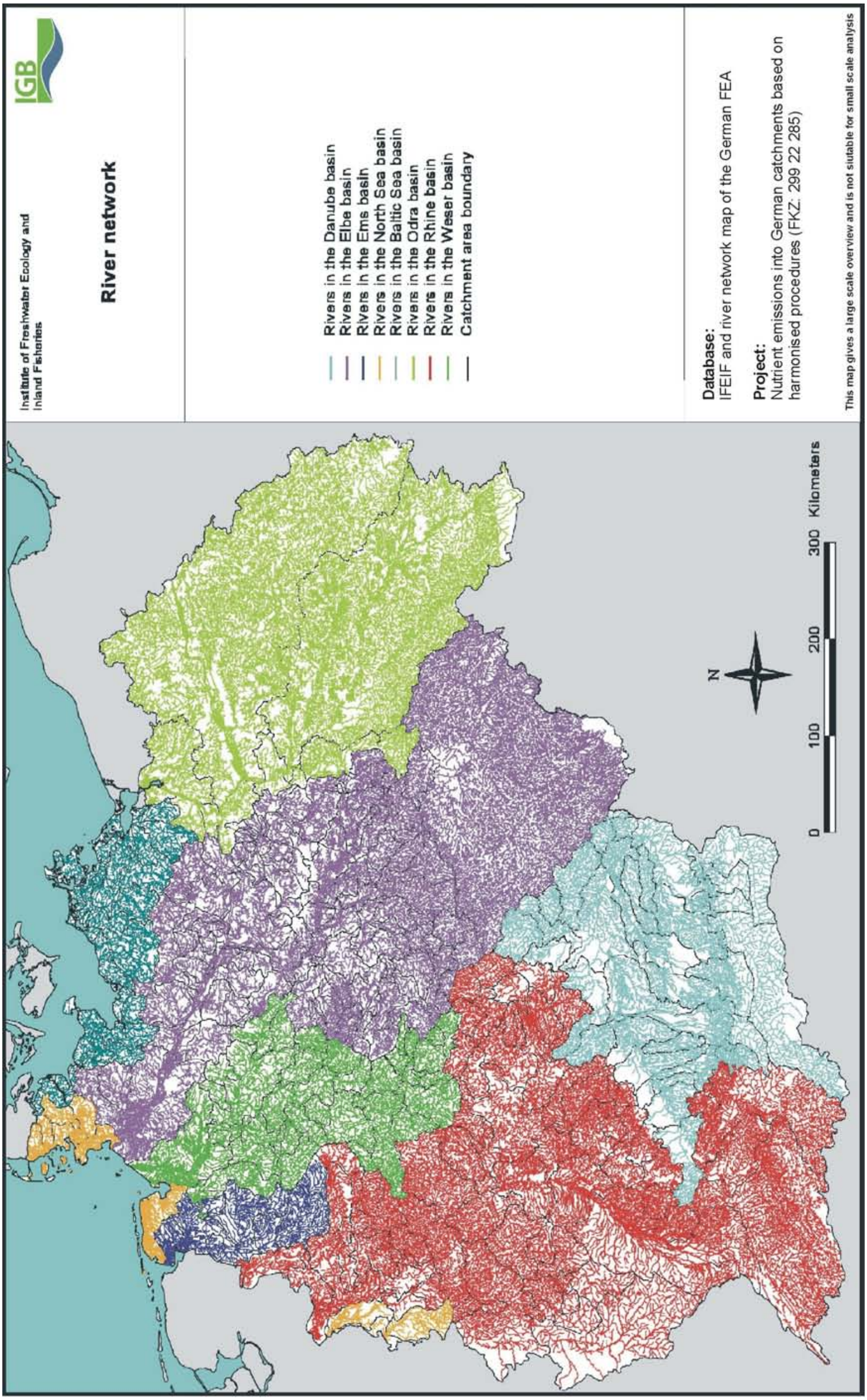
Map 2.2: Soil regions of Germany



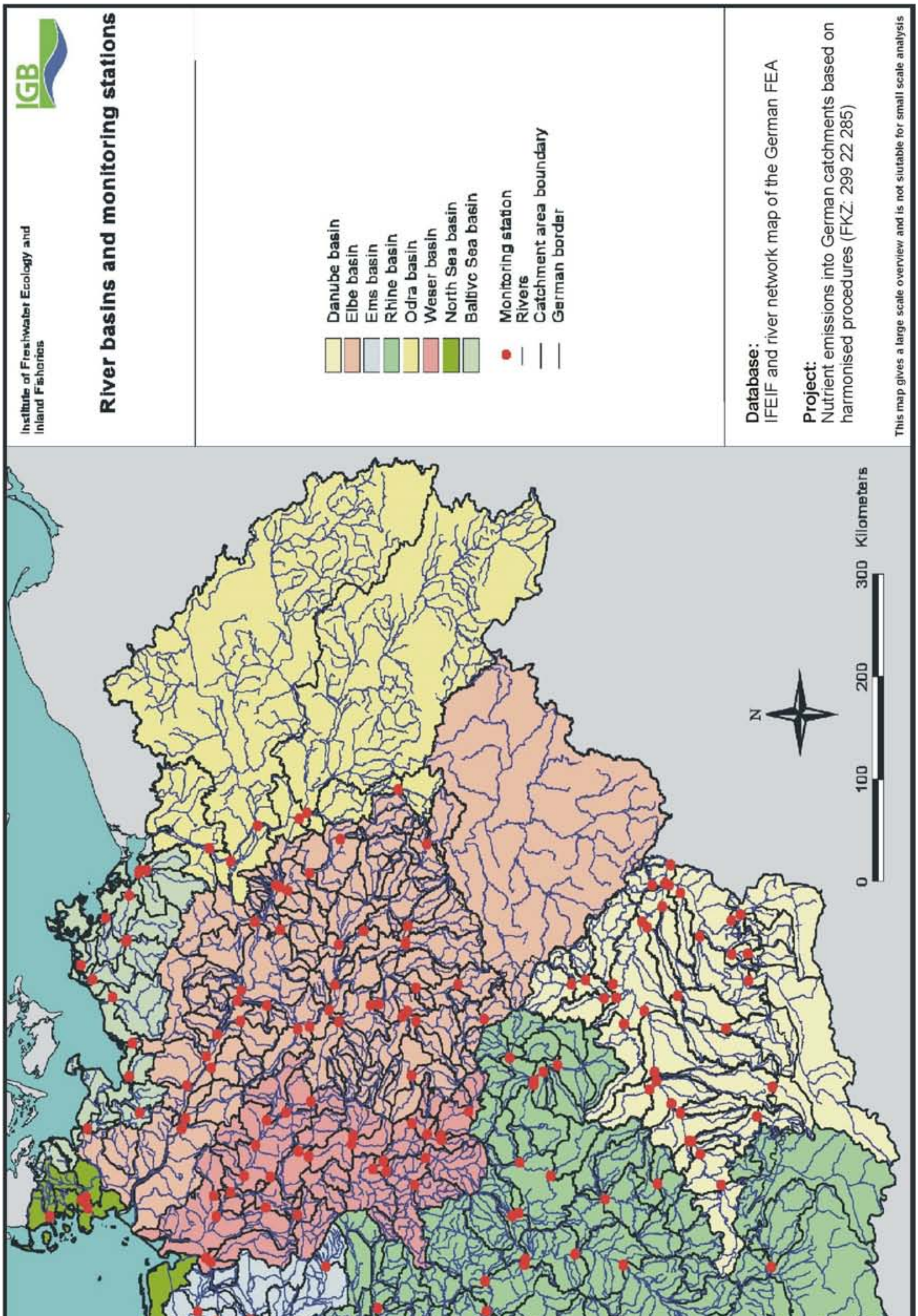
Map 2.3: Hydrogeology



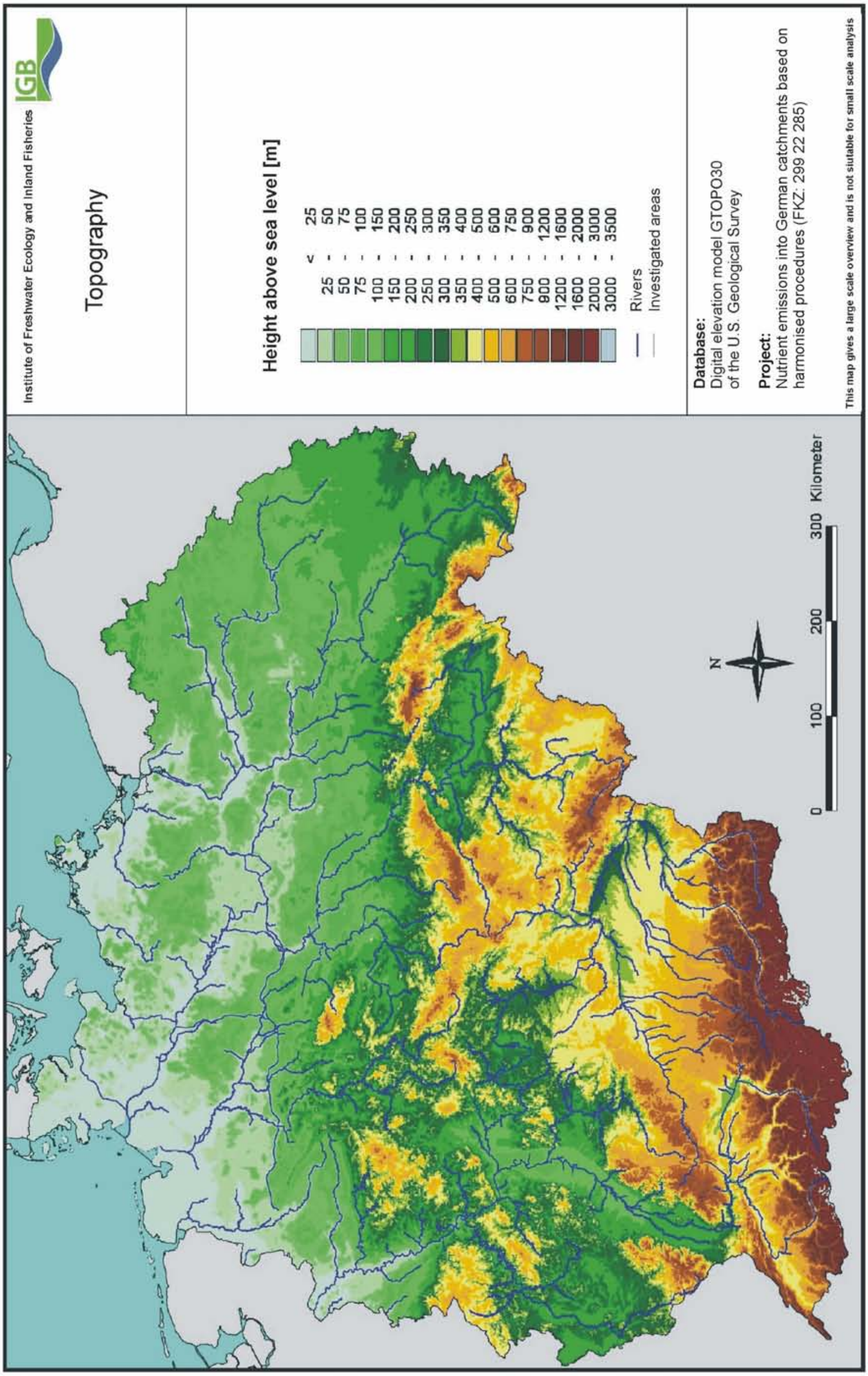
Map 2.4: Map of groundwater bearing formations



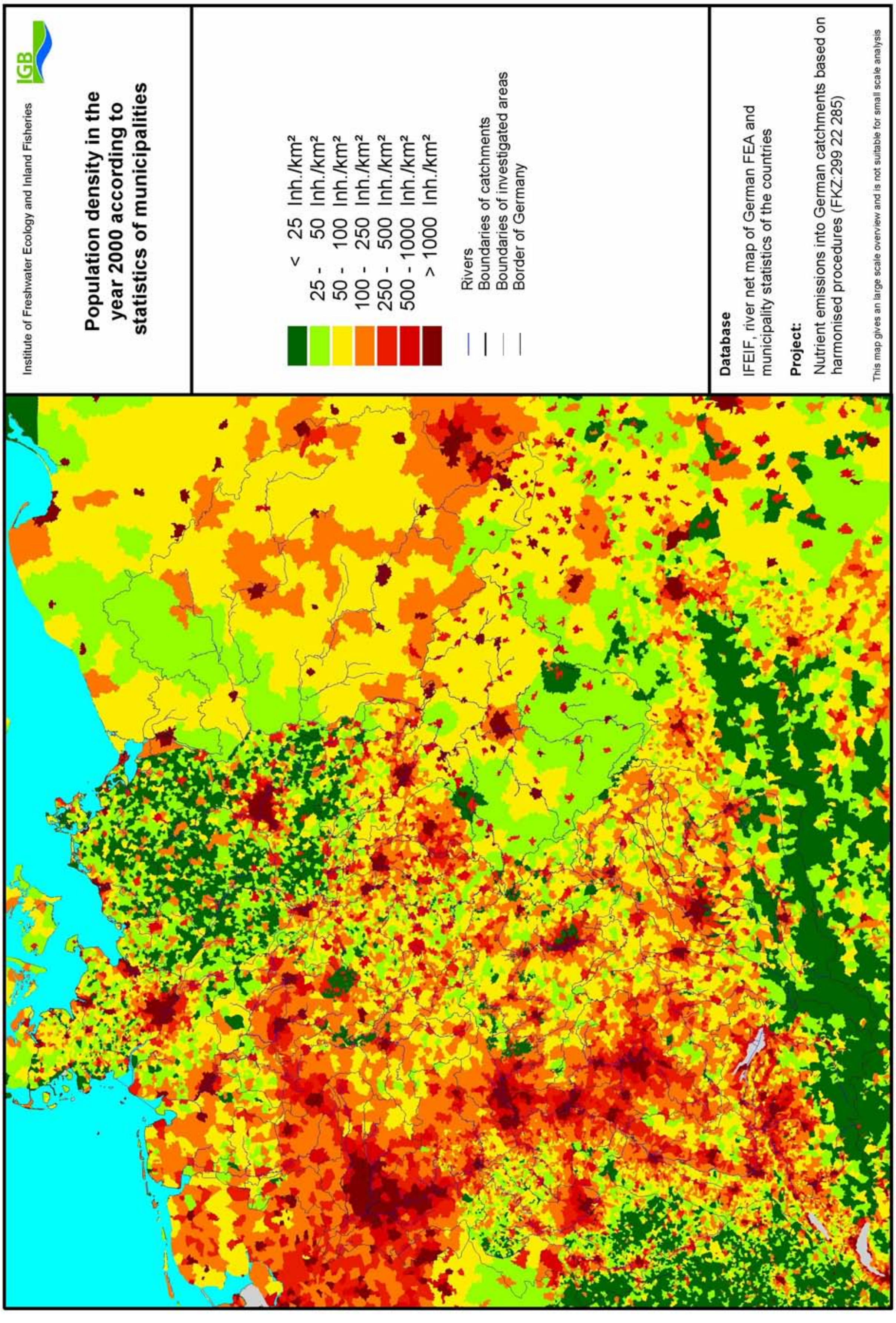
Map 2.5: River network



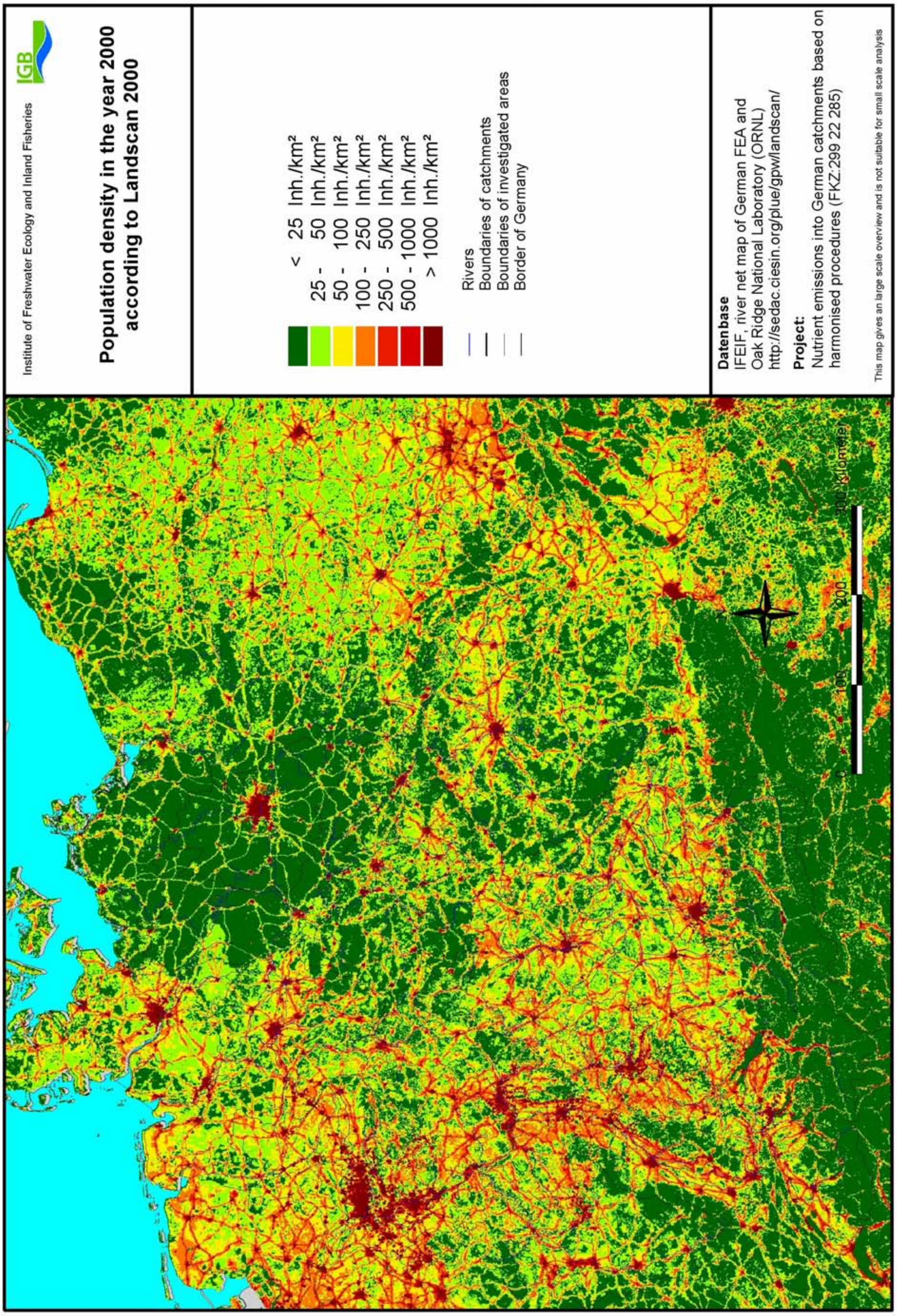
Map 2.6: Catchments and monitoring stations



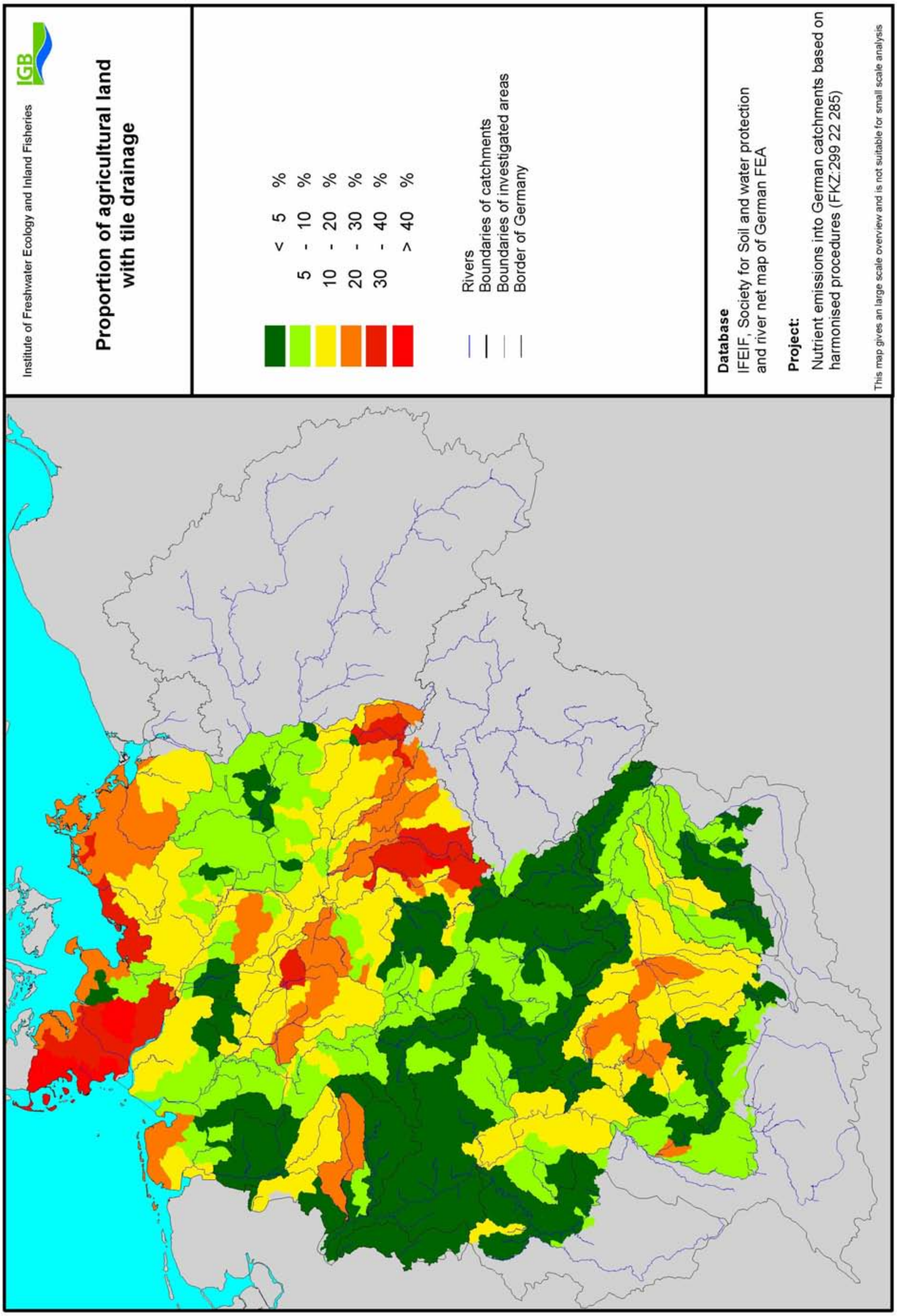
Map 2.7: Topography



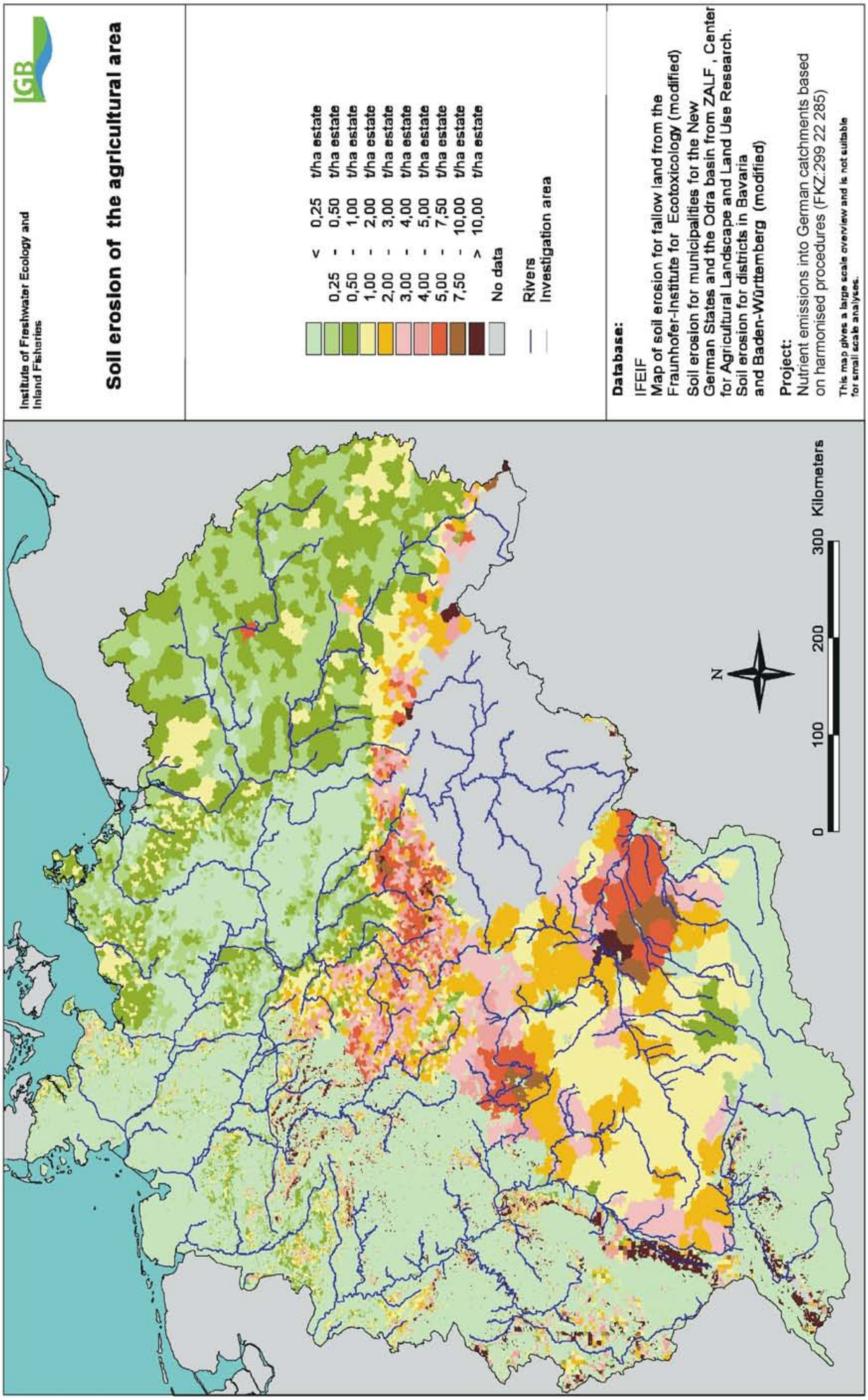
Map 2.8: Population density based on community information



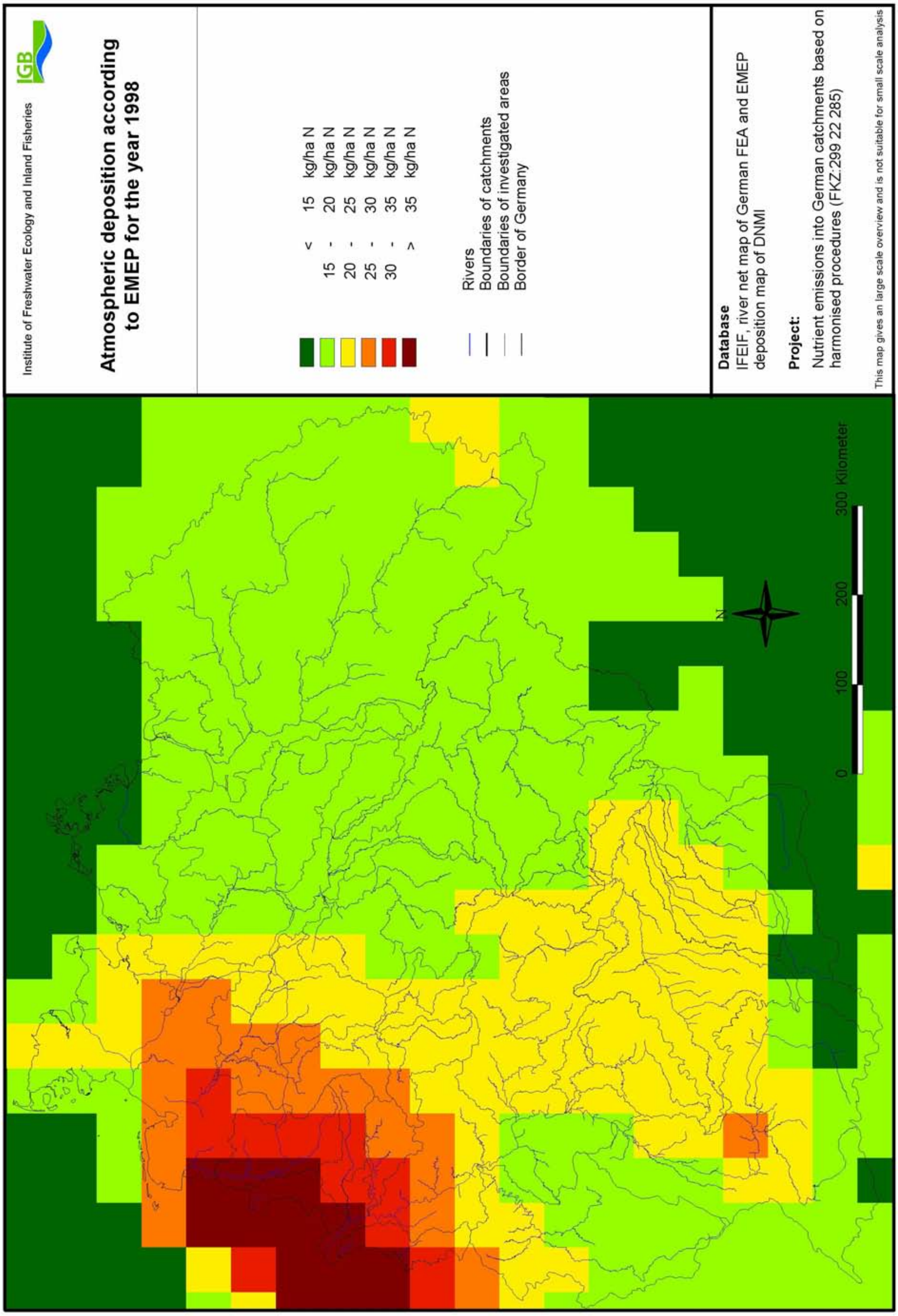
Map 2.9: Population density based on Landscan 2000 (Oak Ridge National Laboratory (ORNL) http://sedac.ciesin.org/plue/gpw/landscan/)



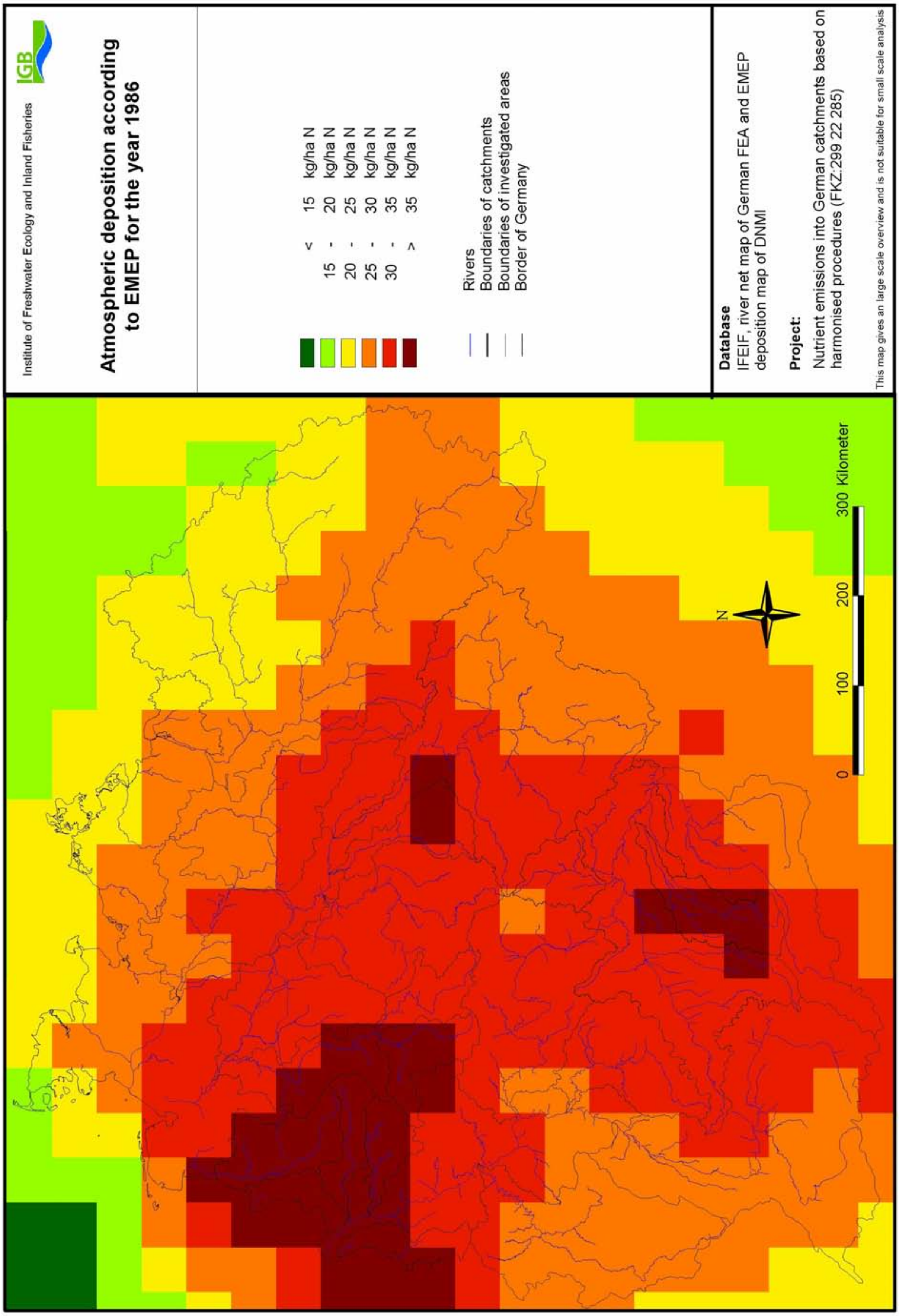
Map 2.10: Proportion of agricultural land with tile-drainage



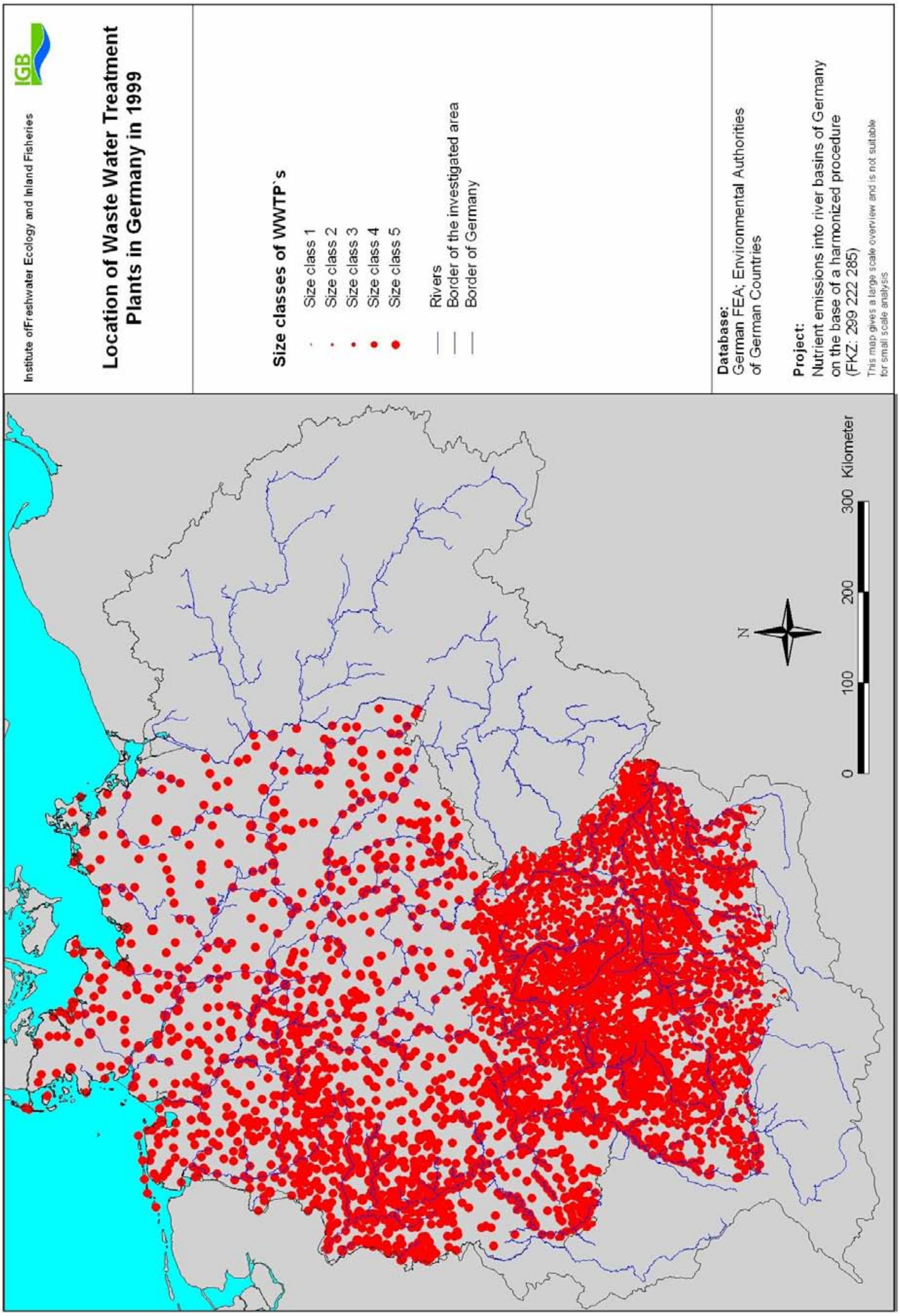
Map 2.11: Soil erosion



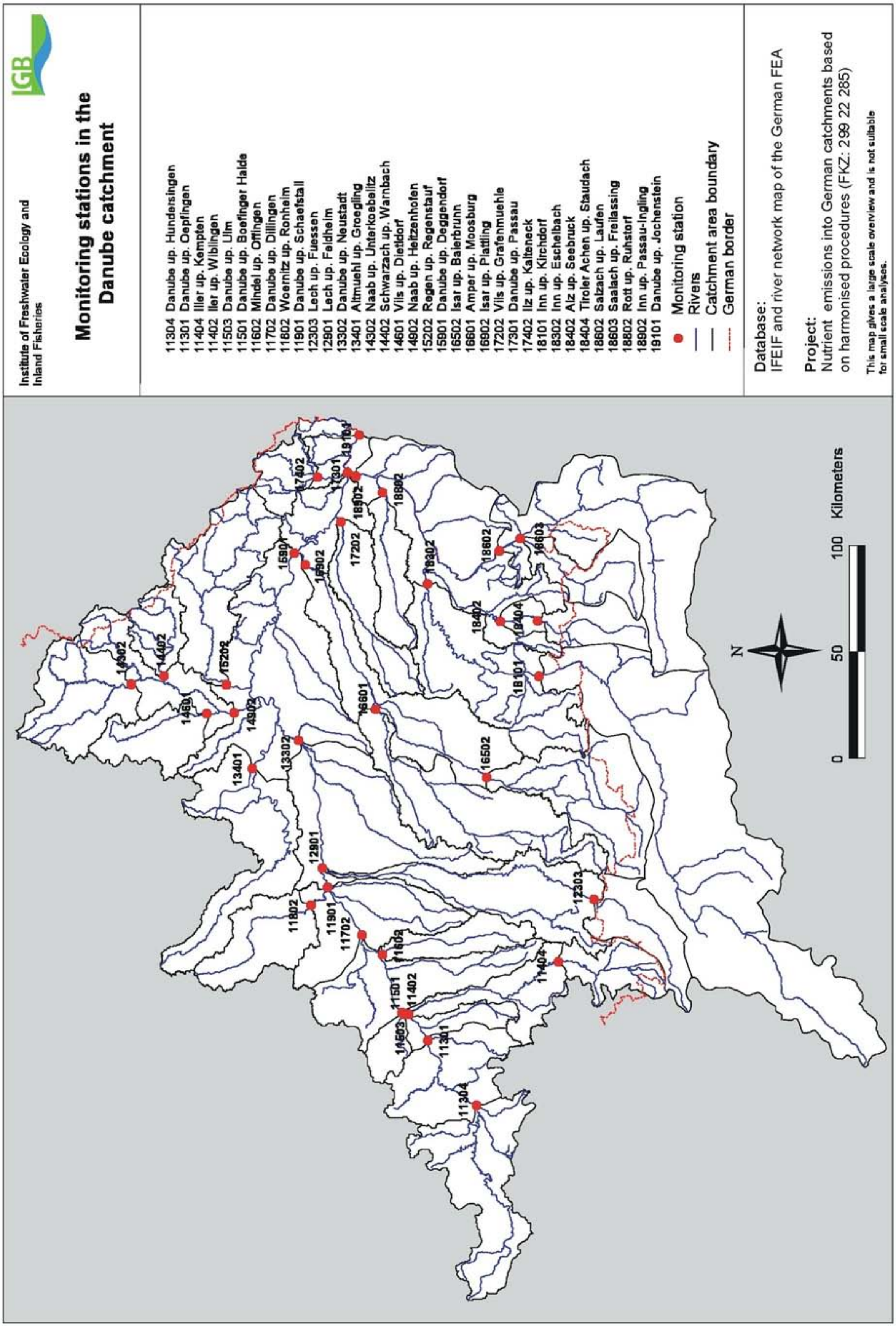
Map 2.12: Atmospheric nitrogen deposition 1999 after EMEP



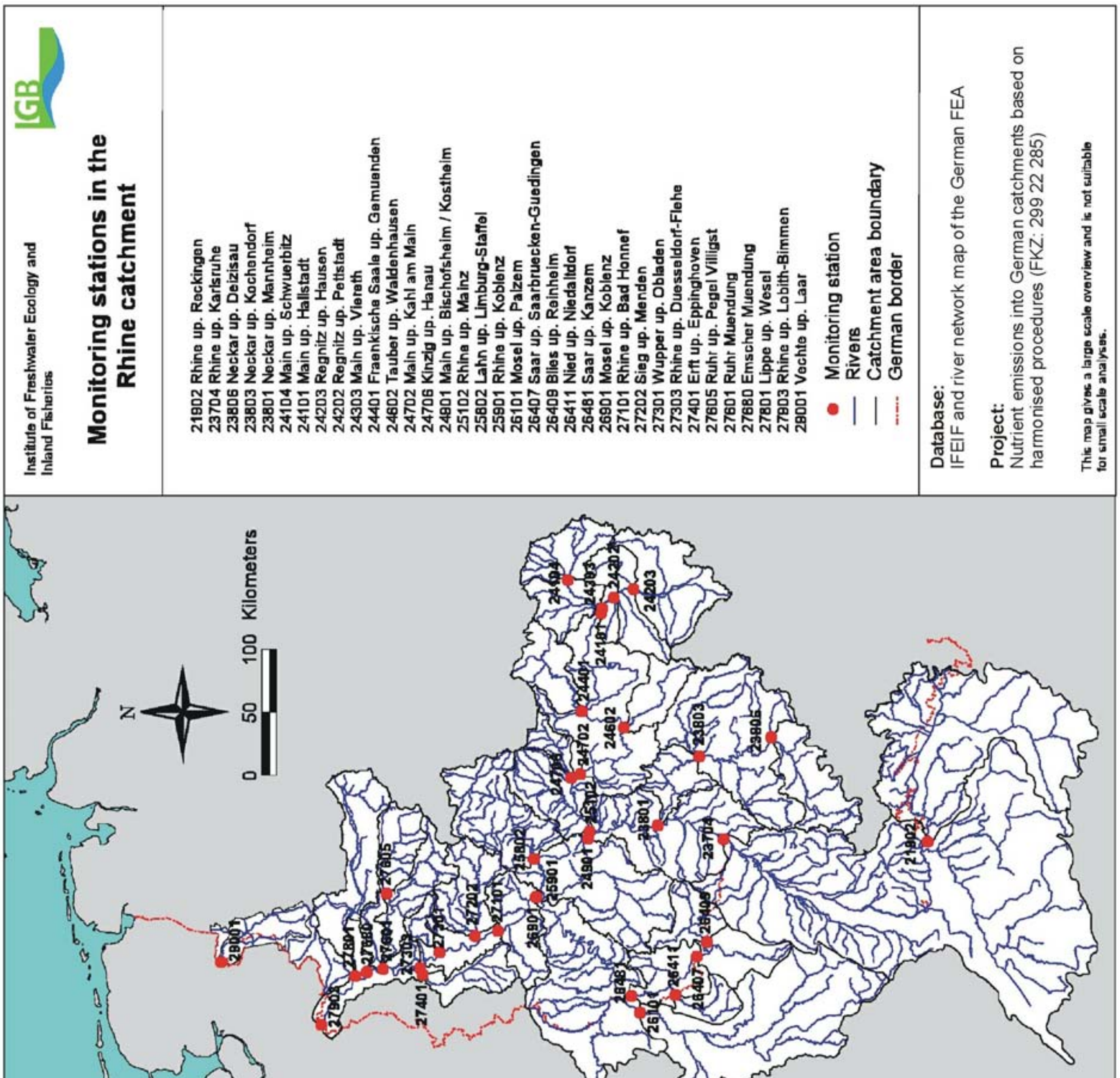
Map 2.13: Atmospheric nitrogen deposition 1986 after EMEP



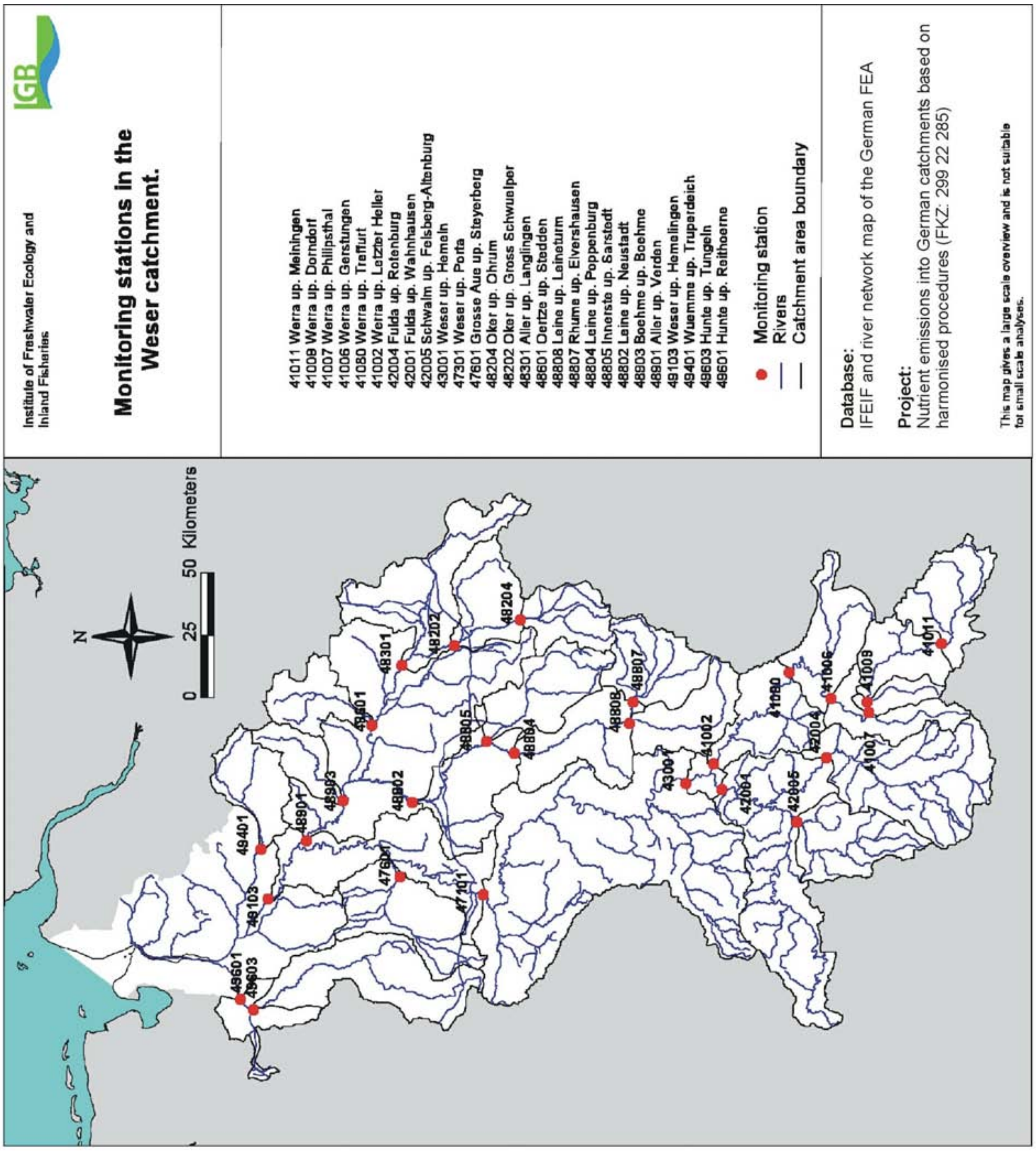
Map 2.14: Locations of municipal wastewater treatment plants



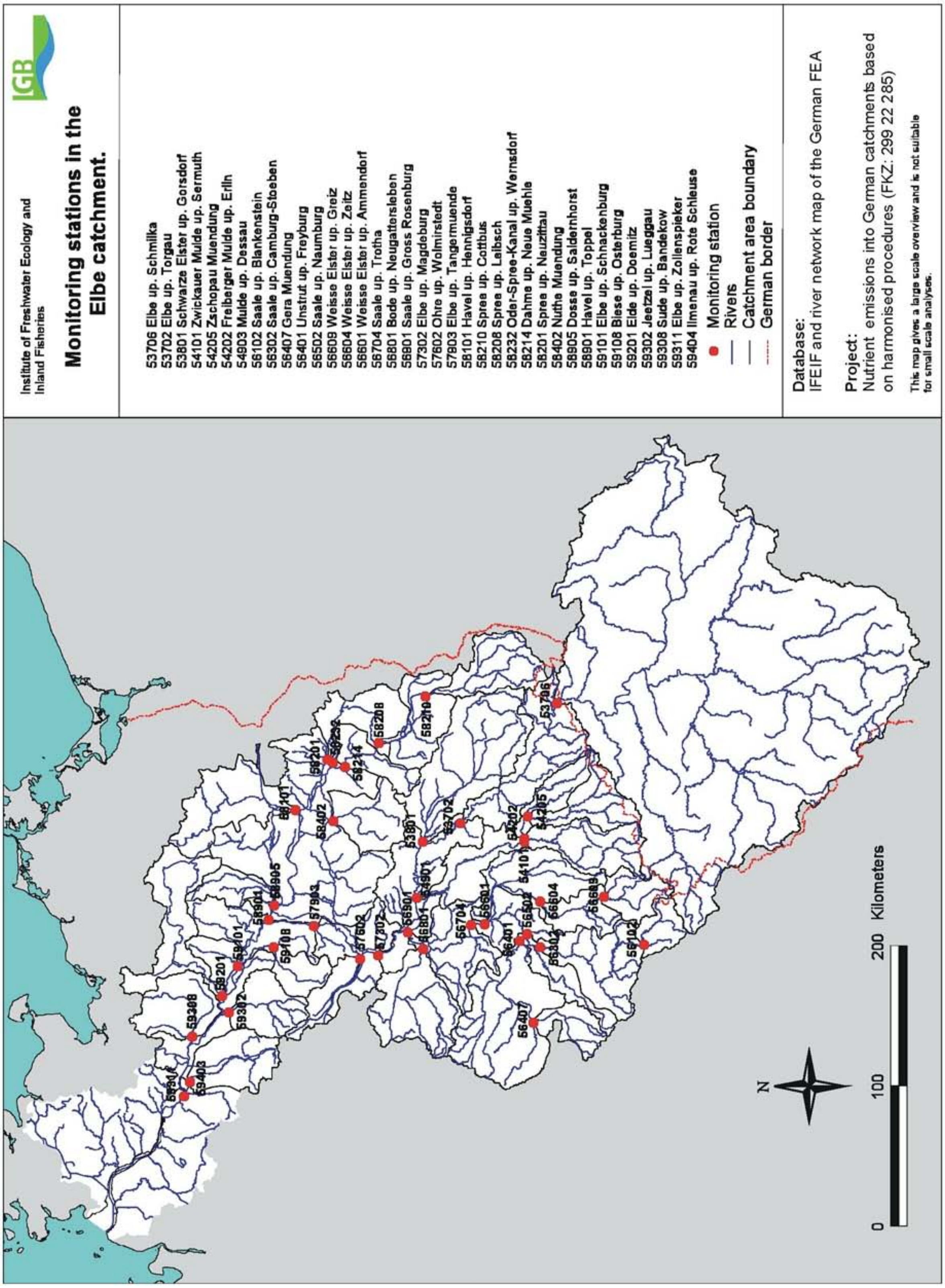
Map 2.15: Studied catchments and monitoring stations in the Danube basin



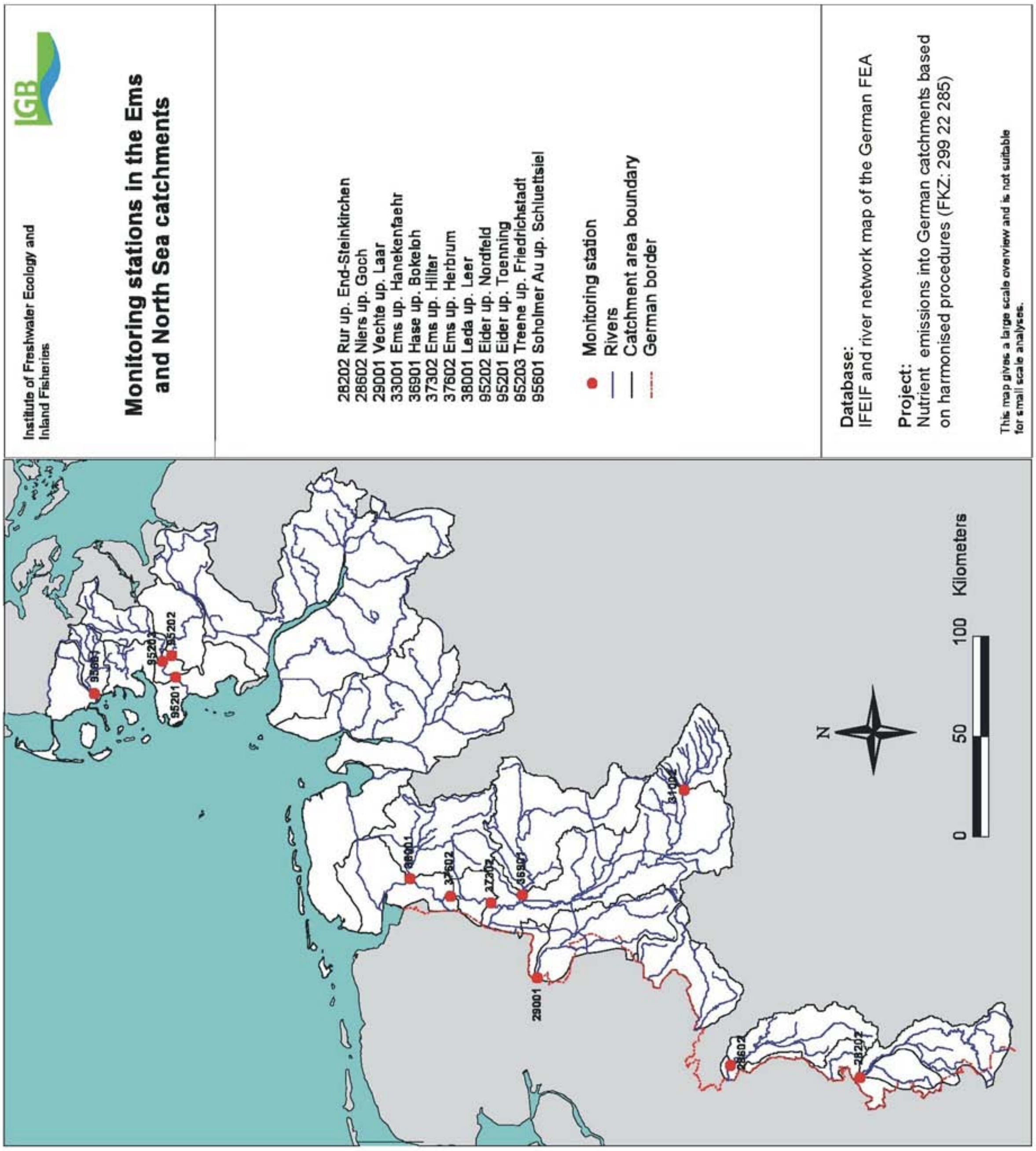
Map 2.16: Studied catchments and monitoring stations in the Rhine basin



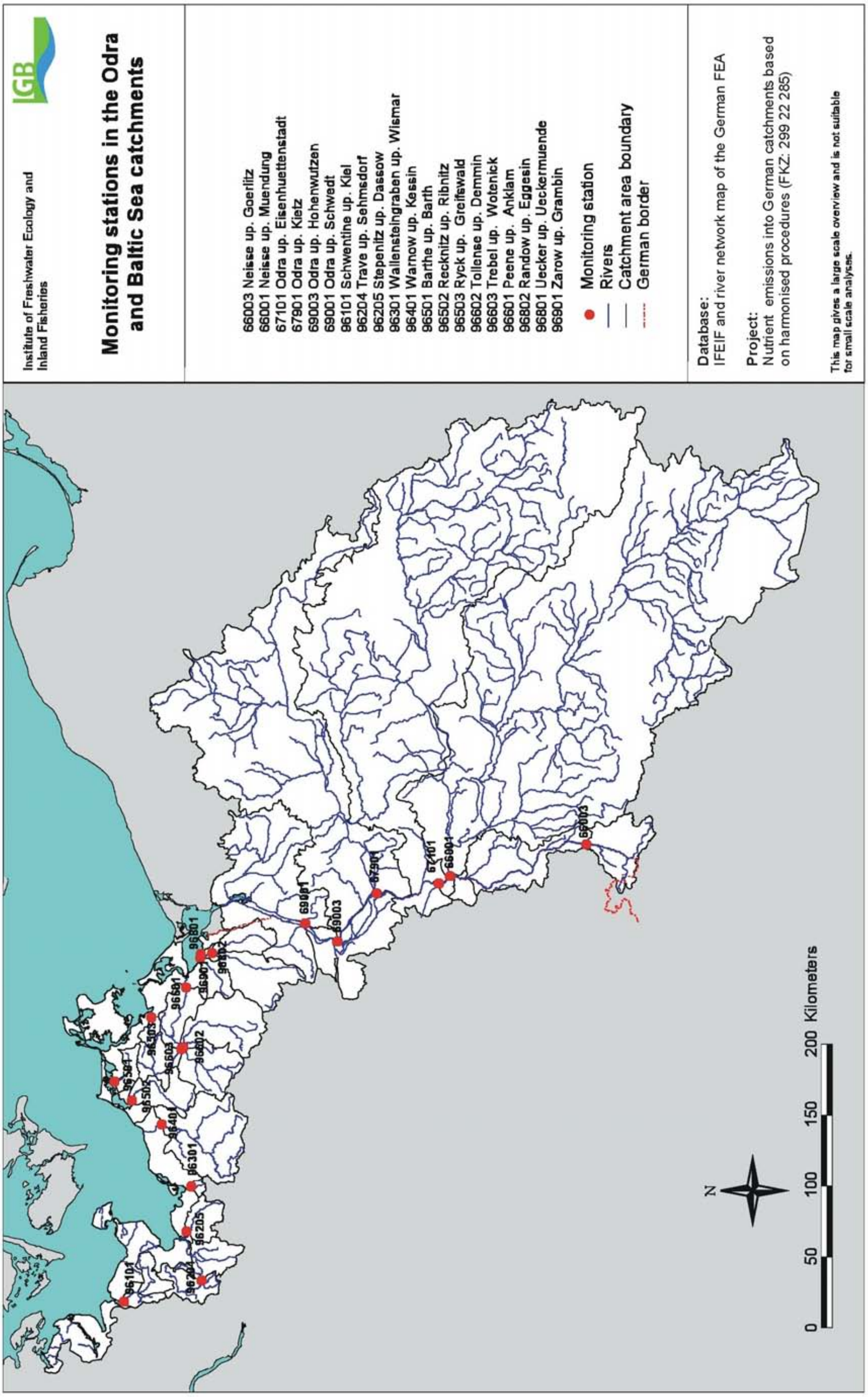
Map 2.17: Studied catchments and monitoring stations in the Weser basin



Map 2.18: Studied catchments and monitoring stations in the Elbe basin



Map 2.19: Studied catchments and monitoring station in the Ems basin and the North Sea coast



Map 2.20: Studied catchments and monitoring stations in the Oder basin and the Baltic Sea coast.

3 Methods

The determination of the nutrient emissions in the subcatchments of the German Elbe catchment via the various point and diffuse pathways utilized the **MONERIS** (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) model. A full description of the basis for the model is given in Behrendt et al. (1999), so only a short description is given here.

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

Whereas the discharges of municipal waste water treatment plants, of direct industrial discharges and from fish farms enter the river system directly, the sum of the diffuse nutrient emissions into the surface waters is the result of different pathways realised by several runoff components (see Figure 4.1).

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

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

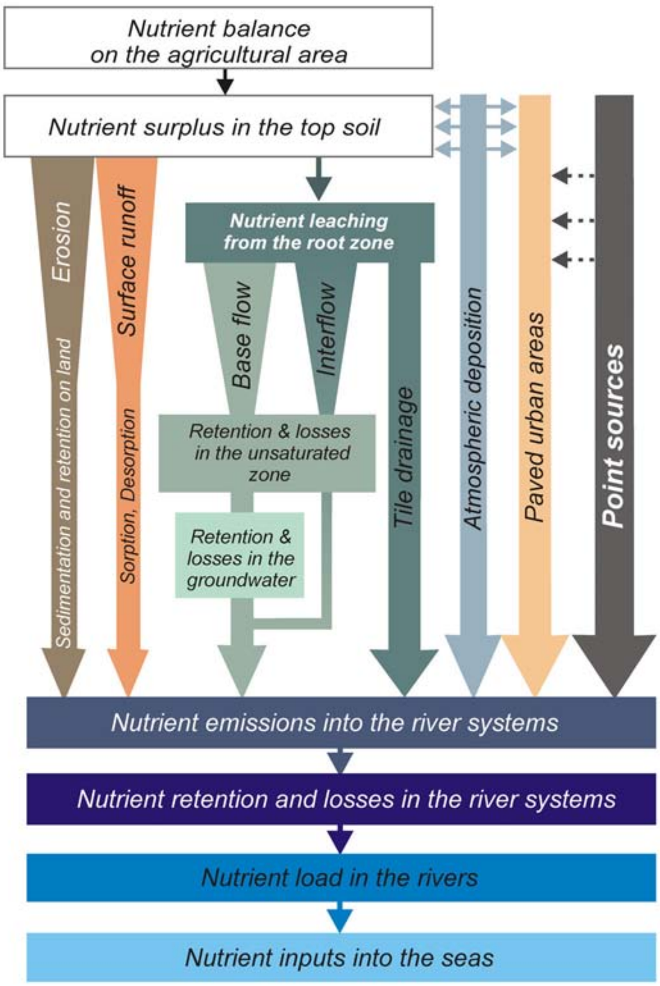


Figure **3.1**: Pathways and processes in MONERIS.

Within the diffuse pathways, various processes of transformation, loss and retention are identified. To quantify and forecast the nutrient emissions in relation to their causes 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 complemented and modified and, if necessary, attempts will be made to derive new applicable conceptual models using MONERIS for the estimation of nutrient emissions via the individual diffuse pathways.

In order to calculate emissions for the period 1998 to 2000 in comparisons with earlier results and changes in emissions, the estimates for 1983-1987 and 1993-1997 were made again with consideration of changes in methods applied. The changes were made with consideration of the various hydrological conditions within these periods as well as anthropologically caused changes.

Since a full description of model MONERIS is given in Behrendt et al. (1999), only a short description is given here in relation to the new approaches used in the model. For the quantification of the individual pathways, the following were considered:

3.1 Point source discharges

3.1.1 Discharges from municipal waste water treatment plants

The regional based estimation of nutrient discharges from municipal waste water treatment plants (WWTP) is based on the area-based GIS inventories for 1999. Since this inventory does not cover all treatment plants, the discharges from smaller treatment plants were determined on the basis of district based state information on outflow nutrients. For these, an almost equal division on the urban areas was employed and the specific inputs of the smaller treatment plants were multiplied by the area of the catchment. These values were then added to the treatment plant inventory.

3.1.2 Direct discharges from industry

The direct discharges from industrial plants for the period 1998 to 2000 were calculated on the basis of the results of the studies of ROSENWINKEL & HIPPEN (1997) for 1995. In addition, it was assumed that the discharges in individual catchments in 1999 changed in the same manner as those via municipal waste water treatment plants.

3.2. Nutrient emissions from diffuse sources

3.2.1 Emissions from urban areas

For the quantification of nutrient emissions from urban areas, the following emissions were calculated separately: (1) Emissions from paved areas via separated sewer systems, (2) emissions from combined sewer overflow, (3) emissions from households and paved areas which are connected to sewers but not to treatment plants. The basis for the calculation is the determination of the area paved. This can be done from the total urban area (from *CORINE-Landcover*) as well as the population density determined from the information in HEANEY ET AL. (1976). For this, the statistics from the German states on the length of combined, dirty-water and separated sewers at the state or district level were used. To determine the total outflow of the various types of sewer systems, knowledge on the specific outflows from the paved urban areas is necessary. This was calculated after HEANEY *ET AL.* (1976) from the average precipitation and the proportion of paved areas within a catchment.

Figure 3.2 provides a schematic overview of the methods employed.

The nutrient emissions via the separated sewer system was calculated on the basis of specific emissions. According to BROMBACH & MICHELBACH (1998), an average emission of 2.5 kg/(ha·a) P is given. For specific N-emissions, the values for atmospheric deposition were used. In addition, emissions of 4 kg/(ha·a) N through leaf-fall and animal excrement were considered.

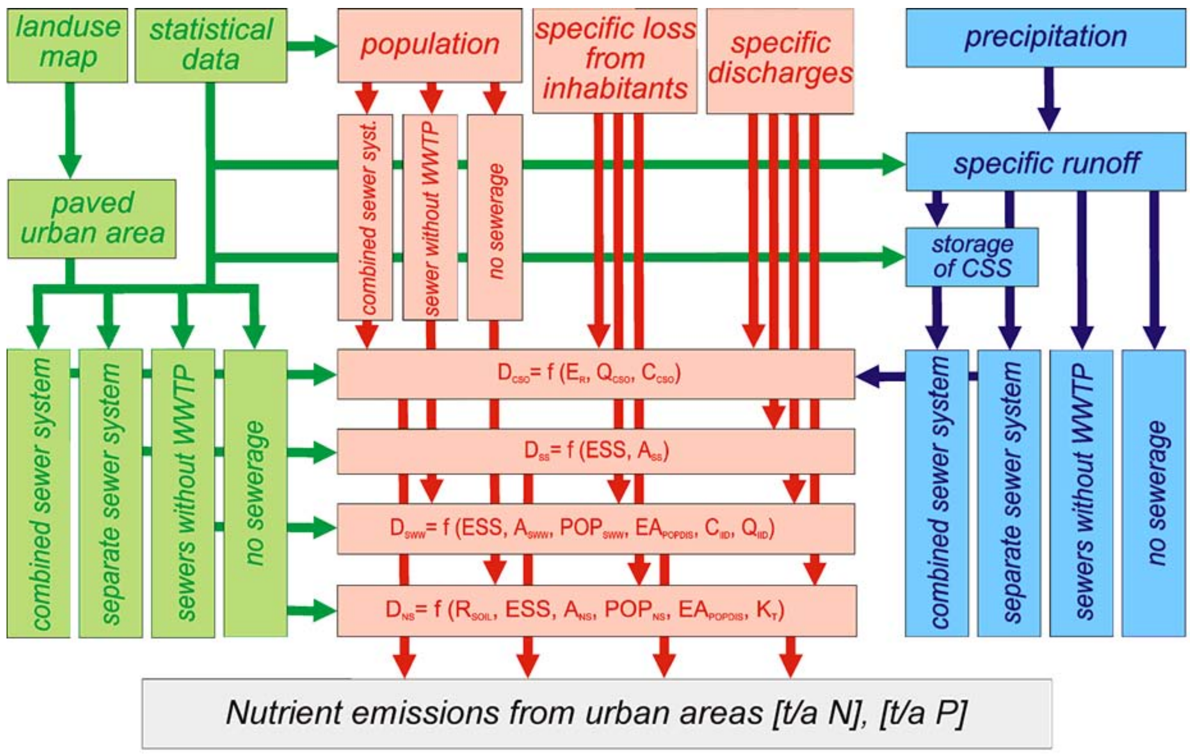


Figure 3.2: Nutrient emissions from urban areas

The N and P emissions in every catchment, paved areas with separated sewers and the specific overflow of combined sewers, the wastewater from households, direct industrial emissions and rainfall runoff entering a sewer and flowing to a water treatment plant were determined. With heavy rain events, not all the water flows to a treatment plant, the excess entering water-bodies. The estimates on overflow of the combined sewer system is based on the work of MOHAUPT *ET AL.* (1998) as well as BROMBACH & MICHELBACH (1998). In this, the quantity of water in the combined sewer system is dependent on the paved urban area, the specific outflow of people connected to sewers, the inhabitant-specific waste-water output (130 L/d) the proportion of urban areas occupied by industry (0.8 %), the area-specific waste-water output from industrial areas (432 m³/(ha·d)) and the number of raindays.

The number of heavy rain days (50) used by Behrendt et al. (1999) was based on the findings of Mohaupt et al. (2002) for the Rhine catchment. In contrast, for Berlin, combined sewer overflow occurs on average 10 days per year (Klein, pers. comm.).

This means that one must conclude that the number of combined sewer overflow days is not constant but dependent on precipitation. In this regard, the following formula was used for the calculation of the number of such days:

$$Z_{NT} = 0{,}0000013 \frac{RE_0}{RE_{ST}} \cdot N_J^{2,5}, \qquad (3.1)$$

where Z_{NT} is the number of days with combined sewer overflow, N_J the annual precipitation and RE_0 or RE_{ST} the overflow rate according to Meißner (1991) for a storage capacity of the combined sewer system of zero and the real value.

On the basis of this formula, the number of days with combined sewer overflow for German catchments ranges from 8 to 90 days with a mean of 22 days. This reduces the calculated nutrient emissions from urban areas for the Elbe, Odra and Baltic Sea coast catchments by 10 to 40 %.

The discharge rates from combined sewers were calculated according to Meißner (1999) depending on the standard or storage volume of the sewers as well as the annual precipitation. For this, waste-water statistics on storage volumes within the combined sewer sysems were used. The nutrient concentrations in combined sewers in the event of overflow can be calculated by using the specific emissions from paved urban areas (see separated sewers), the inhabitant-specific N- and P- output (see WWTP) and also the concentrations in industrial waste-waters (1.0 g/m³ N, 0.1 g/m³ P). The N- and P- emissions in each catchment are estimated from the product of water quantity in combined sewers, the overflow rate and the nutrient concentrations in this discharge water.

In addition to the emissions via the separated and combined sewer systems, those from sewers not linked to municipal water treatment plants must also be considered. For the connected population it was concluded that only the dissolved fraction of nutrient output from the people was lost along the length of the sewers (60 % of the P-respectively 80 % of th N-emission) since the particulate fraction is retained by small treatment plants or septic tanks.

3.2.2 Emissions via atmospheric deposition

The basis for estimation of direct inputs from atmospheric deposition is knowledge on the water area of a catchment determined from the CORINE-Landcover. For the total water area, flowing waters were also considered. With the data on area statistics from the local authorities, which include small standing water bodies and streams, the areas used by Behrendt and Opitz (1999) can be verified and improved. In the results of the analysis, a clear improvement in the relationships through the inclusion of the average slopes in a catchment .

This considers observations from the waterway network (see Map 2.5) in which the density of flowing waters clearly increases in lowland areas which is, however, predominantly a human phenomenon related to the digging of drainage ditches in the past centuries. The area of surface waters in a catchment is then calculated with the following equation:

$$A_W = A_{WSEE} + A_{WFGW} = A_{WCLC} + 0{,}0052 \cdot A_{EZG}^{1{,}09} \cdot SL^{-0{,}278} \tag{3.2}$$

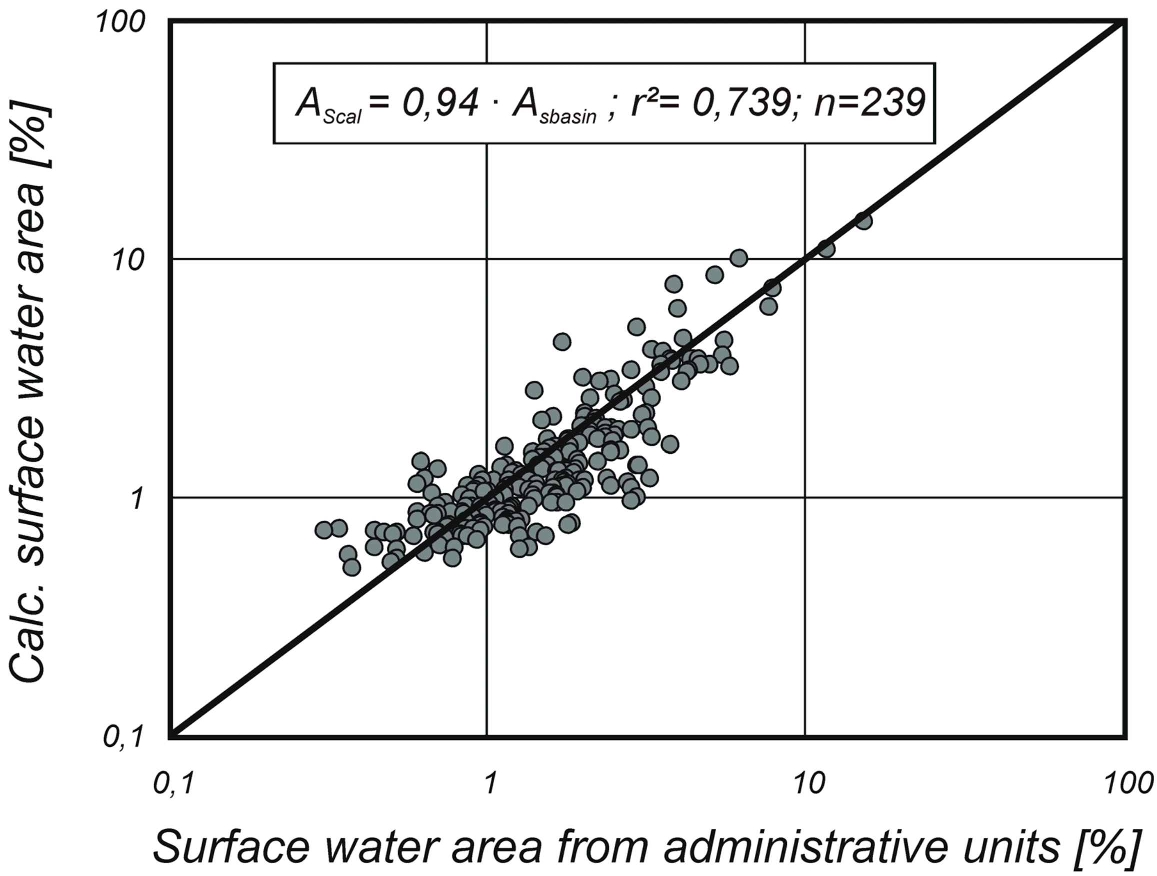


Figure 3.3: Nitrogen inputs from calculated water areas of catchment based on digital maps and municipality statistics.

where A_W = total water area in a river system [km²],
A_{WSEE} = area of standing waters determined from surface-cover maps [km²],
A_{WFGW} = Surface area of flowing waters [km²],
A_{WCLC} = Wasserfläche nach der Bodenbedeckungskarte [km²],
A_{EZG} = catchment area [km²] and
SL = average slope within a catchment according to DHM [%].

A comparison of the total water area calculated, using this equation with the statistical data of municipalities is shown in Figure 3.3. On the basis of Equation 3.2, the water area in all catchments within and outside Germany was calculated.

The calculation of nutrient emissions via atmospheric deposition is carried by the multiplication of the average values of the sum of NO_x-N- and NH_4-N deposition as well as P deposition by the average water area for each catchment. For phosphorus deposition, values of 0.7 kg/(ha·a) P and 0.37 kg/(ha·a) P were used for 1985 and 1995 respectively as used by Behrendt et al. (1999) based on literature studies. Results from the EMEP programme for 1985 and 1986 (TSYRO, 1998a, b; BARTNICKI ET AL. 1998) were used for the calculation of N deposition values. These data are presented as digital maps with a resolution of 150 km for 1985 and 50 km for 1996 with NO_x-N- and NH_4-N dDeposition in kg/(ha·a) N. These maps (Maps 2.12 and 2.13) were made up with the boundaries of the studied catchments and the average NO_x-N- und NH_4-N deposition thus determined.

3.2.3 Nutrient surplus of agricultural areas

For the estimation of the nutrient balances for agriculture one has to distinguish between the area related balance (balance of the plant or soil production) and the total balance (national balance, sectoral balance, farm gate balance). The area related nutrient balance is a part of the total balance. Details of the methods used for the calculation of the different balances are presented in BACH et al. (1997a, 1997b), BACH & FREDE (1998) and BACH et al. (1998). Regionalised nutrient surpluses (e.g for districts or river catchments) can only be calculated for the area related balances, because the statistical input data is available only for this kind of balance. The database needed for the calculations of the N- and P- surpluses for agricultural areas is already listed in Section 2.3. The spatial resolution are the 440 districts and district free cities of Germany. For the calculations the district free cities were partly summarized with neighbouring districts to reduce artefacts related to the low agricultural areas of the district free cities.

The balance calculation were done according to the following approach:

Surplus = Mineral fertilizer + net input of manure + other organic fertilizer (excl. manure) (3.3)
+ atmospheric deposition + N-fixation – harvested crops

The nutrient amount by livestock was calculated by multiplication of the number of animals within the district with the mean N- and P-yield per head (see Table 3.1). For phosphorus the total amount of calculated yield is identical with the net input by manure in equation 3.3. For nitrogen the total amount of livestock has to be deminished by the species specific losses during storage and spreading of manure (see also Table 3.1).

The use of sewgae sludge as fertilizer was assumed to be constant (4 kg/ha N and 1.5 kg/ha P agricultural area) for all districts. The atmospheric N-deposition rate was calculated from a baseline of 10 kg/ha N and an additional deposition rate depending on the livestock number per agricultural area of the districts. The average depostion rate for Germany was estimated to about 23 kg/ha N for the agricultural area.

The Table 3.1 presents further the assumptions taken for the estimation of the nitrogen inputs to agricultural areas by symbiotic nitrogen fixation.

The removal by harvested crops was calculated by multiplication of the used area, the specific harvested crop yield and the N- and P-content of the individual crops. For crops without statistical data a fixed amount of harvested products were assumed. The harvest of some products like straw and leave of sugar beats the harvested amount was estimated proportional to the livestock density.

The largest methodological problem in relation with the calculation of regionalised nutrient balances in Germany is the estimation of the used mineral fertilizer. This is also the most critical and sensitive point, because data on the use of applied mineral fertilizer are not available below the national level in Germany. The published tables for the sale of mineral fertilizer in German states and districts include only data on the sale to the wholesalers, and their sale area is normally not related to the admistrative boundaries. Therefore the use of mineral fertilizers by the farmers have to be estimated without the knowledge of the real amount of saled fertilizers to the enduser.

Data of different agricultural authorities and agricultural consultings on the usual level of fertilizing, as used by some other authors can normally not be used, because the base for such estimates is a proposed amount of mineral fertilizer according to good agricultural practicies but not the real data of the farms. That means such procedures do not use the statistical database but normative values which reflect the wishes of agricultural consulting. But based on such procedures an overfertilizing is often observed especially for livestock farms.

Table 3.1: Nitrogen and phosphorus contents of harvested crops and livestock manure used for the calculation of the area related nutrient balances for German districts

Nutrient contents of harvested crops					
Harvested crops	content in kg/dt		Harvested crops	content in kg/dt	
	N	**P**		**N**	**P**
Wheat	2.0	0.35	Pasture (temporary & permanent)	140	22
Rye	1.5	0.35	Grapevine	30	4
Winter barley	1.7	0.35	Pulses and beans	150	21
Summer barley	1.4	0.35	sonstige[c] Hackfrüchte	120	22
Oats	1.6	0.35	other[c] fodder crops[b]	200	25
Triticale	1.8	0.35	Vegatables and other[c] permanent crops	50	3
Straw	0.5	0.13			
Potatoes	0.35	0.062			
Sugar beets	0.18	0.044	**N-Fixation by Legumes**		
Sugar beet leaf	0.4	0.048	Permanent pasture	20	
Winter rapeseed	3.3	1.06	Pulses	160	
Silage maize	0.38	0.071	other fodder crops[b]	65	

Nutrient contents in excreta of livestock			
	kg/(animal·a)		available N[d]
	N	**P**	
Dairy cows	110	16.7	66 %
Other[c] cattles	50	8.3	66 %
Fattening Pigs (> 50 kg)	11.5	2.3	69 %
Sows	28.3	6.5	69 %
Other pigs[c]	6	1	69 %
Sheeps	9	2.5	60 %
Layers (> 1/2 year)	0.73	0.145	64 %

a) 1995: Maize
b) Clover, Alfalfa, temporary pasture
c) ‚other ...': difference between the total value of the categories and the sub-categories given explizit in the Table
d) for plants available N of organic fertilizer after consideration of N-losses by volatilisation during storage, transport and application

The procedure for the calcualtion of the demand of mineral N- and P-fertilizer for districts within this study corresponds with the method published by BACH ET AL. (1997a, 1997b).

The starting point is the nutrient demand of the crops needed for the expected yield. This nutrient demand is in a first approximation a function of the yield (amount of nutrients taken from agricutural area by harvested goods). But one has to consider that at every kind of fertilisation the efficiency of the applied nutrients is incompletely. That means the input of nutrients has to be in a certain range larger than the output. This situation can be considered by a factor, which represents the extra charge of nutrients for a given level of harvested crops.

$$\text{Nutrient input} = \text{nutrient demand} = \text{harvested crops} \cdot \text{extra charge coefficient} \quad (= \text{harvested crops / rate of expoitation}) \tag{3.4}$$

The total demand of nutrients can be covered by different sources like mineral fertilizer, livestock manure, sewage sludge and N-fixation. Furthermore it has to be considered that the farmers take into account only a part of the livestock manure as available for the plant growth. This can be described by a factor for manure efficiency. If the correction factor for manure efficiency is implemented in the equation for the total nutrient demand the result is the following equation 3.5.

$$\text{Total nutrient demand} = \text{mineral fertilizer} + \text{manure} \cdot \text{manure efficiency} + \text{other organic fertilizer} + \text{N-fixation} \tag{3.5}$$

The segments of the nutrient inputs (livestock manure, sewage sludge, N-fixation) and the harvested outputs can be calculated for each district. After transformation of equation 3.5 the used amount of mineral fertilizers can be calculated acording to equation 3.6:

$$\text{Mineral fertilizer} = \text{harvested crops} \cdot \text{extra chrage coefficient} - \text{manure} \cdot \text{manure efficiency} - \text{other organic fertilizer} - \text{N-fixation} \tag{3.6}$$

Harvested crops:	N- and P-amount in the harvested crops
Extra charge coef.:	considers the limited use of mineral fertilizers by plants; extra charge coefficient nitrogen: 1.2 extra cahrge coefficient phosphorus: 1.1
manure:	net N- and P-input by manure with: net N-input = gross N-inputs by livestock excreta · availability factor considering volatilisation losses of N (see Table 3.1) net P-input = gross P-input by livestock excreta (without losses)
manure efficiency:	correction factor for manure considering the portion of N in manure used by farmers for the plan of fertilizer application (see below)
Other org. fertilizer:	N- and P-inputs by other sources as sewage sludge, urban compost etc.
N-fixation:	N-input by N-fixation of legumes.

The target – the used amount of mineral N- and P-fertilizer - corresponds to the remaining demand of the plants amount, if the total nutrient demand of the plants is diminished by the level of nutrients by manure application, sewage sludge and N-fixation. This approach tries to replicate the reflections of the farmers to estimate the level of needed mineral fertilizers with a simple procedure.

For the estimation of the two factors „extra charge coefficient“ and „manure efficiency“ the following approach was selected:

The extra charge of the individualcrops can be estimated from farmer handbooks by calculation of the quotient between the proposed total nutrient demand and the harvested amount of nutrients for each individual crop. These extra charge coefficients for the individual crops were summarized to a mean extra charge coefficient for N and P by calculation of the average over all individual extracharge coefficients. The result of this procedure was an extra charge coefficient of 1.2 for nitrogen and 1.1 for phosphorus, respectively. These coefficients were applied unified for all crops and all districts of Germany for the years 1995 and 1999.

The estimation of the factor for manure efficiency for the whole of Germany can be done directly according to equation 3.6, because the use of mineral fertilizers in agriculture is known on the national level. The result of equation 3.5 for Germany for the average of the years 1998 to 2000 is a correction factor of 0.4 for nitrogen and 1.05 for phosphorus. That means, at present the farmers do not consider about 60 % of the nitrogen inputs to agricultural area by manure as effective for the fertilisation of plants and increase the N-surplus by the equivalent N-level.

For the calculation of the used mineral fertilizer for the districts the estimated values for the extra charge coefficient (N: 1.2; P: 1.1) and for the correction factor (N: 0.4; P: 1.05) were implemented in equation 3.6 for each district. For the control the amount of the used mineral N- and P-fertilizers of the districts was summarized over all district and compared with the total sale of mineral N- and P-fertilizers within Germany. The difference found was only in a range of few percentages.

3.2.4 Emissions via tile drainage

For the quantification of emissions of nitrogen and phosphorus which enter surface waters via tile drainage, a method based on tile-drained area, tile drainage contribution and the average nutrient concentrations in tile drainage water was used as shown in Figure 3.4.

The estimation of the tile drained area in catchments was based on various information sources, separatly made out for the old and new German states.

For the entire area of the Elbe catchment, available information on drained areas contain gaps. Here, with consideration of the soil types of the MMK (mid-scaled landscape maps), in which the partitioning of the new German states (former GDR) is mapped digitally, some sub-catchments were extrapolated to the whole catchment.

It can be determined that an average of 10.6 % of wetlands, 11.6 % of pastures, 50.5 % of deep clay areas and 9 % of sandy areas are drained. For the old German states (former FRG) the surveys of BACH ET AL. (1998) of drained areas of arable land and grassland were used.

The tile drainage contribution was calculated on the basis of summer and winter precipitation according to KRETZSCHMAR (1977). The tile drainage outflow comprised 50 % of the winter precipitation and 10 % of the summer precipitation. This information was employed since it considers the regional differences in precipitation and outflow contributions.

The P-concentrations were estimated by BEHRENDT ET AL. (1999) on the basis of measurements of tile drain outflows (see Table 3.2).

Table 3.2: Used phosphorus concentrations in drainage water from various soil types.

Soil type	Term	C_{DR_P} [g/m³ P]
Sandy soils	C_{DRS_P}	0.20
Clay	C_{DRL_P}	0.06
Wetlands	C_{DRNM_P}	0.30

The calculation of N-concentrations in the tile drain outflows were based on regionally differentiated N-surpluses (BACH ET AL., 1998) following the work of FREDE & DABBERT (1998) on the potential nitrate concentrations in percolating water which should represent that in tile drainage (see Figure 3.4). It was concluded that the N-concentrations in drainage water should react very rapidly to changes in nitrogen surpluses. Changes in the nitrogen surpluses should in turn result in changes in tile drainage N-concentrations in the study periods. For the 1983-1987 period, there is no area differentiated information available on N-surpluses. These were estimated on the basis of long-term changes in N-surpluses in the German states as calculated by BEHRENDT (2000).

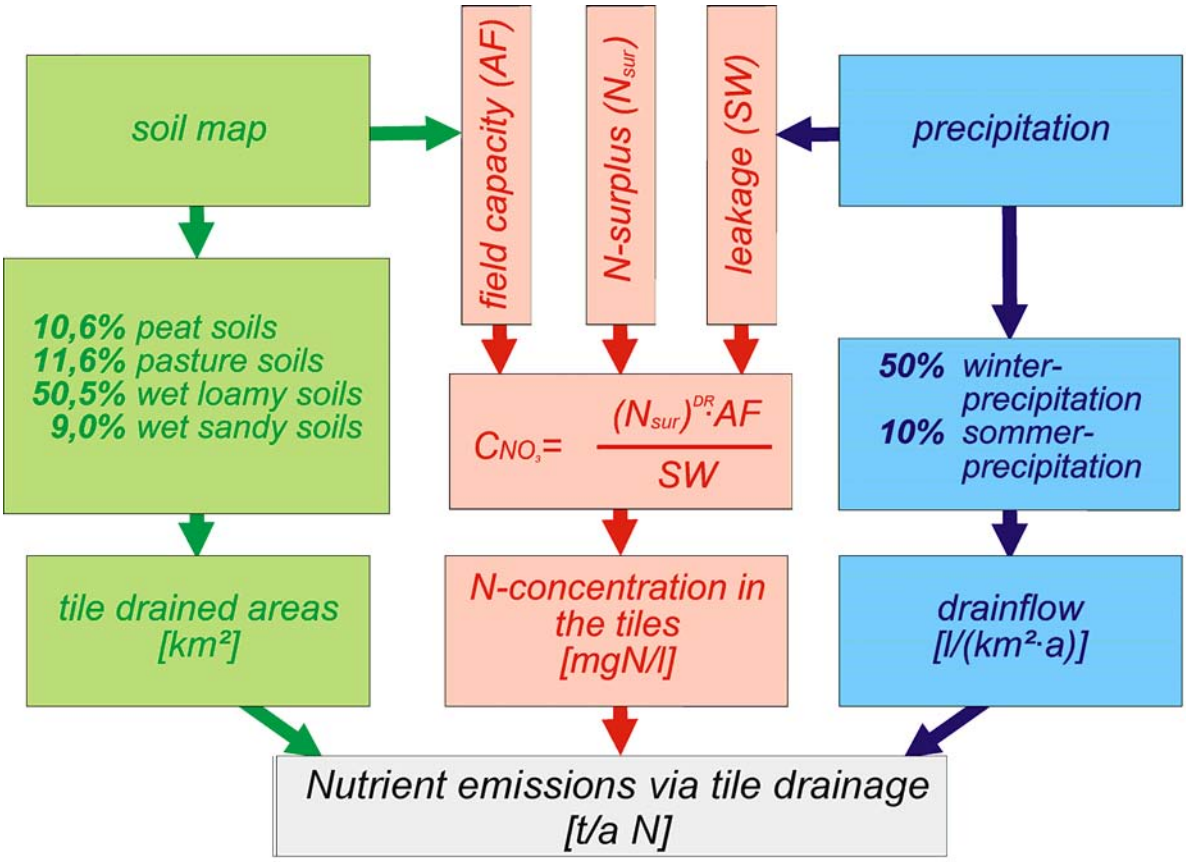


Figure 3.4: Nitrogen emissions through tile drainage

3.2.5 Emissions via groundwater

Nutrient emissions via groundwater were calculated from the product of groundwater outflows (components of natural interflow) and groundwater concentrations as shown in Figure 3.5.

For the derivation of calculated groundwater concentrations used in MONERIS (BEHRENDT ET AL., 1999), data from the individual state offices for the environment were employed. Data was considered only for locations which represent the uppermost groundwater and water (oder: groundwater which is not influenced ...?) not influenced by urban and industrial areas. For the individual locations, an average value was calculated for the considered time periods. In order to transfer point measurements to the water table of individual catchments, station averages were integrated into GIS. From the GIS, a digital map was generated.

P-concentrations in groundwater for the various soil types, the digital map and literature data were employed (Table 3.3).

For anaerobic groundwater, the clear differences in inorganic dissolve phosphorus (or soluble reactive phosphorus, SRP) and total phosphorus as found by DRIESCHER & GELBRECHT (1993) for Mecklenburg-Western Pomerania must be considered. According to BEHRENDT

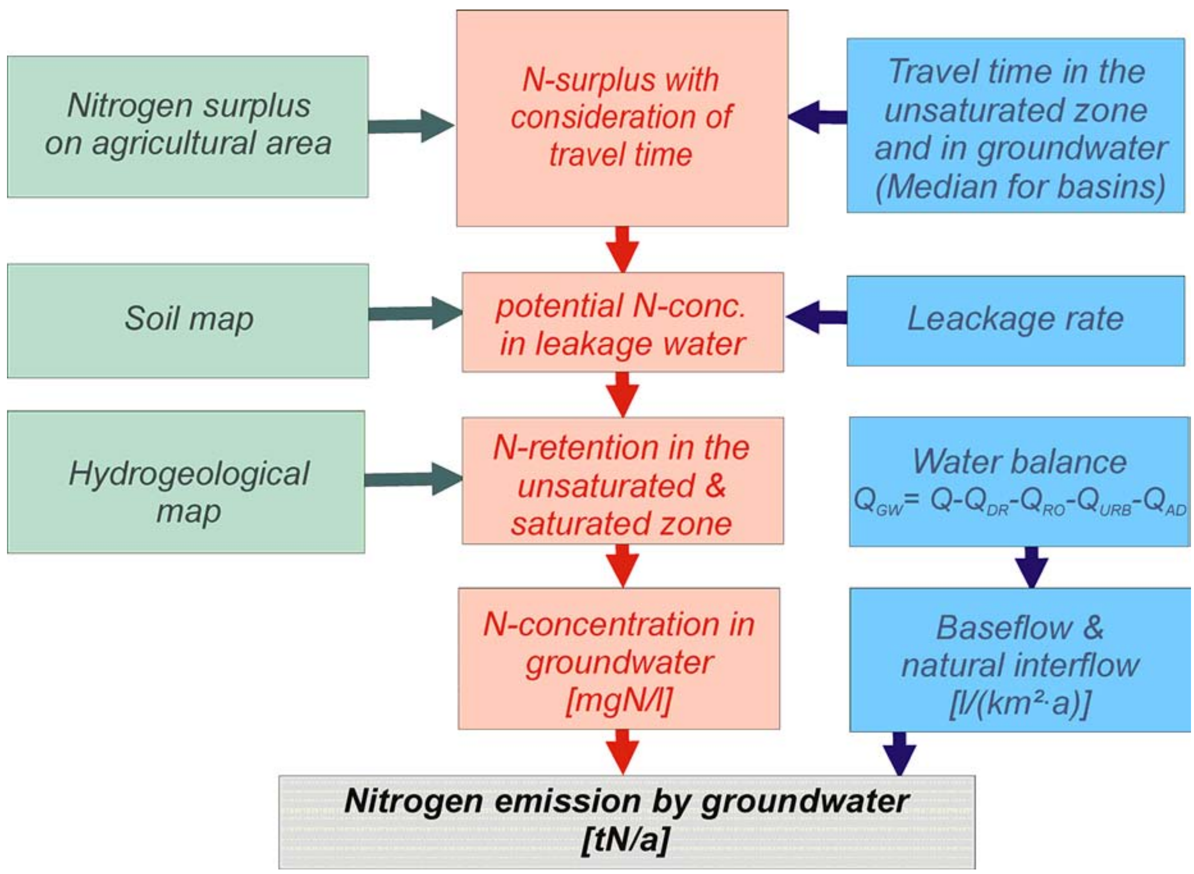


Figure 3.5: Nitrogen emissions via groundwater

Tabelle 3.3: Phosphorus concentrations in groundwater of various soil types.

Soil type	Use	Term	C_{GW_P} [g/m³ P]
Sandy soils	Agriculture	C_{GWS_P}	0.1
Clays	Agriculture	C_{GWL_P}	0.03
Wetland	Agriculture	C_{GWNM_P}	0.1
	Former sewage farms	C_{GWR_P}	0.29
	Woodland/open areas	C_{GWWAOF_P}	0.01

(1996) and DRIESCHER & GELBRECHT (1993), the total phosphorus concentrations are 2 to 5 times as high as the SRP concentrations determined in the standard measuring programme. There is no information available on the area with anaerobic groundwater but one can compare the concentrations of nitrate in groundwater and percolating water in areas with a higher likelihood of having anaerobic conditions. For the total phosphorus concentrations in groundwater, it was therefore assumed that where the groundwater nitrate concentrations are less than 5 % of those in percolating water, the TP-concentrations are 2.5 times as high as those of SRP. Using this, the P concentrations in groundwater of Mecklenburg-Western Pomerania rivers are 0,09 bis 0,14 g/m³ P or similar to measured values (see BEHRENDT, 1996).

In a study carried out in 1999, PÖTHIG ET AL. (1999) it was determined that the near-surface groundwater of a former sewage farm in Berlin had an average P-concentration of 0.29 g/m³. A differentiation according to differences in local conditions has not been possible yet. Since the Berlin sewage farm is digitally mapped, the proportions in individual catchments could be determined and the P transported via groundwater determined through multiplication of the groundwater volume and the above P-concentration.

The N concentration in groundwater was also calculated from the potential nitrate concentrations in percolating water. The derivation of N-concentrations in groundwater using regional differentiated N surpluses requires knowledge on the water retention time in the saturated and unsaturated zones.

In hindsight, the estimates of retention times for percolating water in the unsaturated zone and groundwater used by Behrendt et al. (1999) were only approximate values with small spatial resolution, based on the relationship between changes in N-surpluses over time and the derived N-concentrations in the rivers. An important point of this work is that these very course approximations are carried out through the results of catchment-differentiated model calculations of the retention time in the unsaturated zone and groundwater. For this, the following was used:

Retention times in the unsaturated zone

The estimation of residence times of water in the unsaturated zone is based on a one-dimensional balanced basis. It was concluded that in usual conditions, only the quantity of percolating precipitation is stored in the profile which is in excess of field capacity (Hennings, 1994). From this, water percolation through the soil is rapid so that with the used scale of resolution and with the underlying long term temporal average relationship it plays only a small role and also since the periodic and basic outflow components in most cases have passed through the root-zone. The retention time of water in the unsaturated zone can be calculated from the following:

$$t_{UZ} = \frac{nFK_{UZ}}{Q_t} \cdot M_{UZ} \tag{3.3}$$

where Q_t = Total outflow [mm],
nFK_{UZ} = average field capacity in the unsaturated zone [Vol-%],
M_{UZ} = Groundwater depth [m].

Precise calculation of the retention time of water in the unsaturated zone is, however, beset with a number of problems:

- There is no area-based map of groundwater depth for Germany, and such a map cannot be produced within the framework of this project. As a result, at present it is not possible to determine the parameter M_{UZ} on an area-differentiated basis. The calculated retention times therefore do not reflect the true groundwater depth.
- In soil maps, the physical characteristics of soils only cover the surface 2 m at most. The average field capacity in the unsaturated zone therefore is not exact for areas where the groundwater lies at a depth of more than 2 m.
- Soil maps contain no information on depth of groundwater when it is below 2 m.

Resulting from the lack of data on groundwater depth and field capacity in the unsaturated zone, at present it is not possible to calculate accurate retention times for water in the unsaturated zone. These retention times were estimated on the basis of potential groundwater depths of 1 m, 2 m, 5 m, 10 m amd 20 m.and mapped on an area basis for the whole of Germany.

To interpret the calculated values, it must be borne in mind that the influence of water removal through man-made ditches and drains could not be considered. In regions with such conditions, a groundwater depth of 1 m is used. In saturated soils which have not been drained, an underestimation of retention time is to be expected. The basis for this is that evaporation of the standing water in such soils can not be considered. The calculation of retention time for such saturated soils is only valid when they are drained. This piont of view, however, cannot be studied for the necessary data is not available.

Groundwater residence time

The calculation of groundwater residence time was carried out using the WEKU model (Kunkel & Wendland, 1997), which was developed for macro-scale analysis of time/pathway behaviour of groundwater derived discharges and has already been successfully applied. With this model, the time is calculated for the period that the water takes from percolation in groundwater-laden rocks to the emission to surface waters (rivers, lakes and seas). This is based on the uppermost groundwater with the assumption that the aquifer flow runs approximately parallel to the groundwater surface. The model is digitally-based and comprises two clear phases. Firstly, the velocity of the groundwater at the top of the aquifer is determined on an area differentiated basis. As input, the permeability, the usable porosity and the hydraulic gradient are employed. Secondly, the retention time at the top of the aquifer is calculated. On the basis of the groundwater distribution, a digital model of the groundwater surface is constructed. For this, information on the river network, the groundwater transfer rate, groundwater flow direction, boundaries of groundwater basins and rivers with groundwater discharge are considered. The retention time of groundwater-derived discharge components is given for each outflow component through the summation of velocity and retention times of individual reaches along the flowpath up to the surface water entry point.

The reliability of retention times calculated with WEKU depends on the quality of the database. For the determination of velocity, hydrological model parameters are required. There is much inhomogeneity in the porosity of an aquifer and also variation in the amount of detail in the database. These factors strongly influence the reliability of the calculated groundwater retention time. The modeling of retention time with WAKU is based on stochastic considerations. Thus, it is possible to determine both mean values and evidence on the scatter of retention times.

The model is primarily to be used on regions with unconsolidated rocks. In this project, information is also used for groundwater retention times in regions with consolidated rocks. This brings along a number of problems:

- In consolidated rocks groundwater flow is uniform, so the use of Darcy laws on which WAKU is based is problematical. This is particularly important in karst regions.
- The porosity values for consolidated rocks in literature (e.g. Matthes, 1994; DVWK, 1982) or hydrogeological maps (e.g. Hydrogeological map of the GDR, 1987) are given generally for aligned rock in mountain areas. In many cases, the porosity is less than 10^{-6} m/s, which according to Hölting (1994) means effectively no groundwater flow. Therefore very long retention times apply.
- Various authors (e.g. TML, 1996; Schwarze et al., 1991; Kunkel & Wendland, 1998; Krause, 2001) have proved that the primary discharge in consolidated rocks is via fast-flowing components. This is primarily direct discharge occurring in the more broken-up zone above the consolidated rock. This may comprise more than 80 % of the total flow (see Kunkel & Wendland, 1999). In this broken-up zone, porosity values of around 10^{-4} m/s are postulated, similar to values for unconsolidated rocks. At present, there is no database available which gives porosity values for the broken-up zone of consolidated rock aquifers.

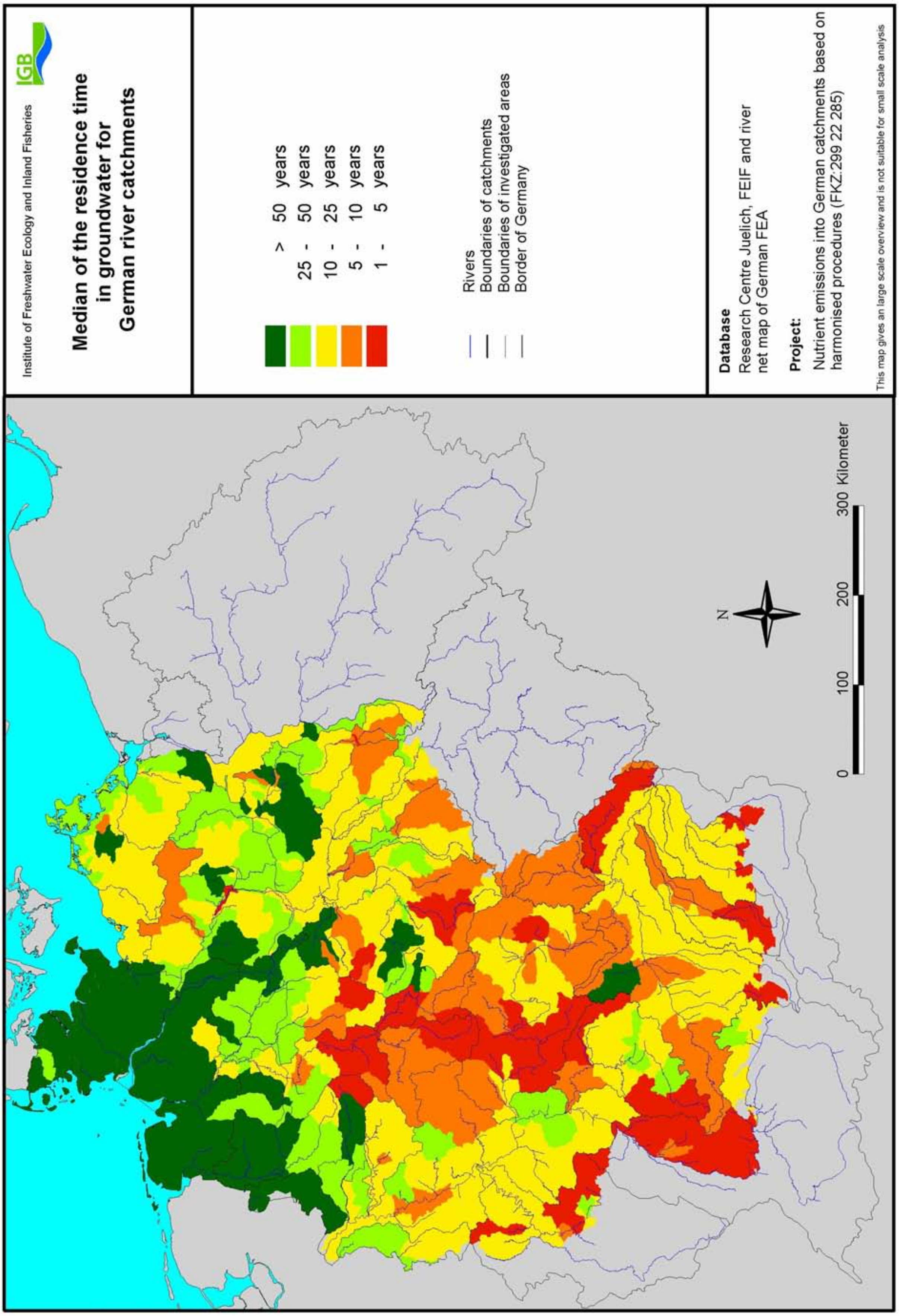
- Hardly any groundwater maps are available for consolidated rock regions. Most existing maps are for areas with unconsolidated rocks.

Therefore, in relation to the goal of this project, it is not very reasonable trying to model the groundwater retention times for consolidated rock areas since only a very small proportion of the discharge is lost this way. In consolidated rock areas, an estimation of the retention time of discharges was carried out for the broken rock zone where most flow occurs. It must be emphasized that because of the methodological difficulties with such retention time calculations and the great uncertainties within the existing database, such estimates may not be very accurate.

The results of the model calculations on catchment-differentiated baseflow retention times in the unsaturated zone and groundwater are shown in Map 3.1.

For the use of such retention times for catchments where estimates exceed 50 years, a value of 50 years was employed. This is on the one hand based on the fact that N surplus calculations are up to now based only on the 1950 to 1999 period. On the other hand, it is based on the simplicity of MONERIS calculations which does not allow for separate modelling of basic or groundwater discharge and natural interflow.

N-surplus values were modified in relation to retention times. For the study periods (1983-1987 and 1993-1997) N-surpluses were calculated as averages of previous years based on retention time. These new N-surplus estimates were employed to calculate the potential nitrate concentration in percolating water. For the relationship between percolating and groundwater concentrations, it was assumed that the N-retention in the unsaturated and saturated zones of soils are a function of the amount of percolating water and the hydrological conditions. The groundwater discharge was calculated from the difference between the measured discharge and the individual discharge components (tile drainage discharge, surface water runoff, runoff from urban areas and atmospheric losses).



Map 3.1: Median retention times of the basic flow in German catchments

3.2.6 Emissions via erosion

The estimation of nutrient emissions from soil erosion followed corresponds to Figure 3.6 with consideration of sediment inputs and the nutrient enrichment ratio.

The calculation of soil erosion within the German part of the Elbe basin used the community-based values of Deumlich & Frielinghaus (1994) for the new German states (former GDR) through overlay of catchment boundaries.

To be able to calculate long-term average on-site soil erosion according to ABAG based on sediment inputs, the sediment delivery ratio (SDR) of a catchment must be determined (WALLING, 1983; 1996). The applicability of the sediment delivery equation of AUERSWALD (1992), at least for the north-east German plain, is doubted since with soil erosion of less than 0.44 t/(ha LN·a) and with catchments of 18 km^2 the sediment input obtained is greater than the total soil erosion of the catchment. Therefore, it was attempted to develop a new equation for the sediment delivery ratio which is applicable to all catchments. For the modelling of sediment input potentials of running waters, a GIS based system was developed which allows the calculation of a catchment area to which running water sediment inputs contribute. For that, a high-resolution digital data-set (river-network, land-use, soil and elevation data) was used. Up to now, this is only possible for some catchments, so a modification was required so that the data could be applied to other catchments. For this, the relationship between the SDR and particular catchment characteristics or parameters from the available low-resolution digital database was sought. Using a non-linear multiple regression, the proportion of arable land is typically identified as the parameter which has the greatest influence on the sediment delivery area ratio (SAR).

In order to apply the SAR model, which defines the potential for inputs in the form of an area ratio of the sensitive area to the total catchment area with out quantifying absolute inputs, the long-term average discharge and suspended particulate concentrations of 23 measuring stations in Bavaria and Baden Württemberg were used. For the calibration of the SAR model, the sediment loading above a critical discharge was used to reduce the influence of point-source discharges as well as autochthonous particulates on the relationship.

For the calibration of the SDR model for a long-term employment, it is necessary to use a weighting factor for two periods in consideration of the great variability of transport of suspended particulates over time. This weighting factor was calculated from the relationship of the number of heavy rain event days (according to ROGLER & SCHWERDTMANN,1981) in the two periods considered to the number in the total period.

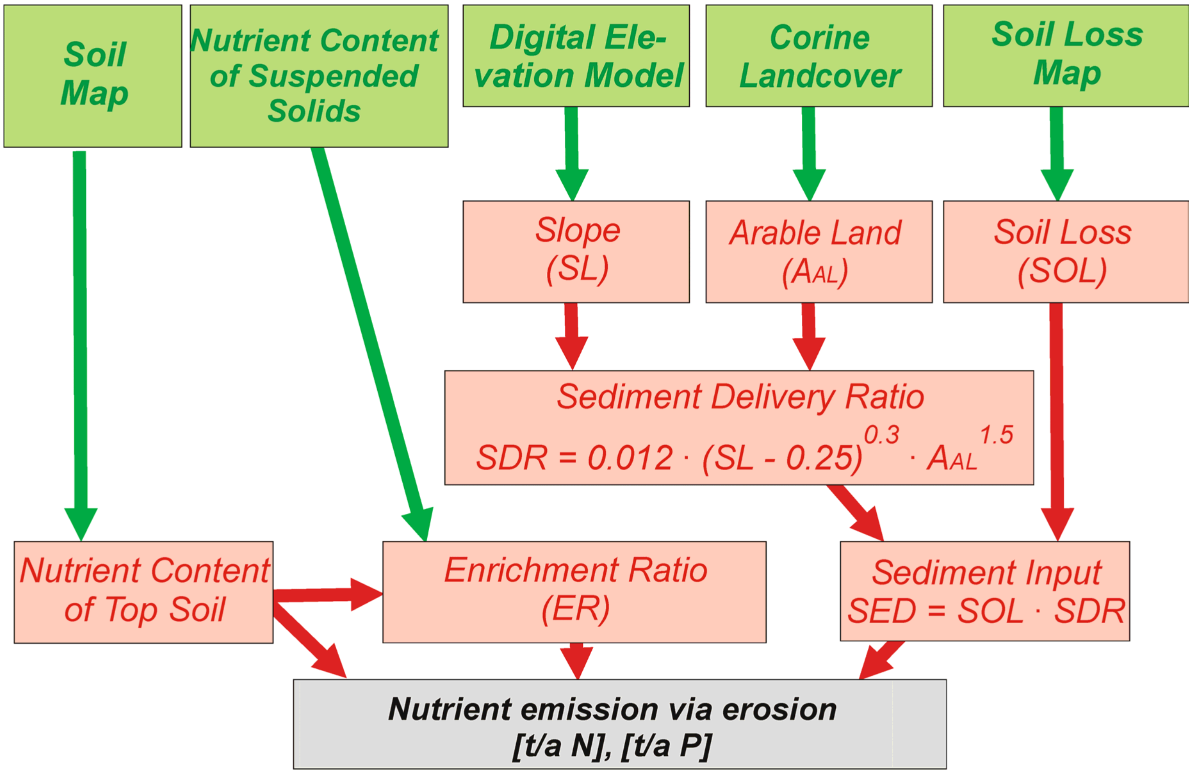


Figure 3.6: Nutrient emissions via erosion

The P-content of surface soils in the two study periods was calculated on the basis of annual P-surplus and its cumulative values for each German states for the period 1955 to 1996. The starting value for the surface-soil P-content in the mid fifties was based on the information of WERNER ET AL. (1991). The spatial differentiation of the starting value was based on the clay content of the various soil types of the general soil map. The particular P-content of arable soils for the two study periods was based on the previous P-accumulation in the individual states and the spatially differentiated background content. For the calculation of N-emissions via erosion, information on N-content of arable soils in the soil map (BÜK) for both time periods was used.

The relationship of phosphorus content in particulates of rivers with high discharges to the estimated P-content of surface soils was the basis for the determination of the enrichment ratio (ER). With this it can be concluded that the ER is inversely proportional to the root of the specific sediment input of a catchment.

For nitrogen, the ER is not identical to that for phosphorus.

Finally, the nutrient emission via erosion is calculated for both N and P from the product of sediment input to a water-body by the average nutrient content of the surface soils in the catchment and the ER.

3.2.7 Emissions via surface runoff

Emissions of dissolved nutrients in surface runoff were determined according to the scheme in Figure 3.7.

For this, the surface runoff and the mean total annual discharge were estimated from the annual precipitation, mean precipitation in the summer half-year and the mean precipitation in the winter half-year. For determination of the total surface runoff from unpaved areas of a catchment, it was assumed that it did not come form woodland, wetlands water bodies or mined land.

In the surface runoff pathway, only dissolved nutrient components which reach water bodies are considered.

For the calculation of carriage in surface runoff, the nutrient concentrations given in Figure 3.6 were used for all catchments.

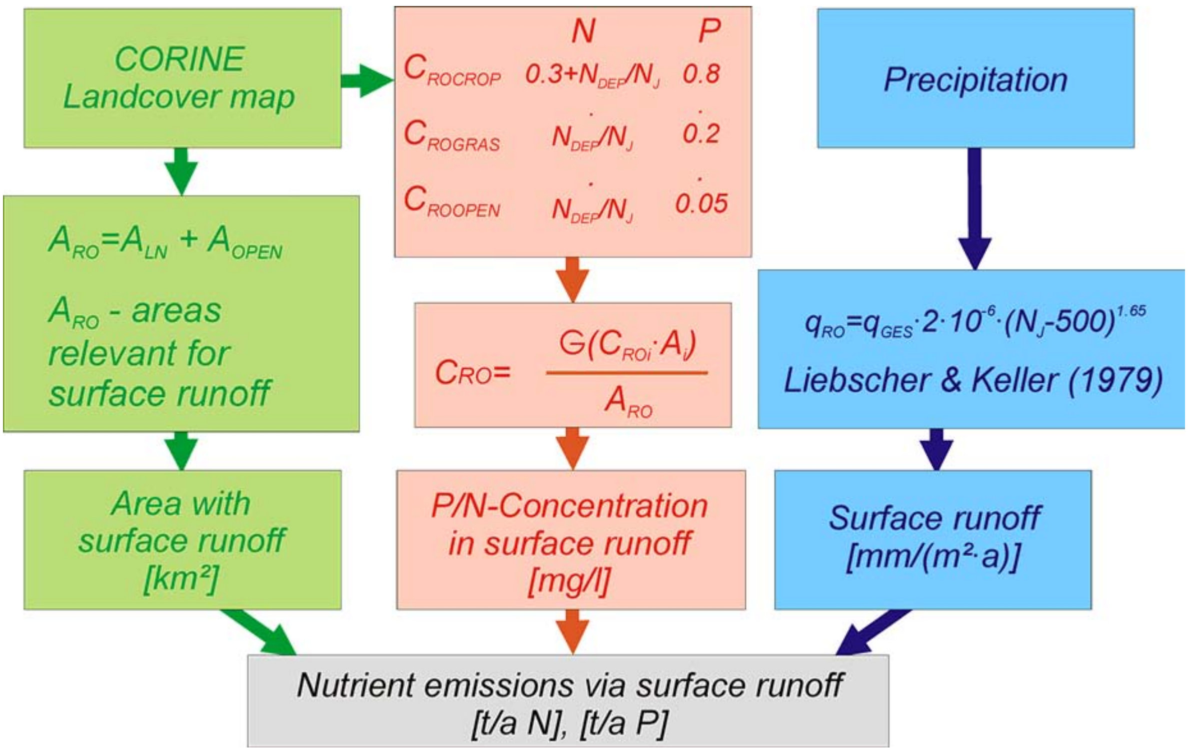


Figure 3.7: Nutrient emissions from surface runoff

3.2.8 Natural background

Up to this point, the model on nutrient emissions has only considered individual pathways. This allows for only a limited analysis of the sources of these emissions, in particular one cannot by this means quantify the proportion of emissions attributable to agriculture. This is only possible when in addition, the emissions for natural background conditions, i.e. the quantity of emissions independent of human influence, are modelled.

Knowledge on natural background is also necessary in relation to the achievement of water quality guidelines i.e. good ecological water conditions as the basis of reference conditions i.e. in the absence of human influence. Above all, the definition of reference conditions for the various ecological components (phytoplankton, phyto- and zoobenthos, macrophytes and fish) in inland waters is related to nutrient concentrations and not to nutrient emissions or loadings.

In the following, an attempt is made to determine realistic background emissions based on the mean annual discharge conditions for 1993-1997 and the following defined conditions:

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

On the basis of these statements, and using the MONERIS model it is possible to calculate both nutrient loadings and concentration with background conditions for individual catchments.

For the calculated background concentrations for the determination of reference conditions in relation to the WRRL, it has to be borne in mind that the calculated concentrations have a retention factor dependent on the hydrological and morphological conditions in the water bodies. The calculated background values clearly represent an upper limit of expected nutrient concentrations under background conditions.

3.3 Nutrient retention in surface waters of a river system

For the calculation of nutrient loading at a particular measuring station within a catchment, the quantification of nutrient emission from the various pathways is not in itself enough. Within the surface water system of a catchment, the nutrients are subject to transformation, retention and loss processes. The model calculation of nutrient emissions and loadings shows, for phosphorus and nitrogen, a strong dependence on retention of specific discharge contributions and the hydraulic loading within the river system of a catchment (BEHRENDT & OPITZ 1999). On the basis of this dependence, retention functions were used which allow for calculation of both retention itself and loadings of nutrients.

BEHRENDT & OPITZ. (1999) considered retention functions for total phosphorus (TP) and inorganic dissolved nitrogen (DIN). On the basis of literature on a total of 50 catchments in central Europe, the relationship between the ratio of total nitrogen load to nitrogen emissions and the hydraulic loading in a catchment or sub-catchment can be used so that the load of total nitrogen can be calculated in addition to DIN. For this, the formula in Figure 3.8 are used.

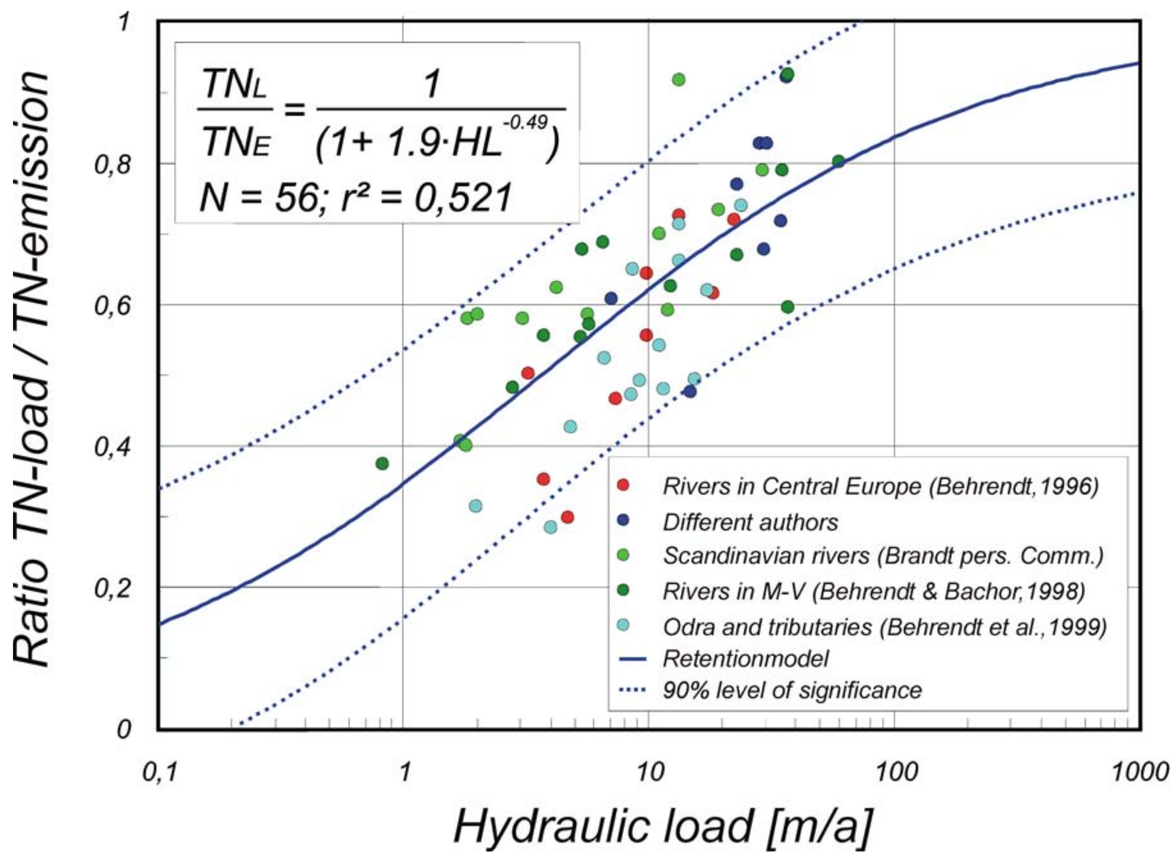


Figure 3.8: Relationship between load/emission ratio and the hydraulic loading of catchments.

$$TN_{LOAD} = \frac{1}{1 + 1{,}9 \cdot HL^{-0{,}49}} \cdot TN_{EMISSION} \tag{3.4}$$

where TN_{LOAD} is the total nitrogen loading at a particular measuring station, $TN_{EMISSION}$ the nitrogen emission to the river system above this measuring station and the hydraulic loading of the river system. This is calculated from the ratio of discharge and the water area within the catchment.

For the calculation of the carriage of DIN, the following formula from BEHRENDT & OPITZ (1999) was used:

$$DIN_{LOAD} = \frac{1}{1 + 5{,}9 \cdot HL^{-0{,}75}} \cdot TN_{EMISSION} \tag{3.5}$$

where DIN_{LOAD} is the DIN carriage at a particular measuring station

For phosphorus, BEHRENDT & OPITZ (1999) used not only the hydraulic loading relationship but also the specific discharge contribution (*q*). At present it is not clear yet which of these relationships is more applicable, especially for catchments with a high proportion of shallow lakes. Therefore, phosphorus carriage was calculated from the mean of the following two equations (3.6 and 3.7):

$$TP_{LOAD} = \frac{1}{1 + 26{,}6 \cdot q^{-1{,}71}} \cdot TP_{EMISSION} \tag{3.6}$$

$$TP_{LOAD} = \frac{1}{1 + 13{,}3 \cdot HL^{-0{,}93}} \cdot TP_{EMISSION} \tag{3.7}$$

In Equations (3.6) and (3.7), TP_{LOAD} is the total phosphorus load at a particular measuring station and $TP_{EMISSION}$ the phosphorus emission to the river system above the measuring station

The retention functions were used in particular for individual sub-catchments and the calculated loadings were added together along the length of the particular river.

3.4 Observed nutrient loads at the monitoring stations

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 3.8 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.

$$L_{J_{N,P}} = \frac{Q_{DAILY}}{Q_{MEAS}} \cdot \left(\frac{1}{J} \cdot \sum_{n=1}^{J} C_{t_{N,P}} \cdot Q_t \cdot U_f \right) \quad \textbf{(3.8)}$$

where $L_{J_{N,P}}$ = annual nutrient load [g/s],
Q_{DAILY} = average annual runoff based on daily measurements [m³/s],
Q_{MEAS} = 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.

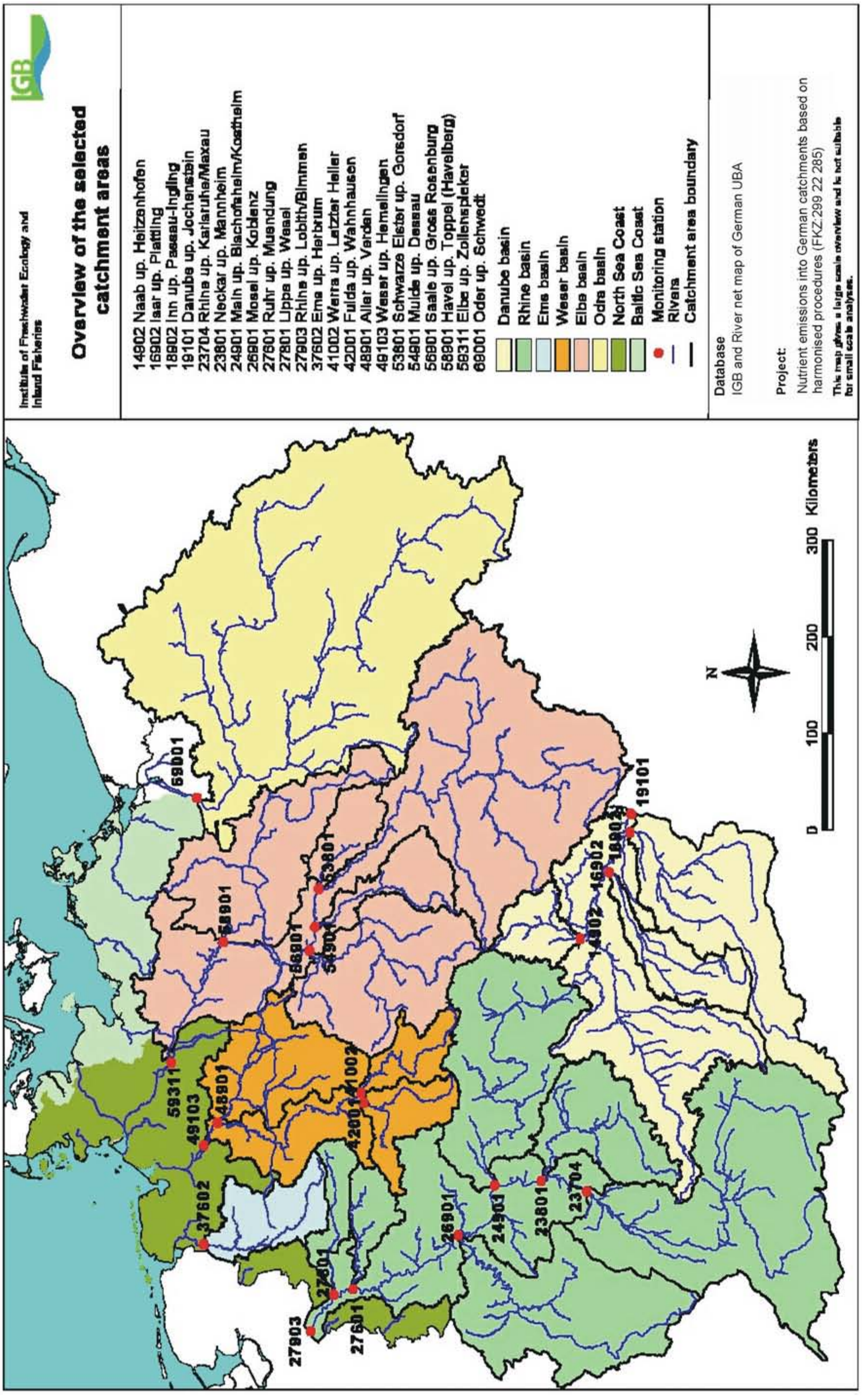
This method for calculation of load is also the favoured method of OSPAR (1996) for calculation of loads into the North Sea. In a comparison of five various methods to estimate load for English rivers, LITTLEWOOD (1995) showed that only this method gave reliable load estimates. This conclusion agrees with the results of a comparison of different methods for load estimation given by KELLER et al. (1997) and BEHRENDT et al. (2000).

4 Results

For an overview of nutrient inputs in Germany, 22 catchments in 6 major river basins were chosen (see Table 4.1 and Map 4.1) as described in Behrendt et al. (1999). They represent both the major rivers and the particular tide-influenced estuaries. In addition, all rivers draining into the North and Baltic Seas as well as the unobserved areas below the tide level are described. From the sum of these and the major river basins, the total inputs to the individual seas are calculated.

Table 4.1: Catchments of German river basins and their major rivers

ADR.	Water body	Measuring 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**



Map 4.1: Overview of the areas of the selected river basins

4.1. Emission methods by MONERIS

4.1.1 Diffuse inputs in Germany

4.1.1.1 Nutrient surpluses from agriculture and their changes

Diffuse nutrient inputs are predominantly caused by agriculture. Models for the quantification of nutrient inputs into rivers from agricultural activities must be appropriately considered. One of the major factors determining the scale of nutrient loadings to catchments from diffuse sources is the annual nutrient surplus of agricultural land. Since there is much information available on the regional differentiation of nutrient inputs in individual catchments, it is also necessary to regionalise the nutrient surpluses.

Maps 4.2 and 4.3 provide an overview of nitrogen and phosphorus surpluses of agricultural land in 1999. In most German regions, the P-surplus was less than 4 kg/(ha·a) P. Only in north-west Germany where there are large populations of livestock is the P-surplus more than 10 kg/(ha·a) P. Nitrogen surpluses give a different picture. In all of north-west Germany and parts of the Danube basin, these reach more than 100 kg/(ha·a) N while in the south-west and eastern Germany the N-surplus is less than 60 kg/(ha·a) N.

The calculation of surpluses was also carried out for 1995 since some model parameters were changed from those of Bach et al. (1998). Comparison of the results for 1995 (Map 4.3) and 1999 (Map 4.4) for nitrogen enables changes in surpluses to be calculated. These are shown in Map 4.5.

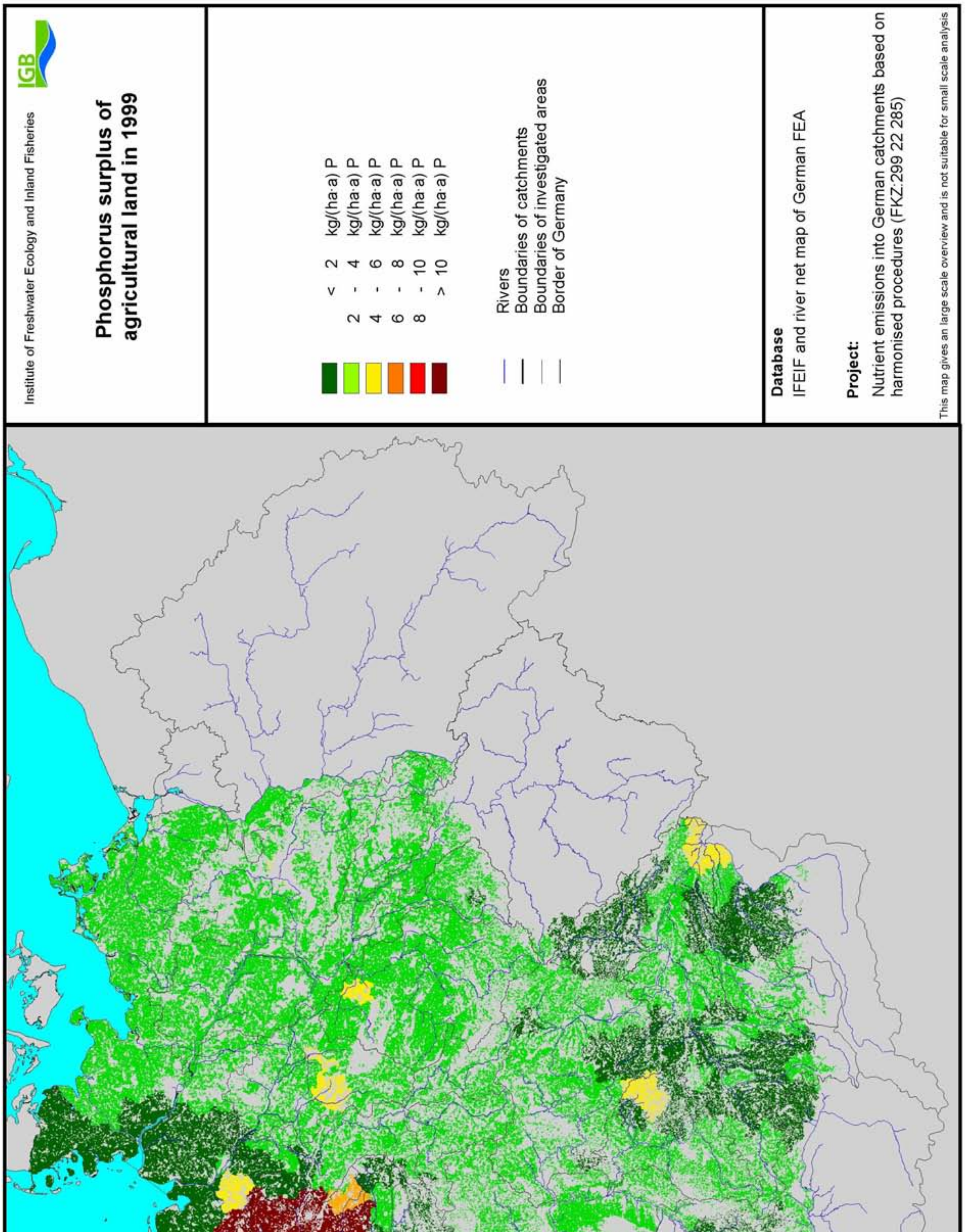
From Map 4.5, one can see that for nearly all agricultural area, the nitrogen surplus decreased by 10 % or more from 1995 to 1999. There was an increase in only three districts. By overlaying the catchment boundaries one can also determine the mean N-surpluses of agricultural land in individual catchments for the various study periods. The results are shown in Table 4.2. The values for 1983-1987 were calculated on the basis of results for the proportions of agricultural land in the states and catchments. On the basis of this, a reduction of 39 kg/(ha·a) N or 33 % in N surplus for the whole of Germany between 1985 and 1999 was calculated.

There are large differences between individual catchments. On must conclude that for the Inn, Ems and North Sea coast area, the nitrogen balance remained almost the same as in 1995. In the catchments of the Elbe and Baltic Sea coast as well as the Weser basin, the N-surpluses decreased by 40 to almost 60 % in the same period.

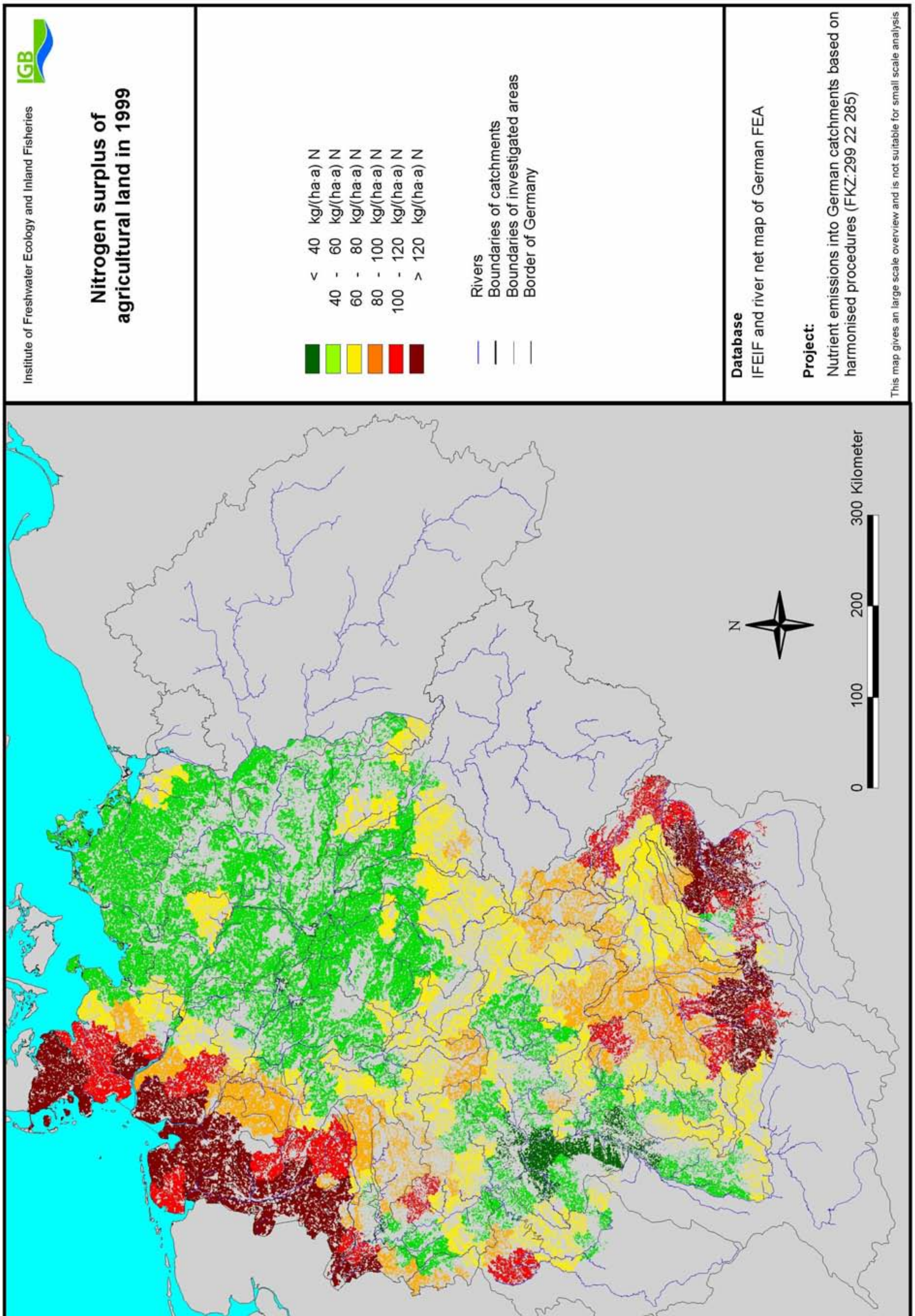
In addition to the regional differentiation of nutrient surpluses, it is also necessary to determine changes over time in catchment nutrient inputs to agricultural land. For this, the results of Behrendt et al. (2001) were used.

Table 4.2: Nitrogen surpluses of agricultural land in the various catchments for the years 1985, 1995 and 1999 as well as their changes.

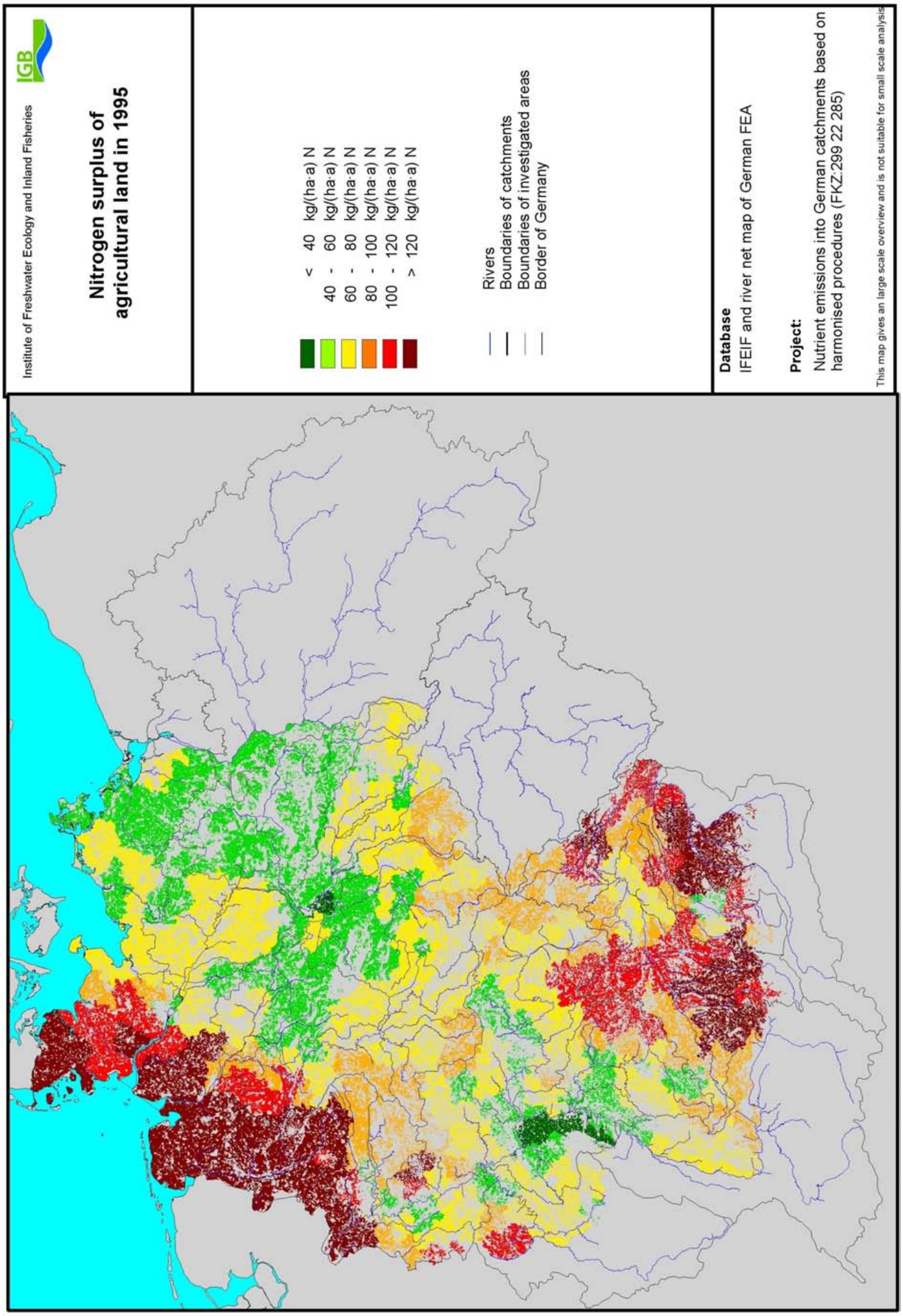
LOC.	RIVER	N-surplus			Change	
		1999	1995	1985	85 to 99	85 to 95
		kg/ha N	kg/ha N	kg/ha N	[%]	[%]
14902	Naab	91	99	124	-27	-20
16902	Isar	91	101	124	-27	-19
18902	Inn	125	135	124	1	8
19101	Danube	100	110	122	-18	-10
23704	Upper Rhine	78	89	107	-27	-17
23801	Neckar	73	83	106	-31	-22
24901	Main	67	75	119	-43	-37
26901	Mosel	74	81	91	-19	-11
27601	Ruhr	85	93	131	-35	-29
27801	Lippe	98	107	131	-25	-19
27903	Rhine	68	76	105	-36	-28
37602	Ems	131	139	128	2	8
41002	Werra	65	71	110	-41	-35
42001	Fulda	77	83	102	-25	-19
48901	Aller	54	60	124	-56	-52
49103	Weser	67	73	119	-44	-38
53801	Schwarze Elster	59	66	124	-52	-47
54901	Mulde	68	77	126	-46	-39
56901	Saale	57	63	115	-50	-45
58901	Havel	52	57	121	-57	-53
59311	Elbe	57	63	119	-52	-47
69001	Odra	51	57	124	-59	-54
	North Sea coast	118	126	126	-6	0
	Baltic Sea coast	60	66	119	-49	-44
	North Sea	77	84	116	-34	-28
	Baltic Sea	59	65	120	-50	-45
	Black Sea	100	110	122	-18	-10
	Germany	79	86	118	-33	-27



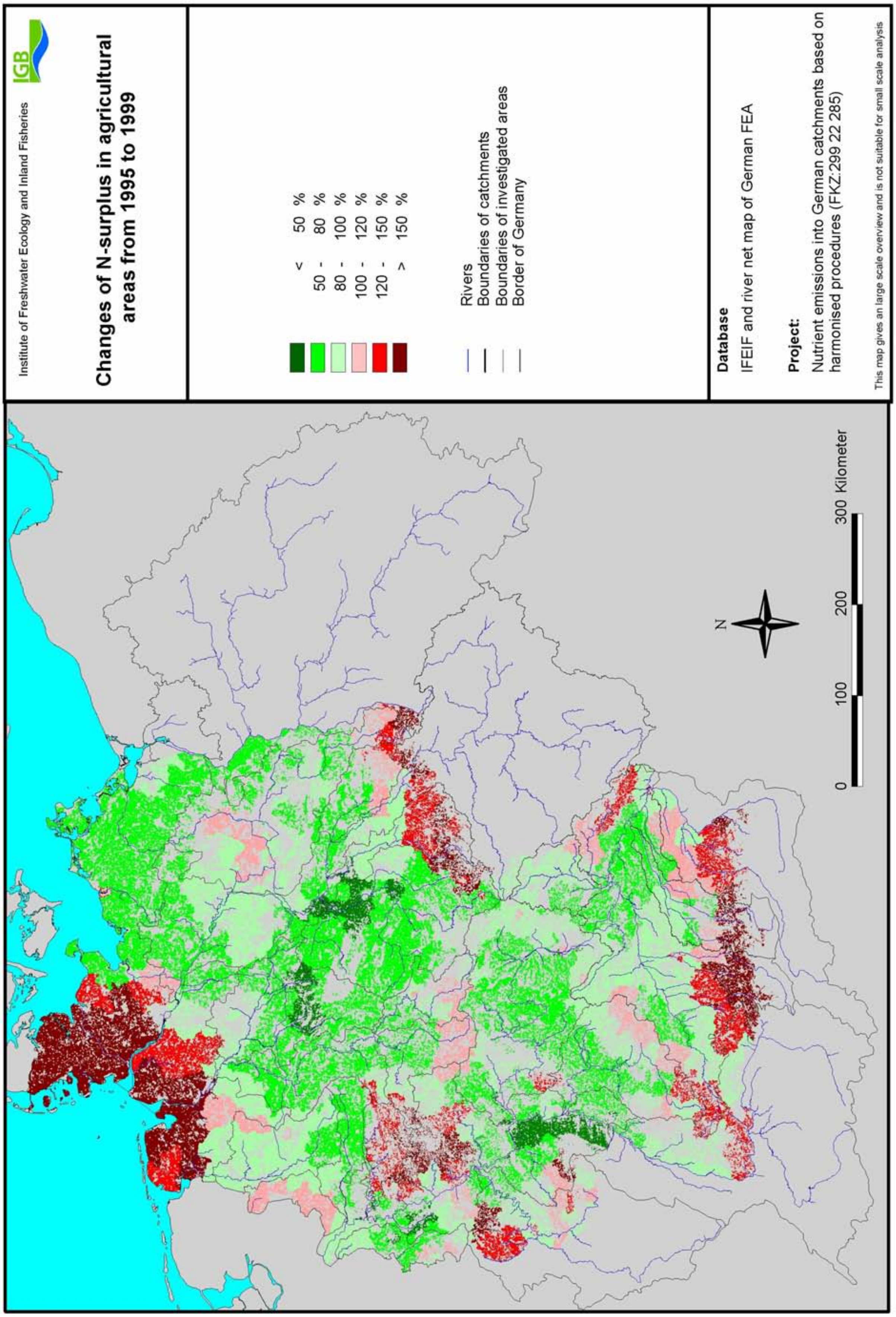
Map 4.2: Phosphorus surpluses of agricultural land in 1999



Map 4.3: Nitrogen surpluses of agricultural land in 1999



Map 4.4: Nitrogen surpluses of agricultural land in 1995



Map 4.5: Changes in nitrogen surpluses of agricultural land from 1995 to 1999.

In this study, the method of Bach et al. (1998) was used to determine phosphorus and nitrogen surpluses of agricultural land for the period 1950 to 1999.

The results of these calculations are shown in Tables 4.3 to 4.5 as well as Figures 4.1 and 4.2.

Since phosphorus is stored in the soil profile only according to the sorption capacity of the particular soil layer, one must conclude the yearly P-surplus remains in the uppermost soil layers where phosphorus will thus accumulate. The quantities of phosphorus accumulated on agricultural land of the individual German states in the past 50 years are shown in Table 4.3. For the old German states (former West Germany), with the exception of Rheinland-Pfalz, approximately 900 to 1100 kg/ha P phosphorus accumulated. In the new German states (former East Germany) in contrast, only 600 to 800 kg/ha P accumulated. If one considers the long-term development of the proportion of land in individual catchments used for agriculture, one can determine the mean annual P-surplus and P-accumulation. The values for 22 catchments in the three study periods are shown in Table 4.4. The table also shows changes in P-accumulation since 1985.

For the basins of the Danube, Ems, Rhine and Weser one can calculate a P-accumulation of ore than 1000 kg/ha P. As shown in Figure 4.1, the increase in P-accumulation in these river

Table 4.3: P-accumulation of agricultural soils of the German states for the period 1950 to 1999

	1950	1960	1970	1980	1985	1990	1995	1999
	[kg/ha P]	[kg/ha P]	[kg/ha P]	[kg/ha P]	[kg/ha P]	[kg/ha P]	[kg/ha P]	[kg/ha P]
Baden-Württemberg	12	178	419	689	807	903	955	965
Bavaria	11	174	416	706	836	943	1000	1010
Brandenburg	-2	60	257	536	663	761	735	741
Hesse	12	180	419	684	797	885	932	945
Mecklenburg-Vorpommern	-4	41	223	500	622	720	739	777
Lower Saxony	12	177	423	721	856	968	1028	1035
Nordrhein-Westfalen	12	185	448	767	916	1040	1104	1110
Rheinland-Pfalz	11	153	340	539	626	696	735	748
Saarland	9	128	283	468	566	645	688	701
Saxony	-1	64	261	568	676	757	776	822
Sachsen-Anhalt	-3	38	198	413	483	543	562	598
Schleswig-Holstein	12	175	429	728	858	962	1017	1026
Thuringia	-3	60	230	479	573	640	660	704

basins has been drastically reduced since 1995 with a rapidly decling annual P-surplus. However, one must conclude that the P-content of agricultural soils has on average increased again in the last decade. At least for their sections in the new German states, the P-accumulation in the Elbe and Baltic Sea catchments has been clearly less. From 1990 to 1995 one can see that the P-accumulation decreased a little with negative annual P-surpluses. Following the analysis of P-balances, one must however conclude that at least since 1995, the P-surpluses have increased greatly again and since this time lie over those of other German states (see Figure 4.1).

The development of nitrogen surpluses from 1950 to 1999 for the German states are shown in Table 4.5. On the basis of this information, one can calculate the long-term trends in N-surpluses for these areas through the overlaying of agricultural areas with the catchment areas.

Figure 4.2 shows the trend in N-surpluses for the Weser and German parts of the Danube, Elbe and Rhine basins. Except for the rather low N-surpluses in the Elbe basin in the fifties, the changes up to the early seventies were similar for all catchments. Since 1970, the N-surpluses for the German part of the Rhine basin have been about 10 to 20 kg/(ha·a) N less than those of other catchments. From the mid-seventies to the end of the eighties, the N-surpluses remained almost constant. As a result of changes in agriculture in the new German states following German reunification, the N-surpluses in 1990 to 1993 in this area returned to the levels of the fifties and subsequently began to rise again. In the lat years of the twentieth century, the N-surpluses in the Elbe basin remained fairly constant at a level under 60 kg/(ha·a) N. For the other catchments, a change in N-surplus trends can be discerned from the late eighties. However, the observed reductions were not as sudden as for the Elbe. Despite these reductions, the N-surpluses remained 20 to 30 kg/(ha·a) N above those of the Elbe.

Table 4.4: Accumulated phosphorus surpluses of agricultural land in catchments for 1985, 1995 and 1999 as well as their changes.

LOC.	RIVER	N-surplus			Change	
		1999	1995	1985	85 to 99	85 to 95
		[kg/ha P]	[kg/ha P]	[kg/ha P]	[%]	[%]
14902	Naab	1010	1000	836	21	20
16902	Isar	1010	1000	836	21	20
18902	Inn	1008	998	834	21	20
19101	Danube	1003	993	831	21	19
23704	Upper Rhine	957	947	801	20	18
23801	Neckar	965	954	807	19	18
24901	Main	987	975	820	20	19
26901	Mosel	740	728	615	20	18
27601	Ruhr	1110	1104	916	21	20
27801	Lippe	1110	1104	916	21	20
27903	Rhine	915	904	762	20	19
37602	Ems	1067	1060	881	21	20
41002	Werra	775	741	639	21	16
42001	Fulda	960	947	807	19	17
48901	Aller	1005	995	830	21	20
49103	Weser	987	974	818	21	19
53801	Schwarze Elster	764	738	652	17	13
54901	Mulde	803	759	660	22	15
56901	Saale	691	652	563	23	16
58901	Havel	729	717	641	14	12
59311	Elbe	728	698	607	20	15
69001	Odra	746	733	657	13	12
	North Sea coast	1041	1034	864	21	20
	Baltic Sea coast	827	799	677	22	18
	North Sea	899	883	747	20	18
	Baltic Sea	818	792	675	21	17
	Black Sea	1003	993	832	21	19
	Germany	907	891	753	20	18

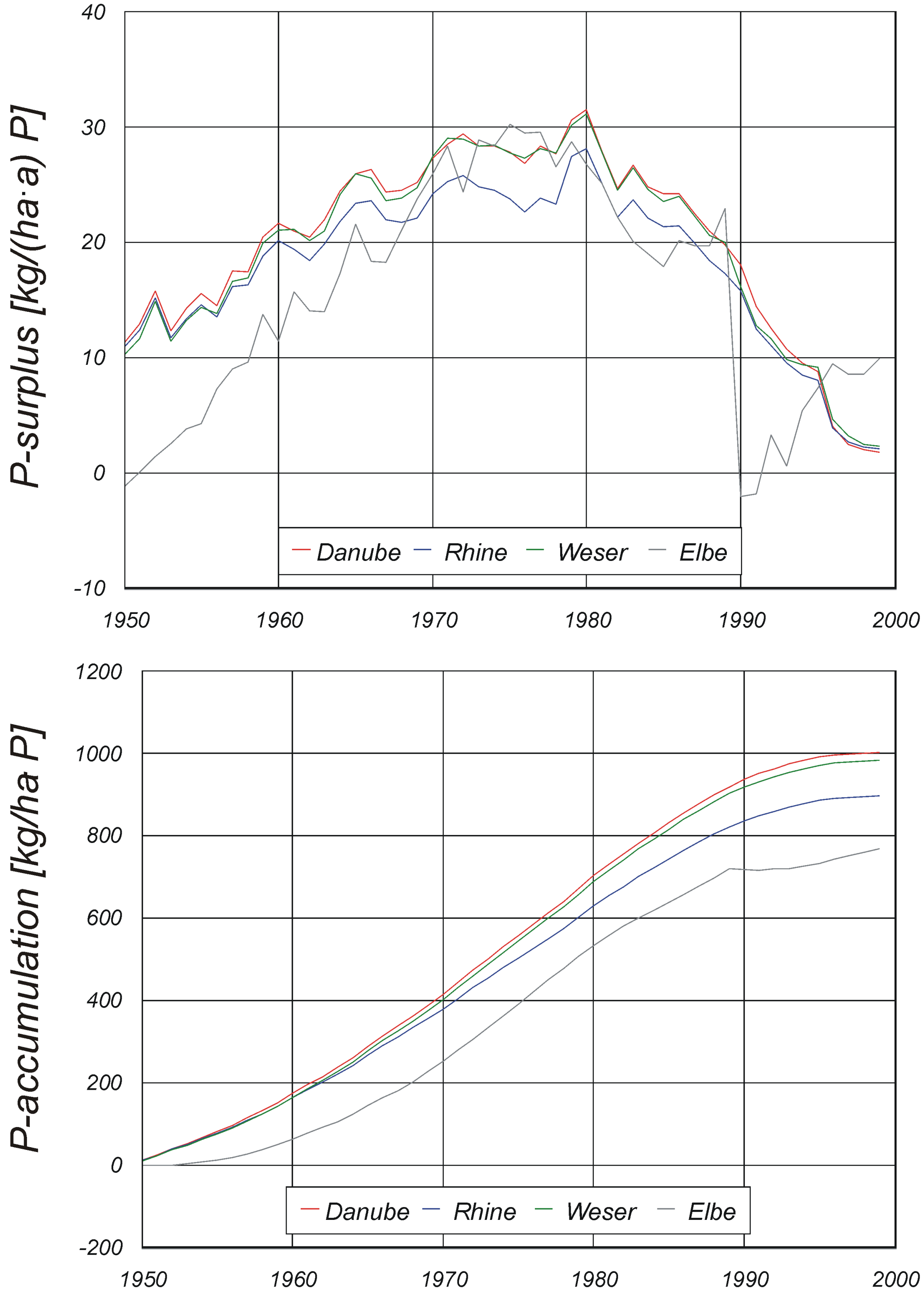


Figure 4.1: P-surpluses and P-accumulation of agricultural land for selected German states for 1950 to 1999

Tab.4.5: Development of N-surpluses [kg/(ha·a) N] in the German states from 1950 to 1999

Year	GER [a]	BW	BA	HE	NS [f]	NRW	RP	SL	SH [g]	BB [h]	MV	SA	ST	TH
1950	28.9	38.7	36.6	37.4	36.6	37.9	34.2	31.4	40.5	14.2	6.6	23.2	10.6	8.3
1951	28.2	37.2	35.3	34.1	32.8	34.6	32.0	30.8	35.5	16.9	10.1	24.9	12.6	12.3
1952	35.0	43.0	43.0	41.8	44.1	44.8	39.2	35.6	47.5	19.6	13.6	26.3	14.6	16.4
1953	34.0	41.9	40.9	39.0	40.4	41.0	35.3	33.3	43.5	22.3	17.1	28.5	16.6	20.5
1954	36.2	44.8	42.9	40.8	41.7	42.4	38.0	33.3	43.7	25.1	20.7	30.7	18.6	24.6
1955	35.2	41.7	41.2	39.3	38.5	39.8	36.4	31.5	41.0	27.7	27.0	29.5	21.2	18.1
1956	38.0	44.6	43.6	40.8	40.8	41.1	38.3	32.0	44.3	29.2	22.5	37.4	23.0	42.4
1957	41.9	48.6	47.2	44.2	45.8	46.6	40.6	35.5	48.5	34.9	32.2	36.5	24.8	38.1
1958	42.6	49.8	47.2	44.3	45.4	46.7	41.3	35.9	47.6	35.2	35.6	43.2	20.9	44.2
1959	52.8	59.3	57.4	52.2	54.1	55.7	47.5	39.5	59.4	45.2	44.0	50.0	42.7	57.5
1960	46.4	53.8	51.0	49.1	50.3	50.8	44.8	38.0	52.8	39.0	39.9	45.4	27.2	39.3
1961	55.8	60.4	57.6	53.4	55.5	56.5	48.0	42.1	60.6	48.3	48.5	60.7	49.6	78.2
1962	56.0	60.7	60.0	54.6	59.4	60.1	47.4	39.8	64.4	47.6	47.3	62.3	41.4	60.4
1963	58.6	66.2	64.5	60.0	62.5	63.6	52.2	45.0	67.3	54.0	48.7	54.3	48.9	39.3
1964	61.8	68.4	68.4	61.7	69.5	70.2	53.5	45.9	74.4	50.7	47.6	56.2	48.7	47.8
1965	67.9	71.5	70.5	66.0	71.3	71.9	57.2	48.4	77.4	61.0	69.7	71.1	60.0	52.1
1966	72.2	75.9	75.2	70.2	73.2	75.9	59.6	51.2	80.4	62.2	72.4	73.6	72.1	65.7
1967	68.5	71.8	71.3	66.1	69.4	72.8	56.8	49.7	76.1	58.9	69.7	71.2	70.0	56.6
1968	69.8	73.2	74.6	69.0	71.8	74.8	58.1	51.9	78.5	65.3	66.9	68.7	65.9	53.5
1969	78.6	75.4	77.6	70.8	74.4	78.8	58.6	53.3	80.7	85.9	91.6	93.6	85.3	72.8
1970	86.8	86.5	91.3	83.7	90.4	94.8	68.5	62.7	94.4	85.3	90.7	85.1	77.3	71.0
1971	89.6	86.5	91.2	81.5	91.2	94.0	66.7	63.7	94.4	94.7	92.8	95.9	90.0	89.3
1972	89.0	85.1	91.0	81.0	90.1	92.2	66.5	62.9	94.0	91.9	103.1	97.3	81.8	81.9
1973	97.9	89.8	95.4	83.7	94.9	97.6	67.4	65.4	101.3	110.0	113.5	113.1	101.2	93.8
1974	88.0	80.0	85.5	75.1	85.0	86.6	60.9	57.7	91.8	98.7	102.0	112.0	94.4	91.8
1975	99.1	90.2	98.5	85.2	96.6	99.0	68.0	62.5	104.0	114.1	114.4	112.0	105.5	101.2
1976	116.6	103.5	112.9	95.0	115.0	117.1	74.4	64.7	123.5	141.0	117.4	140.3	135.9	134.5
1977	107.7	96.9	108.2	91.9	107.6	109.3	73.4	66.2	116.7	123.0	116.2	126.3	109.4	110.3
1978	111.9	96.1	107.3	91.6	108.3	109.3	72.4	65.4	115.1	139.4	125.8	134.6	127.5	127.0
1979	114.5	107.3	116.3	101.1	115.2	120.5	80.8	80.9	120.3	123.8	124.3	125.4	110.5	114.9
1980	128.4	118.0	130.5	111.4	130.7	137.7	88.9	89.3	134.1	144.3	129.6	142.5	126.2	129.1
1981	126.3	118.6	131.4	110.9	132.3	138.7	88.5	93.9	135.7	132.0	127.5	135.9	113.4	121.4
1982	112.0	100.9	112.1	92.9	112.1	117.8	75.2	79.8	118.1	126.0	112.1	134.3	114.1	124.3
1983	126.1	119.6	136.7	112.9	139.0	146.3	88.6	94.8	141.9	120.4	120.3	116.3	109.2	112.5
1984	110.5	103.3	117.9	95.4	120.5	125.2	78.4	82.9	122.6	109.4	104.2	114.4	93.7	110.2
1985	118.1	105.8	124.5	100.2	125.4	131.5	81.0	86.7	125.4	123.9	116.5	126.5	111.3	113.9
1986	121.1	111.5	128.7	102.9	132.3	139.1	82.5	90.2	129.9	120.5	121.9	121.0	107.7	112.6
1987	124.8	117.8	135.5	107.3	138.4	145.8	87.8	95.9	133.6	116.7	126.2	118.5	103.6	113.1
1988	130.0	112.3	130.4	99.7	130.7	138.6	82.4	91.0	128.9	145.1	139.0	146.1	143.0	146.3
1989 [b]	125.5	108.1	126.1	96.4	128.1	134.4	78.9	87.0	125.9	141.0	141.9	136.0	129.9	132.4
1990 [b]	88.7	104.9	123.2	93.9	127.3	132.7	76.7	84.7	125.5	17.5	22.9	20.9	22.7	22.8
1991	78.1	93.5	110.6	81.8	114.4	118.2	68.3	73.9	113.8	13.6	19.6	16.1	21.8	17.9
1992	83.8	94.5	110.4	83.7	114.3	120.4	70.6	76.1	112.4	27.9	33.1	40.3	32.4	39.1
1993	75.8	88.1	101.1	75.1	107.0	110.4	64.2	70.1	105.7	23.7	28.1	29.7	28.1	28.9
1994	78.8	85.4	98.0	72.8	104.8	106.5	63.5	66.8	102.2	40.4	42.1	52.4	43.6	50.1
1995 [d]	83.9	87.8	100.1	76.6	110.1	110.8	66.1	72.0	106.3	48.2	51.7	62.2	51.8	59.5
1996	81.7	83.2	94.4	72.4	102.4	103.8	62.0	67.8	99.0	55.3	56.1	70.3	56.5	66.9
1997	74.5	72.5	83.6	63.0	91.8	90.0	55.1	59.5	88.8	50.8	55.5	66.2	53.1	61.2
1998	74.4	71.7	83.8	65.8	91.3	88.6	55.1	58.8	88.3	51.7	56.3	66.0	53.6	61.8
1999 [c]	82.9	80.2	93.8	72.7	102.1	100.0	60.9	64.9	98.1	56.6	61.1	72.9	57.8	68.1

a) To 1989: Former FRG and GDR together b) Information for states of the former GDR partly estimated
c) 1999: Provisional values d) From 1996, the statistical information were no longer separately identified for F/N parts of states; balances for the old and new German states were calculated together e) To 1989 Berlin was not separately considered f) Excluding Bremen
g) Excluding Hamburg h) From 1990 excluding Berlin

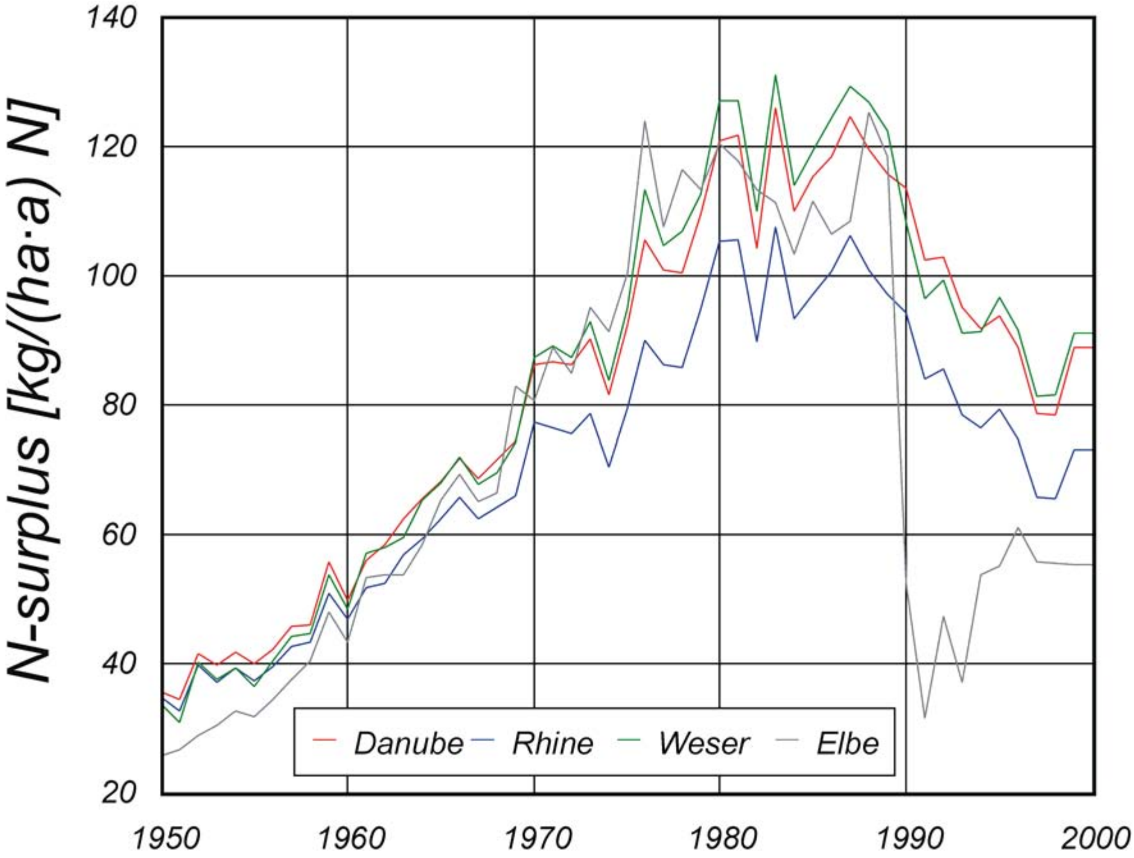


Figure 4.2: N-surpluses of agricultural land in the Weser basin and the German parts of the Danube, Rhine, and Elbe basins from 1950 to 1999

4.1.1.2 Direct emissions to surface waters via atmospheric deposition

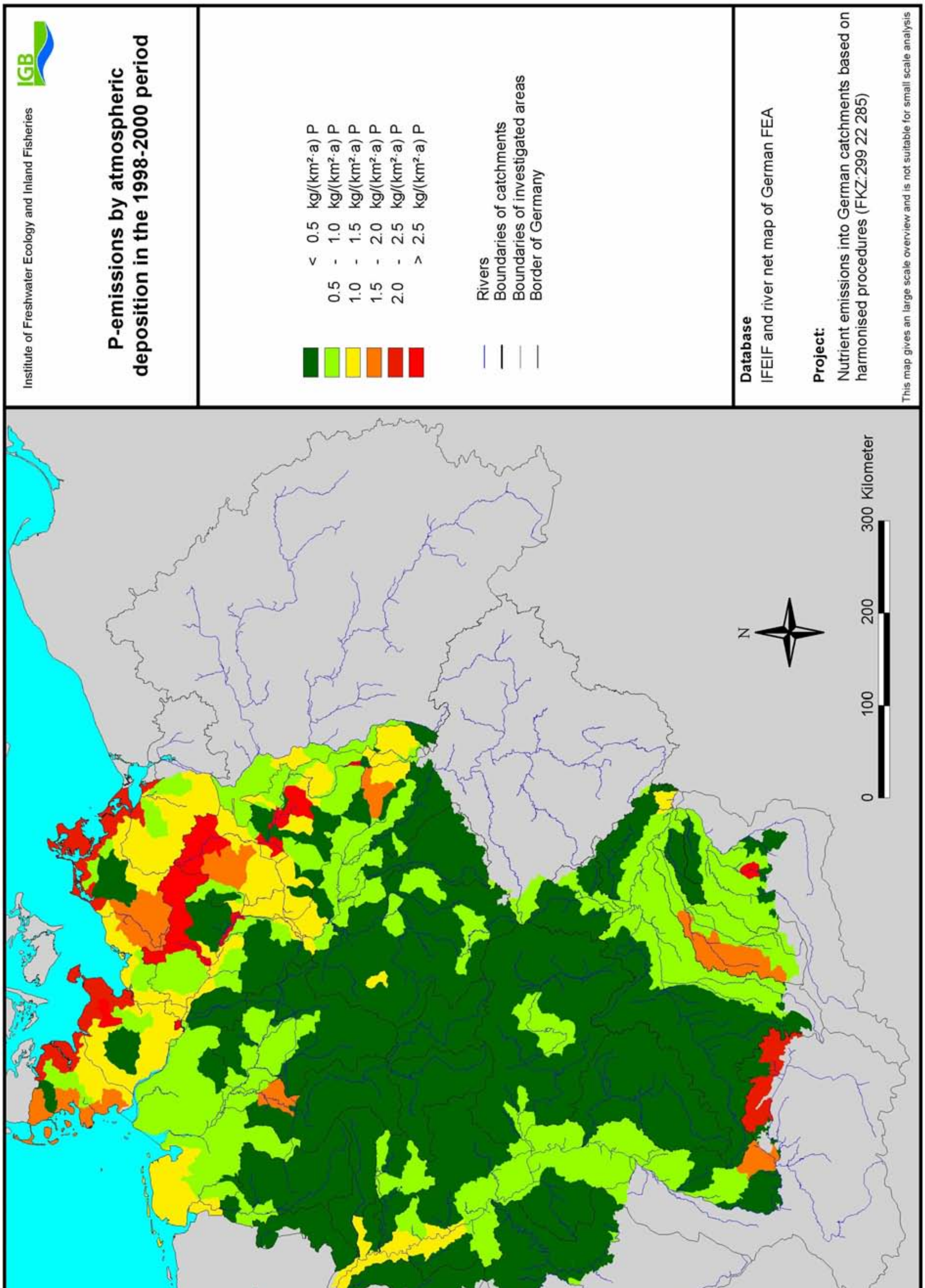
Direct P emissions to waters via atmospheric deposition for the periods 1983-1987, 1993-1997 and 1998-2000 are shown in Table 4.6. This table also shows changes in these emissions. Since the emission situation depends strongly on the hydrological conditions in the individual catchments, part of the changes is attributable to other discharge components. Therefore, all calculations of emissions for the three periods were carried out on the basis of normalised discharge conditions.

During the period 1985 to 1995, there was an overall decrease in phosphorus emissions through atmospheric deposition for German catchments from 0.7 (NBL) or 0.4 (ABL) to 0.37 kg/(ha·a) P (see BEHRENDT et al., 2000). For the period 1998-2000, the values remained around 0.37 kg/(ha·a). Since a new formula was used for the calculation of water surface area in the sub-catchments, there were differences from those of BEHRENDT et al. (2000). On the basis of the deposition rates used, P-emissions from direct deposition was reduced overall by about 100 tP/a or 29 %. One can conclude that the deposition-determined P emissions were 260 tP/a for 1998-2000, the same as for 1993-1997. Map 4.6 shows the calculated, catchment-specific P-emissions through atmospheric deposition. Table 4.7 provides an overview from the EMEP grid data (see Map 2.12) for calculated nitrogen emissions to water bodies for individual catchments through direct deposition as well as their changes. As with phosphorus, there was a sharp reduction from the values given in BEHRENDT et al. (2000) from the period 1983-1987 (8000 t/a N) to 1993-1997 (2500 t/a N). Maps 4.9 and 4.10 show the catchment-specific N-emissions in the water-bodies through deposition and their changes since 1985. The changes use normalised hydrological conditions (from the 1993-1997 period). While in the eastern part of Germany these N-emissions decreased more than 50 % from 1985 in some areas, a slight increase was found for catchments neighbouring the Netherlands border. As shown in Table 4.7, the overall reduction in deposition determined N-emissions was more than 40 % in eastern catchments whereas in the Ems catchment and the North Sea coast area it was less than 20 %. Overall for the period 1998-2000, N-emissions through direct deposition were 15200 t/a N or a reduction of 7000 t/a N or 31 % from the 1983-1987 period. On the other hand, they represent an increase of 3000 t/a N from the 1993-1997 estimates. This is attributable to the increase in deposition rates.

In this regard, one must consider that up to now, only EMEP-deposition rates for individual years can be considered. With this, the deposition rates can be strongly influenced by the particular precipitation conditions. Since the EMEP deposition rates in recent years were calculated on a yearly basis and are also available over the internet, they can, with an eventual improvement in resolution, provide a very good data base for a harmonised quantification of nitrogen emissions via deposition. Unfortunately, for phosphorus, such a scenario does not exist. Although the calculated P-emissions through deposition are relatively small, they can have an important role, particularly for individual lakes.

Table 4.6: Phosphorus emissions via atmospheric deposition and their changes for the periods 1983-1987, 1993-1997 and 1998-2000

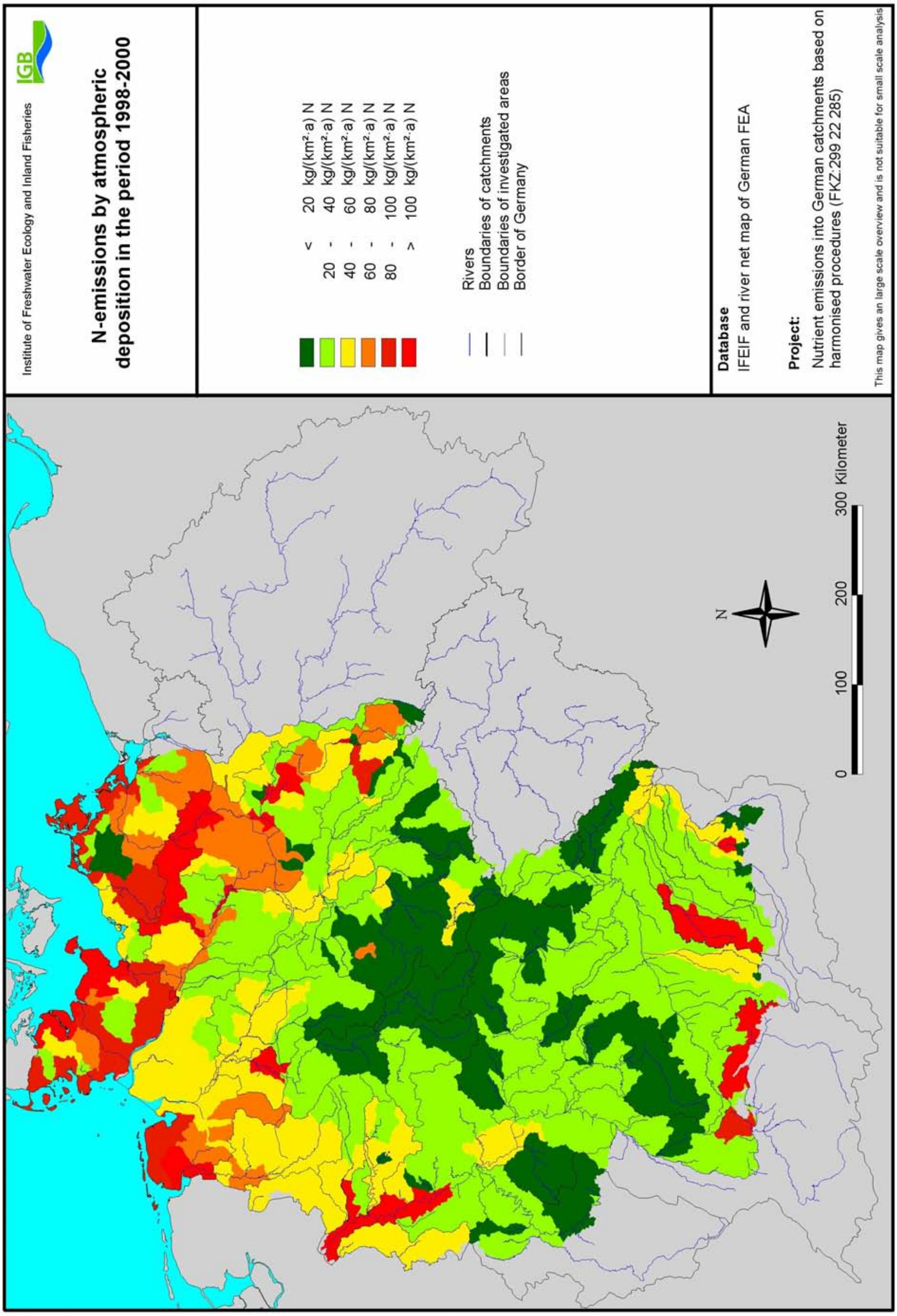
LOC.	River	EAD_P			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]
14902	Naab	2	2	2	-8	-8
16902	Isar	9	9	9	-8	-8
18902	Inn	8	8	8	-8	-8
19101	Danube	35	35	38	-7	-8
23704	Upper Rhine	11	11	12	-8	-8
23801	Neckar	4	4	5	-8	-8
24901	Main	10	10	11	-8	-8
26901	Mosel	4	4	4	-8	-8
27601	Ruhr	2	2	3	-8	-8
27801	Lippe	2	2	2	-8	-8
27903	Rhine	53	53	57	-7	-7
37602	Ems	5	5	5	-8	-8
41002	Werra	1	1	3	-47	-47
42001	Fulda	2	2	3	-7	-8
48901	Aller	7	7	8	-8	-8
49103	Weser	16	16	19	-13	-13
53801	Schwarze Elster	5	5	9	-47	-47
54901	Mulde	3	3	6	-47	-47
56901	Saale	10	10	19	-47	-47
58901	Havel	32	32	61	-47	-47
59311	Elbe	79	79	147	-46	-46
69001	Odra	4	4	7	-47	-47
	North Sea coast	32	32	35	-7	-7
	Baltic Sea coast	39	39	63	-39	-39
	North Sea	185	185	263	-30	-30
	Baltic Sea	42	42	70	-40	-40
	Black Sea	35	35	38	-8	-8
	Germany	262	262	371	-29	-29



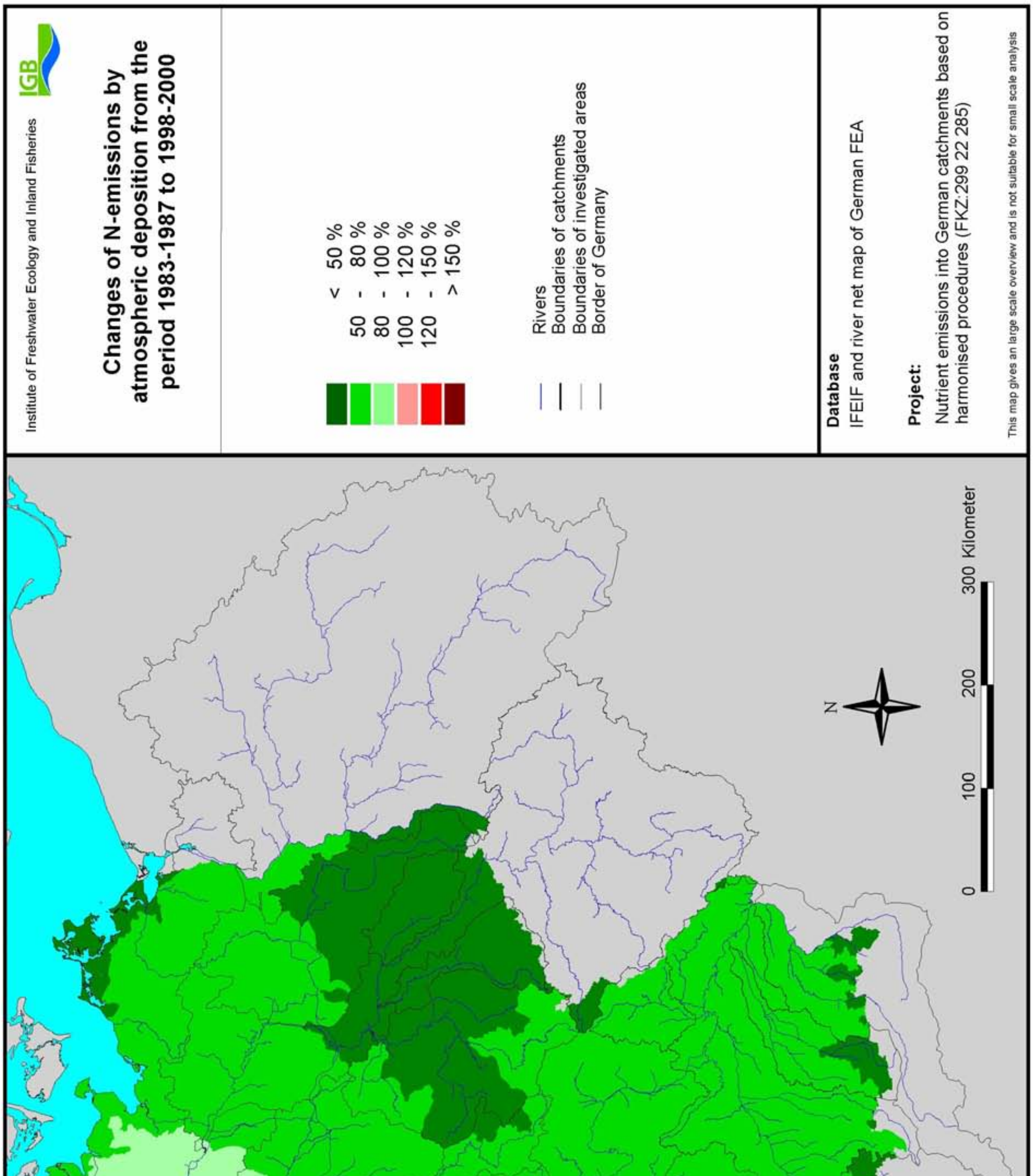
Map 4.6: Specific P-emissions through direct deposition to surface waters

Table 4.7: Nitrogen emissions via atmospheric deposition and their changes for the periods 1983-1987, 1993-1997 and 1998-2000

LOC.	RIVER	EAD_N			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]
14902	Naab	120	90	190	-37	-53
16902	Isar	520	480	830	-37	-42
18902	Inn	390	430	640	-39	-33
19101	Danube	2050	1780	3150	-35	-43
23704	Upper Rhine	600	450	920	-35	-51
23801	Neckar	260	180	360	-28	-50
24901	Main	590	410	880	-33	-53
26901	Mosel	230	190	320	-28	-41
27601	Ruhr	190	150	260	-27	-42
27801	Lippe	170	140	210	-19	-33
27903	Rhine	3310	2620	4610	-28	-43
37602	Ems	430	310	500	-14	-38
41002	Werra	80	60	130	-38	-54
42001	Fulda	150	120	230	-35	-48
48901	Aller	470	360	650	-28	-45
49103	Weser	1080	840	1500	-28	-44
53801	Schwarze Elster	240	180	430	-44	-58
54901	Mulde	160	130	290	-45	-55
56901	Saale	520	430	890	-42	-52
58901	Havel	1550	1210	2580	-40	-53
59311	Elbe	3970	3060	6550	-39	-53
69001	Odra	170	140	270	-37	-48
	North Sea coast	2370	1860	2690	-12	-31
	Baltic Sea coast	1800	1450	2700	-33	-46
	North Sea	11150	8680	15850	-30	-45
	Baltic Sea	1970	1580	2970	-34	-47
	Black Sea	2060	1780	3150	-35	-43
	Germany	15180	12040	21980	-31	-45



Map 4.7: N-deposition through direct emission to surfaces of waterbodies



Map 4.8: Changes in direct N-emissions to surfaces of waterbodies

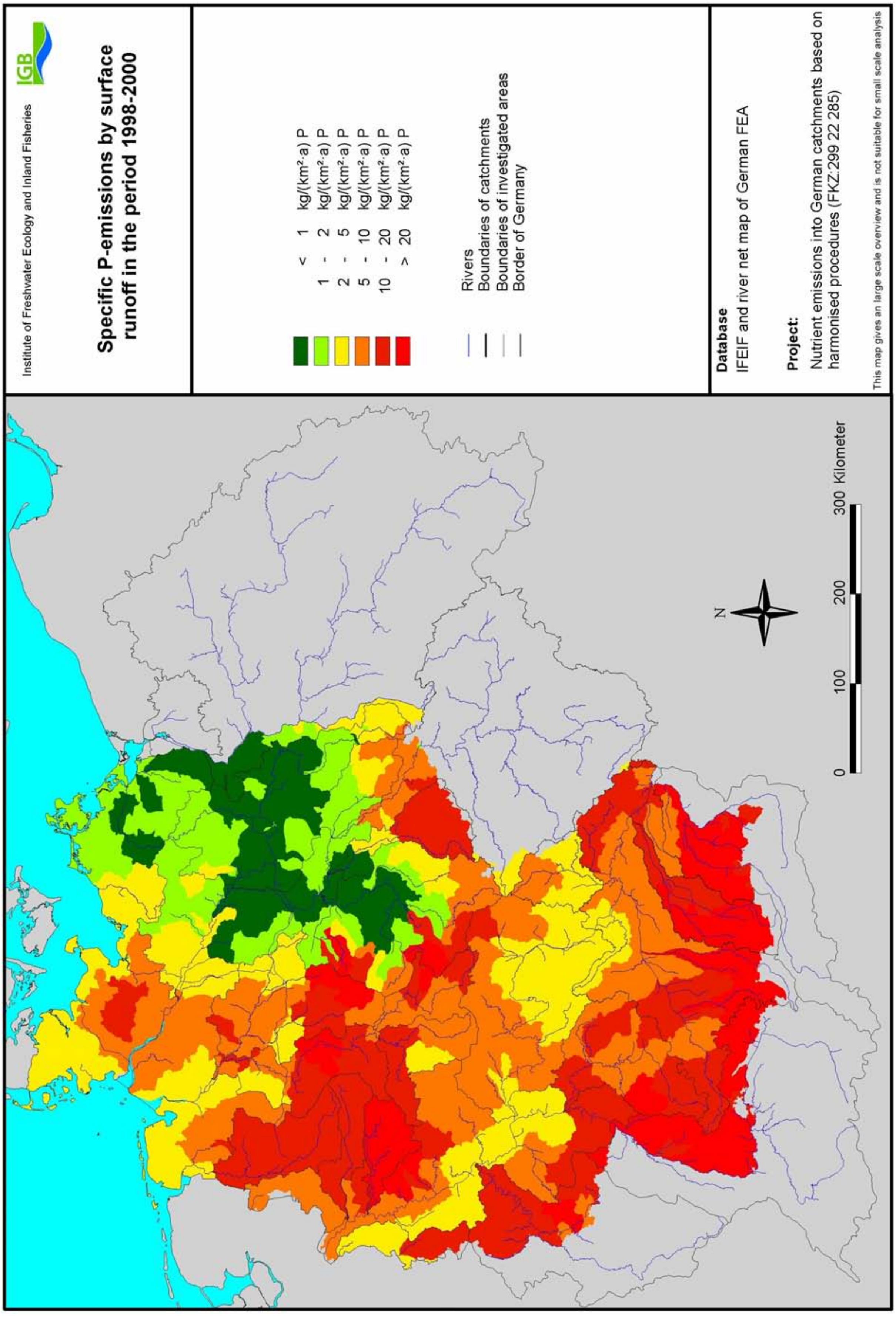
4.1.1.3 Nutrient emissions via surface runoff

Maps 4.9 and 4.10 provide an overview of the regional differentiation of area-specific phosphorus and nitrogen emissions from to surface runoff for the period 1998-2000. Corresponding to the basic assumptions catchments which are hot-points for surface-flow phosphorus emission are marked by a relatively high proportion of arable land (e.g..foothills of the Alps and the upper Rhine catchment). In contrast, surface runoff emissions in the north-east German plain and the lower Saale are at least an order or magnitude less.

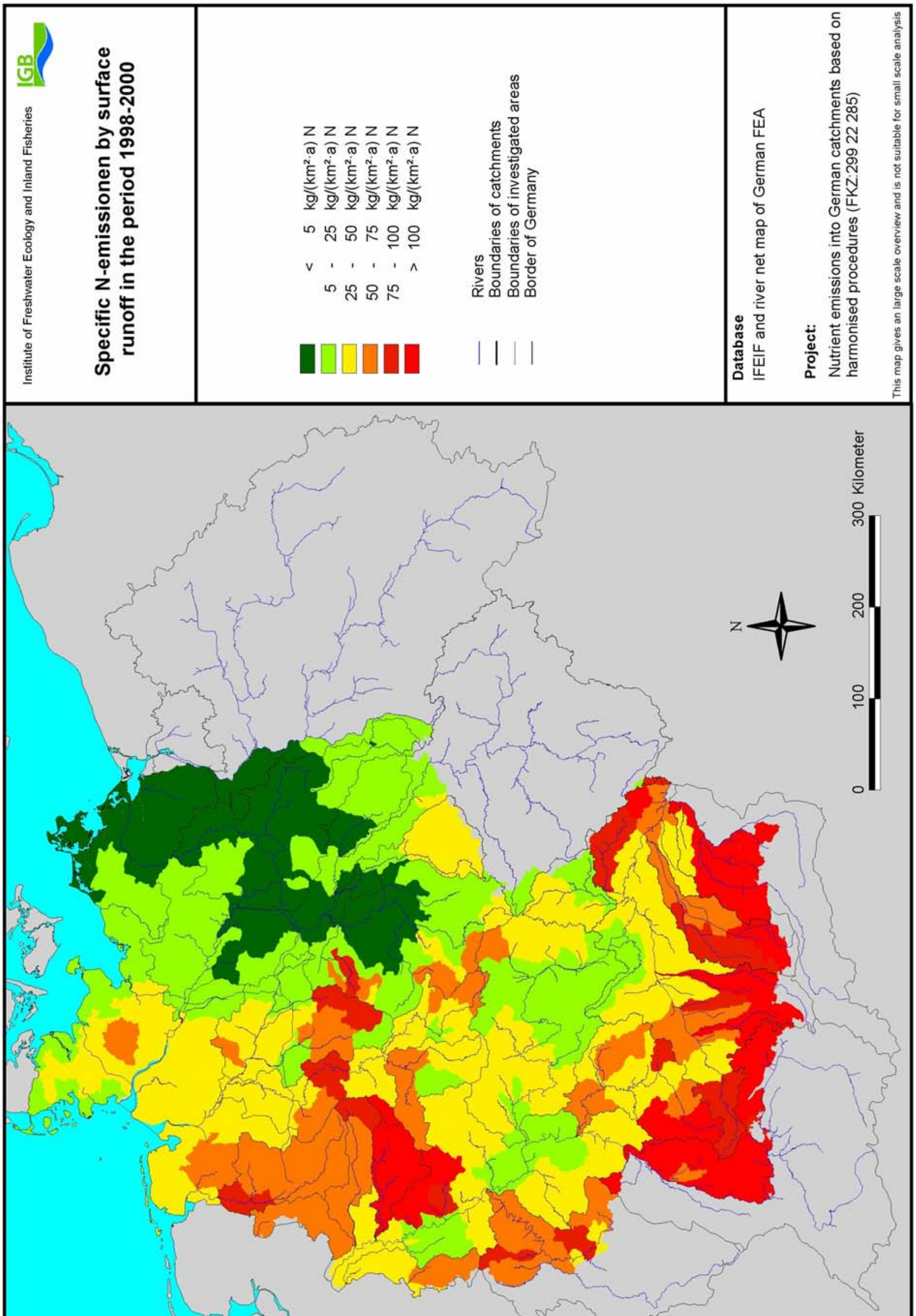
For nitrogen, this is collaborated by the conclusions of BEHRENDT et al. (2000) in which the relatively small variation in concentrations in precipitation were shown and also a clearer relationship between catchments with high surface discharges and high area-specific emissions from surface-flow. This is also shown here for the Alpine foothill catchment, the upper Rhine catchment and the lower east Rhine catchment. In the Elbe catchment, similar high specific surface runoff emissions are found for the upper Unstrut and upper Bode. For most catchments of the north-east German plain, very low nitrogen emissions via surface runoff were quantified.

Tables 4.8 and 4.9 list nutrient emissions via surface runoff and their changes for German catchments. For phosphorus, one can conclude that in the 1998-2000 period, a sum of 2600t/a P for surface runoff emissions for the German catchments. This is 32 % more than for 1983-1987. Estimated emissions increased from the 1993-1997 period by 300t/a P. The cause of this is the higher calculated surface drainage for both 1993-1997 and 1998-2000. However, one can see from the table that in the 1998-2000 period, large parts of other catchments exhibited higher P-emissions than in1983-1987. According to the model parameters, one must conclude that surface runoff emissions of phosphorus have not changed. In comparison to the calculations of BEHRENDT et al. (2000), P-emissions through surface runoff for the periods 1993-1997 and 1983-1987 are about 1000 and 500 t/a P less respectively. This is due to calculation of surface run-off without both measured surface outflow (after 3.2.7) and the total outflow calculated from catchment precipitation according to LIEBSCHER & KELLER (1979) which was used by BEHRENDT et al. (2000).

According to Table 4.9, nitrogen emissions through surface runoff for the 1998-2000 period were estimated as 13700 t/a N. This is 1700 t/a N or 11 % less than for the 1983-1987 period but 3500 t/a N higher than for 1993-1997. The cause is the higher surface flow estimates for the 1993-1997 period. With nitrogen, one can conclude following the reduction of atmospheric deposition that the surface runoff emissions have decreased since 1983-1987. On average, this reduction was 28 % based on the 1993-1997 normalised ouflow conditions. The size of the reduction is however very variable from catchment to catchment and reflects again the clear changes in deposition shown in Map 4.8. The greatest reductions of more than 40 % were calculated fro the Mulde and Schwarze Elster. In contrast, the smallest decreases were calculated for the small rivers flowing into the North Sea and the Ems catchment. One can conclude, in particular for the catchments near the Netherlands border that N-emissions through surface flow have increased a little.



Map 4.9: Specific P-emissions via surface runoff



Map 4.10: Specific N-emissions via surface runoff.

Table 4.8: Phosphorus emissions in German catchments via surface runoff ($ERO_{N,P}$) and their changes for the periods 1983-1987, 1993-1997 and 1998-2000.

LOC.	RIVER	ERO_P			Change		Q-normalised change	
		2000	1995	1985	2000 to 1995	1995 to 1985	2000 to 1995	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	22	16	17	29	-7	0	0
16902	Isar	153	135	106	44	27	0	0
18902	Inn	180	126	108	67	16	0	0
19101	Danube	675	587	503	34	17	0	0
23704	Upper Rhine	351	277	282	25	-2	0	0
23801	Neckar	121	143	128	-6	12	0	0
24901	Main	125	104	101	24	3	0	0
26901	Mosel	93	92	91	2	0	0	0
27601	Ruhr	118	114	103	15	11	0	0
27801	Lippe	54	53	40	34	32	0	0
27903	Rhine	1078	953	937	15	2	0	0
37602	Ems	108	94	57	88	64	0	0
41002	Werra	41	40	30	39	34	0	0
42001	Fulda	50	36	40	24	-10	0	0
48901	Aller	99	94	69	44	36	0	0
49103	Weser	301	251	206	46	22	0	0
53801	Schwarze Elster	3	10	4	-21	134	0	0
54901	Mulde	40	55	26	54	111	0	0
56901	Saale	59	79	46	27	72	0	0
58901	Havel	5	25	8	-35	232	0	0
59311	Elbe	130	211	100	29	110	0	0
69001	Odra	2	5	3	-31	74	0	0
	North Sea coast	261	181	138	89	31	0	0
	Baltic Sea coast	54	49	29	87	69	0	0
	North Sea	1877	1690	1438	31	17	0	0
	Baltic Sea	56	54	32	75	69	0	0
	Black Sea	679	588	504	35	17	0	0
	Germany	2612	2332	1974	32	18	0	0

Table 4.9: Nitrogen emissions in German catchments via surface runoff ($ERO_{N,P}$) and their changes for the period 1983-1987, 1993-1997 and 1998-2000

LOC.	RIVER	ERO_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1995	1995 to 1985	2000 to 1995	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	140	80	180	-22	-56	-35	-52
16902	Isar	980	770	1110	-12	-31	-36	-40
18902	Inn	1110	780	1180	-6	-34	-38	-38
19101	Danube	4220	3210	5030	-16	-36	-34	-42
23704	Upper Rhine	1660	1250	2180	-24	-43	-28	-44
23801	Neckar	550	450	800	-31	-44	-24	-48
24901	Main	580	360	720	-19	-50	-33	-51
26901	Mosel	460	360	600	-23	-40	-28	-40
27601	Ruhr	590	590	750	-21	-21	-27	-27
27801	Lippe	250	210	260	-4	-19	-22	-36
27903	Rhine	5220	3990	6680	-22	-40	-27	-41
37602	Ems	570	370	400	43	-8	-13	-37
41002	Werra	160	120	200	-20	-40	-37	-51
42001	Fulda	240	140	300	-20	-53	-33	-48
48901	Aller	380	290	400	-5	-28	-27	-42
49103	Weser	1230	830	1310	-6	-37	-29	-43
53801	Schwarze Elster	10	30	30	-67	-0	-41	-54
54901	Mulde	130	140	160	-19	-13	-45	-52
56901	Saale	190	220	270	-30	-19	-37	-47
58901	Havel	20	80	50	-60	60	-39	-51
59311	Elbe	450	600	630	-29	-5	-39	-50
69001	Odra	10	20	20	-50	-0	-37	-47
	North Sea coast	1720	1000	1140	51	-12	-11	-29
	Baltic Sea coast	200	140	160	25	-13	-27	-41
	North Sea	9190	6800	10150	-9	-33	-26	-41
	Baltic Sea	200	160	180	11	-11	-28	-42
	Black Sea	4250	3220	5050	-16	-36	-34	-42
	Germany	13650	10180	15380	-11	-34	-28	-41

4.1.1.4 Nutrient emissions by erosion

The real starting point for the calculation of erosion-determined nutrient emissions is the map of soil losses. This was a prerequisite for a harmonised procedure for the calculation of emissions via this pathway. However, for the period covered in this study, no overall map of soil losses was available and the soil-loss map of BEHRENDT et al. (2000) had to be used. This was assembled from three parts from various sources.

From the researcher's point of view, a unified soil-loss map is urgently required in the coming years, both to be able to quantify nutrient emissions via the erosion pathway and the scientific formulation of the Sediment Delivery Ratio as well as to be better able to test and improve the enrichment ratio. As the studies on nutrient emissions in the Odra basin have shown, various emissions for both processes yielded comparable results. However, recent analyses of the results of individual estimates show large discrepancies (BEHRENDT et al., 2002).

Furthermore, in relation to the studies for water quality regulations, the existence of a unified and if possible high definition soil-loss map is certainly required since for the quantification of the emission situation smaller catchment sizes are needed.

An overview of the erosion-determined nutrient emissions and their change since the mid-eighties in the major German river basins is shown in Tables 4.10 and 4.11. The highest specific P emissions through erosion with more than 35 kg/(km²·a) P were determined for the Saale, Main, Mulde and Inn catchments. The lowest values of less than 5 kg/(km²·a) P were found in the Havel, Ruhr and North Sea coast catchments. While this is due to the low gradients in the Havel and North Sea coast catchments, for the Ruhr, it is due to the very small proportion of arable land.

The regional partitioning of the erosion-determined nutrient emissions are shown in Maps 4.11 and 4.12. The hot-points for nutrient emissions due to erosion lie in the catchments of the lower Danube, the upper parts of the Mulde and Saale as well as the middle reaches of the Weser and Leine. In all of these catchments, there is a high proportion of arable land with only average storage capacity. At present low estimated erosion-derived nutrient emissions are found in the catchments of the lower Ems and Weser as well as the North Sea coastal region and the central part of the north-east German lowlands in addition to those of the Havel and Schwarze Elster.

The total phosphorus emissions attributable to erosion in German catchments were estimated as 8900 t/a P for the period 1998-2000 and are thus nearly as large as for the period 1993-1997 (see Table 4.10). With consideration of normalised discharges, one must conclude that these emissions increased by an estimated 1 % between the two periods.

This is attributable to a very slow but definite increase in P-accumulation in soils (see 4.1.1.1). If one considers the changes over the period since 1985, the model calculations give an increase 22 %, 8 % when normalised for discharges. While the outflow normalised change in P-emissions only fluctuated a little between the individual catchments, one can see a very different relationship between the erosion-determined P-emissions and the change. In sections of the Danube catchment, (Naab, Inn) the erosion determined P-emissions decreased by 15 to 30 %. In the Ems, Weser and Elbe as well as the Lippe and Ruhr catchments, one can see in contrast a 30 to 70 % increase in such emissions. These differences are attributable to the different precipitation conditions in the individual sub-catchments during the study periods (see 4.1.1.1).

Table 4.11 and Map 4.11 show the N-emissions due to erosion. Overall, an N-emission of 13300 t/a N for the period 1998-2000 was estimated. This emission is almost identical to that for 1993-1997 and 11 % higher than that for the period 1983-1987 which is based on model parameters and is not related to soil N-content but only to the differences in precipitation conditions.

These differences in erosion-determined N-emissions are analogous to those for P-emissions.

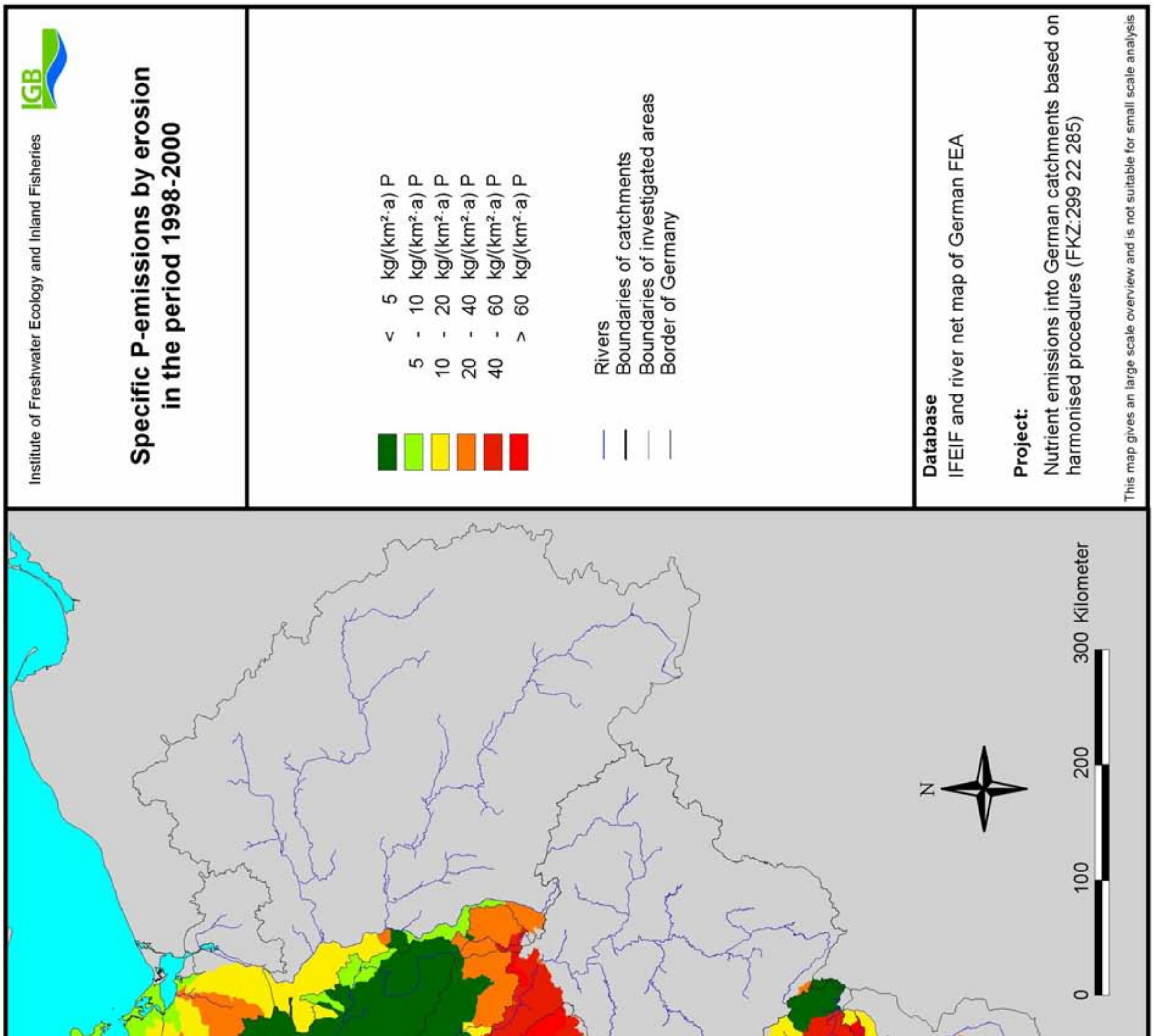
Compared to the results of BEHRENDT et al. (2000), nutrient emissions were 2 % less than for the 1983-1987 period and 10 % less than for the 1993-1997 period. This change is mainly due to the the change in the area which is relevant for erosion. The model estimations of BEHRENDT et al (2000) support this based on the results of the parish and district statistics on the agricultural area. In contrast, the analysis from the CORINE soil maps concerning also the other emission pathways use the same data.

Table 4.10: Phosphorus emissions via erosion and their changes for the periods 1983-1987, 1993-1997 and 1998-2000

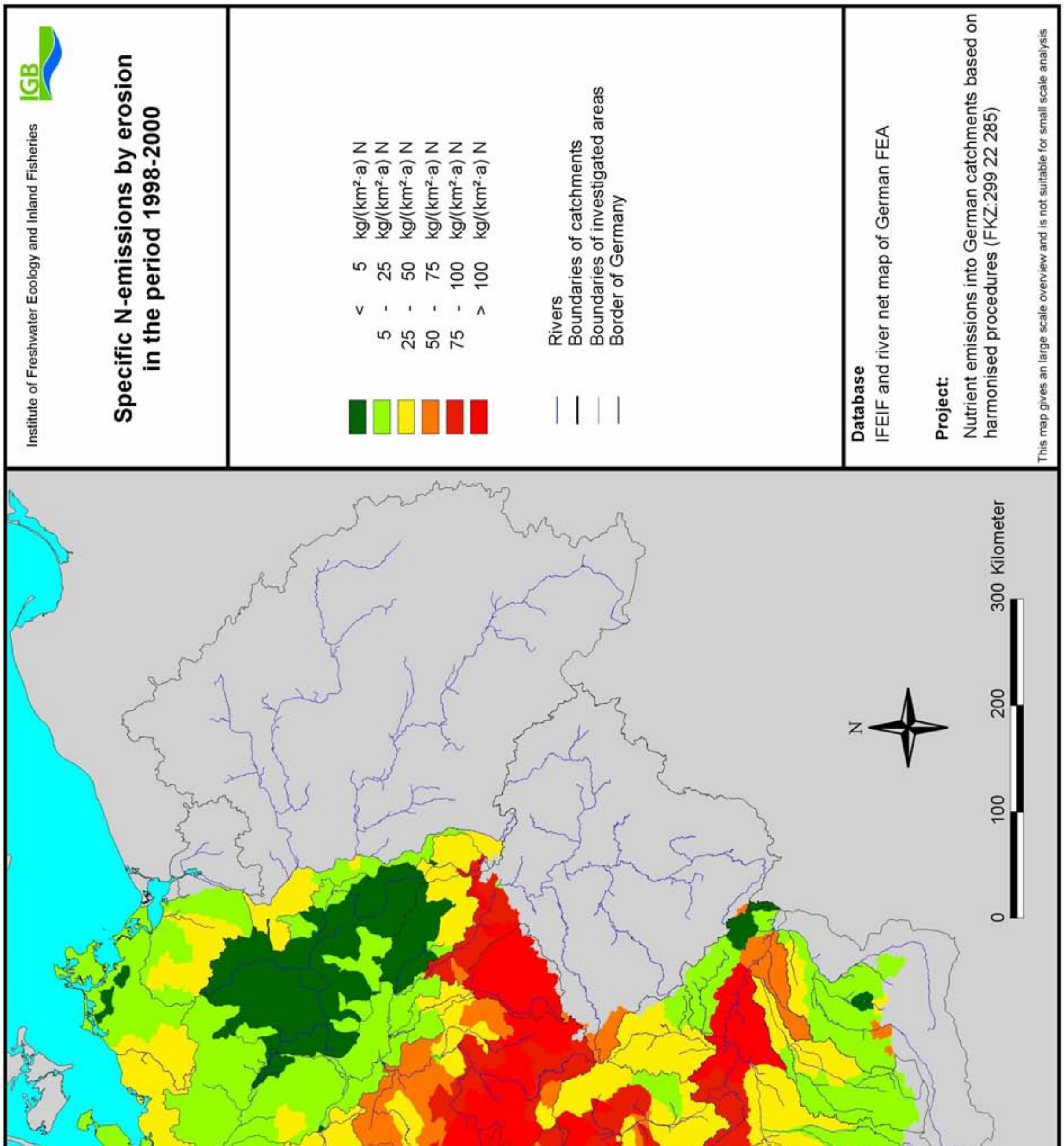
LOC.	CATCHMENT	EER_P			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	86	84	125	-31	-33	10	9
16902	Isar	272	270	240	13	13	8	8
18902	Inn	219	208	257	-15	-19	7	6
19101	Donau	1835	1822	1719	7	6	8	8
23704	Oberrhein	362	343	335	8	3	6	6
23801	Neckar	483	491	454	6	8	7	7
24901	Main	1171	1167	1145	2	2	8	8
26901	Mosel	123	125	117	6	7	8	7
27601	Ruhr	37	36	21	70	68	10	9
27801	Lippe	141	140	99	43	42	10	10
27903	Rhein	2915	2891	2666	9	8	8	7
37602	Ems	140	136	85	64	60	12	11
41002	Werra	201	202	133	51	52	8	6
42001	Fulda	140	139	121	16	15	9	8
48901	Aller	506	508	381	33	34	10	9
49103	Weser	1265	1258	870	45	45	9	8
53801	Schwarze Elster	69	74	43	62	73	9	7
54901	Mulde	340	354	222	53	59	9	6
56901	Saale	1194	1218	858	39	42	8	6
58901	Havel	110	122	82	34	49	8	7
59311	Elbe	2112	2189	1481	43	48	8	6
69001	Odra	71	76	60	18	26	7	6
	North Sea coast	167	160	134	25	20	11	11
	Baltic Sea coast	395	397	294	34	35	9	8
	North Sea	6597	6634	5235	26	27	8	7
	Baltic Sea	466	473	354	31	33	9	7
	Black Sea	1835	1822	1720	7	6	8	8
	Germany	8898	8929	7310	22	22	8	7

Table 4.11: Nitrogen emissions via erosion and their changes for the periods1983-1987, 1993-1997 and 1998-2000

LOC.	CATCHMENT	EER_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	190	180	300	-37	-40	0	0
16902	Isar	220	220	210	5	5	0	0
18902	Inn	180	170	240	-25	-29	0	0
19101	Donau	2210	2210	2350	-6	-6	0	0
23704	Oberrhein	530	500	520	2	-4	0	0
23801	Neckar	700	720	710	-1	1	0	0
24901	Main	1970	1970	2120	-7	-7	0	0
26901	Mosel	290	300	300	-3	-0	0	0
27601	Ruhr	50	40	30	67	33	0	0
27801	Lippe	180	180	140	29	29	0	0
27903	Rhein	4690	4680	4710	-0	-1	0	0
37602	Ems	280	270	190	47	42	0	0
41002	Werra	430	440	310	39	42	0	0
42001	Fulda	210	210	200	5	5	0	0
48901	Aller	660	660	540	22	22	0	0
49103	Weser	1800	1810	1360	32	33	0	0
53801	Schwarze Elster	80	90	60	33	50	0	0
54901	Mulde	660	700	470	40	49	0	0
56901	Saale	1940	2010	1510	28	33	0	0
58901	Havel	140	160	120	17	33	0	0
59311	Elbe	3460	3650	2650	31	38	0	0
69001	Odra	110	120	100	10	20	0	0
	North Sea coast	250	240	210	19	14	0	0
	Baltic Sea coast	500	510	410	22	24	0	0
	North Sea	10490	10650	9120	15	17	0	0
	Baltic Sea	610	630	500	22	26	0	0
	Black Sea	2210	2210	2350	-6	-6	0	0
	Germany	13300	13490	11980	11	13	0	0



Map 4.11: Phosphorus emissions via erosion for the period 1998-2000



Map 4.12: Nitrogen emissions via erosion for the period 1998-2000

4.1.1.5 Nutrient emissions from tile drainage

The emissions of phosphorus and nitrogen through tile drainage for the periods 1983-87, 1993-97 and 1998-2000 are shown in Tables 4.12 and 4.13. In addition to the emissions, these tables indicate changes since the initial study period (1983-1987) under the particular precipitation and discharge regimes and on the basis of normalised discharges.

Total emissions through tile drainage of 3270 t/a P and 106000 t/a N were calculated for the period 1998-2000. The emission for phosphorus was essentially the same as for the 1993-1997 period. For nitrogen, a decrease of 5 % or 8000 t/a N was estimated between these periods, with or without outflow-normalised conditions. Comparison with the estimates of BEHRENDT et al (2000) for the period 1983-1987, the 1993-1997 estimates indicate a 6 or 4 % (with normalisation) reduction which can be conclusively related to the altered N surpluses.

An overview of tile drainage emissions for German catchments in the period 1998-2000 is shown in Maps 4.13 and 4.14. Loading hot-points were found for phosphorus where factors such as intensity of land-use, the extent of tile drainage and the proportion of bog area come together in a particular catchment. The highest specific phosphorus emissions were estimated for the Ems, Aller and Weser catchments. The smallest nitrogen emissions were found for the Naab catchment which has only 0.3 % of its area under agriculture and with the lowest proportion of tile-drained land of all 22 catchments. The Lippe catchment has the highest estimated N-emission via tile drainage followed by the Mulde catchment. In retrospect, the change in nitrogen emissions via tile drainage shows for all catchments a clear decrease of 17 to 56 % with an average of 34 %. This decrease can be explained by a reduction in soil nitrogen surplus which are used for calculation of nitrogen concentrations in tile drainage water.

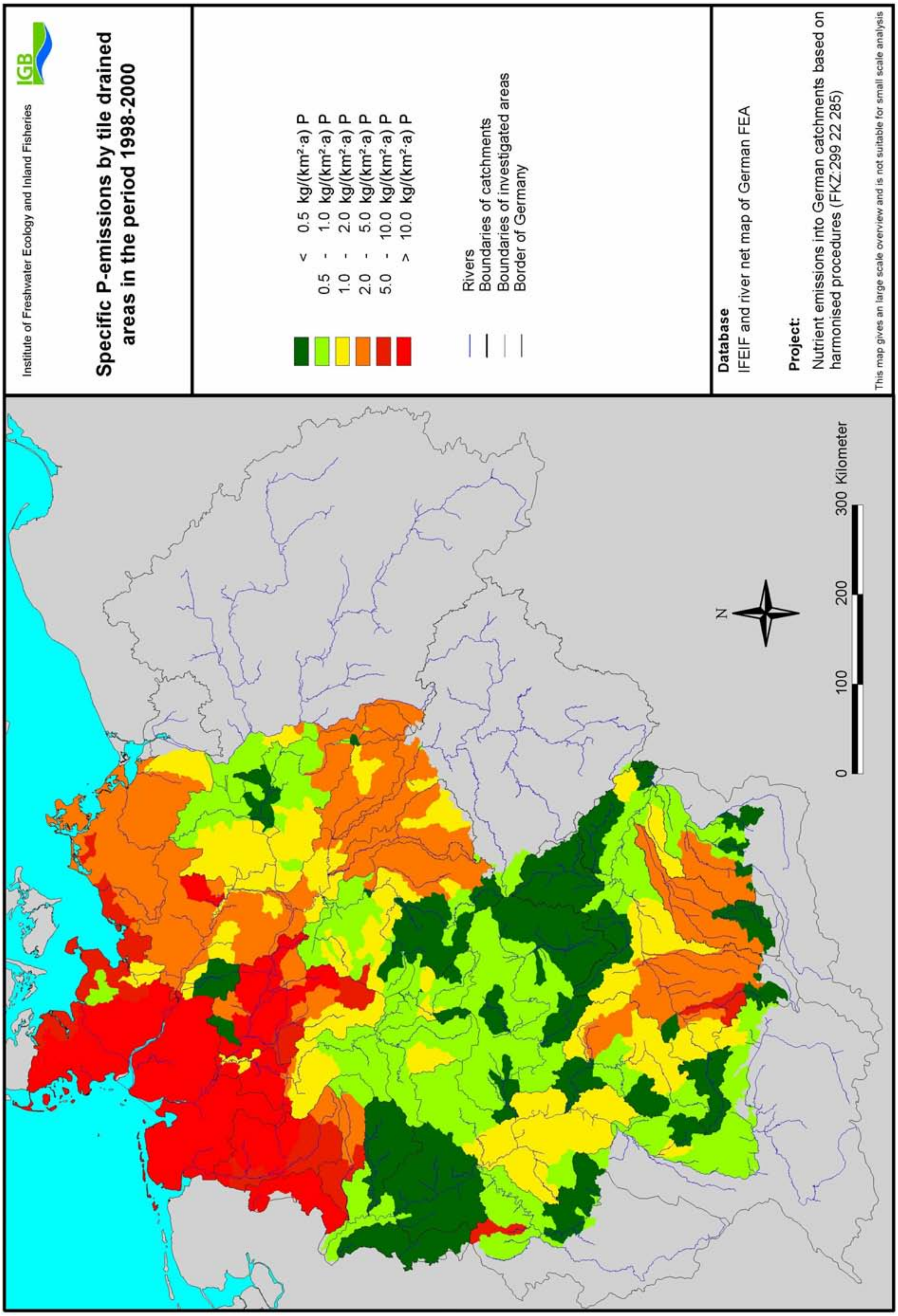
In addition, Map 4.15 shows the outflow normalised changes in nitrogen emissions through tile drainage in the period 1998-2000 compared to that for 1983-1987. This picture is almost identical to the changes in N-surpluses for this period. Only for individual parts of the Danube and Rhine catchments as well as the catchment of the Ems there was a small increase in N-emissions through tile drainage. In other catchments of the former German Federal Republic such emissions decreased by up to 20 % and in the former East Germany up to 50 % overall with even greater decreases in Brandenburg and the Uecker catchment, i.e. the north-east German plain.

Table 4.12: Phosphorus emissions through tile drainage and their changes for the periods1983-1987, 1993-1997 and 1998-2000

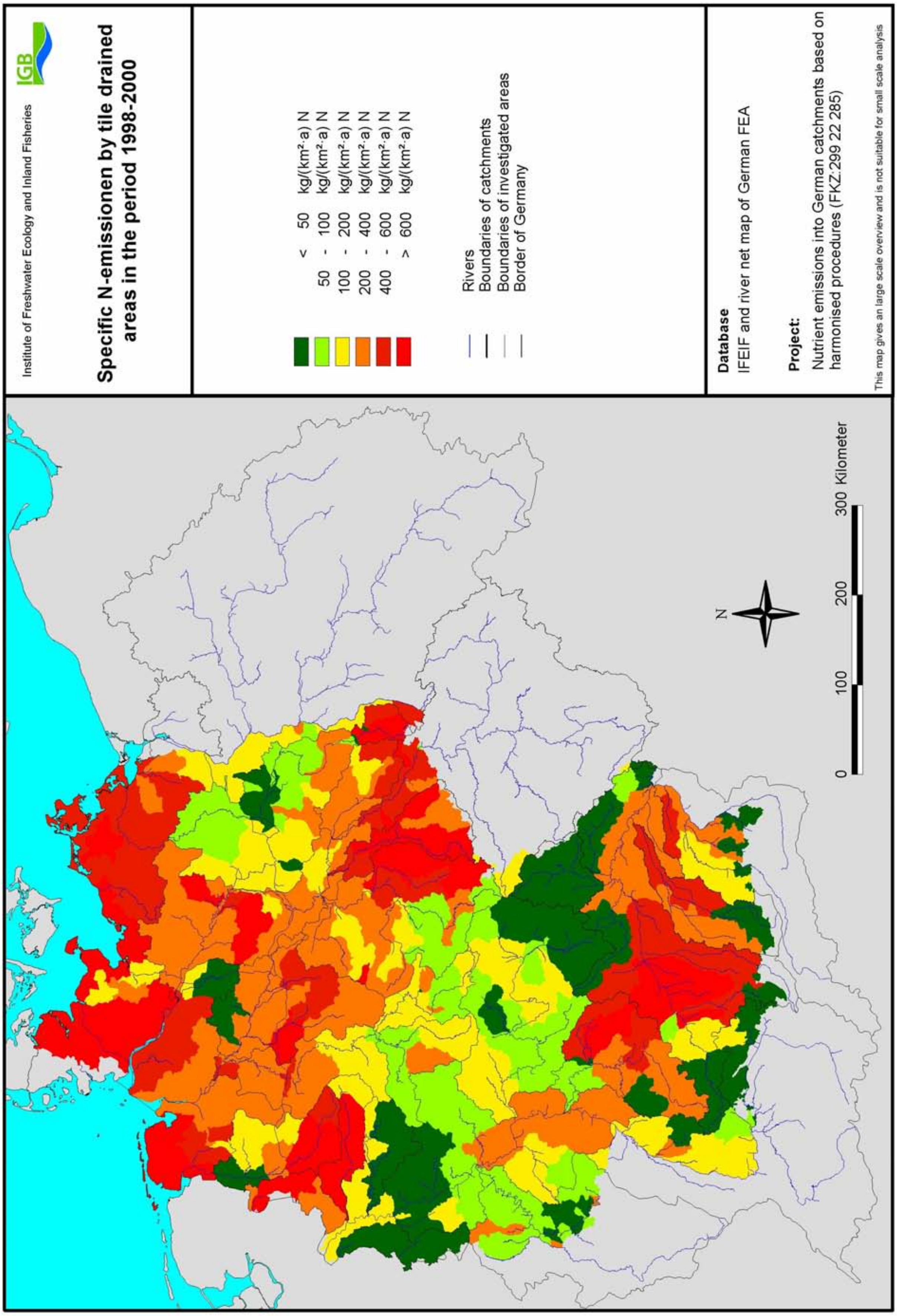
LOC.	CATCHMENT	EDR_P			Changes		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	0	0	0	-18	-1	0	0
16902	Isar	21	21	24	-14	-14	0	0
18902	Inn	14	14	15	-1	-6	0	0
19101	Danube	88	89	99	-10	-9	0	0
23704	Upper Rhine	10	9	11	-14	-24	0	0
23801	Neckar	15	17	17	-8	0	0	0
24901	Main	11	13	13	-13	1	0	0
26901	Mosel	11	13	13	-10	5	0	0
27601	Ruhr	1	1	1	-2	10	0	0
27801	Lippe	18	20	18	0	13	0	0
27903	Rhine	90	98	97	-7	1	0	0
37602	Ems	83	87	85	-2	2	0	0
41002	Werra	4	5	4	2	11	0	0
42001	Fulda	5	5	5	-8	5	0	0
48901	Aller	238	263	272	-13	-3	0	0
49103	Weser	328	361	380	-14	-5	0	0
53801	Schwarze Elster	14	15	13	5	15	0	0
54901	Mulde	16	17	14	9	17	0	0
56901	Saale	31	32	29	8	11	0	0
58901	Havel	31	34	30	2	13	0	0
59311	Elbe	159	170	150	6	13	0	0
69001	Odra	7	7	7	3	8	0	0
	North Sea coast	2427	2367	2614	-7	-9	0	0
	Baltic sea coast	88	90	85	4	5	0	0
	North Sea	3087	3083	3325	-7	-7	0	0
	Baltic Sea	95	97	92	4	6	0	0
	Black Sea	88	89	99	-10	-9	0	0
	Germany	3271	3269	3515	-7	-7	0	0

Table 4.13: Nitrogen emissions through tile drainage and their changes for the periods1983-1987, 1993-1997 and 1998-2000

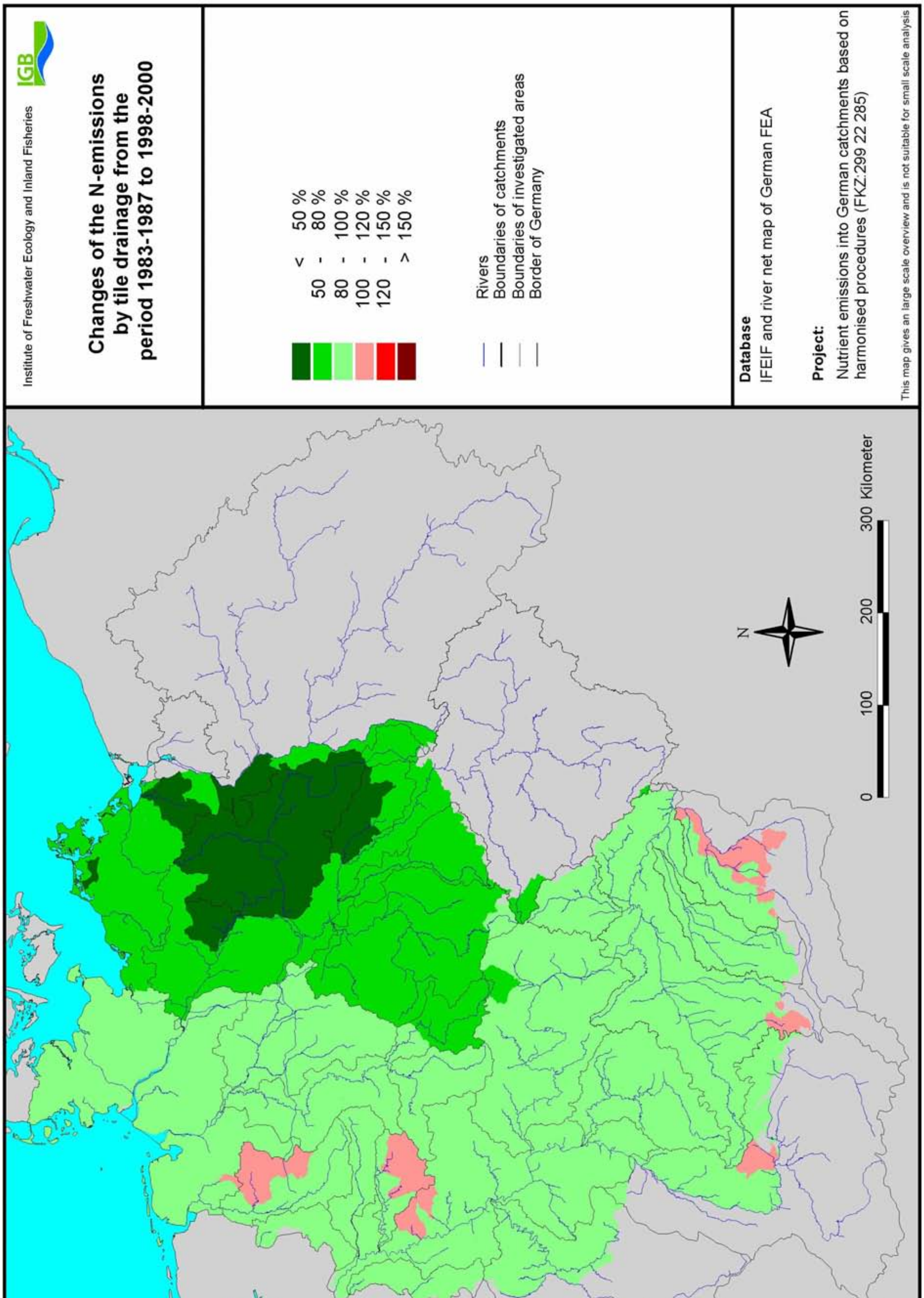
LOC.	CATCHMENT	EDR_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	40	40	50	-20	-20	-24	-18
16902	Isar	2090	2290	2760	-24	-17	-24	-17
18902	Inn	1370	1450	1710	-20	-15	-20	-15
19101	Danube	13380	14590	17470	-23	-16	-17	-16
23704	Upper Rhine	1090	1170	1510	-28	-23	-20	-15
23801	Neckar	4090	4520	5310	-23	-15	-23	-15
24901	Main	1970	2160	2660	-26	-19	-26	-19
26901	Mosel	710	760	900	-21	-16	-22	-16
27601	Ruhr	130	140	160	-19	-13	-20	-14
27801	Lippe	3510	3770	4360	-19	-14	-19	-14
27903	Rhine	14890	16320	19440	-23	-16	-23	-15
37602	Ems	3370	3610	4140	-19	-13	-19	-13
41002	Werra	610	660	1060	-42	-38	-42	-38
42001	Fulda	710	760	950	-25	-20	-25	-20
48901	Aller	4740	5170	5970	-21	-13	-21	-13
49103	Weser	8350	9070	10820	-23	-16	-23	-16
53801	Schwarze Elster	1640	1790	3550	-54	-50	-54	-50
54901	Mulde	3990	4400	8060	-50	-45	-51	-45
56901	Saale	7180	7810	14090	-49	-45	-49	-45
58901	Havel	3280	3570	7410	-56	-52	-56	-52
59311	Elbe	24840	26700	50300	-51	-47	-51	-47
69001	Odra	680	720	1390	-51	-48	-51	-48
	North Sea coast	28480	30000	34270	-17	-12	-17	-12
	Baltic Sea coast	11890	12880	23260	-49	-45	-49	-45
	North Sea	79930	85700	118970	-33	-28	-33	-28
	Baltic Sea	12570	13610	24650	-49	-45	-49	-45
	Black Sea	13380	14590	17470	-23	-16	-17	-16
	Germany	105880	113900	161090	-34	-29	-34	-29



Map 4.13: P-emissions through tile drainage for the period 1998-2000



Map 4.14: N-emissions through tile drainage for the period 1998-2000



Map 4.15: Change in N-emissions through tile drainage for the period 1985 to 1999.

4.1.1.6 Nutrient emissions via groundwater

Table 4.14 shows the calculated P-emissions via groundwater for the three study periods. For the period 1998-2000, total P-emissions via this pathway were estimated to be 57000 t/a P which represents a 14-16 % reduction from the previous periods. This can be attributed to changes in percolating water quantities. Map 4.16 shows that P-emissions via groundwater are highest in catchments with a high proportion of agriculturally used bogs.

Nitrogen emissions via groundwater and natural interflow were estimated as 385000 t/a N for the period 1998-2000 (see Table 4.15), a reduction of 5 and 12 % from the two earlier study periods. Outflow-normalised conditions yield a reduction of 10 or 11 % for the sum of all German catchments.

Due to a different basis for the calculations, a greater change in N-emissions via groundwater is to be expected. However, for the large river basins, this is only the case for the Elbe and Weser. Table 4.16 shows the changes for the estimations for 1983-1987 and 1993 to 1997 with consideration of the new model parameters. From this, it can be seen that there are large changes in nitrogen emissions for some of the smaller catchments. Overall, the simulation shows a clear tendency for higher emissions for 1983-1987 and lower emissions for 1993 to 1997 in comparison to the results of BEHRENDT et al (2000). This can only be explained if the newly calculated retention times are less than those used in the earlier study. Whether this relationship can be verified by measured values, e.g. the patterns of nitrate concentrations over time, must be clarified in future studies.

Maps 4.17 and 4.18 show regional differences in calculated percolating water and groundwater concentrations. The catchment-differentiated retention picture remains valid. In eastern Germany, the percolating water concentrations are highest and in the north-east German plain, the groundwater concentrations the lowest. This pattern is also reflected in the underground nitrogen retention times shown in Map 4.19. In most of the north-east German plain and the Saale catchment, this retention is more than 90 % and in some cases 95 % of the total N-pool. In contrast, in the upper Rhine and Mosel catchments, less than 60 % of the N-surplus is removed from the water phase by denitrification.

Map 4.20 shows the regional differentiation of N-emissions for the period 1998-2000. Once again, the greatest role for groundwater lies in the north-east German plain. On the other hand, the lowest proportion of underground N-retention was found for the north-west German lowlands and the Danube basin with less than 70 % of the N-surplus.

Finally, Map 4.21 shows changes in calculated changes in groundwater N-emissions in individual German catchments since the 1983-1987 period. Overall, changes are often around or more than 20 %. Groundwater N-emissions have increased since this period in the north-west German plain and parts of the Danube basin.

Table 4.14: Phosphorus emissions via groundwater and their changes for the periods 1983-1987, 1993-1997 and 1998-2000

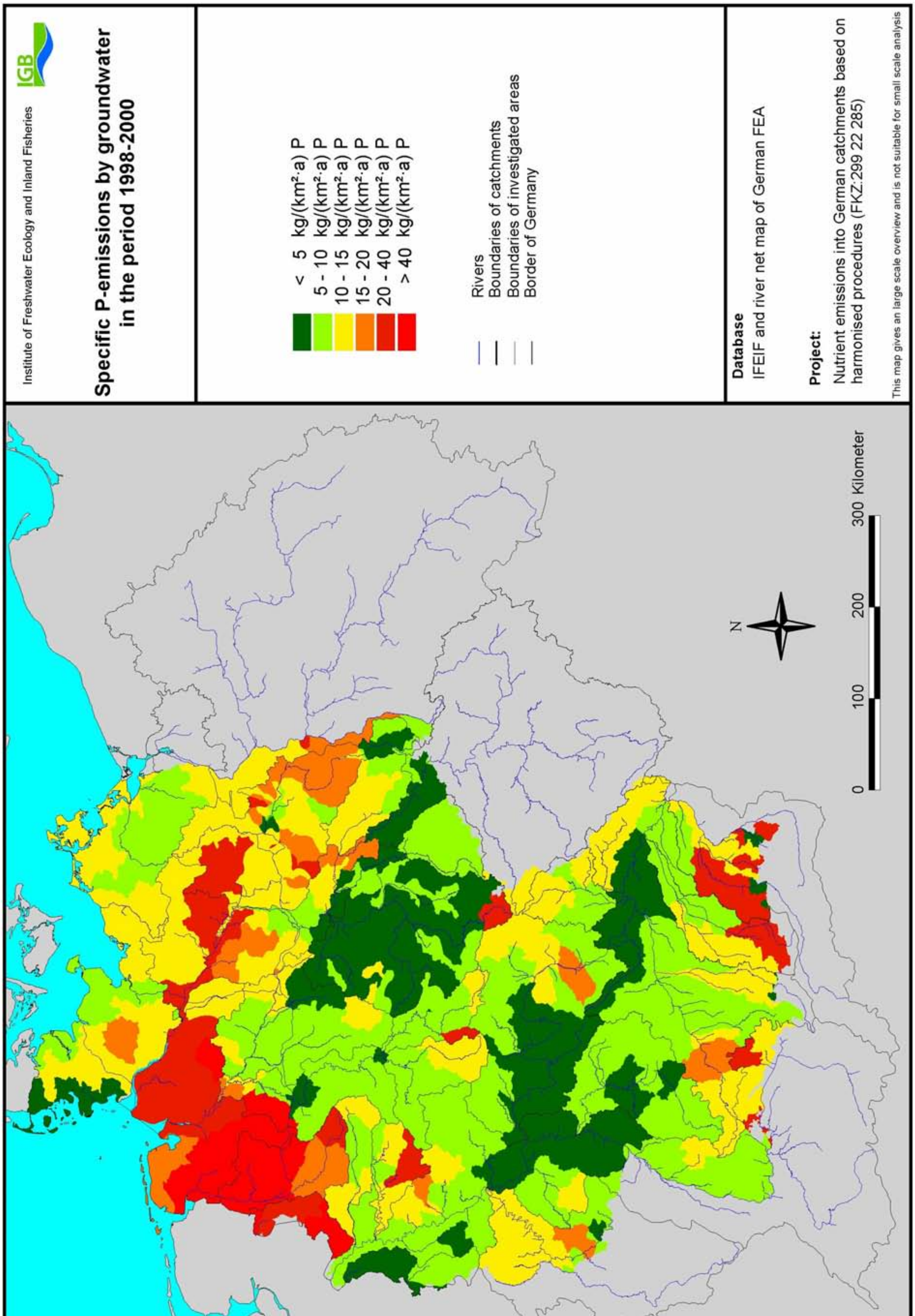
LOC.	CATCHMENT	EGW_P			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	56	48	56	-0	-15	0	0
16902	Isar	113	109	102	10	6	0	0
18902	Inn	150	127	144	4	-12	0	0
19101	Danube	643	578	679	-5	-15	0	0
23704	Upper Rhine	142	127	132	8	-4	0	0
23801	Neckar	94	94	96	-2	-2	0	0
24901	Main	225	206	201	12	2	0	0
26901	Mosel	131	106	113	15	-6	0	0
27601	Ruhr	64	64	64	1	1	0	0
27801	Lippe	47	49	46	3	8	0	0
27903	Rhine	947	869	888	7	-2	0	0
37602	Ems	659	672	847	-22	-21	0	0
41002	Werra	57	50	54	6	-7	0	0
42001	Fulda	81	68	76	6	-10	0	0
48901	Aller	161	133	204	-22	-35	0	0
49103	Weser	456	405	711	-36	-43	0	0
53801	Schwarze Elster	52	54	60	-13	-9	0	0
54901	Mulde	41	39	40	1	-2	0	0
56901	Saale	105	113	113	-7	0	0	0
58901	Havel	270	374	398	-32	-6	0	0
59311	Elbe	720	987	950	-24	4	0	0
69001	Odra	53	55	51	4	8	0	0
	North Sea coast	1975	1770	2191	-10	-19	0	0
	Baltic Sea coast	256	243	290	-12	-16	0	0
	North Sea	4757	4702	5587	-15	-16	0	0
	Baltic Sea	308	298	341	-9	-13	0	0
	Black Sea	646	581	681	-5	-15	0	0
	Germany	5712	5580	6609	-14	-16	0	0

Table 4.15: Nitrogen emissions via groundwater and their changes for the periods 1983-1987, 1993-1997 and 1998-2000

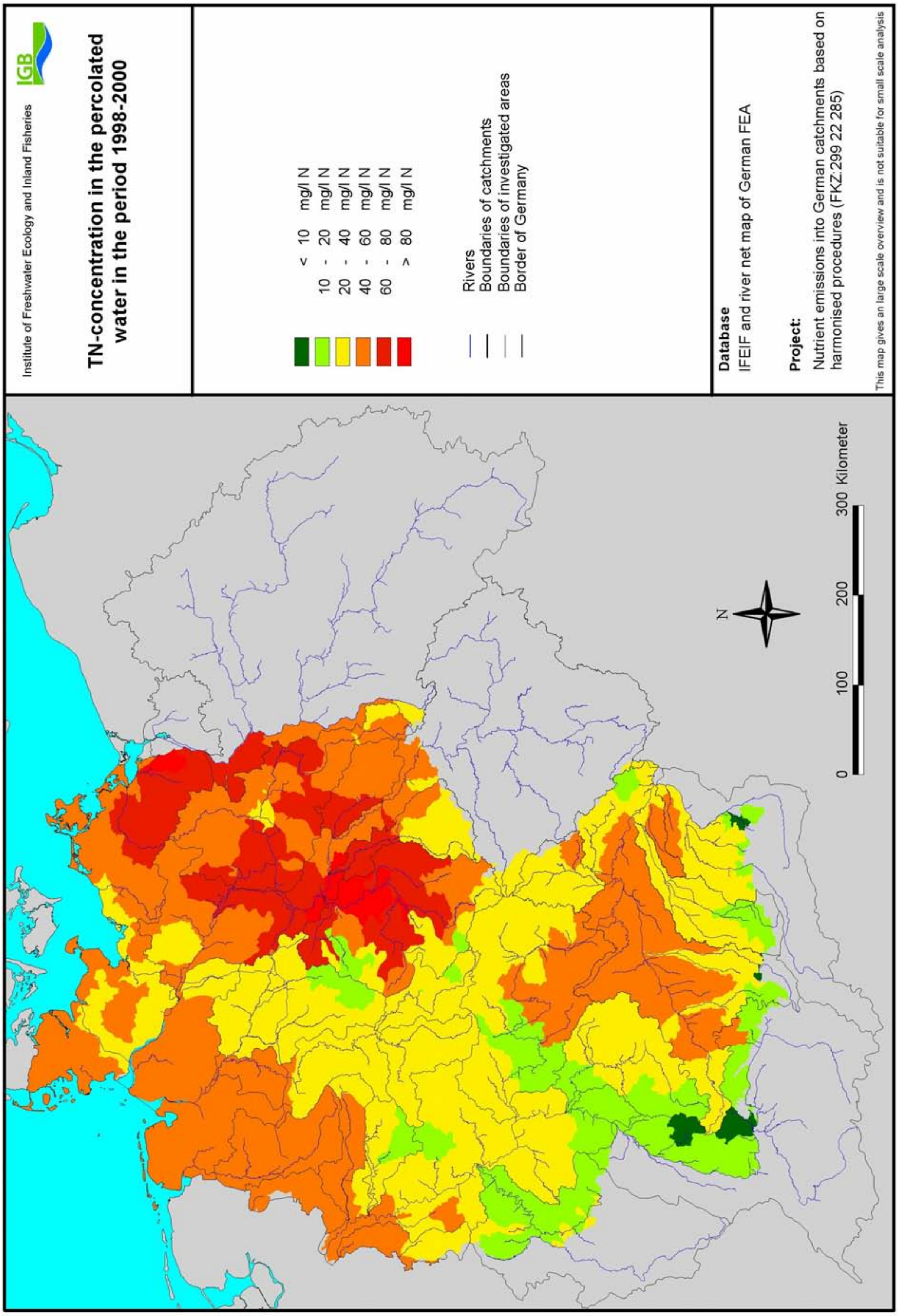
LOC.	CATCHMENT	EGW_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	6990	6170	8490	-18	-27	-17	-15
16902	Isar	12470	12930	13120	-5	-1	-17	-11
18902	Inn	17380	13740	12610	38	9	16	14
19101	Danube	85120	77370	82770	3	-7	-6	-4
23704	Upper Rhine	14860	12200	15190	-2	-20	-13	-20
23801	Neckar	18190	18390	21270	-14	-14	-16	-15
24901	Main	30880	28890	36800	-16	-21	-26	-24
26901	Mosel	12830	10770	14200	-10	-24	-22	-21
27601	Ruhr	6140	5190	5870	5	-12	-1	-14
27801	Lippe	6650	6320	5950	12	6	8	-2
27903	Rhine	123630	112310	138390	-11	-19	-18	-19
37602	Ems	18370	16740	12740	44	31	31	20
41002	Werra	7090	5700	8170	-13	-30	-22	-28
42001	Fulda	9300	8000	10410	-11	-23	-17	-17
48901	Aller	12260	10940	16760	-27	-35	-27	-28
49103	Weser	42210	36020	50710	-17	-29	-20	-22
53801	Schwarze Elster	2310	2730	4280	-46	-36	-28	-22
54901	Mulde	7480	6810	9290	-19	-27	-27	-25
56901	Saale	14770	16920	21560	-31	-22	-25	-22
58901	Havel	5970	8850	11150	-46	-21	-20	-13
59311	Elbe	38910	48750	60770	-36	-20	-25	-20
69001	Odra	1240	1480	1960	-37	-24	-30	-23
	North Sea coast	62430	51150	45210	38	13	24	13
	Baltic Sea coast	11170	10810	12420	-10	-13	-11	-5
	North Sea	285540	264960	307810	-7	-14	-11	-13
	Baltic Sea	12410	12290	14380	-14	-15	-13	-7
	Black Sea	85500	77650	83060	3	-7	-6	-4
	Germany	383450	354900	405250	-5	-12	-10	-11

Table 4.16: Change in nitrogen emissions via groundwater in the periods 1983-1987, 1993-1997 with consideration of the catchment differentiated retention times

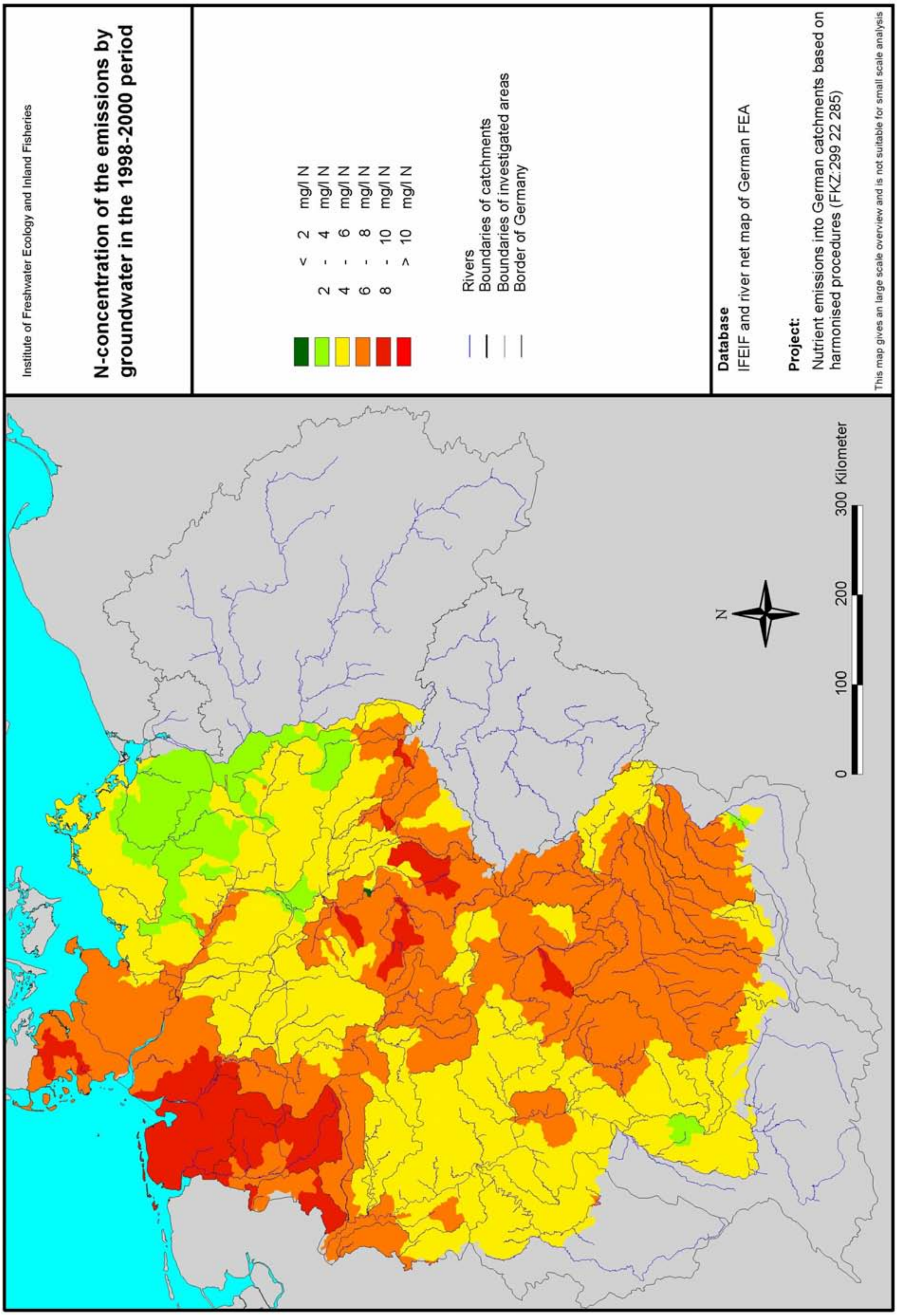
LOC.	CATCHMENT	1993-1997			1983-1987		
		new	**old**	**Diff**	**new**	**old**	**Diff**
		[t/a N]	[t/a N]	**[%]**	[t/a N]	[t/a N]	**[%]**
14902	Naab	6170	6990	-12	8490	8230	3
16902	Isar	12930	12780	1	13120	11370	15
18902	Inn	13740	12980	6	12610	13120	-4
19101	Danube	77370	78090	-1	82770	79400	4
23704	Upper Rhine	12200	12890	-5	15190	14160	7
23801	Neckar	18390	18960	-3	21270	20520	4
24901	Main	28890	32980	-12	36800	34870	6
26901	Mosel	10770	11670	-8	14200	13310	7
27601	Ruhr	5190	4810	8	5870	5010	17
27801	Lippe	6320	8620	-27	5950	8240	-28
27903	Rhine	112310	122750	-9	138390	132580	4
37602	Ems	16740	21850	-23	12740	19080	-33
41002	Werra	5700	7550	-25	8170	7600	8
42001	Fulda	8000	8680	-8	10410	9680	8
48901	Aller	10940	14800	-26	16760	16400	2
49103	Weser	36020	45820	-21	50710	50060	1
53801	Schwarze Elster	2730	2860	-5	4280	3270	31
54901	Mulde	6810	6840	-0	9290	6710	38
56901	Saale	16920	23360	-28	21560	21990	-2
58901	Havel	8850	9000	-2	11150	9270	20
59311	Elbe	48750	57270	-15	60770	53760	13
69001	Odra	1480	1740	-15	1960	1670	17
	North Sea coast	51150	54000	-5	45210	52770	-14
	Baltic Sea coast	10810	12600	-14	12420	11840	5
	North Sea	264960	301690	-12	307810	308240	-0
	Baltic Sea	12290	14340	-14	14380	13510	6
	Black Sea	77650	78390	-1	83060	79680	4
	Germany	354900	394430	-10	405250	401430	1



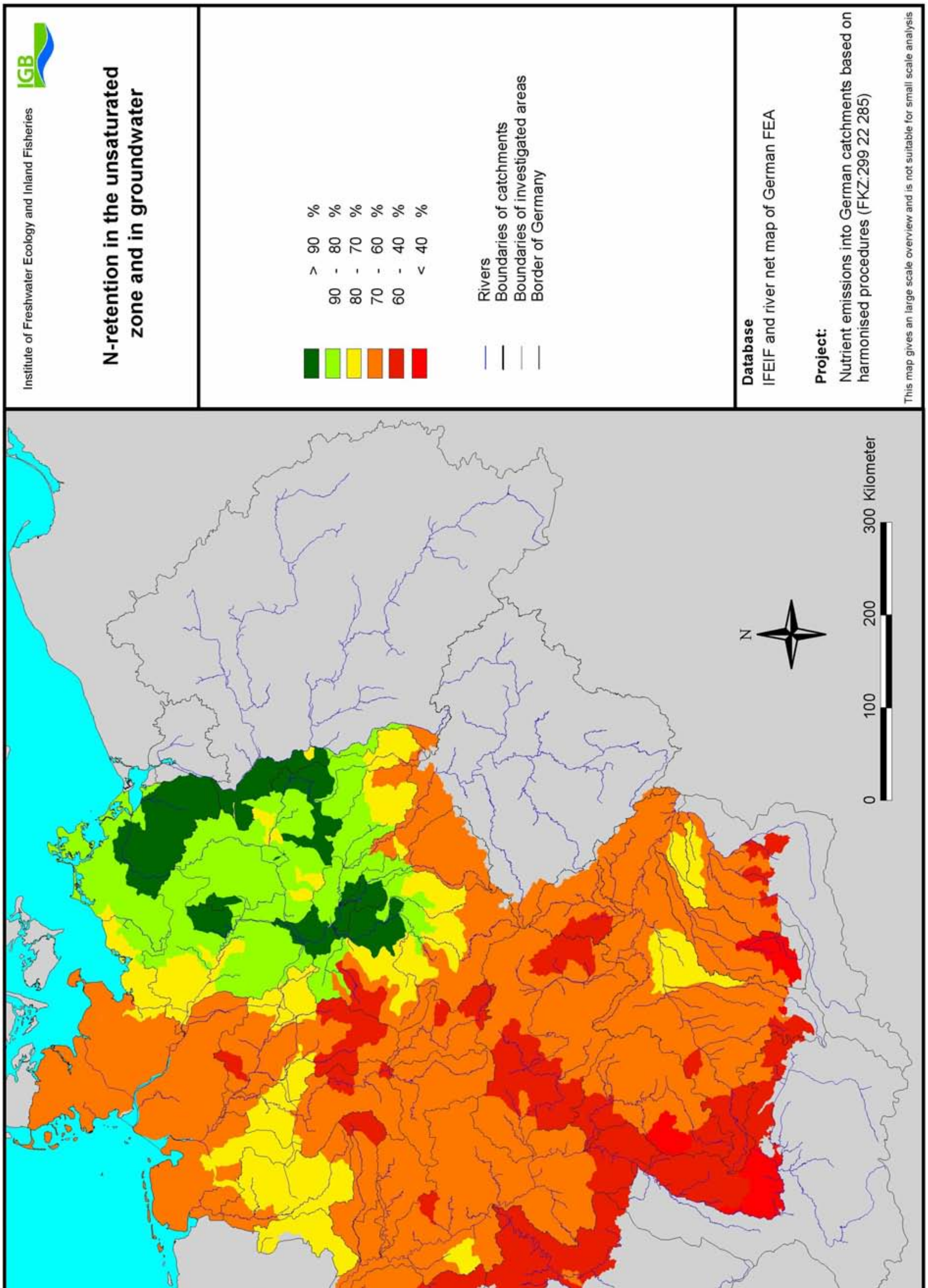
Map 4.16: P-emissions via groundwater for the period 1998-2000



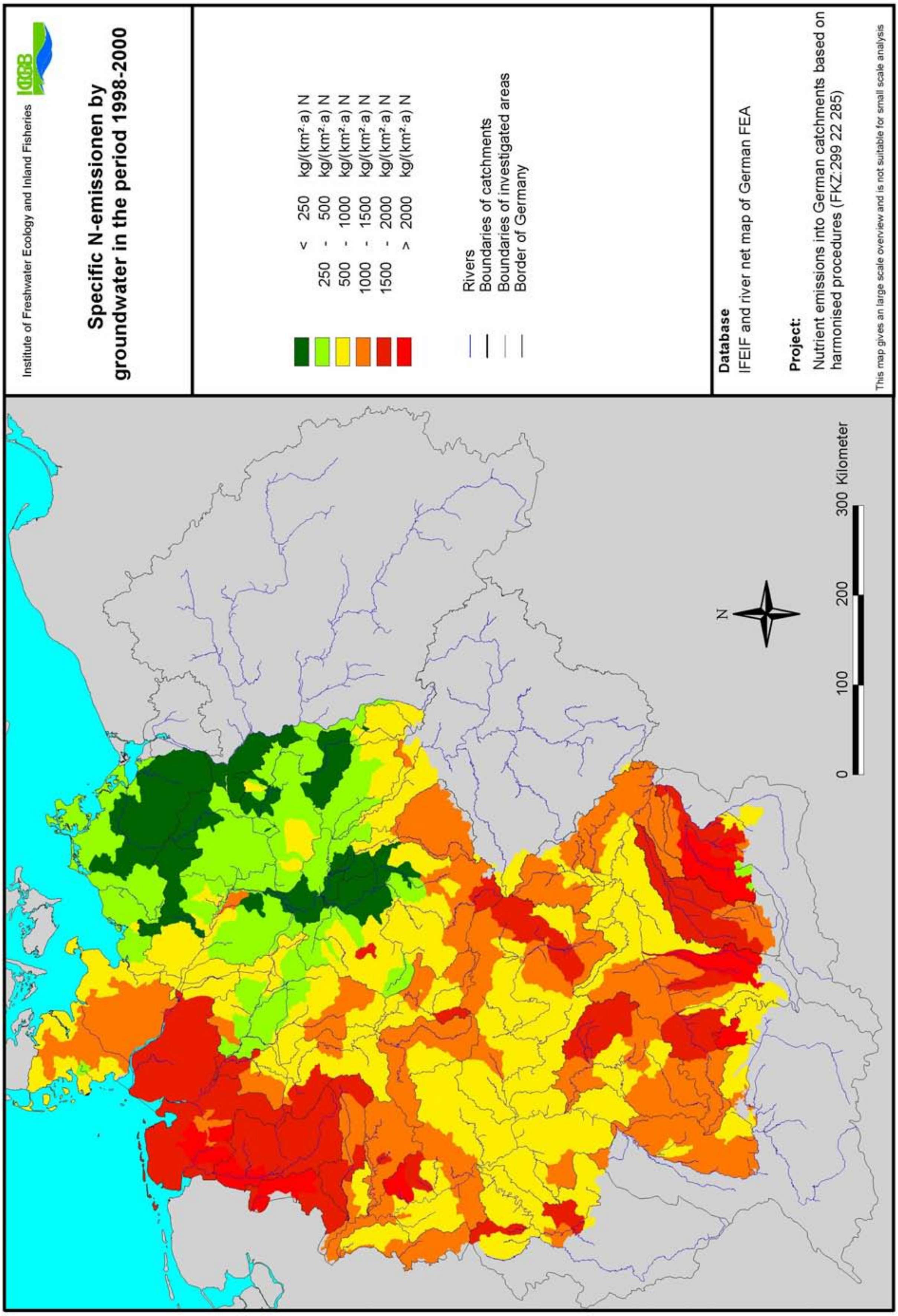
Map 4.17: N-concentrations in the percolating water for the period 1998-2000



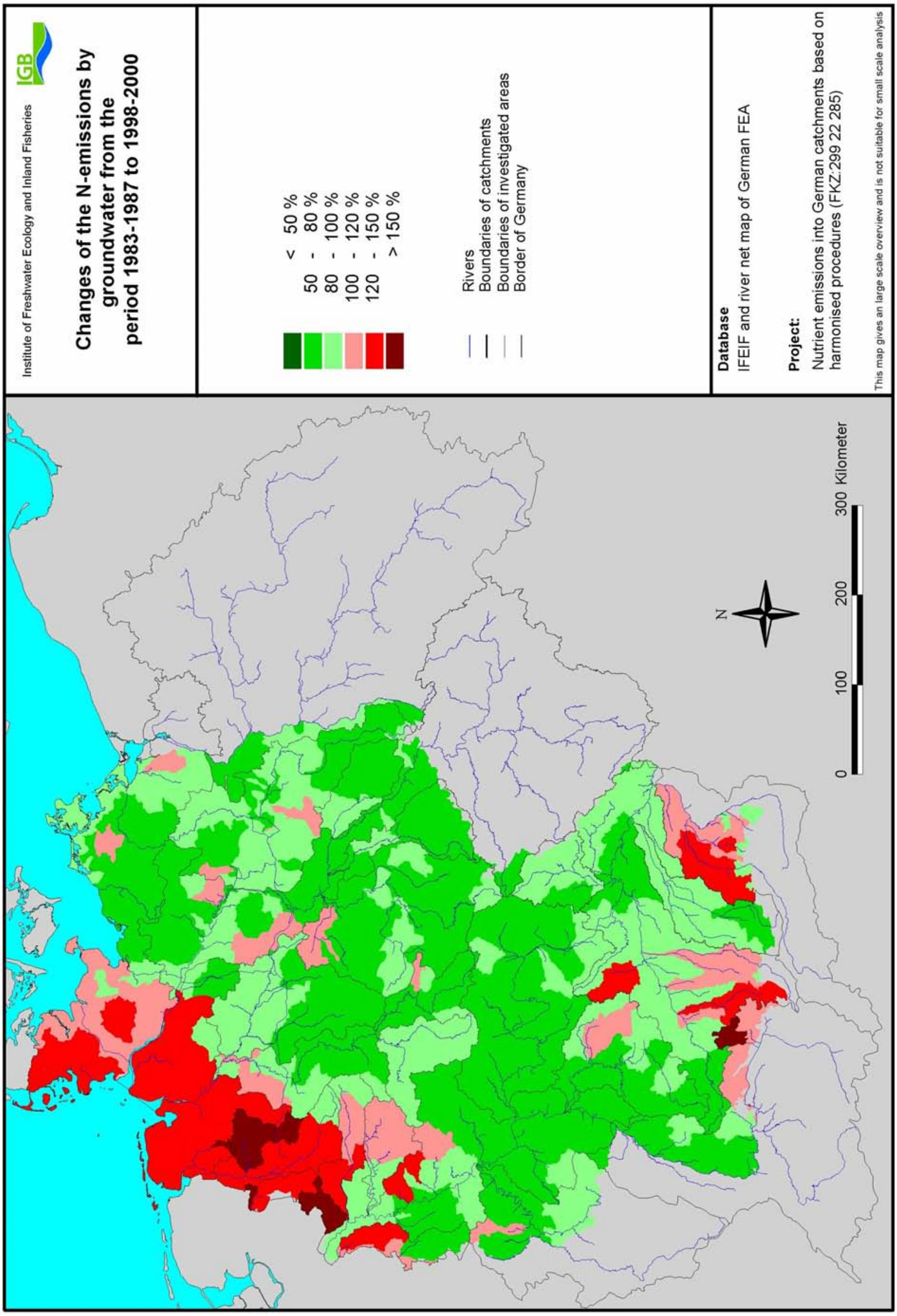
Map 4.18: Groundwater N-concentrations for the period 1998-2000



Map 4.19 N-retention in the unsaturated zone of soils and groundwater



Map 4.20: N-emissions via groundwater for the period 1998-2000



Map 4.21: Changes in N-emissions via groundwater between 1983-1987 and 1998-2000.

4.1.1.7 Nutrient emissions from urban areas

Table 4.17 shows the estimated P-emissions from urban areas for the three study periods. This pathway includes emissions from the sewer system in the form of combined sewer overflow and separate sewers, from urban areas and from the population not connected to the sewer system. Apart from the point source emissions, the diffuse emissions from urban areas show the greatest reductions. In the period 1998-2000, the P-emission from this pathway was estimated as 3300 t/a P representing a 59 % reduction from the estimated emission of 4800 t/a P for the 1983-1987 period.

As shown in Map 4.22, the present hot-spots for urban P-emissions are in the catchments of the Saale, Mulde, the upper Elbe and the lower Rhine. For the Mulde and upper Elbe, the cause is the high proportion of the population of Saxony and Thuringia connected to small water treatment plants. For the Rhine and Saar, the most important contributory factors are the high population and the total saturation of the storage capacity of the mixed sewer system.

For the 22 catchments considered Map 4.23 shows that the decreases in P-emissions from urban areas can be found in regions dominated by separated sewer systems, e.g. Ems.

In comparison to BEHRENDT et al. (2000) methodological changes lead to a 12 % reduction in P-emissions and to more than 20 % for nitrogen for the 1993-1997 period.

The N-emissions from urban areas are shown in Table 4.18 as well as in Maps 4.24 and 4.25. Overall these emissions were estimated as 25000 t/a N for 1998-2000 or a decrease of 37 % since the 1983-1987 period. The regional hot-spots were the same as for phosphorus.

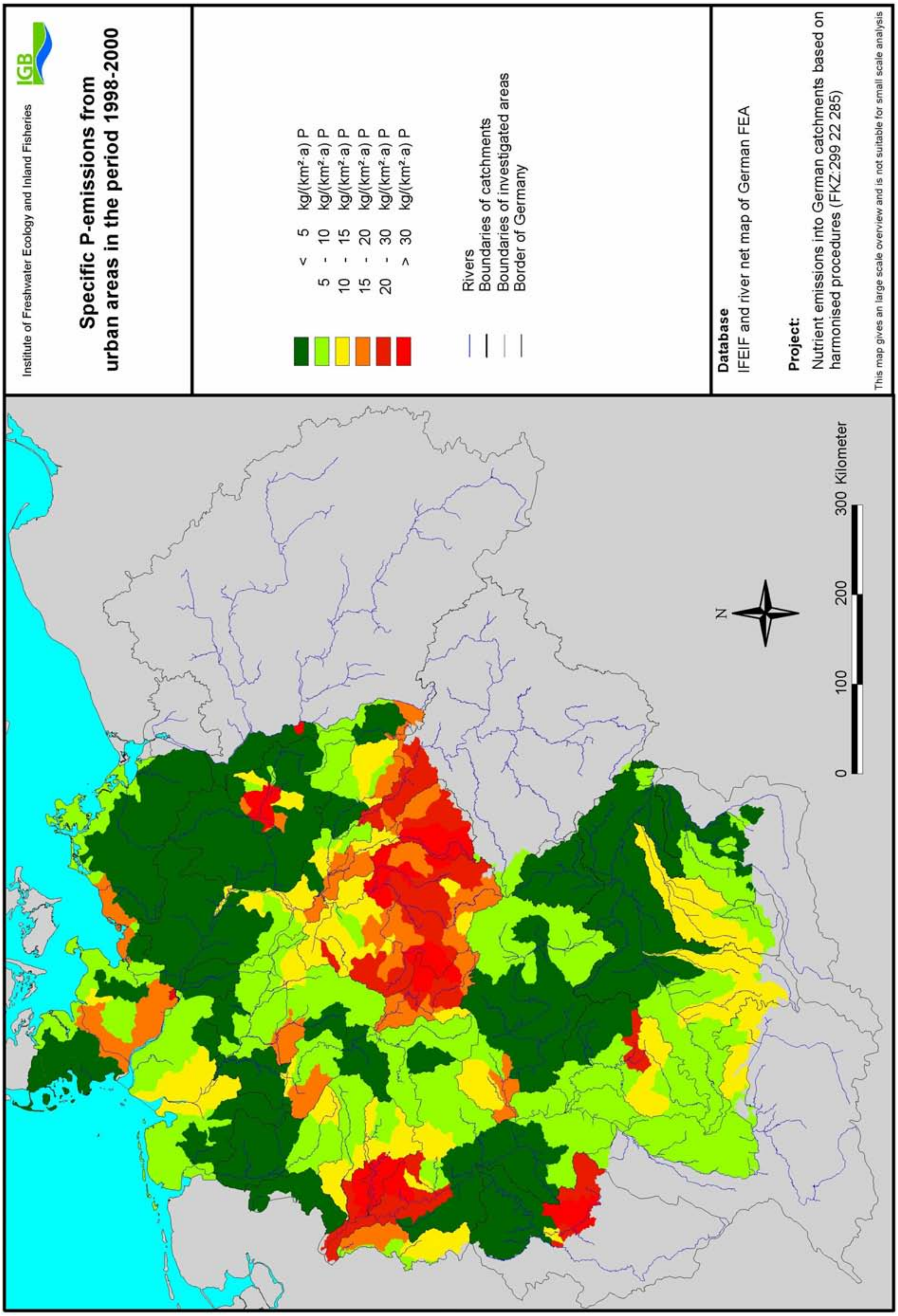
Map 4.25 shows that from 1985 to 2000 the changes are clearly due to changes in atmospheric nitrogen deposition.

Table 4.17: Phosphate emissions from urban areas for the periods 1983-1987, 1993-1997 and 1998-2000 and their changes

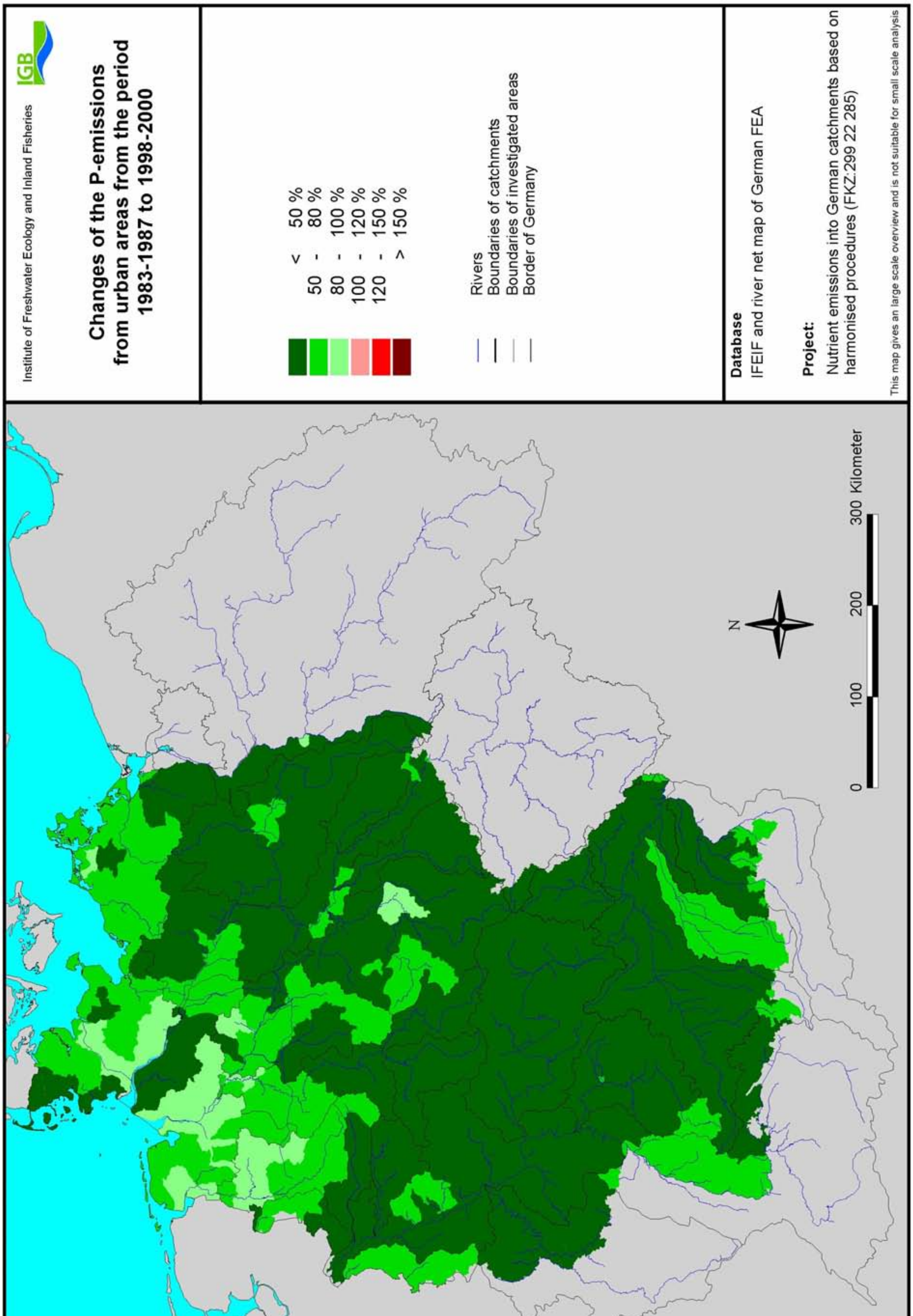
LOC.	RIVER	EUR_P			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	19	21	53	-64	-60	-66	-61
16902	Isar	89	85	156	-43	-46	-49	-50
18902	Inn	45	38	80	-44	-53	-54	-56
19101	Danube	331	340	764	-57	-55	-59	-58
23704	Upper Rhine	115	103	191	-40	-46	-46	-47
23801	Neckar	106	128	279	-62	-54	-59	-57
24901	Main	155	172	550	-72	-69	-73	-68
26901	Mosel	130	149	455	-71	-67	-71	-67
27601	Ruhr	90	95	222	-60	-57	-59	-57
27801	Lippe	41	41	73	-43	-44	-48	-48
27903	Rhine	1057	1044	2845	-63	-63	-65	-63
37602	Ems	54	52	72	-26	-28	-29	-31
41002	Werra	117	118	315	-63	-62	-63	-63
42001	Fulda	39	49	158	-75	-69	-76	-69
48901	Aller	108	116	204	-47	-43	-48	-44
49103	Weser	327	345	791	-59	-56	-60	-57
53801	Schwarze Elster	43	54	136	-68	-60	-68	-61
54901	Mulde	164	186	532	-69	-65	-69	-66
56901	Saale	518	540	1293	-60	-58	-60	-59
58901	Havel	157	174	376	-58	-54	-57	-55
59311	Elbe	1068	1161	2863	-63	-59	-62	-60
69001	Odra	36	38	74	-51	-48	-50	-48
	North Sea coast	310	300	433	-28	-31	-32	-32
	Baltic Sea coast	125	128	220	-43	-42	-44	-43
	North Sea	2816	2903	7004	-60	-59	-61	-59
	Baltic Sea	161	167	293	-45	-43	-46	-44
	Black Sea	332	341	766	-57	-55	-59	-58
	Germany	3309	3411	8063	-59	-58	-60	-58

Table 4.18: Nitrogen emissions from urban areas for the periods 1983-1987, 1993-1997 and 1998-2000 and their changes

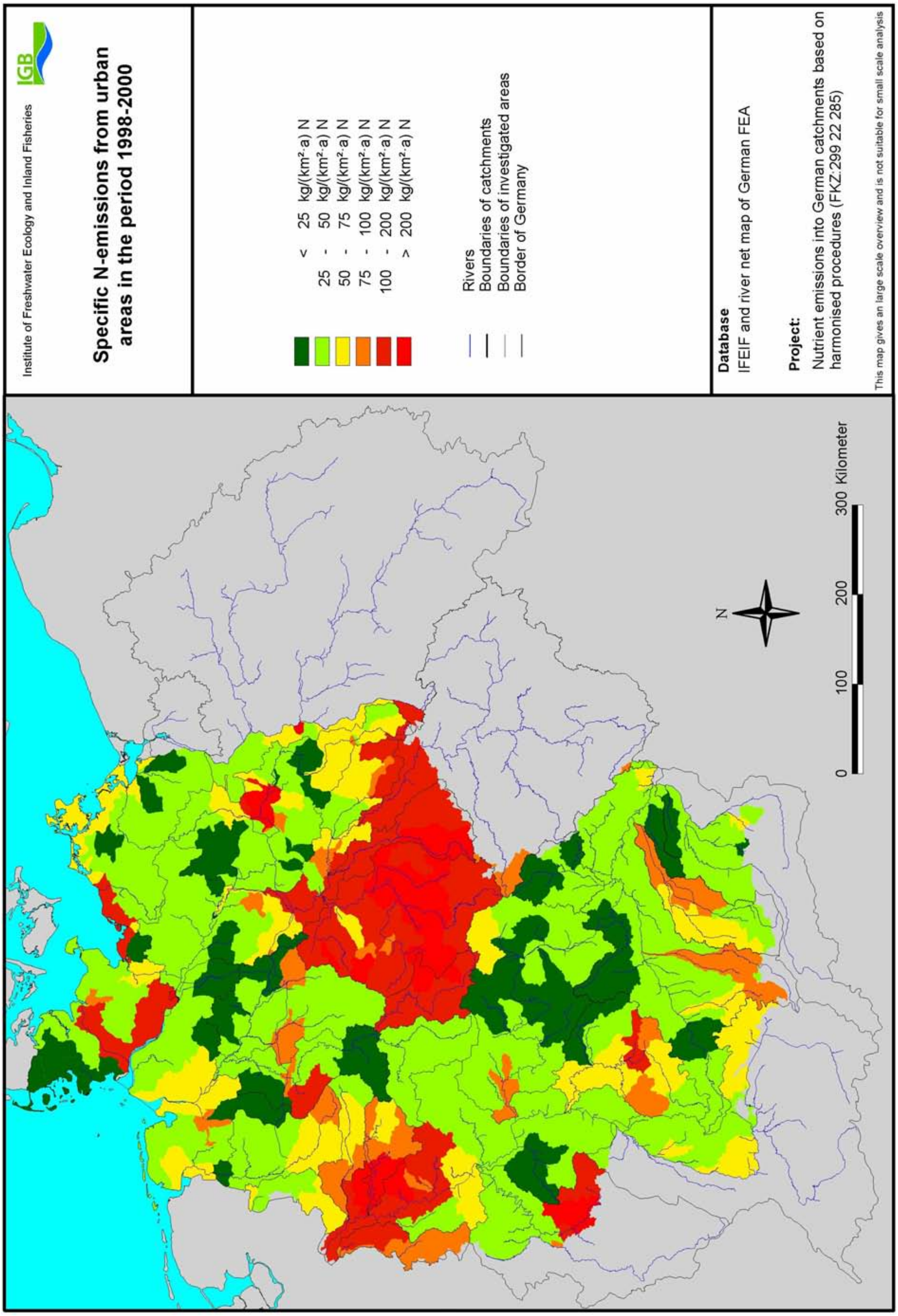
LOC.	RIVER	EUR_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	140	150	250	-44	-40	-46	-39
16902	Isar	570	520	840	-32	-38	-38	-42
18902	Inn	310	280	460	-33	-39	-42	-43
19101	Danube	2230	2280	3730	-40	-39	-43	-42
23704	Upper Rhine	690	580	870	-21	-33	-29	-34
23801	Neckar	650	740	1140	-43	-35	-38	-40
24901	Main	990	1090	2270	-56	-52	-58	-51
26901	Mosel	920	1080	1710	-46	-37	-46	-37
27601	Ruhr	600	620	1090	-45	-43	-43	-43
27801	Lippe	310	280	440	-30	-36	-34	-39
27903	Rhine	6960	6680	12520	-44	-47	-47	-47
37602	Ems	470	400	560	-16	-29	-17	-30
41002	Werra	990	990	1190	-17	-17	-17	-18
42001	Fulda	260	330	630	-59	-48	-60	-48
48901	Aller	640	640	980	-35	-35	-36	-37
49103	Weser	2320	2360	3470	-33	-32	-34	-33
53801	Schwarze Elster	440	540	730	-40	-26	-39	-26
54901	Mulde	1450	1650	2260	-36	-27	-35	-28
56901	Saale	4430	4540	5340	-17	-15	-17	-16
58901	Havel	1330	1550	2330	-43	-33	-42	-35
59311	Elbe	9370	10130	13260	-29	-24	-29	-25
69001	Odra	360	360	650	-45	-45	-45	-46
	North Sea coast	2150	1840	2770	-22	-34	-25	-34
	Baltic Sea coast	990	980	1530	-35	-36	-36	-36
	North Sea	21270	21410	32570	-35	-34	-36	-35
	Baltic Sea	1350	1340	2190	-38	-39	-39	-39
	Black Sea	2240	2290	3740	-40	-39	-43	-42
	Germany	24860	25040	38500	-35	-35	-37	-36



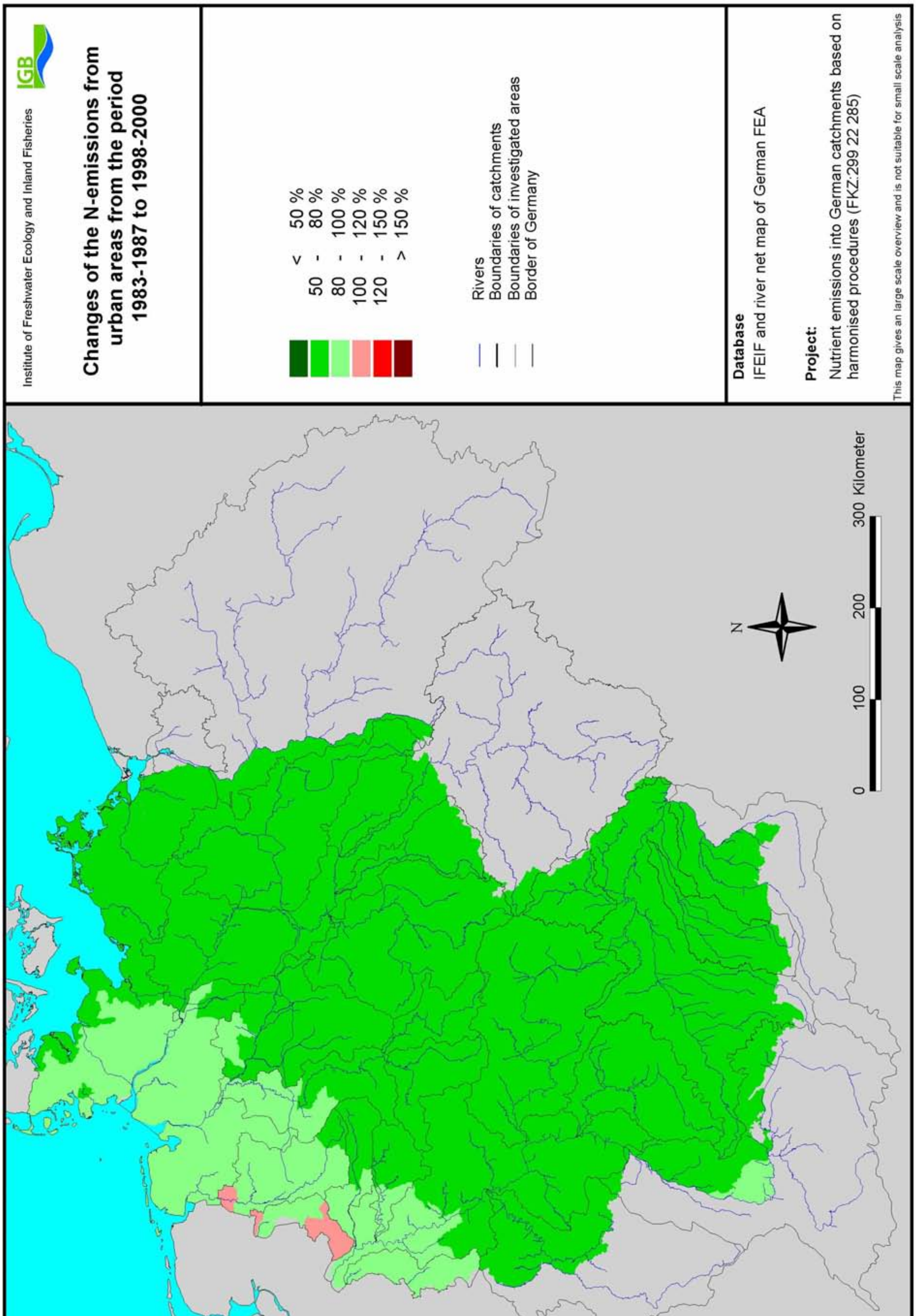
Map 4.22: Specific phosphorus emissions from urban areas for the period 1998-2000.



Map 4.23: Change in phosphorus emissions from urban areas from 1985 to 2000.



Map 4.24: Specific nitrogen emissions from urban areas in the period 1998 to 2000.



Map 4.25: Change in nutrient emissions from urban areas from1985 to 2000.

4.1.1.8 Total nutrient emissions from diffuse sources

In Chapters 4.1.12 to 4.1.2.7 the results of estimations of nutrient emissions via the various diffuse emission pathways were shown. A comparison of these with the results of other authors are given in Section 4.2.

Phosphorus

The overall results for estimates of diffuse phosphorus emissions are shown in Tables 4.19 and 4.20 as well as in Figure 4.7 and Maps 4.26 and 4.27.

For the 1998-2000 period, a value of 24100 t/a P was estimated for diffuse phosphorus emissions, a small increase of 200 t/a P from the estimate for 1993-1997. However, since the 1983-1987 period these emissions decreased by about 3700 t/a P or 15 %. Using outflow-normalised values the reduction remained at about 15 %.

As shown in Map 4.26, the specific diffuse P-emissions for the Mulde and Ems catchments were the highest. Comparatively low specific diffuse P-emissions can be seen for the Havel catchment, the tributaries of the Danube, the Main and in the catchments of the Baltic Sea coast.

In most catchments, the decrease in diffuse P-emissions over the study periods was up to 20 %. On the basis of the model calculations at least a small decrease occurred in all catchments attributable, above all, to a reduction in P-emissions from urban areas.

Table 4.20 and Figure 4.7 show the proportion of P-emissions through the individual diffuse pathways for 1998-2000. Overall, erosion was the most important P-emission pathway with 37 % of total diffuse emissions. Groundwater with 24 % was the next most important followed by drainage and emissions from urban areas, both with 14 %. There were large variations in these proportions for individual catchments which is important for the consideration of measures for further emission reductions. For example, in the North Sea coast and Ems catchments, about 70 % of diffuse P-emissions were underground emissions from cultivated former wetland areas which often cover less than 5 % of the total catchment area.

Nitrogen

Estimated diffuse nitrogen emissions are shown in Tables 4.22 and 4.23, Figure 4.7 and Maps 4.28 and 4.29.

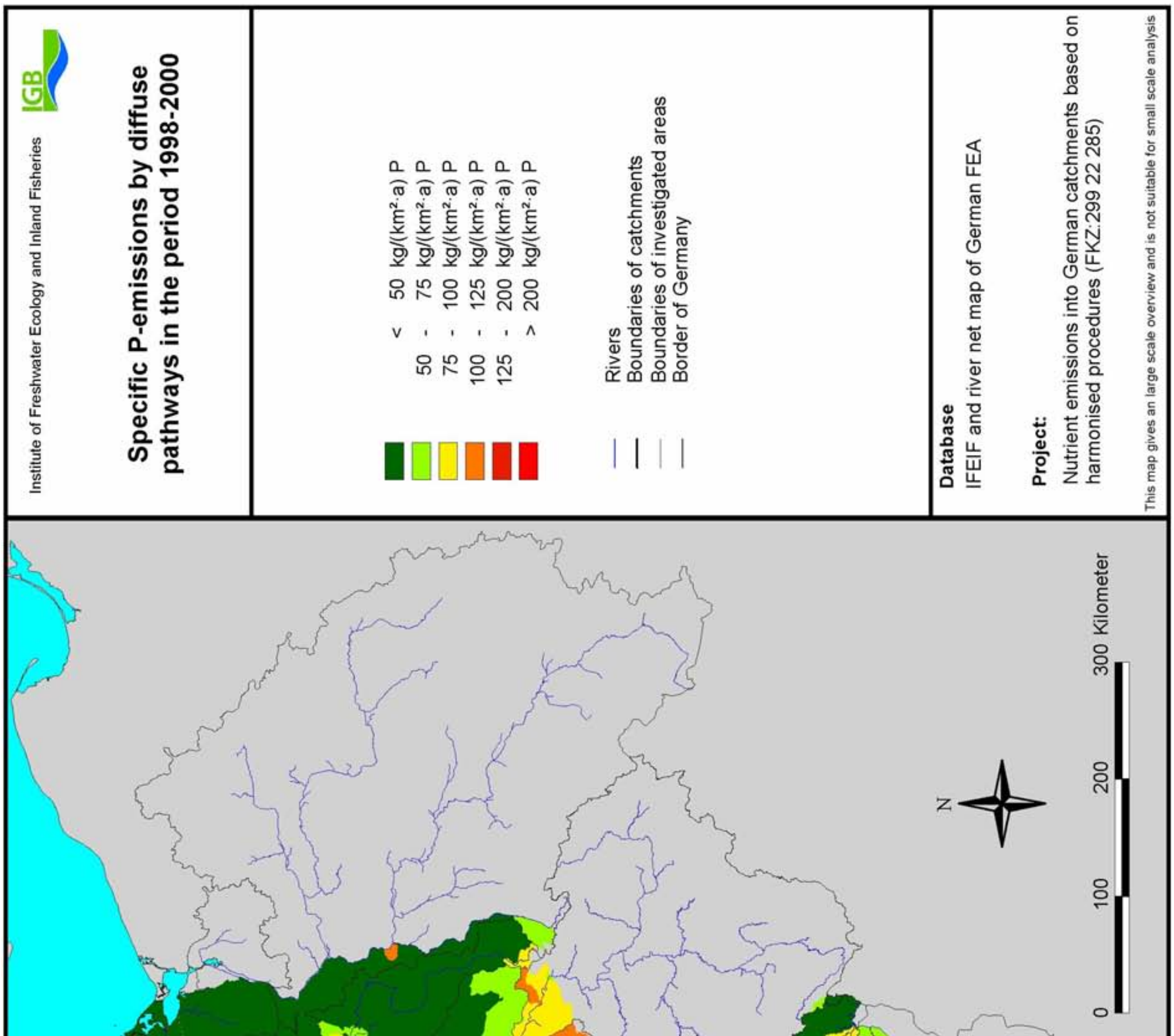
For the 1998-2000 period one can conclude that the total diffuse N-emission was 557000 t/a N. Using outflow-normalised values this represents a 19 % reduction since the 1983-1987 period but no change from the 1993-1997 estimates.

Table 4.19: Phosphorus emissions via diffuse sources in the periods1983-1987, 1993-1997 and 1998-2000 as well as their changes

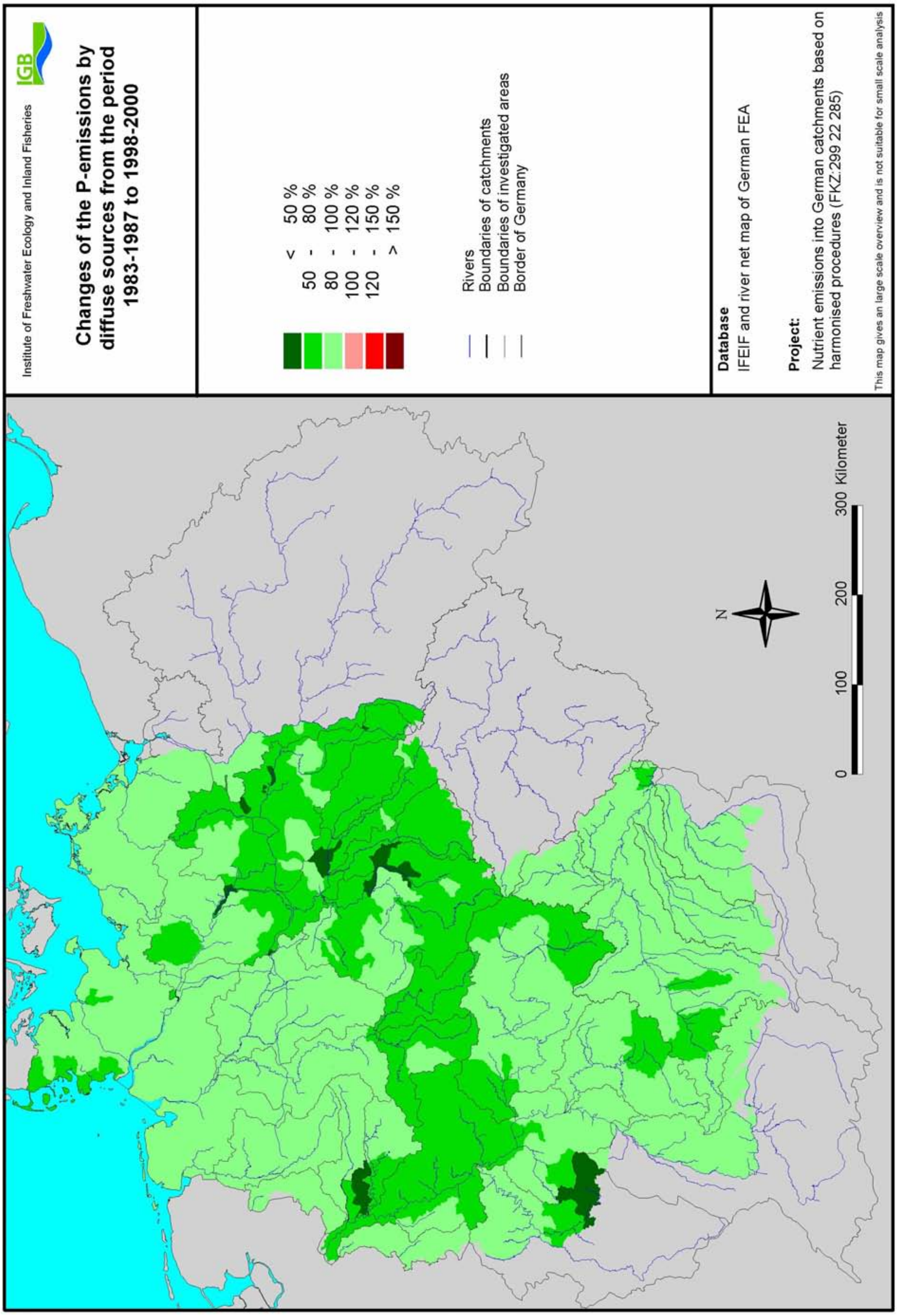
LOC.	RIVER	ED_P			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	185	171	254	-27	-33	-14	-13
16902	Isar	657	627	638	3	-2	-9	-10
18902	Inn	623	519	612	2	-15	-6	-7
19101	Danube	3620	3452	3801	-5	-9	-9	-9
23704	Upper Rhine	1010	870	963	5	-10	-8	-8
23801	Neckar	823	877	978	-16	-10	-14	-14
24901	Main	1698	1672	2022	-16	-17	-16	-15
26901	Mosel	492	488	793	-38	-38	-40	-38
27601	Ruhr	312	313	414	-25	-24	-29	-29
27801	Lippe	303	306	278	9	10	-7	-8
27903	Rhine	6158	5907	7490	-18	-21	-22	-21
37602	Ems	1047	1045	1151	-9	-9	-1	-1
41002	Werra	422	416	538	-22	-23	-31	-31
42001	Fulda	317	299	402	-21	-26	-27	-25
48901	Aller	1119	1122	1138	-2	-1	-5	-4
49103	Weser	2693	2637	2976	-9	-11	-12	-12
53801	Schwarze Elster	186	212	264	-30	-20	-31	-28
54901	Mulde	603	654	841	-28	-22	-35	-34
56901	Saale	1917	1992	2358	-19	-16	-26	-26
58901	Havel	605	762	954	-37	-20	-25	-24
59311	Elbe	4268	4798	5691	-25	-16	-27	-26
69001	Odra	173	185	201	-14	-8	-16	-16
	North Sea coast	5172	4809	5545	-7	-13	-3	-2
	Baltic Sea coast	955	945	981	-3	-4	-9	-9
	North Sea	19338	19196	22853	-15	-16	-17	-17
	Baltic Sea	1128	1130	1182	-5	-4	-10	-10
	Black Sea	3629	3458	3808	-5	-9	-9	-9
	Germany	24095	23783	27843	-13	-15	-16	-15

Table 4.20: Proportion of diffuse P-emissions via the various pathways in German catchments for 1998-2000

LOC.	RIVER	EGW_P [%]	EDR_P [%]	$EDEP_P$ [%]	EER_P [%]	EOF_P [%]	$EURB_P$ [%]
14902	Naab	30	0	1	46	12	10
16902	Isar	17	3	1	41	24	14
18902	Inn	24	2	1	35	30	7
19101	Danube	18	2	1	51	19	9
23704	Upper Rhine	14	1	1	36	37	11
23801	Neckar	11	2	0	59	15	13
24901	Main	13	1	1	69	7	9
26901	Mosel	27	2	1	25	19	26
27601	Ruhr	21	0	1	12	38	29
27801	Lippe	16	6	1	47	18	14
27903	Rhine	15	1	1	47	18	17
37602	Ems	63	8	0	13	10	5
41002	Werra	14	1	0	48	10	28
42001	Fulda	26	2	1	44	16	12
48901	Aller	14	21	1	45	9	10
49103	Weser	17	12	1	47	11	12
53801	Schwarze Elster	28	8	3	37	2	23
54901	Mulde	7	3	0	56	7	27
56901	Saale	5	2	1	62	3	27
58901	Havel	45	5	5	18	1	26
59311	Elbe	17	4	2	49	3	25
69001	Odra	31	4	2	41	1	21
	North Sea coast	38	47	1	3	5	6
	Baltic Sea coast	27	9	4	41	6	13
	North Sea	25	16	1	34	10	15
	Baltic Sea	27	8	4	41	5	14
	Black Sea	18	2	1	51	19	9
	Germany	24	14	1	37	11	14



Map 4.26: Specific phosphorus emissions from diffuse sources for the period 1998 to 2000.



Map 4.27: Change in total phosphorus emissions from diffuse sources from 1985 to 2000.

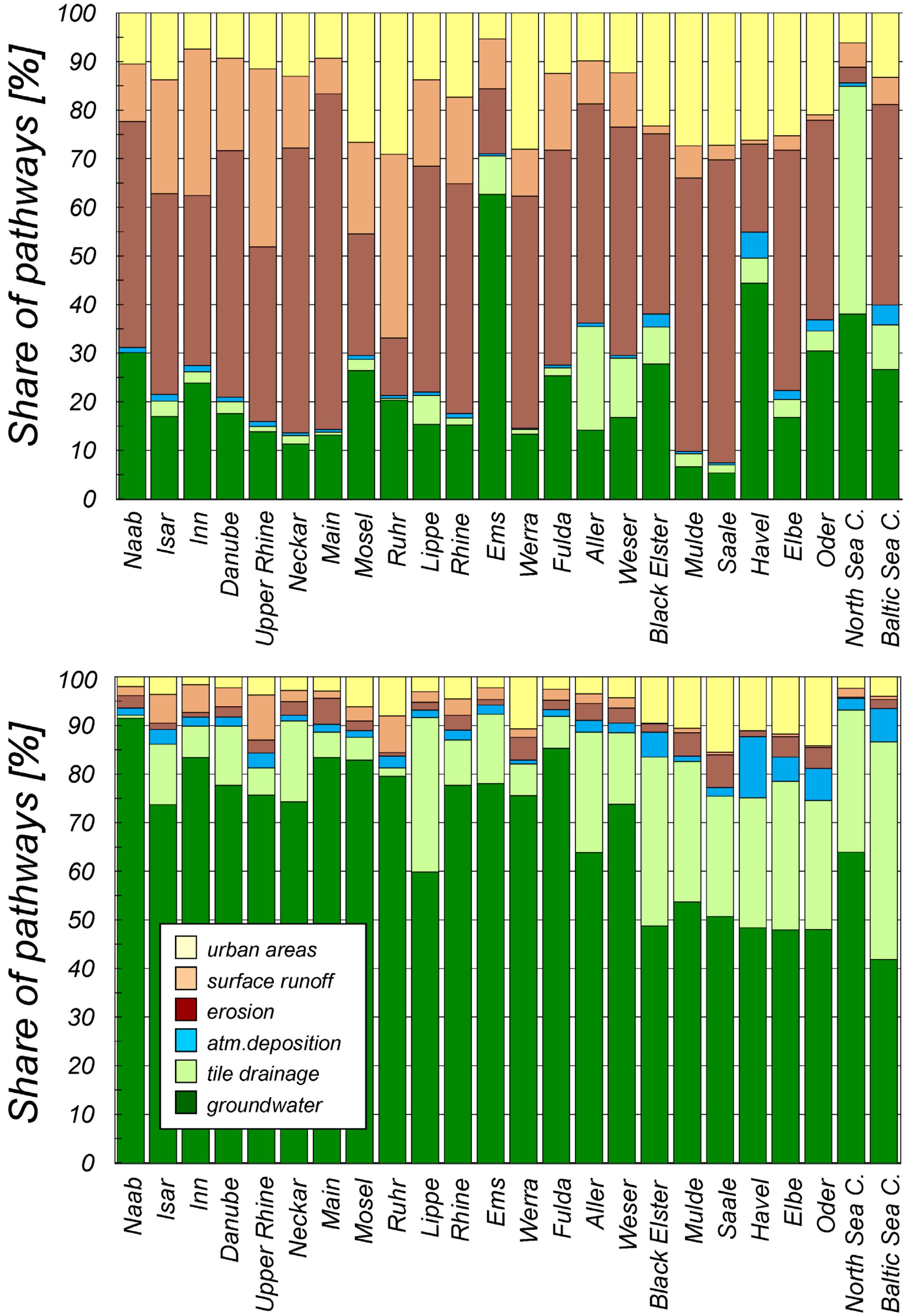


Figure 4.3: Proportions of phosphorus and nitrogen via the various diffuse emission pathways for in the period 1998-2000.

For the two study periods most of the diffuse N-emission in all catchments was caused by groundwater and drainage. For 1998-2000, these two pathways accounted for 69 % and 191 % respectively of the total diffuse N-loading. The proportion of such emissions via groundwater ranged from 42 % (Baltic Sea coast) to 92 % (Naab). The lowest proportion via drainage was for the Naab with 0 % and the highest on the Baltic Sea coast with 45 %. The proportion of diffuse N-emissions via drainage decreased during the study period. Out of the other diffuse N-emission pathways, it is notable that for the former GDR states, emissions from urban areas represented somewhat more than 10 % of the total. Due to the large lake area at the Baltic Sea coast and Havel catchments, the proportion of diffuse N-emissions through direct atmospheric deposition was relatively high at 7 % and 13 % respectively.

The highest specific diffuse N-emissions were in the catchments of the North Sea coast, the Ems and parts of the Mulde and Danube catchments (see Map 4.28). With the exception of the Mulde, these are also the regions in which diffuse N-emissions have increased since the mid-eighties. In other areas a moderate reduction in such emissions was estimated.

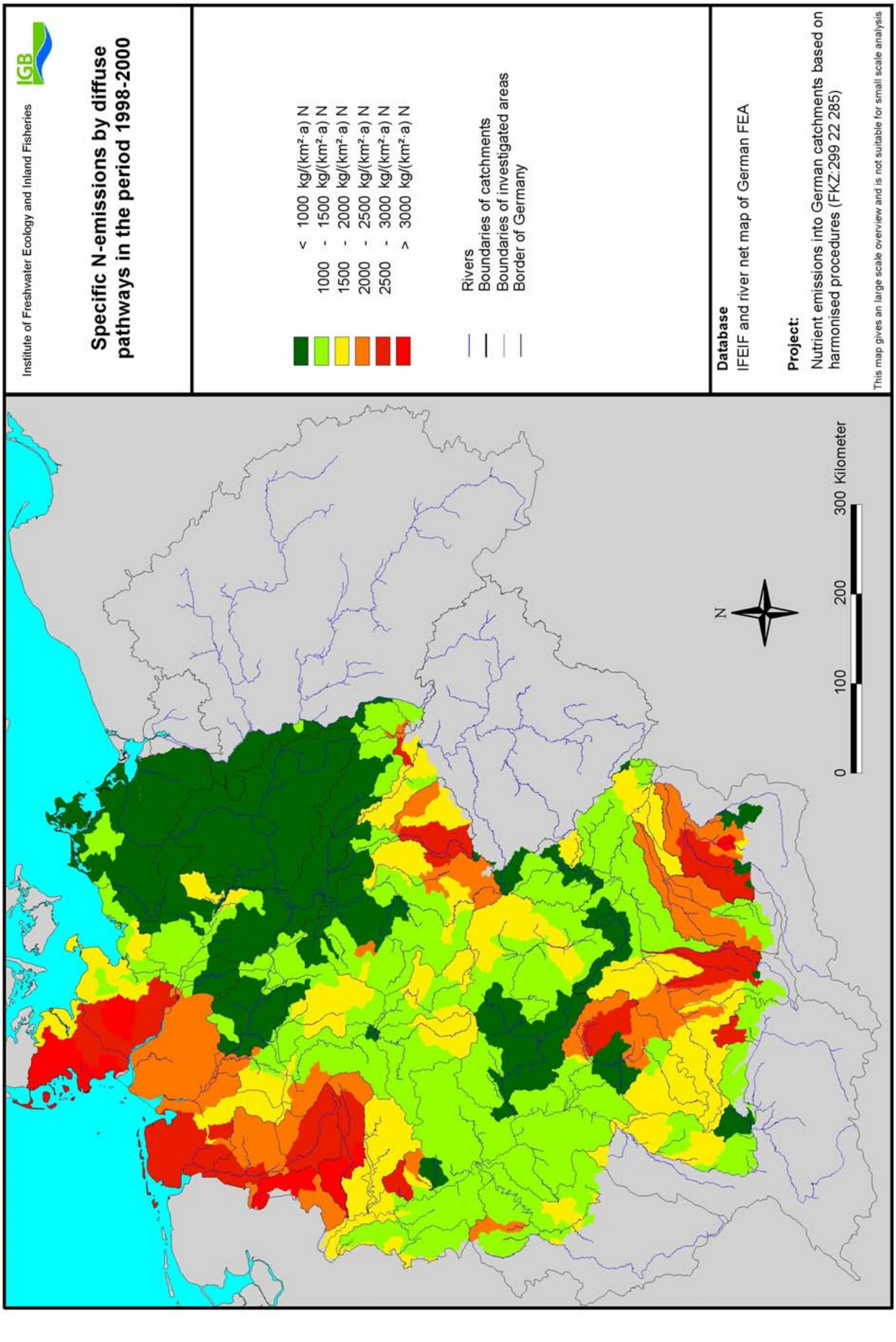
Compared to the results of BEHRENDT et al. (2000), a similar total diffuse N-emission was calculated for the 1983-1987 period. For the 1993-1997 period, due to differences in methodology and new information available for area-differentiated N-surpluses estimates in the present study are about 10 % lower than in BEHRENDT et al. (2000).

Table 4.21: Nitrogen emissions from diffuse sources in the periods 1983-1987, 1993-1997 and 1998-2000 and their changes

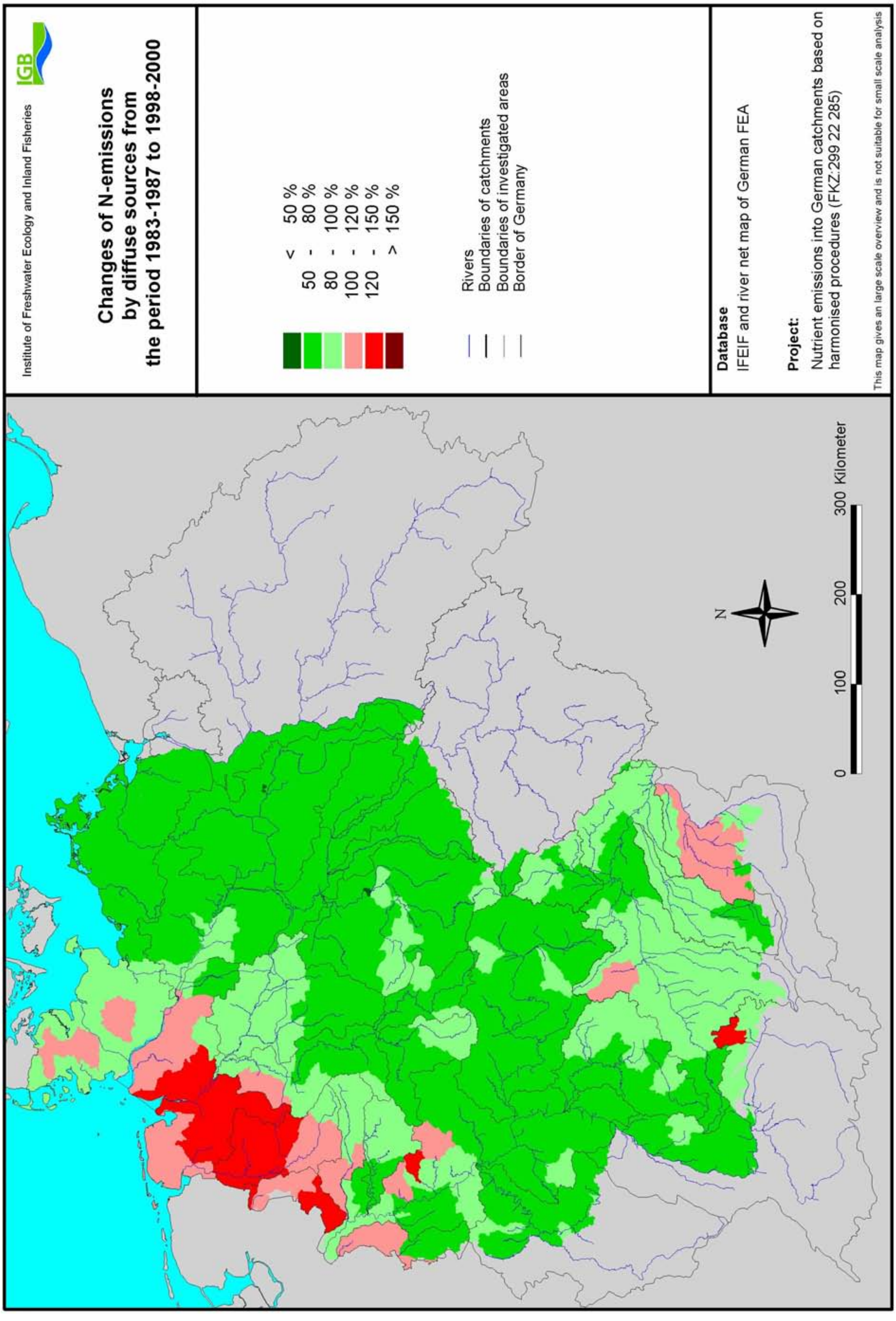
LOC.	RIVER	ED_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	7610	6710	9460	-20	-29	-19	-17
16902	Isar	16880	17210	19000	-11	-9	-21	-17
18902	Inn	20810	16850	16900	23	-0	4	3
19101	Danube	109350	101440	114840	-5	-12	-11	-10
23704	Upper Rhine	19590	16140	21320	-8	-24	-17	-24
23801	Neckar	24450	25010	29790	-18	-16	-19	-17
24901	Main	36970	34900	45670	-19	-24	-27	-25
26901	Mosel	15430	13450	18110	-15	-26	-25	-23
27601	Ruhr	7700	6740	8160	-6	-17	-11	-20
27801	Lippe	11070	10890	11390	-3	-4	-6	-9
27903	Rhine	158860	146590	187330	-15	-22	-21	-22
37602	Ems	23480	21700	18580	26	17	16	8
41002	Werra	9370	7970	11070	-15	-28	-23	-28
42001	Fulda	10870	9560	12760	-15	-25	-21	-20
48901	Aller	19150	18060	25430	-25	-29	-26	-25
49103	Weser	57000	50940	69410	-18	-27	-22	-22
53801	Schwarze Elster	4720	5360	9090	-48	-41	-41	-36
54901	Mulde	13870	13830	20590	-33	-33	-37	-33
56901	Saale	29030	31930	43800	-34	-27	-31	-29
58901	Havel	12280	15410	23790	-48	-35	-37	-33
59311	Elbe	81000	92880	134590	-40	-31	-36	-32
69001	Odra	2570	2830	4410	-42	-36	-39	-36
	North Sea coast	97390	86090	86440	13	-0	5	-1
	Baltic Sea coast	26540	26780	40520	-35	-34	-36	-32
	North Sea	417730	398200	496340	-16	-20	-19	-20
	Baltic Sea	29110	29610	44930	-35	-34	-36	-33
	Black Sea	109770	101740	115160	-5	-12	-11	-10
	Germany	556610	529550	656430	-15	-19	-19	-19

Table 4.22: Proportion of diffuse N-emissions through the various pathways in the period 1998-2000.

LOC.	RIVER	EGW_N [%]	EDR_N [%]	$EDEP_N$ [%]	EER_N [%]	EOF_N [%]	$EURB_N$ [%]
14902	Naab	92	1	2	2	2	2
16902	Isar	74	12	3	1	6	3
18902	Inn	84	7	2	1	6	1
19101	Danube	78	12	2	2	4	2
23704	Upper Rhine	76	6	3	3	9	4
23801	Neckar	74	17	1	3	2	3
24901	Main	84	5	2	5	2	3
26901	Mosel	83	5	1	2	3	6
27601	Ruhr	80	2	2	1	8	8
27801	Lippe	60	32	2	2	2	3
27903	Rhine	78	9	2	3	3	4
37602	Ems	78	14	2	1	2	2
41002	Werra	76	7	1	5	2	11
42001	Fulda	86	7	1	2	2	2
48901	Aller	64	25	2	3	2	3
49103	Weser	74	15	2	3	2	4
53801	Schwarze Elster	49	35	5	2	0	9
54901	Mulde	54	29	1	5	1	10
56901	Saale	51	25	2	7	1	15
58901	Havel	49	27	13	1	0	11
59311	Elbe	48	31	5	4	1	12
69001	Odra	48	26	7	4	0	14
	North Sea coast	64	29	2	0	2	2
	Baltic Sea coast	42	45	7	2	1	4
	North Sea	68	19	3	3	2	5
	Baltic Sea	43	43	7	2	1	5
	Black Sea	78	12	2	2	4	2
	Germany	69	19	3	2	3	4



Map 4.28: Specific nitrogen emissions from diffuse sources in the period 1998 to 2000.



Map 4.29: Change in total diffuse nitrogen emissions from 1985 to 2000.

4.1.2 German point-source emissions

4.1.2.1 Nutrient emissions from municipal wastewater treatment plants

The development of phosphate emissions from public water-treatment plants in Germany is shown in Table 4.24 and Map 4.30. From Map 4.30 one can see that in some catchments there are higher values for inhabitant-specific emissions.

On the basis of UBA information on treatment plant inventories as well as data from the Bavarian Ministry for the Water Industry and state treatment plant statistics, one can conclude that total P-emissions from treatment plants for the 1998-2000 period were 8100 t/a P. Compared to the 1993-1997 period, this represents a reduction of 3200 t/a P and a reduction of 86 % from the 1983-1987 period.

For the fact that statistical information is not available for all states, and therefore a correction for information which is concentrated on large treatment plants was not possible, the estimated P-emissions in particular for the Elbe as well as the North Sea and Baltic coast catchments are underestimated and the actual emissions for 1998-2000 were probably 10-20 % greater than those calculated. For the smaller catchments, errors in the inventories of treatment plants likely lead to inaccurate estimates of emissions for the earlier periods. Such errors include uncertainties relating to coordinates on digital maps. There is an urgent need to improve the information from the treatment plants, particularly for the states of Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, Thuringia, Hesse and Brandenburg. The errors in the coordinates for the WWTP`s, and the reduction in the data bases to larger treatment plants with the exception of Baden-Württemberg and Bavaria also hinder the quantification of P-emissions in comparison to the estimates of BEHRENDT et al. (2000).

Despite the problems of comparisons of the results of the three data bases, one can at least say that there has been a reduction of 80 % or more in P-emissions from communal water treatment plants since 1983-1987 for about 80 % of the catchments considered (see Map 4.31). For the few catchments where the reduction was estimated as less than 40 %, the figures are either an artefact relating to errors in treatment plant statistics at the state level, new treatment plant regulations or as yet unidentified errors in the area-coordinates used for the treatment-plant inventories.

Changes in nitrogen emissions from German water treatment plants are shown in Table 4.25 and Map 4.33. Map 4.32 gives an overview of catchment scale differentiated differences in inhabitant-specific N-emissions form treatment plants for the 1998-2000 period. Possible sources of error are the same as those considered above for P-emissions.

As shown in Table 4.24, the total N-emissions from water treatment plants for the period 1998-2000 were estimates as 155000 t/a N or about 62 % less than for the 1983-1987. It is astounding that this comparison also shows a reduction of more than 80000 t/a N since the 1993-1997 period. This substantial reduction within four years indicates the total implementation of EU water quality guidelines for treatment plant outflows.

On the other hand, for nitrogen it has to be considered that the N-emission values for 1998-2000 are around 10 to 20 % too low for the Elbe as well as the North Sea and Baltic Sea coasts. This is due to the incomplete data base for these areas. Since one can also find a 50 % decrease in N-emissions for the Danube catchment for this period, where the information is very precise, one must conclude that the scale of the reduction in N-emissions from water treatment plants is not necessarily so greatly influenced by a lack of information.

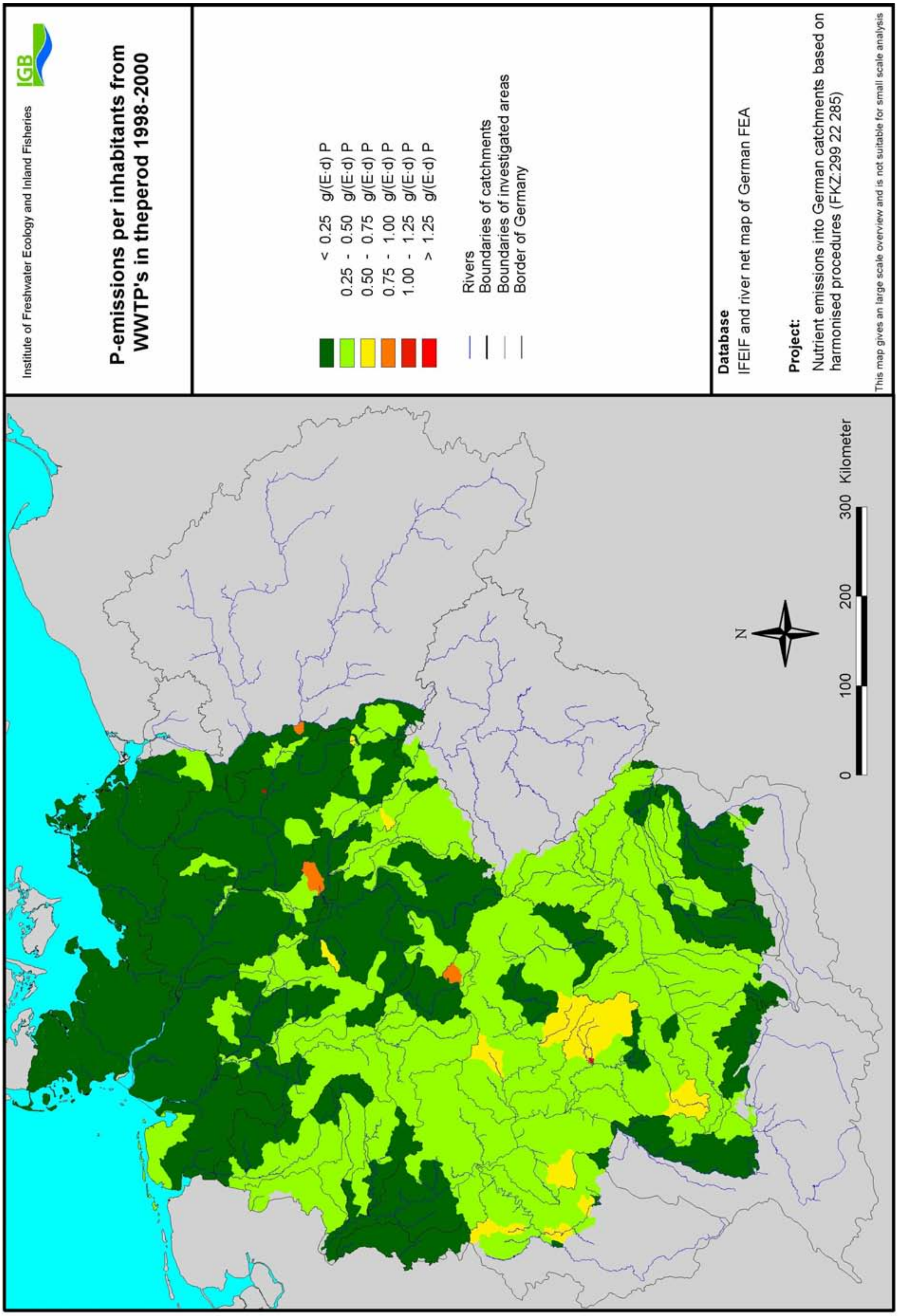
Map 4.32 shows that, with few exceptions (e.g. upper Elbe and the Baltic Sea area of Schleswig-Holstein), inhabitant-specific N-emissions from water treatment plants have sunk to less than 8g/(E·d). However, it must be borne in mind that this figure is based on the quotient of N-emission from treatment plants and the total number of inhabitants in a catchment. Consequently this quotient is also very low for such river basins, where the proportion of inhabitants connected to water treatment plants is low. Map 4.33 indicates that as for phosphorus, P emissions from water treatment plants show considerable inhomogeneity in relation to time and the conditions used for the estimations. In some catchments, there has been an apparent increase in N-emissions from water treatment plants since 1985.

Table 4.23: Phosphorus emissions from water treatment plants in the periods 1983-1987, 1993-1997 and 1998-2000 and their changes.

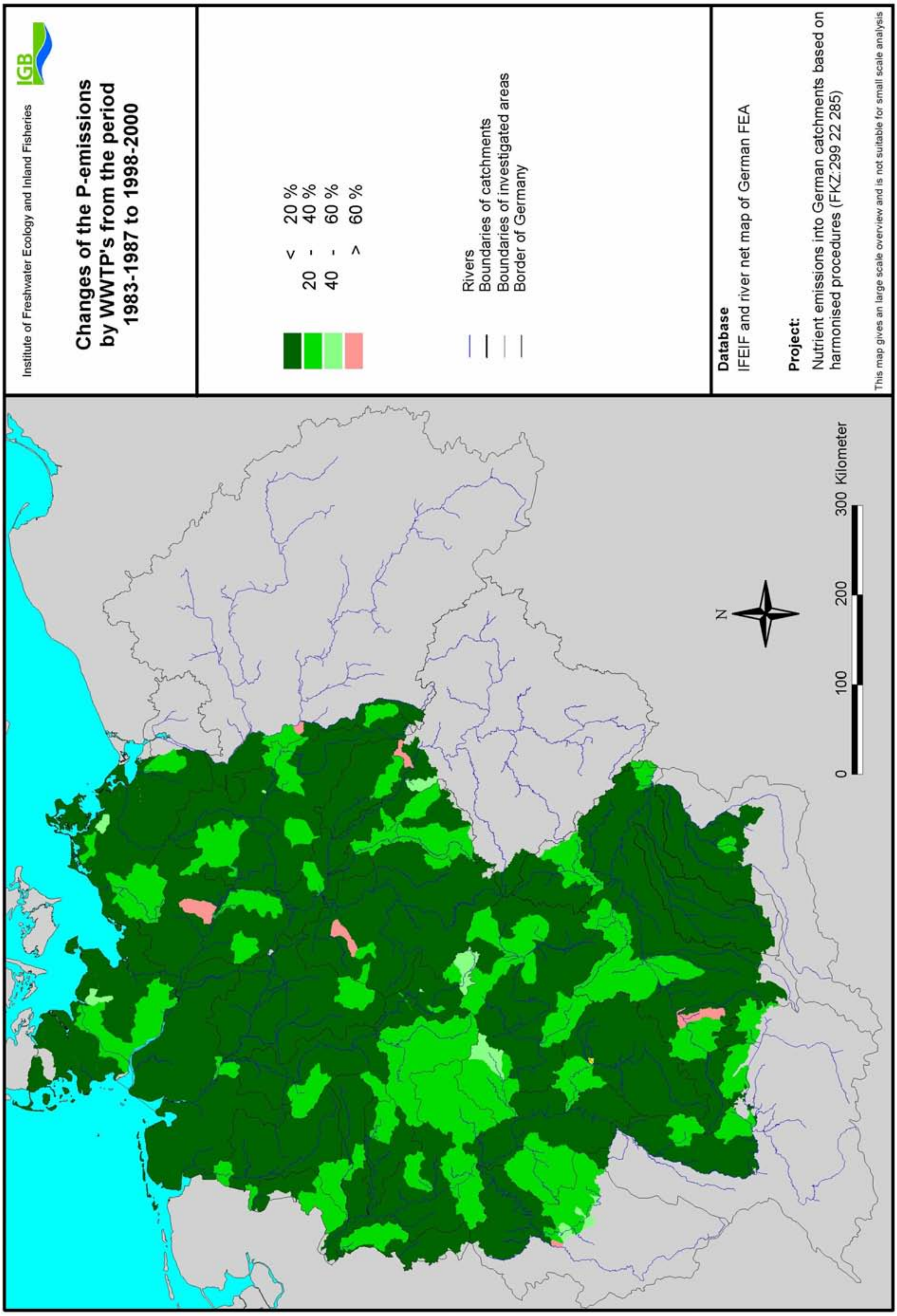
LOC.	RIVER	$EWWTP_P$			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]	[%]	[%]
14902	Naab	54	104	342	-84	-70	-84	-70
16902	Isar	229	283	1814	-87	-84	-87	-84
18902	Inn	94	146	651	-86	-78	-86	-78
19101	Danube	964	1409	6140	-84	-77	-84	-77
23704	Upper Rhine	201	342	1417	-86	-76	-86	-76
23801	Neckar	693	823	4004	-83	-79	-83	-79
24901	Main	879	913	4585	-81	-80	-81	-80
26901	Mosel	336	409	1254	-73	-67	-73	-67
27601	Ruhr	237	263	1133	-79	-77	-79	-77
27801	Lippe	196	213	1199	-84	-82	-84	-82
27903	Rhine	4183	4985	25974	-84	-81	-84	-81
37602	Ems	182	237	1320	-86	-82	-86	-82
41002	Werra	85	84	516	-84	-84	-84	-84
42001	Fulda	174	192	599	-71	-68	-71	-68
48901	Aller	320	482	2384	-87	-80	-87	-80
49103	Weser	842	1067	5007	-83	-79	-83	-79
53801	Schwarze Elster	50	103	471	-89	-78	-89	-78
54901	Mulde	236	526	1173	-80	-55	-80	-55
56901	Saale	364	838	4157	-91	-80	-91	-80
58901	Havel	196	426	2096	-91	-80	-91	-80
59311	Elbe	1083	2383	10212	-89	-77	-89	-77
69001	Odra	38	170	440	-91	-61	-91	-61
	North Sea coast	663	845	5638	-88	-85	-88	-85
	Baltic Sea coast	170	257	2114	-92	-88	-92	-88
	North Sea	6953	9516	48152	-86	-80	-86	-80
	Baltic Sea	208	427	2554	-92	-83	-92	-83
	Black Sea	965	1411	6147	-84	-77	-84	-77
	Germany	8127	11354	56853	-86	-80	-86	-80

Table 4.24: Nutrient emissions from water treatment plants in the periods 1983-1987, 1993-1997 and 1998-2000 and their changes.

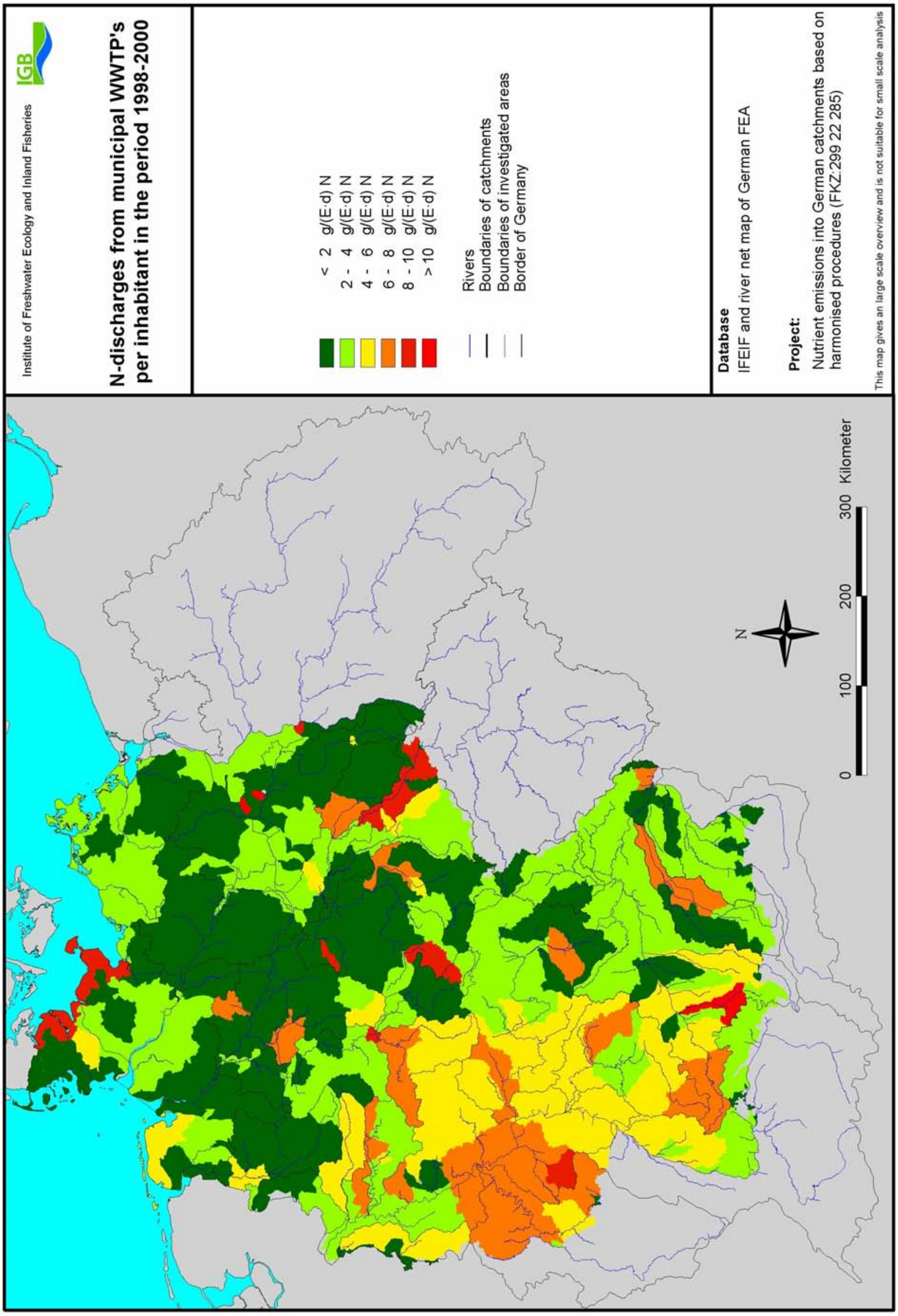
LOC.	RIVER	$EWWTP_N$			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	410	1230	1650	-75	-25	-75	-25
16902	Isar	4190	8010	9430	-56	-15	-56	-15
18902	Inn	1000	2320	3540	-72	-34	-72	-34
19101	Danube	12610	24420	32750	-61	-25	-61	-25
23704	Upper Rhine	3530	7000	10100	-65	-31	-65	-31
23801	Neckar	9280	15140	20620	-55	-27	-55	-27
24901	Main	10730	18290	23640	-55	-23	-55	-23
26901	Mosel	4470	4350	5840	-23	-26	-23	-26
27601	Ruhr	3510	6020	6170	-43	-2	-43	-3
27801	Lippe	2520	5310	6790	-63	-22	-63	-22
27903	Rhine	64670	98010	138250	-53	-29	-53	-29
37602	Ems	1610	4970	7650	-79	-35	-79	-35
41002	Werra	610	1020	1740	-65	-41	-65	-41
42001	Fulda	2620	3330	3230	-19	3	-19	3
48901	Aller	3170	7130	12930	-75	-45	-75	-45
49103	Weser	8330	17050	26310	-68	-35	-68	-35
53801	Schwarze Elster	450	910	1410	-68	-35	-68	-35
54901	Mulde	1920	4250	4120	-53	3	-53	3
56901	Saale	4720	12740	18440	-74	-31	-74	-31
58901	Havel	4560	8080	16590	-73	-51	-73	-51
59311	Elbe	14980	32230	49340	-70	-35	-70	-35
69001	Odra	390	1560	3070	-87	-49	-87	-49
	North Sea coast	9120	20840	34910	-74	-40	-74	-40
	Baltic Sea coast	3560	5760	11010	-68	-48	-68	-48
	North Sea	98700	173110	256470	-62	-33	-62	-33
	Baltic Sea	3950	7320	14070	-72	-48	-72	-48
	Black Sea	12620	24440	32770	-61	-25	-61	-25
	Germany	115270	204860	303310	-62	-32	-62	-32



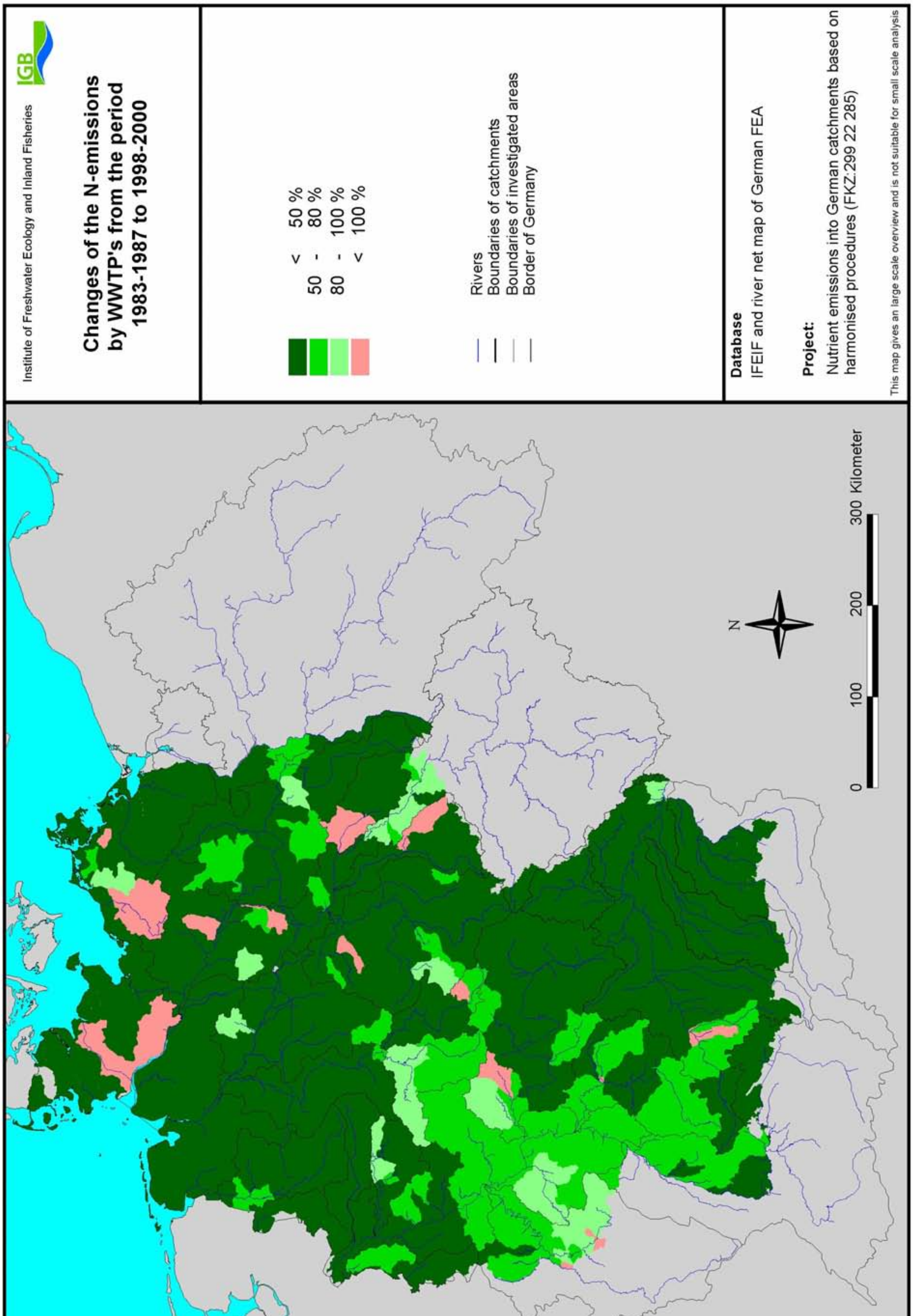
Map 4.30: Specific phosphorus emissions from water treatment plants in the period 1998 to 2000.



Map 4.31: Change in phosphorus emissions from water treatment plants from 1985 to 2000.



Map 4.32: Specific nitrogen emission from water treatment plants in the period 1998 to 2000.



Map 4.33: Change in nitrogen emissions from water treatment plants from 1985 to 2000.

4.1.3 Overall summary of nutrient emissions from diffuse and point sources

In Section 4.1.1 and 4.1.2, the results for the individual emission pathways and the sum of diffuse emissions were presented. In the following, an overview of the total nutrient emissions in German catchments in the period 1998 to 2000 as well as their changes since the mid-eighties are presented.

Phosphorus

Tables 4.25 and 4.26 together with Maps 4.34 and 4.36 show the P-emissions in German catchments for the periods 1998-2000, 1993-1997 and 1983-1987.

The overall P-emission within Germany for the 1998-2000 period was estimated as 31200 t/a P. Of this total, at least 73 % comes from diffuse sources as shown in Figure 4.4 and Table 4.26. In comparison with the 1983-1987 period, this represents a more than doubling in the proportion deriving from diffuse emissions. Since the 1993-1997 period, there was an increase of 8 % in this proportion.

As shown in the previous sections, the total P-emissions from diffuse sources have declined by around 15 %. In 1998-2000, total phosphorus emission of 60000 tP/a was around 64 % less than for the 1983-1987 period when total P-emissions were estimated as 91800 tP/a. The largest reductions of 70 to 79 % were found for the Rhine, Neckar, Elbe and Havel catchments. Already by the 1993-1997 period, reductions of around 50 % since the mid-eighties have been found overall and in most of the larger catchments. In all 22 studied catchments, the target of a 50 % reduction in P-emissions had been achieved. As shown in Map 4.35, this 50 % reduction was not reached in a minority of smaller catchments only .

As shown in Figure 4.4 and Table 4.26, the proportion of total P-emissions from point sources remains high at 45 % to 50 % in some catchments (Neckar, Mosel, Ruhr, Rhine and Mulde). This is also the case for smaller catchments with high population densities (e.g. Berlin, Halle, Leipzig, Nuremberg, Hamburg and Munich) as shown in Map 4.36. Despite the large overall reductions in point-source P-emissions, one can conclude that in catchments with a high proportion of point-source emissions, there remains a high potential for a reduction in P-emissions to achieve the goals of the WWRL.

Table 4.25: Sum of diffuse and point-source phosphorus emissions in the periods 1983-1987, 1993-1997 and 1998-2000 as well as their changes

LOC.	**CATCHMENT**	**EG_P**			**Change**		**Q-normalised change**	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a P]	**[t/a P]**	**[t/a P]**	**[%]**	**[%]**	**[%]**	**[%]**
14902	Naab	239	274	600	-60	-54	-59	-49
16902	Isar	894	920	2512	-64	-63	-66	-64
18902	Inn	756	735	1644	-54	-55	-59	-54
19101	Danube	4643	4962	10524	-56	-53	-57	-53
23704	Upper Rhine	1249	1313	2615	-52	-50	-57	-49
23801	Neckar	1566	1750	5458	-71	-68	-74	-72
24901	Main	2777	2786	7210	-61	-61	-62	-61
26901	Mosel	874	947	2219	-61	-57	-61	-57
27601	Ruhr	549	576	1550	-65	-63	-65	-63
27801	Lippe	499	519	1484	-66	-65	-67	-66
27903	Rhine	10925	11486	36833	-70	-69	-72	-69
37602	Ems	1237	1300	2574	-52	-49	-50	-47
41002	Werra	511	504	1056	-52	-52	-55	-55
42001	Fulda	491	491	1004	-51	-51	-54	-51
48901	Aller	1438	1604	3535	-59	-55	-60	-55
49103	Weser	3576	3759	8280	-57	-55	-58	-55
53801	Schwarze Elster	237	315	773	-69	-59	-68	-61
54901	Mulde	920	1229	2300	-60	-47	-61	-50
56901	Saale	2308	2896	7224	-68	-60	-68	-62
58901	Havel	817	1212	3893	-79	-69	-76	-69
59311	Elbe	5523	7342	18254	-70	-60	-69	-62
69001	Odra	240	399	741	-68	-46	-67	-47
	North Sea coast	5881	5929	11228	-48	-47	-48	-44
	Baltic Sea coast	1127	1206	3332	-66	-64	-68	-65
	North Sea	27142	29816	77169	-65	-61	-66	-62
	Baltic Sea	1368	1605	4073	-66	-61	-67	-62
	Black Sea	4654	4970	10538	-56	-53	-57	-53
	Germany	33163	36391	91780	-64	-60	-65	-61

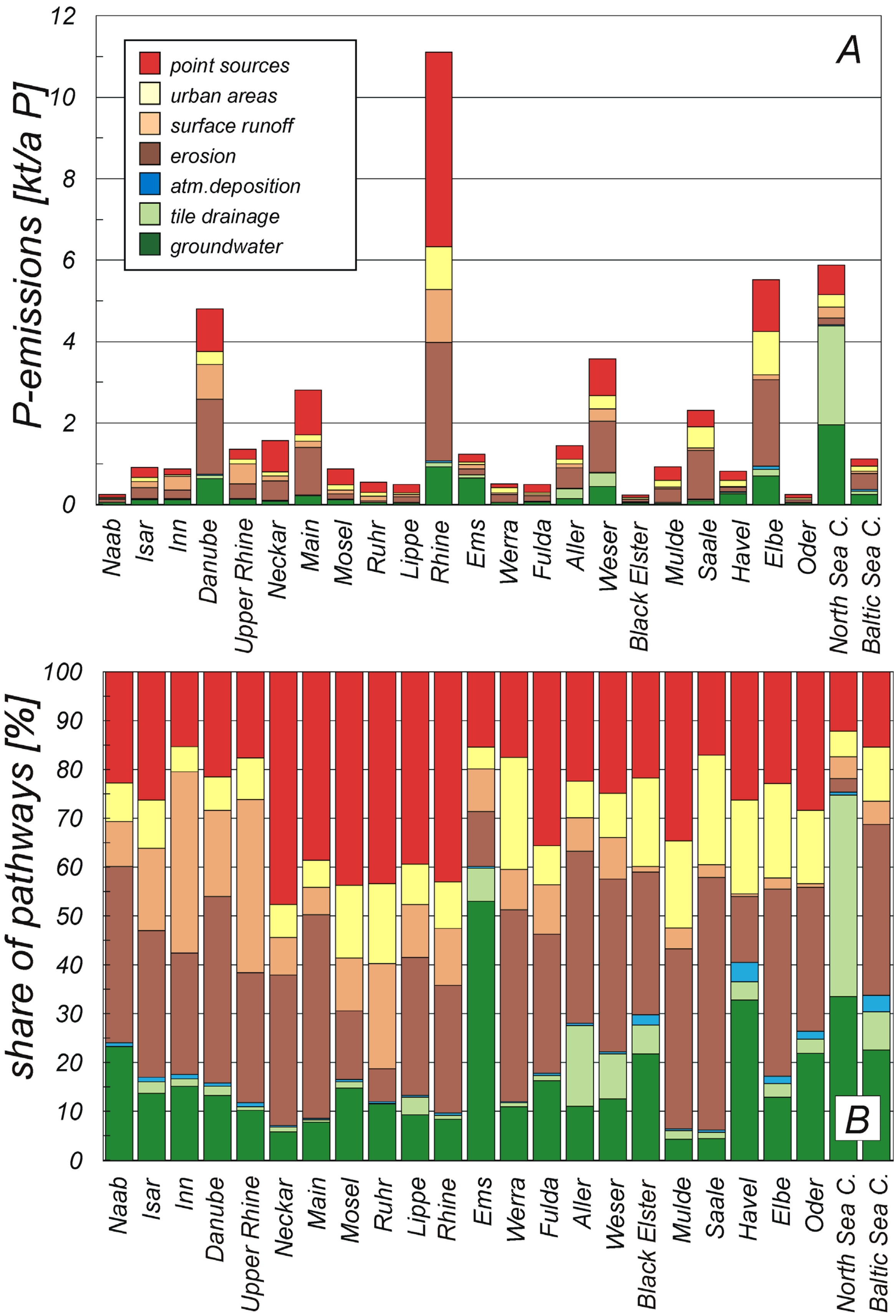
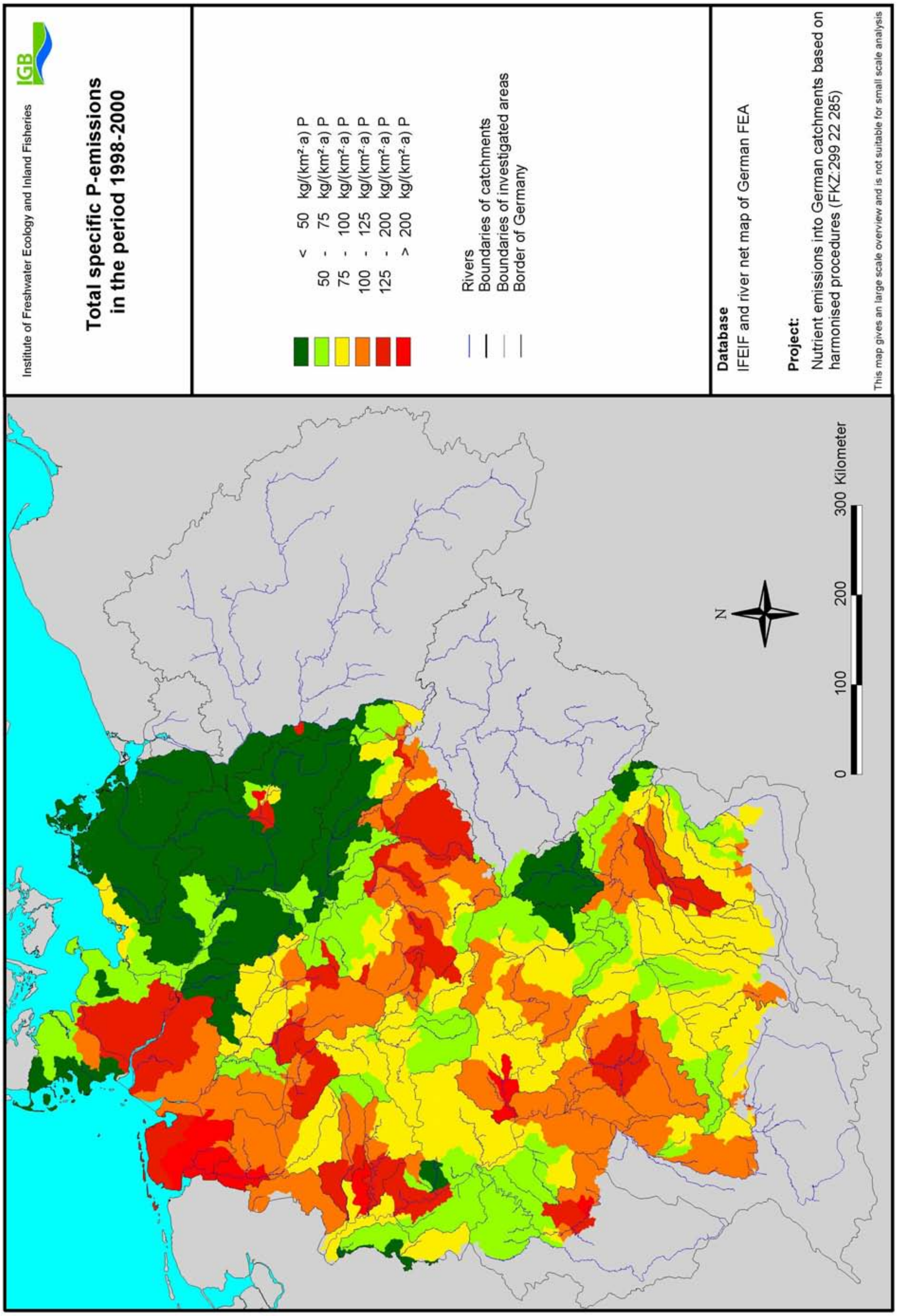
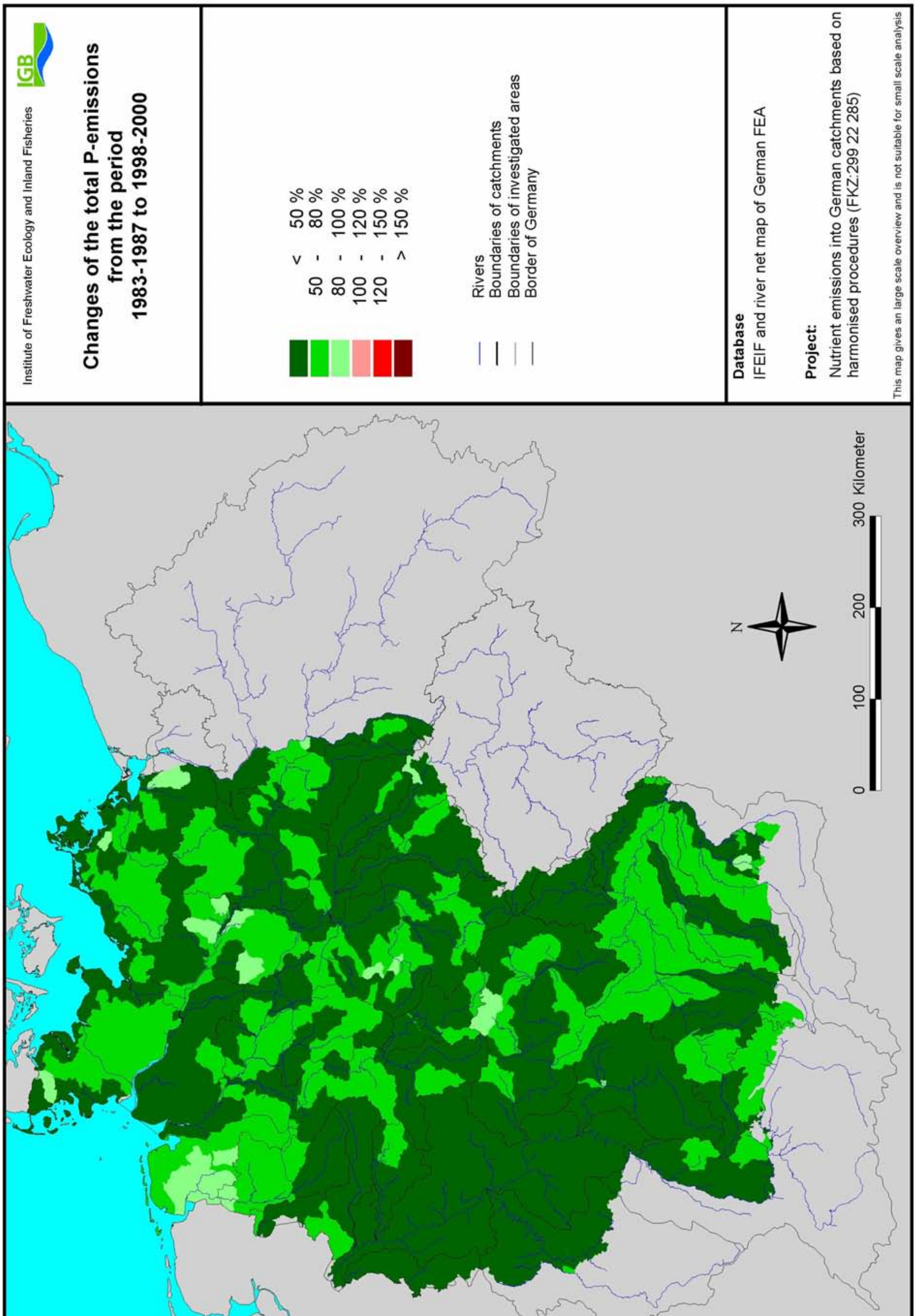


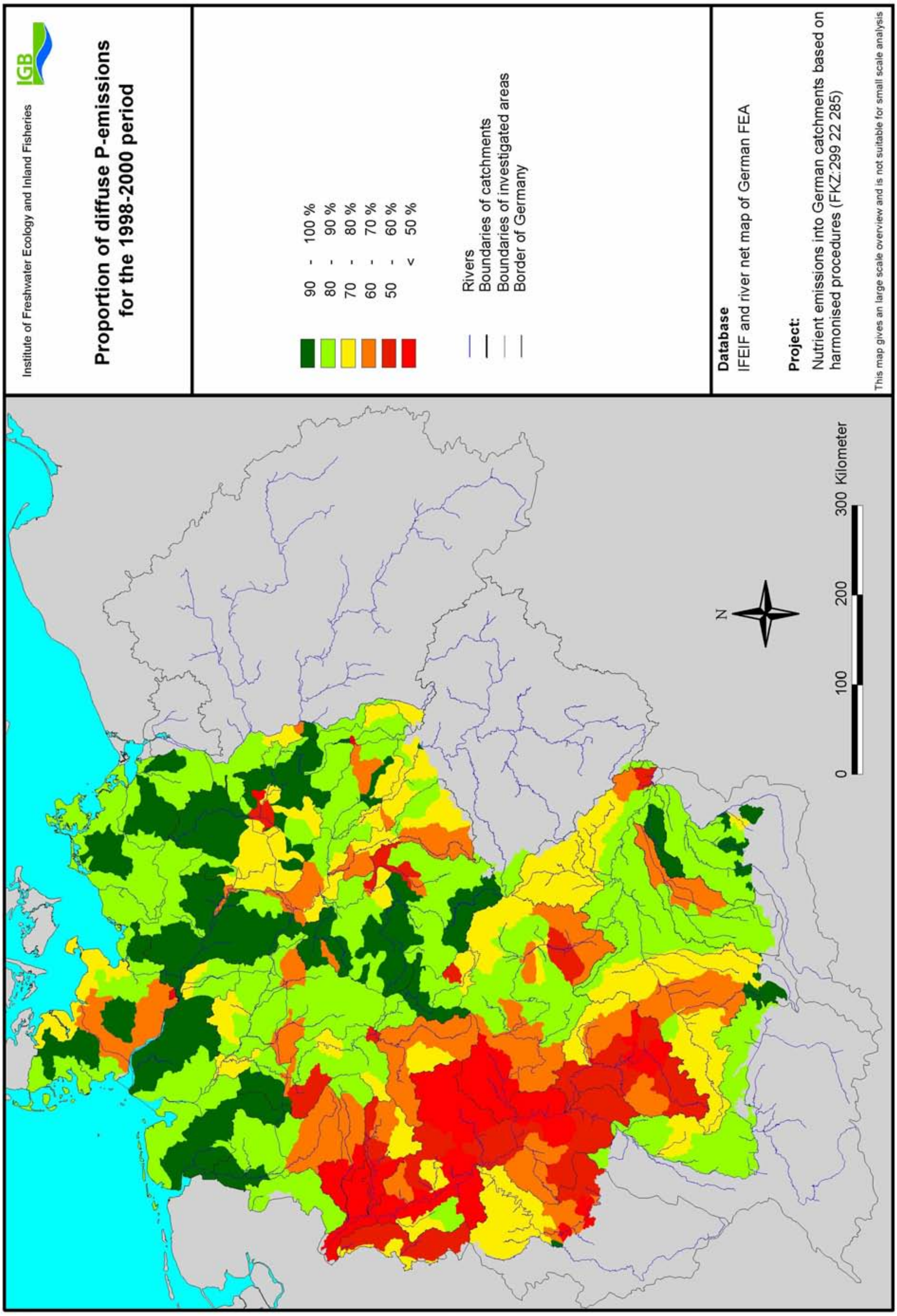
Figure 4.4: Phosphorus emissions (A) and the contribution of individual pathways to total P-emissions (B) for the studied German catchments.



Map 4.34: Area-specific phosphorus emissions from all sources in the 1998-2000 period



Map 4.35: Changes in the sum of phosphorus emissions from 1985 to 2000.



Map 4.36: Proportion of diffuse phosphorus emissions for the 1998-2000 period.

Table 4.26: Proportion of diffuse phosphorus and nitrogen emissions in the 1983-1987, 1993-1997 and 1998-2000 periods.

ADR	CATCHMENT	ED_P/EG_P			ED_N/EG_N		
		2000	1995	1985	2000	1995	1985
		[%]	[%]	[%]	[%]	[%]	[%]
14902	Naab	77	62	42	95	85	85
16902	Isar	73	68	25	80	68	67
18902	Inn	82	71	37	94	84	70
19101	Danube	78	70	36	89	80	75
23704	Upper Rhine	81	66	37	84	67	59
23801	Neckar	53	50	18	69	59	49
24901	Main	61	60	28	74	61	56
26901	Mosel	56	52	36	76	73	66
27601	Ruhr	57	54	27	69	53	57
27801	Lippe	61	59	19	81	67	63
27903	Rhine	56	51	20	69	57	47
37602	Ems	85	80	45	94	80	68
41002	Werra	83	83	51	94	88	86
42001	Fulda	65	61	40	81	74	80
48901	Aller	78	70	32	86	72	66
49103	Weser	75	70	36	87	74	69
53801	Schwarze Elster	79	67	34	81	77	80
54901	Mulde	66	53	37	84	73	63
56901	Saale	83	69	33	83	65	54
58901	Havel	74	63	25	65	60	51
59311	Elbe	77	65	31	79	69	58
69001	Odra	72	46	27	64	52	56
	North Sea coast	88	81	49	91	80	71
	Baltic Sea coast	85	78	29	88	82	77
	North Sea	71	64	30	79	67	57
	Baltic Sea	82	70	29	85	78	75
	Black Sea	78	70	36	89	80	75
	Germany	73	65	30	81	70	60

Nitrogen

Table 4.25, Figure 4.5 and Maps 4.37 to 4.31 show the N-emissions to German catchments for the periods 1998-2000, 1993-1997 and 1983-1987. The total nitrogen emissions for the 1998-2000 period were estimated as 688 kt/a N. Of this total, more than 81 % are derived from diffuse sources. This proportion increased by around 10 % from that of the earlier study periods, although the total diffuse N-emission clearly decreased. In the 1983-1987 period, the total nitrogen emission of 1,088 kt/a N or 400 kt/a N (37 %) was higher than in the 1998-2000 period. Under the same hydrological conditions, this decrease would be 39 %. The greatest reductions of 50 % or more were achieved in the Elbe catchment. At least since 1985-1987 the goal of a 50 % reduction was reached in this catchment . In the German part of the Odra catchment, this goal was achieved a little earlier and for the Rhine and Baltic coast catchments the goal is near with a 44 % reduction in N-emissions. In contrast, reductions of only 8 to 12 % have occurred since the mid eighties. These small reductions are the cause of the overall reduction of only around 40 % for German catchments draining into the North Sea.

Figure 4.5, Table 4.26 and Map 4.39 show that the proportion of point-source N-emissions are relatively high at 30 % or more for catchments with a high population density (Isar, Neckar, Main, Ruhr, Rhine, Saale und Havel). In the Havel and Odra catchments, the N-emissions from point sources are greater than from ground-water, the dominant diffuse emission pathway. In contrast, the proportion of point-source N-emissions in the Naab, Inn, Danube, Ems, Werra and Baltic Sea coast catchments is only 5 to 20 %.

The highest area-specific N-emissions in the 1998-2000 period with more than 27 kg/(ha·a) N were estimated for the Lippe, Ems, Inn and North Sea coast catchments. The cause for this is the very large N-emission from diffuse sources. In the Neckar, Ruhr and Isar catchments, too, the area specific N-emissions are as high (around 25 kg/(ha·a) N), but here this can be attributed to the above average emissions from point sources. The lowest area-specific emissions at less than 10 kg/(ha·a) N were estimated for the Havel and the German part of the Odra catchment.

Table 4.27: Sum of diffuse and point-source nitrogen emissions in the 1983-1987, 1993-1997 and 1998-2000 periods as well as their changes

ADR	CATCHMENT	EG_N			Change		Q-normalised change	
		2000	1995	1985	2000 to 1985	1995 to 1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]	[%]	[%]
14902	Naab	8020	7940	11110	-28	-29	-29	-19
16902	Isar	21090	25250	28520	-26	-11	-32	-17
18902	Inn	22190	20140	24090	-8	-16	-22	-15
19101	Danube	122650	127130	152370	-20	-17	-25	-16
23704	Upper Rhine	23430	24110	36270	-35	-34	-41	-34
23801	Neckar	35430	42140	60440	-41	-30	-42	-31
24901	Main	50090	57310	81740	-39	-30	-43	-31
26901	Mosel	20380	18460	27490	-26	-33	-33	-31
27601	Ruhr	11210	12760	14340	-22	-11	-24	-12
27801	Lippe	13590	16190	18170	-25	-11	-26	-14
27903	Rhine	230960	258340	395030	-42	-35	-44	-35
37602	Ems	25100	26970	27360	-8	-1	-13	-7
41002	Werra	10000	9010	12810	-22	-30	-29	-29
42001	Fulda	13490	12890	15990	-16	-19	-20	-15
48901	Aller	22320	25200	38360	-42	-34	-43	-32
49103	Weser	65540	69300	100620	-35	-31	-38	-29
53801	Schwarze Elster	5820	6930	11360	-49	-39	-43	-35
54901	Mulde	16490	18900	32860	-50	-42	-52	-43
56901	Saale	35150	49180	81830	-57	-40	-55	-41
58901	Havel	19010	25720	46730	-59	-45	-54	-44
59311	Elbe	102290	134120	230680	-56	-42	-53	-42
69001	Odra	3990	5480	7870	-49	-30	-48	-30
	North Sea coast	106880	107650	121350	-12	-11	-18	-12
	Baltic Sea coast	30130	32590	52430	-43	-38	-44	-37
	North Sea	530770	596380	875040	-39	-32	-41	-32
	Baltic Sea	34120	38070	60300	-43	-37	-44	-36
	Black Sea	123080	127450	152710	-19	-17	-25	-16
	Germany	687970	761900	1088050	-37	-30	-39	-30

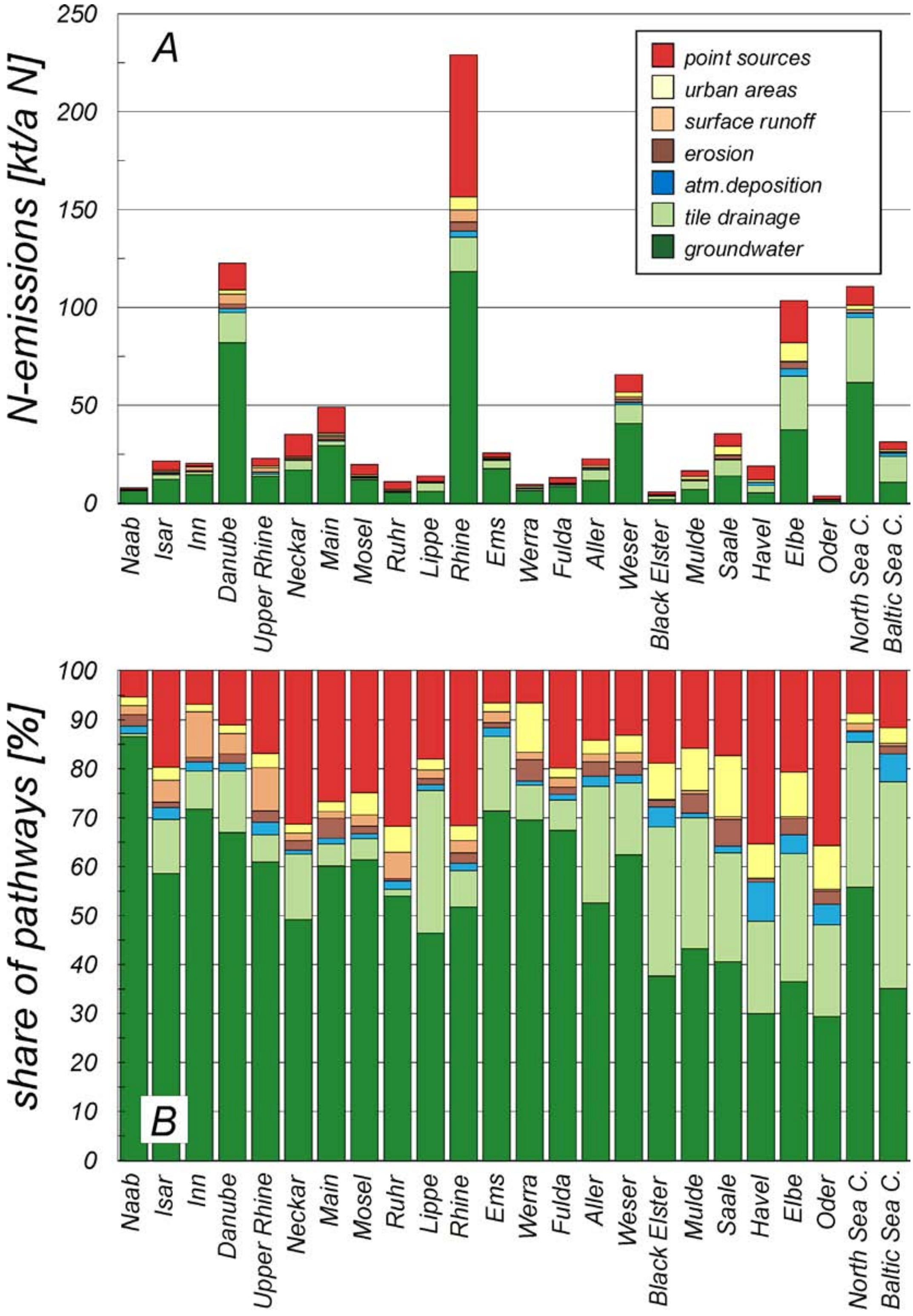
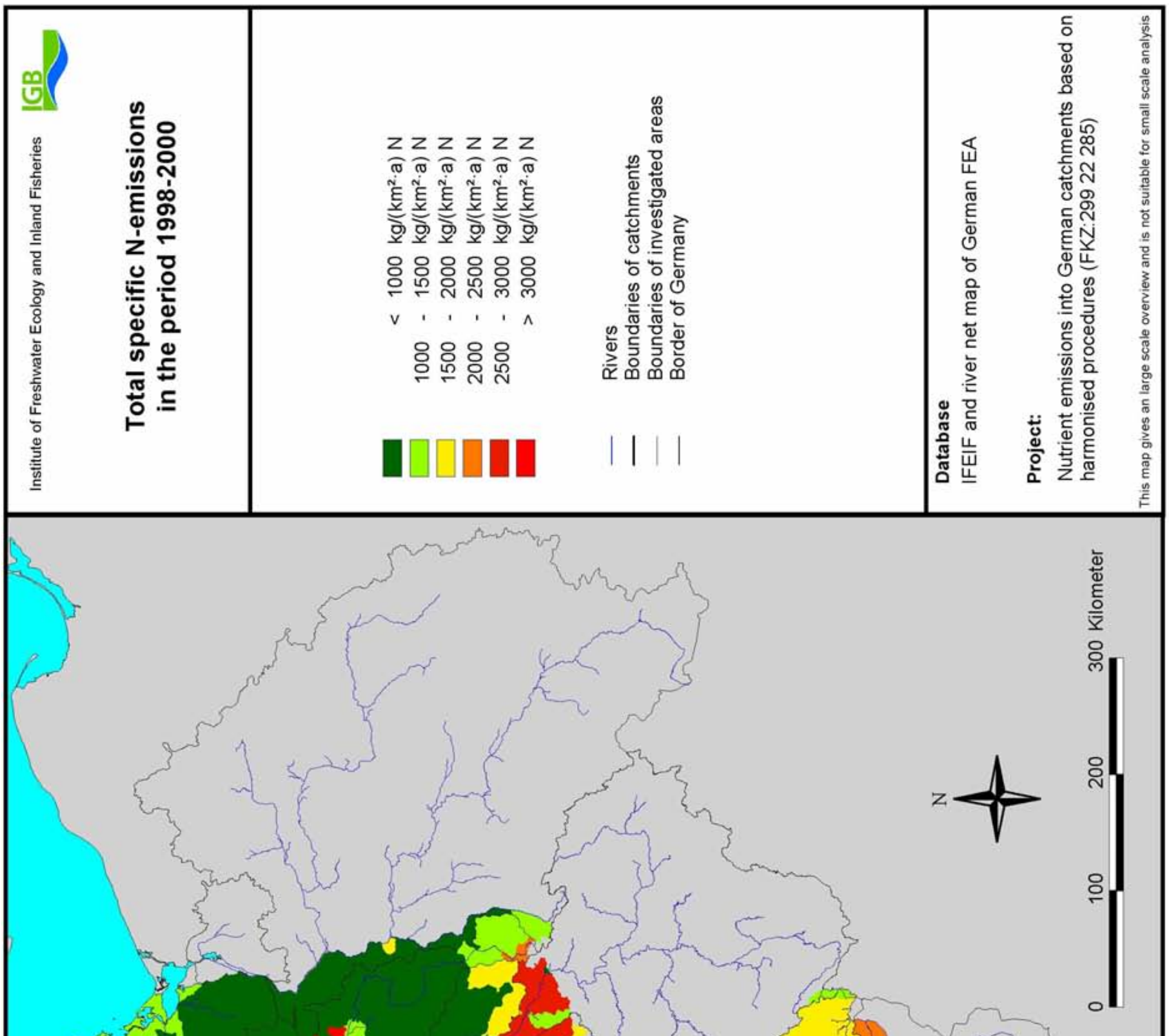
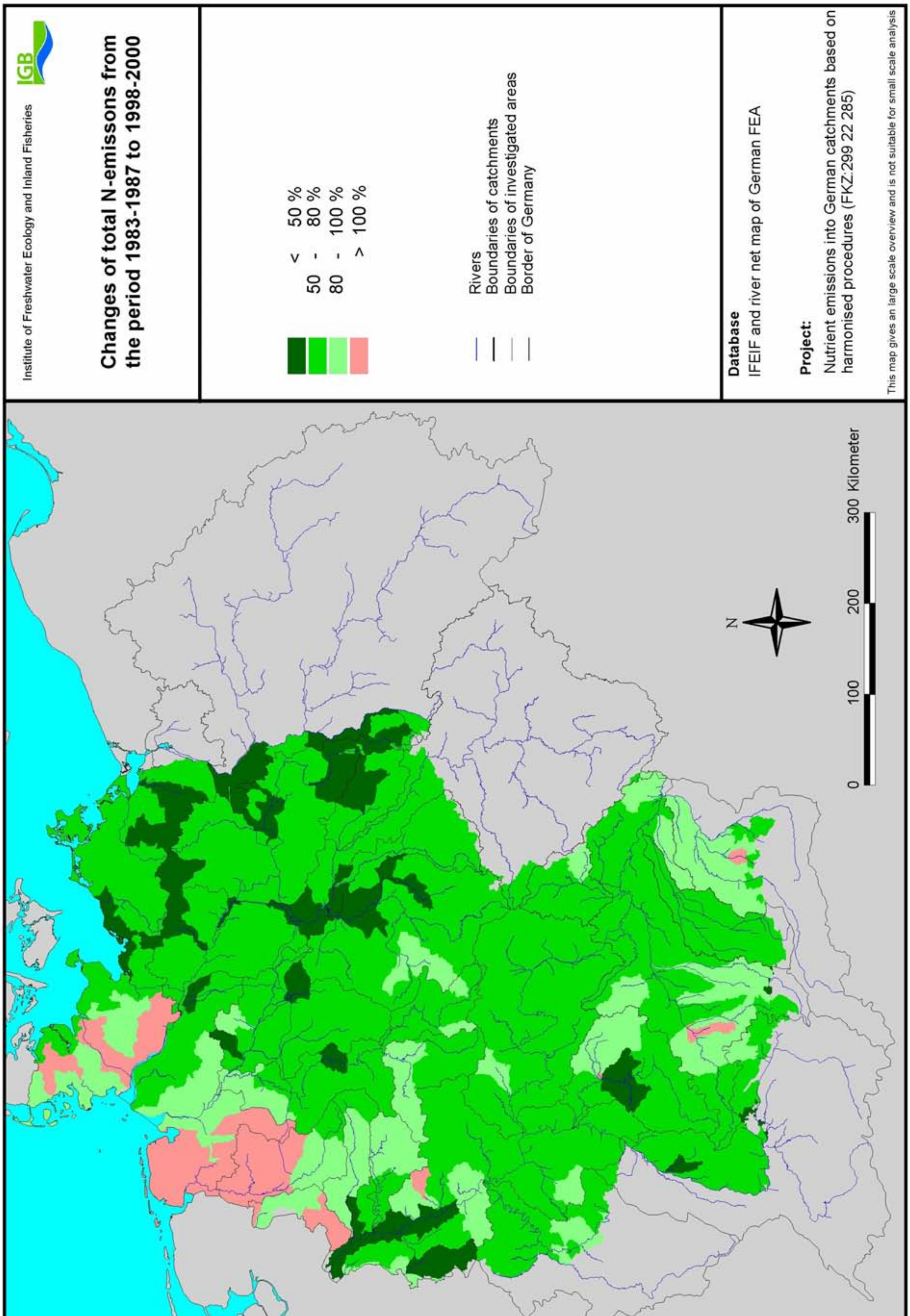


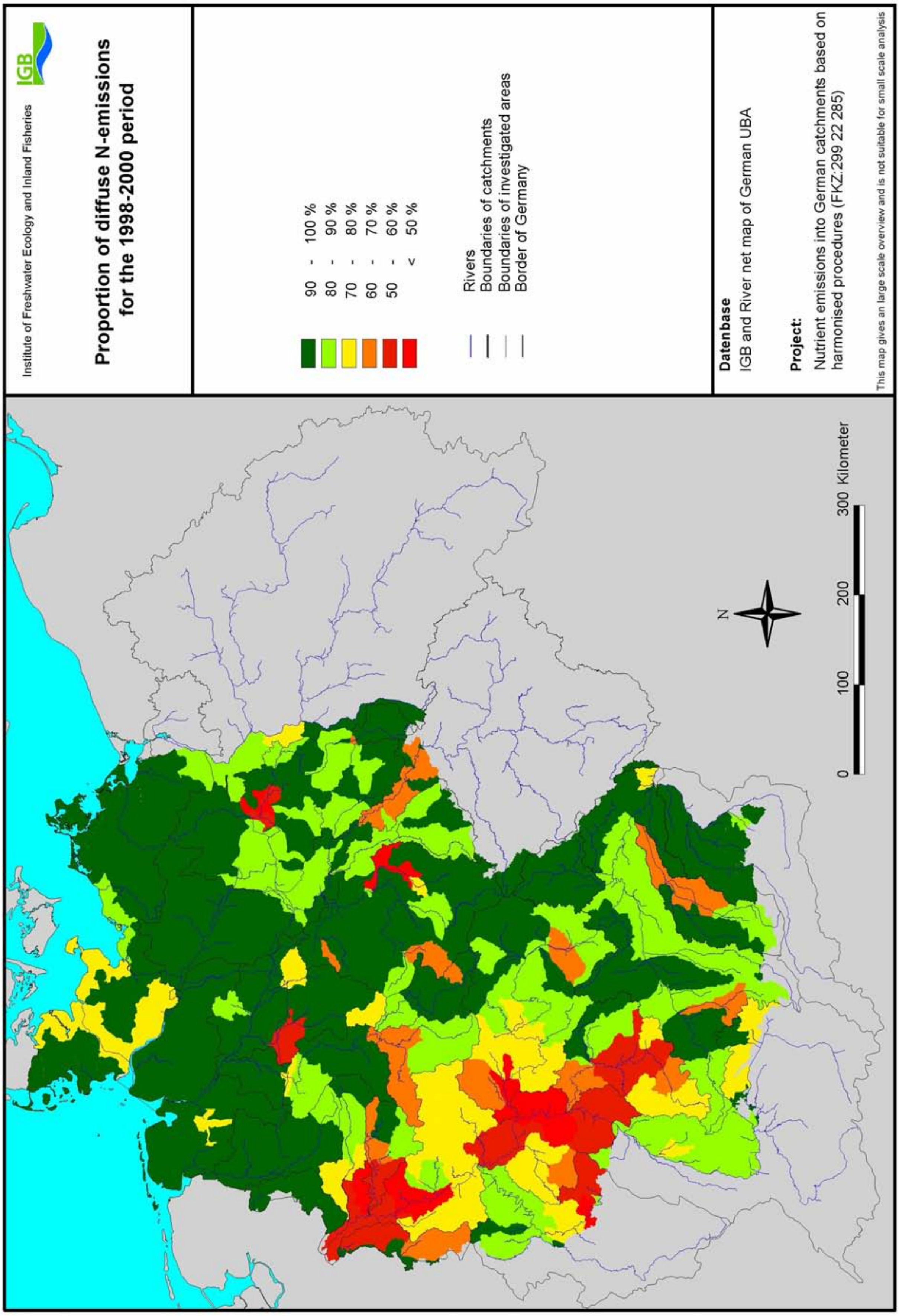
Figure 4.5: Nitrogen emissions (A) and contribution of pathways (B) for the studied German catchments.



Map 4.37: Area-specific nitrogen emissions from all sources in the period 1998-2000.



Map 4.38: Change in total nitrogen emissions from 1985 to 2000.



Map 4.39: Proportion of nitrogen emissions from diffuse pathways in the 1998-2000 period.

4.1.4 Nutrient emissions for natural background

Table 4.28 and Maps 4.40 to 4.43 provide an overview of the calculated nutrient emissions and concentrations under background conditions and in particular their regional differences.

According to the model calculations, P-concentrations in emissions under background conditions are not more than 30 µg/l P. In lowland areas, the P-concentrations in interflow water are around 30-60 µg/l P depending on the existing wetland area and areas with anaerobic conditions. In exceptional cases such as the Ems catchment, background P-concentrations of more than 60 µg/l P are possible.

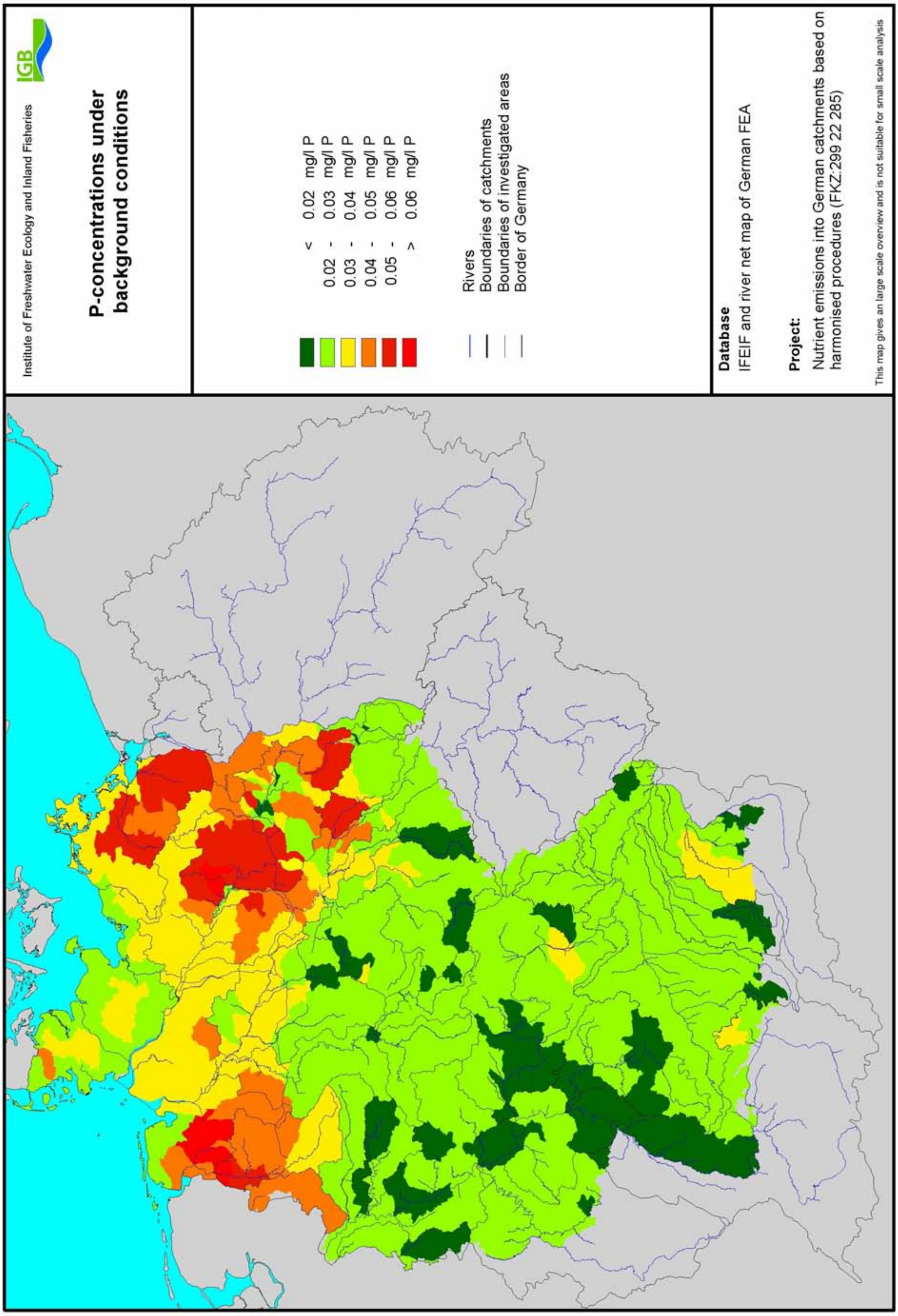
The overall picture of background emissions is shown in Map 4.41 and is clearly different from that for P-concentrations. The highest background P-emissions were calculated for the Alpine rivers and the north-west German plain. The lowest values were calculated for central German catchments and the north-east German plain as well as the Main catchment.

The values for nitrogen concentration in emissions to catchments under background conditions are mostly in the range 0.4 to 1.0 mg/l N as shown in Map 4.42. Only for the Peene and Uecker catchments on the Baltic Sea coast values of less than 0.4 mg/l N are calculated. The highest N-concentrations were calculated for catchments in consolidated rock regions characterised by a relatively low outflow rate (Thuringian Forest and Ore Mountains and the catchment of Main). With the N-emissions under background conditions shown in Map 4.43, there are sharp differences between the east German catchments with unconsolidated rocks with very low emissions and all other catchments. Exceptionally high background emissions, on the other hand, were calculated for the Alpine areas.

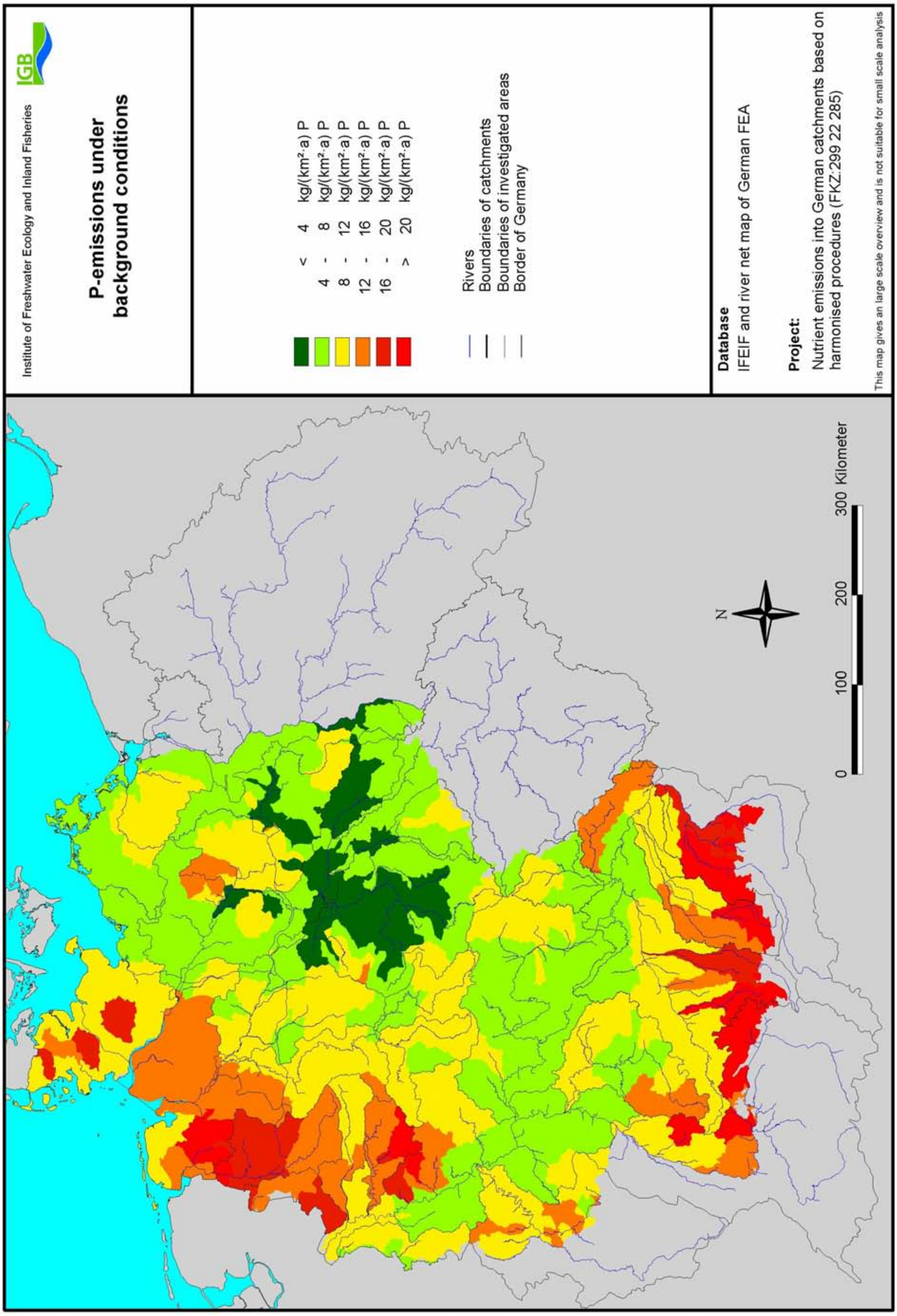
According to the model studies, one can conclude that overall, 93000 t/a N and 3600 t/a P enter German catchments under background conditions.

Table 4.28: Total phosphorus and nitrogen background emissions for the period 1993-1995 with normalised hydrological conditions.

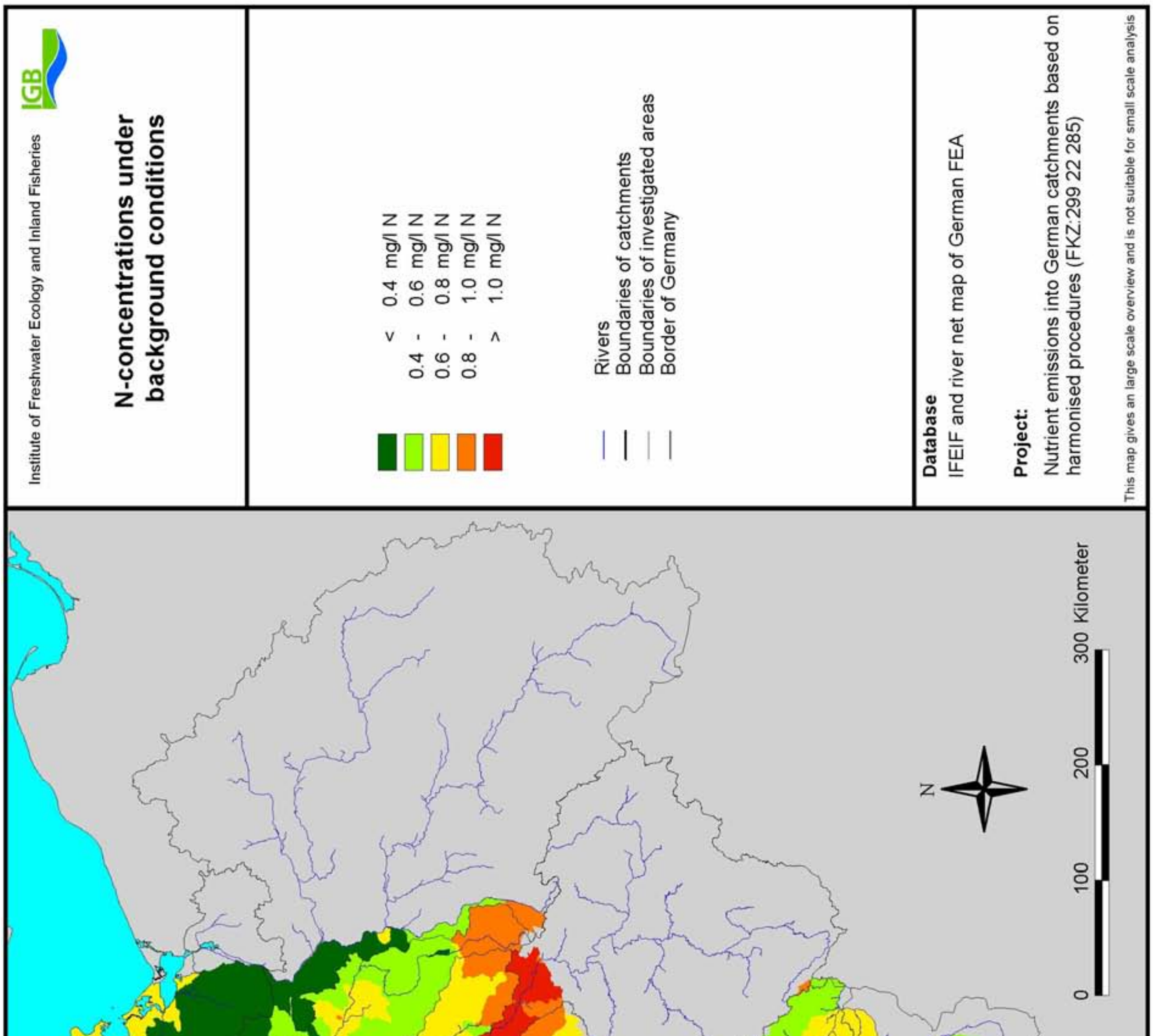
LOC.	CATCHMENT	EHG_P	CHG_P	EHG_N	CHG_N
		[t/a P]	[mg/l P]	[t/a N]	[mg/l N]
14902	Naab	40	0.024	1560	0.92
16902	Isar	147	0.033	3030	0.62
18902	Inn	195	0.065	3180	0.44
19101	Danube	793	0.047	18830	0.56
23704	Upper Rhine	275	0.037	4540	0.48
23801	Neckar	129	0.022	5040	0.86
24901	Main	202	0.024	8190	0.97
26901	Mosel	107	0.023	3320	0.76
27601	Ruhr	69	0.024	1470	0.51
27801	Lippe	53	0.029	1520	0.82
27903	Rhine	1087	0.030	32990	0.65
37602	Ems	151	0.044	2860	0.84
41002	Werra	44	0.024	1730	0.95
42001	Fulda	59	0.025	2130	0.91
48901	Aller	127	0.027	4100	0.87
49103	Weser	335	0.027	11100	0.89
53801	Schwarze Elster	31	0.033	770	0.98
54901	Mulde	43	0.024	1510	0.88
56901	Saale	106	0.025	4380	1.05
58901	Havel	174	0.041	2120	0.78
59311	Elbe	506	0.028	11970	0.97
69001	Odra	23	0.034	360	0.83
	North Sea coast	493	0.036	12000	0.89
	Baltic Sea coast	186	0.035	3190	0.72
	North Sea	2572	0.030	70920	0.76
	Baltic Sea	210	0.034	3560	0.79
	Black Sea	796	0.047	18890	0.56
	Germany	3578	0.034	93370	0.71



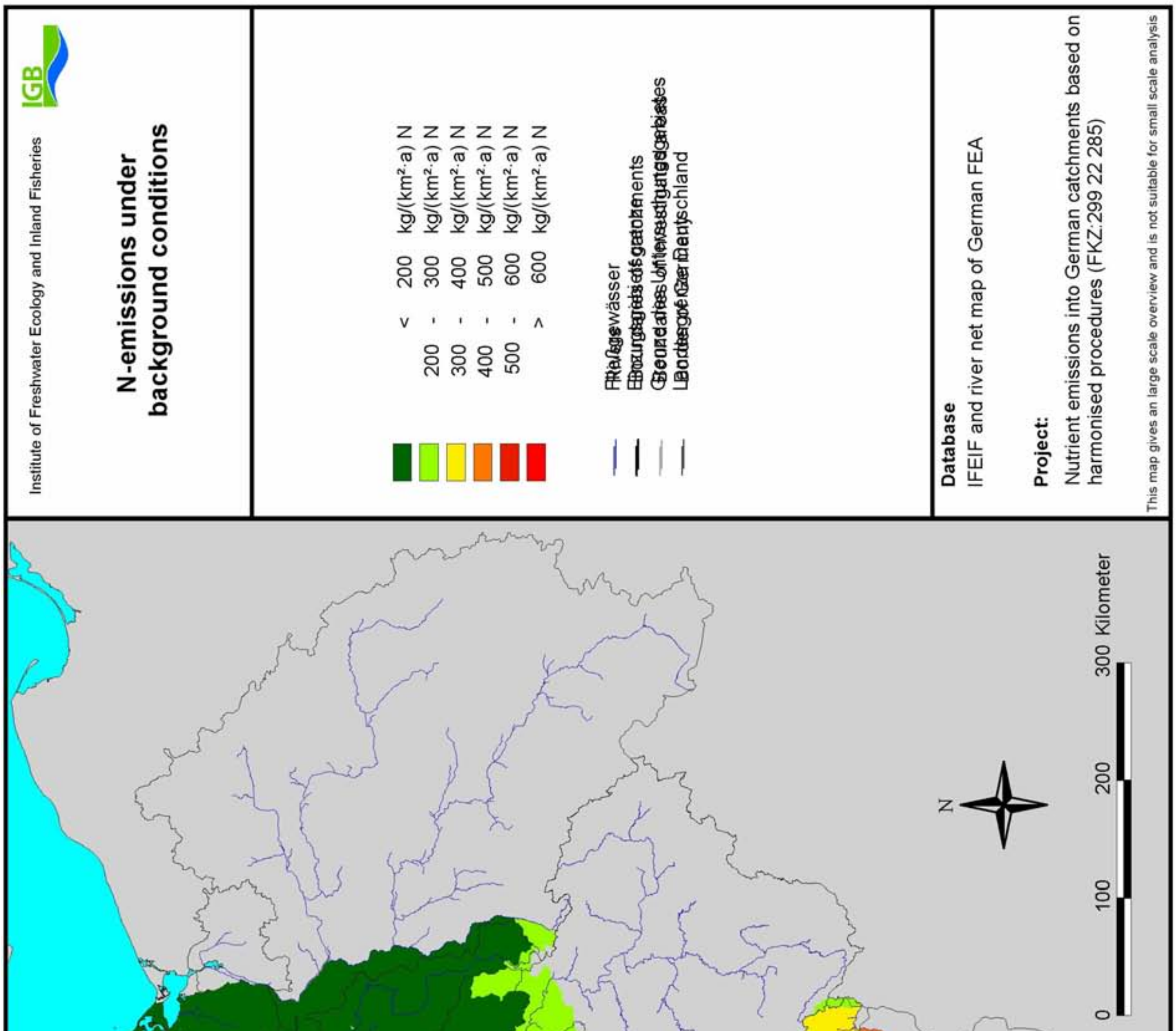
Map 4.40: Flow weighted phosphorus concentrations under background conditions.



Map 4.41: Area-specific P-emissions under background conditions.



Map 4.42: Flow weighted nitrogen concentrations under background conditions.



Map 4.43: Nitrogen emissions under background conditions

4.2 Quantification of human influences on nutrient emissions according to cause or sector

From the estimates of nutrient emissions under background conditions, it is also possible to distinguish the proportion of emissions related to human activities, namely agriculture, forestry and urban activities. The results are shown in Tables 4.29 to 4.34. Since the relative contributions estimated from the background conditions are of interest in relation to water quality guidelines, these are also shown in Tables 4.31 and 4.34 as well as Maps 4.44 to 4.47. It should be noted that these P and N-emissions related to human activities for the 1998-2000 are normalised for the hydrological conditions in the 1993-1997 period.

Although nutrient emissions and loadings, particularly for phosphorus, have been reduced dramatically in the last 15 years (more than 50 % for phosphorus in almost all of Germany), the values clearly remain well above background conditions as can be seen in Maps 4.44 to 4.47. With the exception of the Lake Constance area as well as the Alpine region, the North Sea coast and the north-east German plain, P-emissions related to human activity are 5 to 6 times as high as background values.

If one accepts that the good ecological conditions required by WRRL with double the background values could be achieved, today this goal has only been reached for phosphorus in parts of the Lake Constance catchment. Although phosphorus emissions due to agriculture have clearly been greatly reduced, they remain over 5 times background values in the most intensely agricultural regions.

For nitrogen, the current situation is even more serious. In no catchment the good ecological state (according to WRRL) of double the background values has been achieved.

For agricultural areas, nitrogen emissions are still more than 300 % of background values in about 80 % of the catchments and in the case of agricultural areas in the plains and the Danube, N-emissions are often more than 5 times as high than those of background conditions.

Figure 4.6 shows the proportions of current nutrient emissions attributed to various types of factor, namely point-sources, agriculture, other human related diffuse emissions and background values for the larger German catchments in 1998-2000. The fractions were based on values normalised to 1993-1997 hydrological conditions. Only in the upper Rhine and Inn catchments the background P-loading was more than 20 % of the total. In the Rhine and its sub-catchments, point sources with more than 40 % are the main source of P-loading. With the exception of the Rhine, Havel, Fulda and Mulde catchments, agricultural activity was responsible for 40 to 60 % of phosphorus emissions in the 1998 to 2000 period. In the North Sea coast area, this figure is even higher at around 70 %.

Table 4.29: Phosphorus emissions related to human activity for the periods 1983-1987, 1993-1997 and 1998-2000 as well as their changes.

LOC.	CATCHMENT	EANT$_P$			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]
14902	Naab	182	234	502	-64	-53
16902	Isar	721	773	2422	-70	-68
18902	Inn	462	540	1394	-67	-61
19101	Danube	3681	4169	9722	-62	-57
23704	Upper Rhine	837	1038	2322	-64	-55
23801	Neckar	1489	1620	6066	-75	-73
24901	Main	2531	2584	6947	-64	-63
26901	Mosel	745	839	2104	-65	-60
27601	Ruhr	478	507	1505	-68	-66
27801	Lippe	449	466	1484	-70	-69
27903	Rhine	9566	10399	36474	-74	-71
37602	Ems	1084	1149	2323	-53	-51
41002	Werra	463	460	1079	-57	-57
42001	Fulda	405	432	941	-57	-54
48901	Aller	1310	1477	3444	-62	-57
49103	Weser	3174	3423	7971	-60	-57
53801	Schwarze Elster	229	289	777	-71	-63
54901	Mulde	923	1188	2416	-62	-51
56901	Saale	2293	2793	7471	-69	-63
58901	Havel	850	1100	3832	-78	-71
59311	Elbe	5572	6931	18663	-70	-63
69001	Odra	235	382	743	-68	-49
	North Sea coast	5022	5437	10120	-50	-46
	Baltic Sea coast	966	1053	3290	-71	-68
	North Sea	24418	27340	75552	-68	-64
	Baltic Sea	1201	1436	4033	-70	-64
	Black Sea	3685	4173	9731	-62	-57
	Germany	29304	32949	89316	-67	-63

Table 4.30: Nitrogen emissions related to human activity for the periods 1983-1987, 1993-1997 ans 1998-2000 as well as their changes.

LOC.	CATCHMENT	$EANT_N$			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]
14902	Naab	5300	6380	8050	-34	-21
16902	Isar	17210	22210	26790	-36	-17
18902	Inn	15080	16960	20250	-26	-16
19101	Danube	93420	108300	130240	-28	-17
23704	Upper Rhine	16270	19570	30830	-47	-37
23801	Neckar	29900	37100	55050	-46	-33
24901	Main	38230	49120	73410	-48	-33
26901	Mosel	14390	15150	23070	-38	-34
27601	Ruhr	9440	11280	12980	-27	-13
27801	Lippe	12290	14680	17220	-29	-15
27903	Rhine	183710	225360	357130	-49	-37
37602	Ems	22090	24110	25970	-15	-7
41002	Werra	7150	7280	10770	-34	-32
42001	Fulda	9700	10760	12730	-24	-15
48901	Aller	16800	21100	32640	-49	-35
49103	Weser	47990	58190	84680	-43	-31
53801	Schwarze Elster	5250	6160	9790	-46	-37
54901	Mulde	14120	17390	31330	-55	-44
56901	Saale	32280	44800	77970	-59	-43
58901	Havel	18910	23600	43510	-57	-46
59311	Elbe	96370	122150	219290	-56	-44
69001	Odra	3720	5120	7450	-50	-31
	North Sea coast	87820	95650	109320	-20	-13
	Baltic Sea coast	25850	29400	48300	-46	-39
	North Sea	437980	525460	796390	-45	-34
	Baltic Sea	29570	34520	55750	-47	-38
	Black Sea	93660	108560	130540	-28	-17
	Germany	561220	668530	982670	-43	-32

Table 4.31: Relationship of phosphorus and nitrogen emissions related to human activity with background values for the 1983-1987, 1993-1997 and 1998-2000 values.

LOC.	**CATCHMENT**	**$EANT_P/EH_P$**			**$EANT_N/EH_N$**		
		2000	**1995**	**1985**	**2000**	**1995**	**1985**
		[%]	**[%]**	**[%]**	**[%]**	**[%]**	**[%]**
14902	Naab	452	581	1246	340	409	516
16902	Isar	492	528	1652	568	733	884
18902	Inn	237	277	715	474	533	637
19101	Danube	464	525	1225	496	575	692
23704	Upper Rhine	305	378	845	358	431	679
23801	Neckar	1150	1251	4684	593	736	1092
24901	Main	1254	1281	3443	467	600	896
26901	Mosel	693	781	1957	433	456	695
27601	Ruhr	696	738	2190	642	767	883
27801	Lippe	844	874	2786	809	966	1133
27903	Rhine	880	957	3356	557	683	1083
37602	Ems	720	764	1544	772	843	908
41002	Werra	1047	1038	2439	413	421	623
42001	Fulda	684	731	1592	455	505	598
48901	Aller	1033	1165	2716	410	515	796
49103	Weser	946	1021	2376	432	524	763
53801	Schwarze Elster	883	1118	3002	682	800	1271
54901	Mulde	2278	2932	5963	935	1152	2075
56901	Saale	2217	2700	7222	737	1023	1780
58901	Havel	757	979	3411	892	1113	2052
59311	Elbe	1356	1686	4540	805	1020	1832
69001	Odra	1425	2314	4496	1033	1422	2069
	North Sea coast	1019	1104	2054	732	797	911
	Baltic Sea coast	633	691	2158	810	922	1514
	North Sea	986	1104	3051	618	741	1123
	Baltic Sea	711	849	2386	831	970	1566
	Black Sea	463	524	1222	496	575	691
	Germany	851	957	2595	601	716	1052

For nitrogen, the proportion of the total emissions related to agriculture and forestry was below 50 % in the Havel catchment and the German part of the Odra catchment. In contrast, for the Ems catchment, 80 % of nitrogen emissions are related to agriculture.

While one can conclude for phosphorus that yet further reductions can be achieved, particularly in the Rhine catchment, for nitrogen, measures to further reduce point-source emissions in the catchments of the Danube, Ems, Werra as well as the North Sea and Baltic Sea coasts could clearly be improved. In these area as well as others where the goal of a 50 % reduction in nitrogen emissions has not been achieved yet, it is necessary to introduce further measures, particularly in relation to agricultural emissions.

Figures 4.7 and 4.8 show the changes in the proportions of N and P emissions with various causes in the North Sea and Baltic Sea coastal areas as well as Germany as a whole. It can be seen that in the 1998-2000 period, about 50 % of P-emissions and 62 % of N-emissions are related to agricultural activities. In contrast, the proportion of point source emissions for both P and N have been greatly reduced and for the 1998-2000 period represented only 27 and 19 % respectively of total emissions. Only 11 % of P-emissions and 13 % of N emissions are attributed to background conditions in these areas.

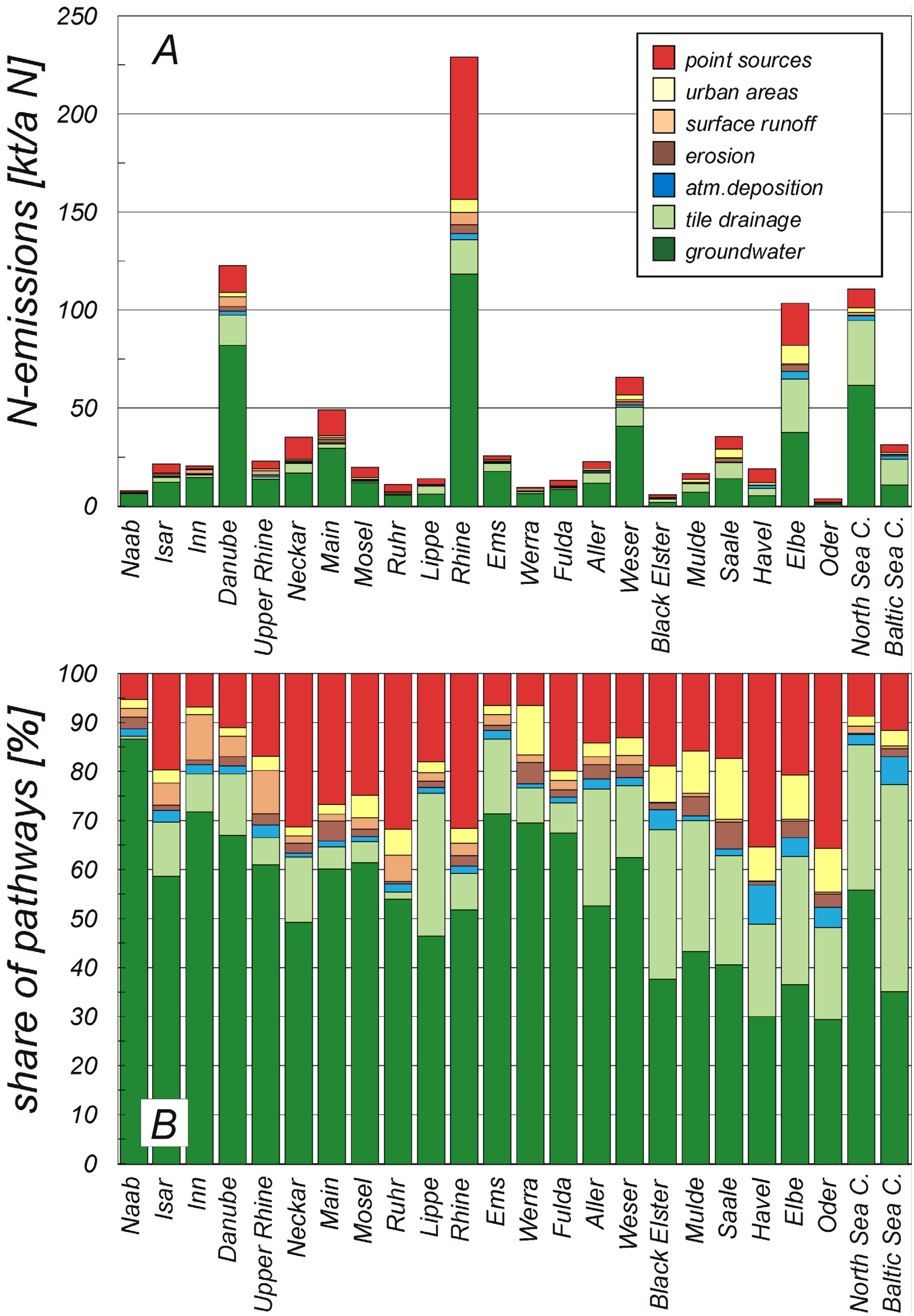


Figure 4.6: Proportions of various sources of nutrient emissions to German catchments in the periods 1983-1987, 1993-1997 and 1998 to 2000.

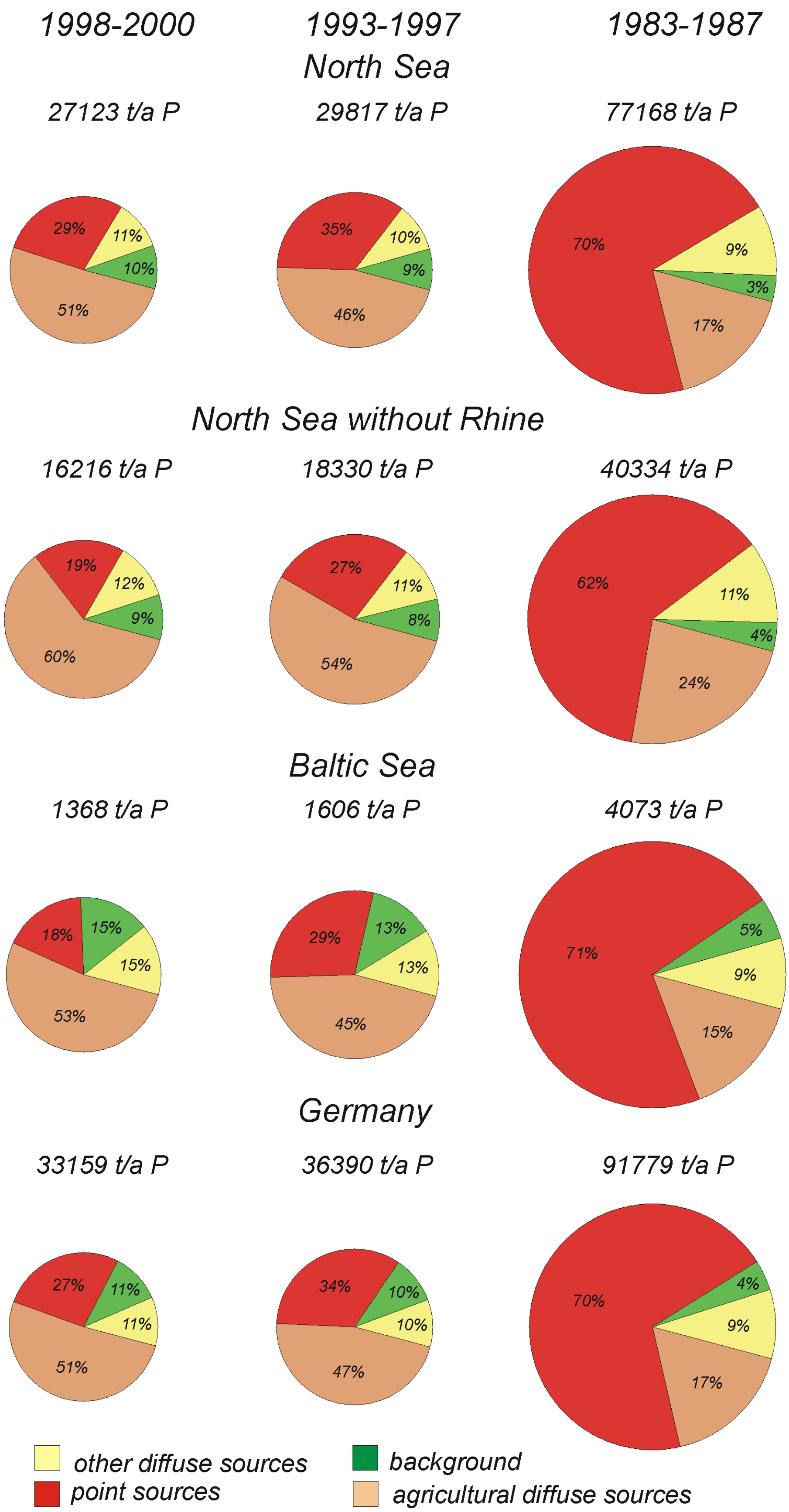


Figure 4.7: Proportions of phosphorus emissions from Germany to seas attributed to various sources for the periods 1983-1987, 1993-1997 and 1998-2000.

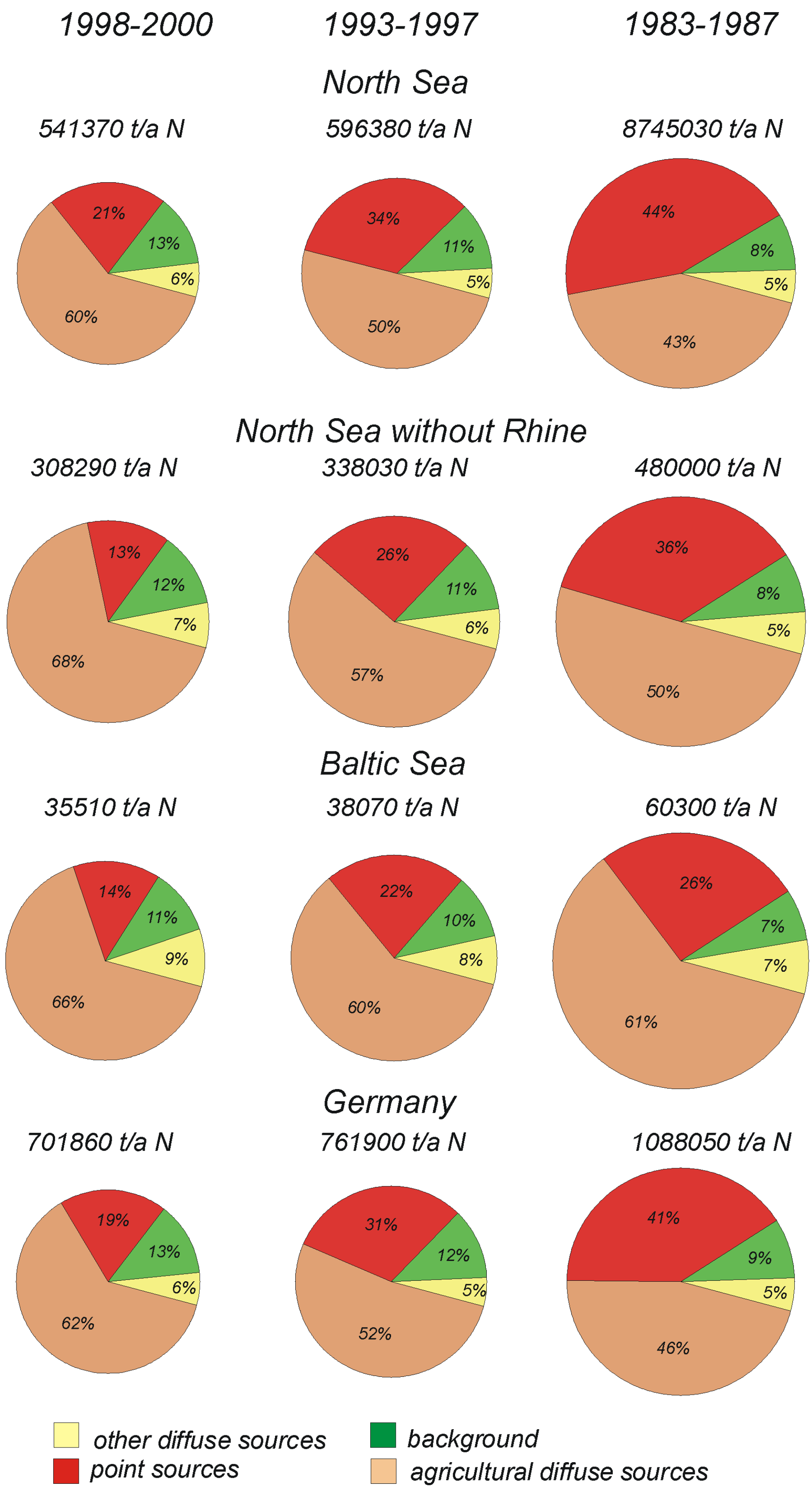


Figure 4.8: Proportions of nitrogen emissions from Germany to seas attributed to various sources in the periods 1983-1987, 1993-1997 and 1998-2000.

Table 4.32: Phosphorus emissions related to agriculture in the periods 1983-1987, 1993-1997 and 1998-2000 as well as their changes.

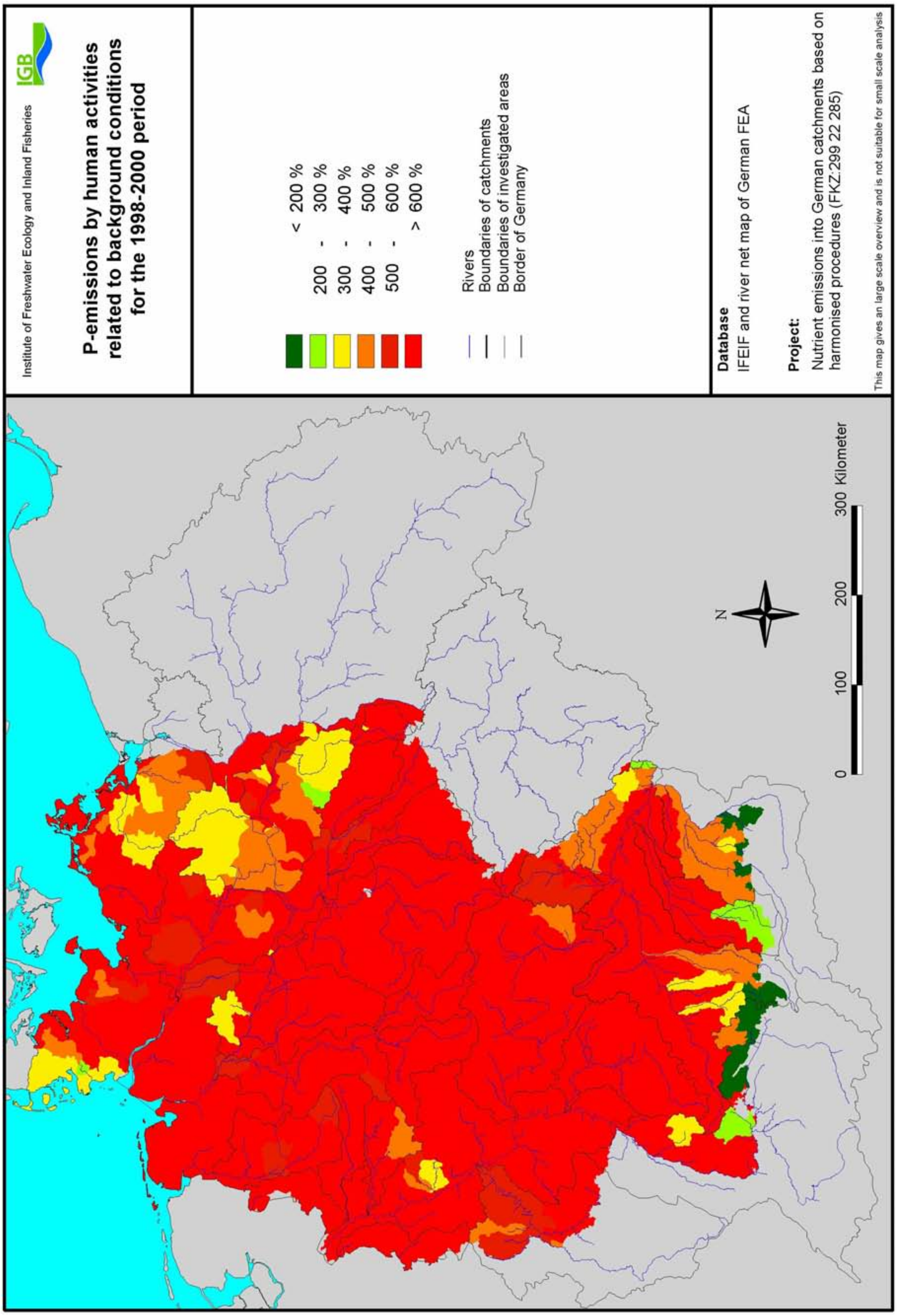
LOC.	CATCHMENT	ELW_P			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a P]	[t/a P]	[t/a P]	[%]	[%]
14902	Naab	108	107	100	8	7
16902	Isar	389	387	368	6	5
18902	Inn	281	279	268	5	4
19101	Danube	2294	2283	2152	7	6
23704	Upper Rhine	483	481	463	4	4
23801	Neckar	617	615	584	6	5
24901	Main	1295	1288	1206	7	7
26901	Mosel	229	228	220	4	4
27601	Ruhr	147	147	143	2	2
27801	Lippe	210	210	197	7	7
27903	Rhine	3740	3723	3527	6	6
37602	Ems	836	838	821	2	2
41002	Werra	255	252	240	6	5
42001	Fulda	190	189	179	6	6
48901	Aller	875	872	830	5	5
49103	Weser	1949	1940	1843	6	5
53801	Schwarze Elster	129	127	122	5	4
54901	Mulde	432	424	403	7	5
56901	Saale	1365	1339	1270	7	5
58901	Havel	439	443	442	-1	0
59311	Elbe	3138	3146	3023	4	4
69001	Odra	127	127	122	4	4
	North Sea coast	3981	3984	3963	0	1
	Baltic Sea coast	631	625	597	6	5
	North Sea	13645	13632	13177	4	3
	Baltic Sea	758	752	719	5	5
	Black Sea	2295	2285	2153	7	6
	Germany	16698	16668	16049	4	4

Table 4.33: Nitrogen emissions related to agriculture in the periods 1983-1987, 1993-1997 and 1998 to 2000 as well as their changes.

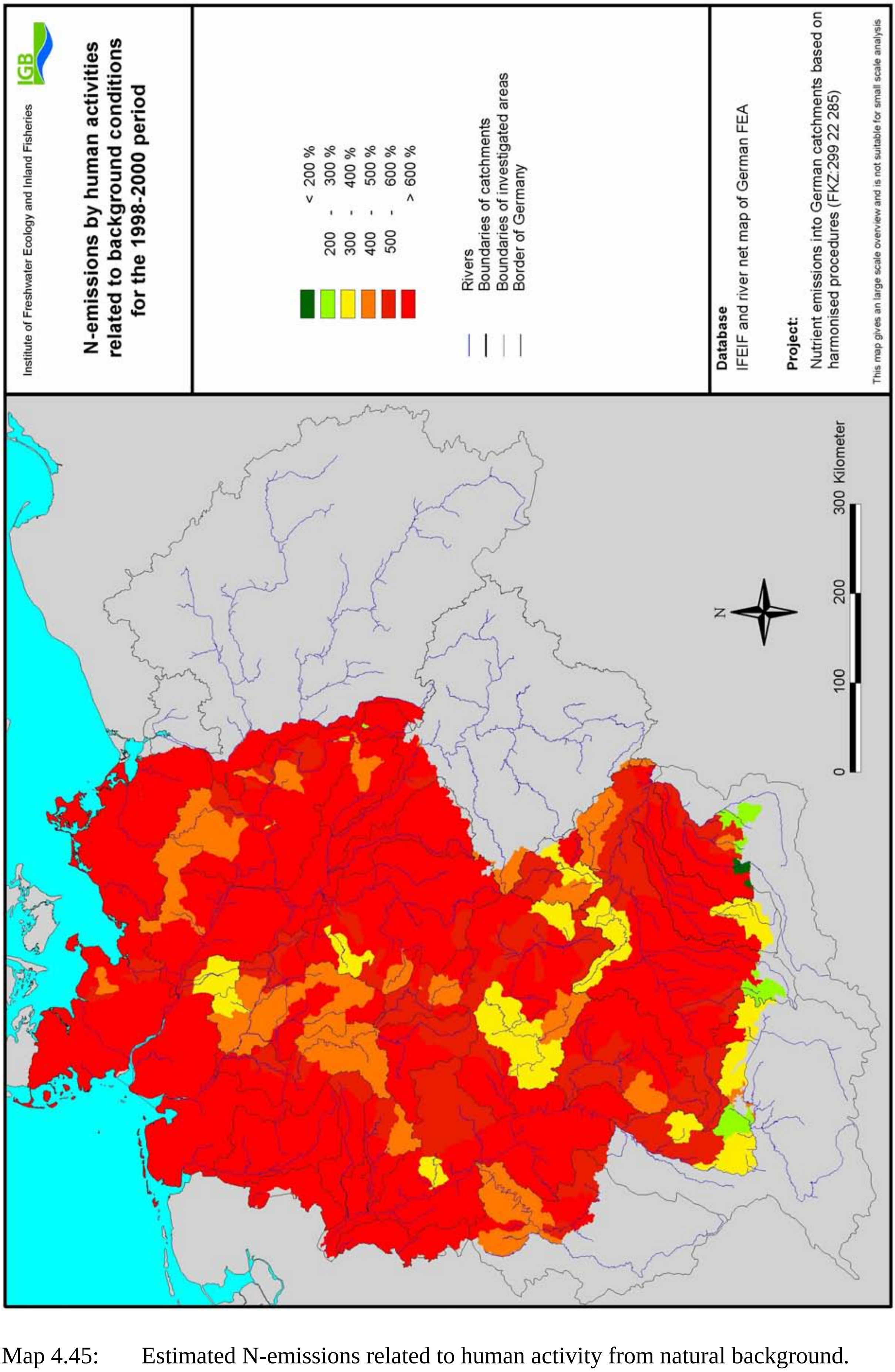
LOC.	CATCHMENT	$EANT_N$			Change	
		2000	1995	1985	2000 to 1985	1995 to 1985
		[t/a N]	[t/a N]	[t/a N]	[%]	[%]
14902	Naab	4640	4900	5940	-22	-18
16902	Isar	11930	13180	15420	-23	-15
18902	Inn	13020	12960	11880	10	9
19101	Danube	75840	78550	85320	-11	-8
23704	Upper Rhine	11200	10570	13940	-20	-24
23801	Neckar	17900	19040	22610	-21	-16
24901	Main	23580	25200	34010	-31	-26
26901	Mosel	8280	8860	11580	-28	-23
27601	Ruhr	5130	4490	5450	-6	-18
27801	Lippe	9300	8950	9720	-4	-8
27903	Rhine	101640	104310	131290	-23	-21
37602	Ems	19580	18130	16070	22	13
41002	Werra	5440	5190	7680	-29	-32
42001	Fulda	6670	6980	8590	-22	-19
48901	Aller	12510	12970	17930	-30	-28
49103	Weser	36060	36630	48210	-25	-24
53801	Schwarze Elster	3460	3870	6340	-45	-39
54901	Mulde	9850	10550	16410	-40	-36
56901	Saale	21170	22580	33510	-37	-33
58901	Havel	9250	10530	15460	-40	-32
59311	Elbe	61570	67720	102750	-40	-34
69001	Odra	1760	1980	3040	-42	-35
	North Sea coast	73880	70390	68780	7	2
	Baltic sea coast	19480	21150	32100	-39	-34
	North Sea	292730	297190	367090	-20	-19
	Baltic Sea	21240	23130	35140	-40	-34
	Black Sea	76060	78780	85580	-11	-8
	Germany	390040	399110	487810	-20	-18

Table 4.34: Relationship of agriculture related phosphorus and nitrogen emissions related to background values for the periods 1983-1987, 1993-1997 and 1998-2000.

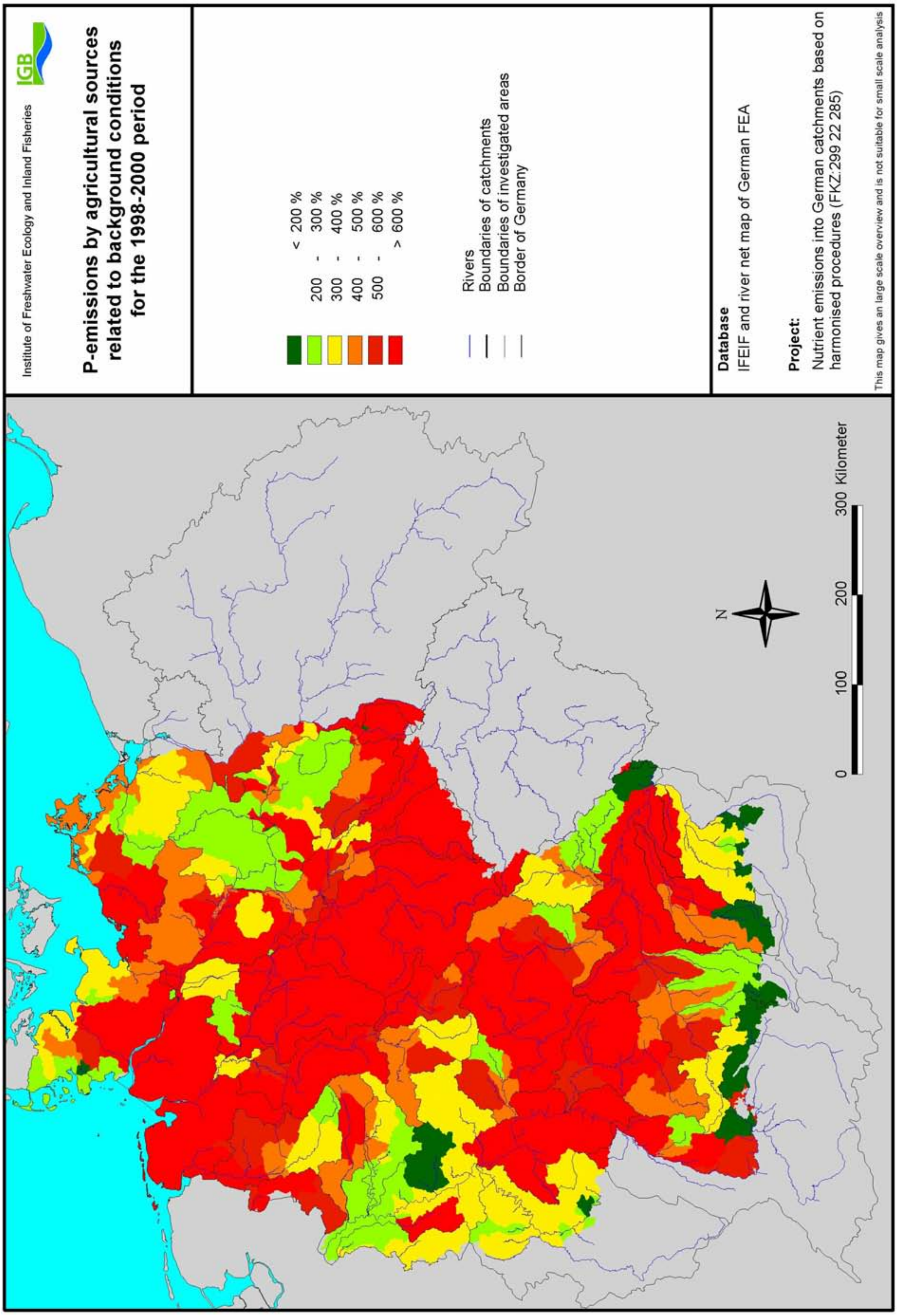
LOC.	CATCHMENT	$EANT_P/EH_P$			$EANT_N/EH_N$		
		2000	1995	1985	2000	1995	1985
		[%]	[%]	[%]	[%]	[%]	[%]
14902	Naab	267	266	248	297	314	381
16902	Isar	265	264	251	394	435	509
18902	Inn	144	143	137	409	408	374
19101	Danube	289	288	271	403	417	453
23704	Upper Rhine	176	175	168	247	233	307
23801	Neckar	477	475	451	355	378	449
24901	Main	642	638	598	288	308	415
26901	Mosel	213	212	205	249	267	349
27601	Ruhr	213	213	209	349	305	371
27801	Lippe	394	394	369	612	589	639
27903	Rhine	344	343	325	308	316	398
37602	Ems	555	557	545	685	634	562
41002	Werra	577	569	543	314	300	444
42001	Fulda	322	320	303	313	328	403
48901	Aller	690	687	655	305	316	437
49103	Weser	581	578	549	325	330	434
53801	Schwarze Elster	497	491	473	449	503	823
54901	Mulde	1066	1047	995	652	699	1087
56901	Saale	1319	1294	1228	483	516	765
58901	Havel	391	395	394	436	497	729
59311	Elbe	763	765	735	514	566	858
69001	Odra	770	766	739	489	550	844
	North Sea coast	808	809	805	616	587	573
	Baltic Sea coast	414	410	391	611	663	1006
	North Sea	551	550	532	413	419	518
	Baltic Sea	449	445	425	597	650	987
	Black Sea	288	287	270	403	417	453
	Germany	485	484	466	418	427	522



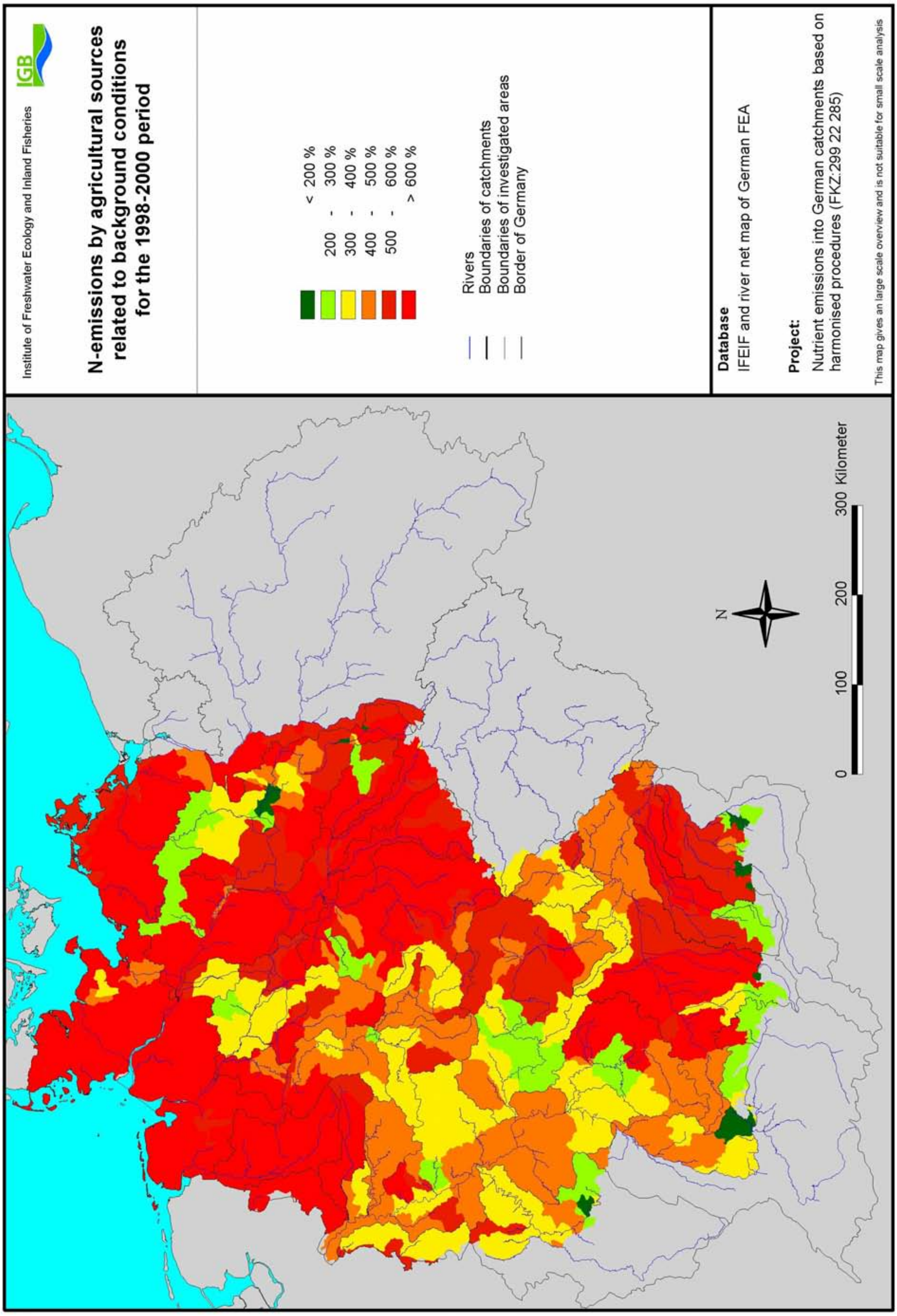
Map 4.44: Estimated P-emissions related to human activity from natural background.



Map 4.45: Estimated N-emissions related to human activity from natural background.



Map 4.46: Estimated agricultural P-emissions from natural background.



Map 4.47: Estimated agricultural P-emissions from natural background.

4.3 Comparison of calculated and measured nutrient loadings

With retention functions included in the MONERIS model it is possible to calculate nutrient loadings in addition to emissions and therefore model results can be directly compared with measured loadings. In addition to that, for the validation of the necessary comparison of the model, the probability of the loading calculations also requires determination of the emissions to seas from the rivers and particularly with scenario calculations, to demonstrate possible changes in loadings. For that, one can also calculate the average flow-through weighted nutrient concentrations for the inclusion of retention functions and the outflow from the emissions. Thus the model is linked to the ecological condition of the water-body. This is important above all for the implementation of water quality guidelines for the various ecological components of the loading grade are determined by concentrations and not by loadings.

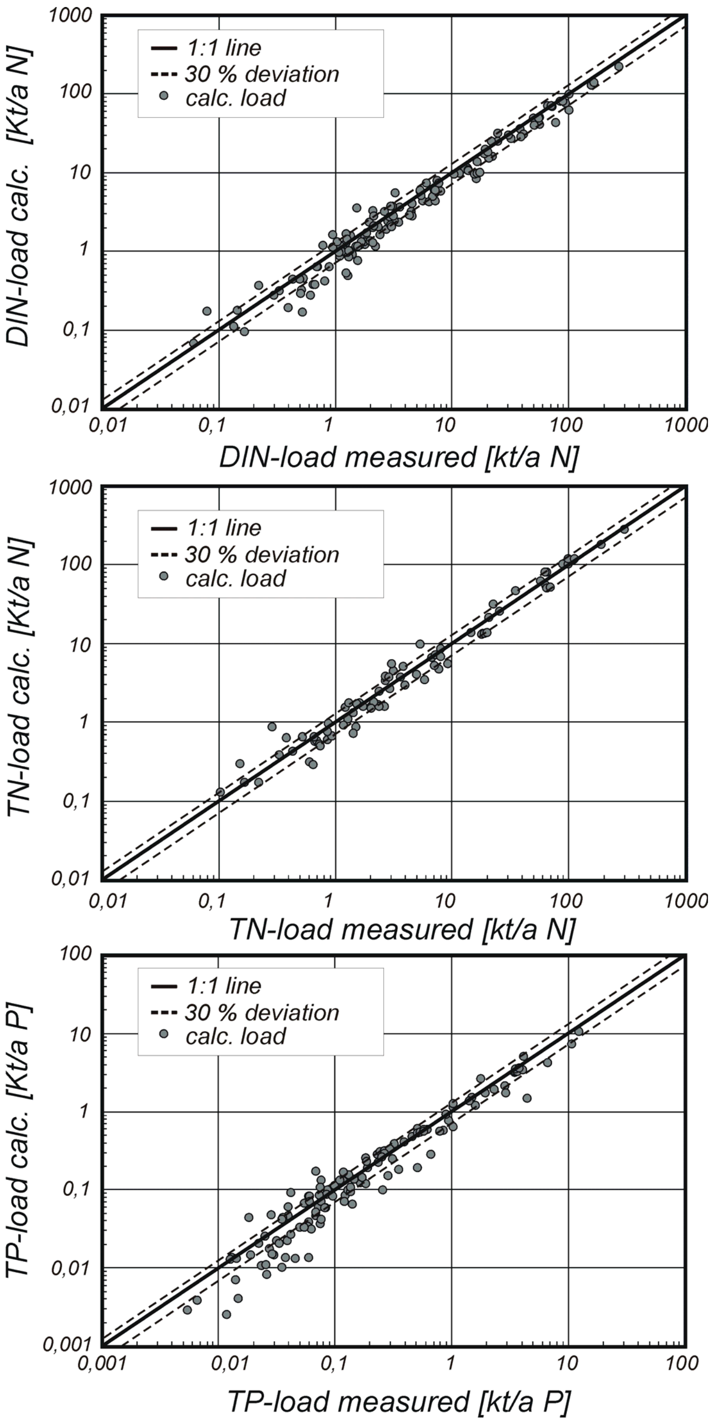


Figure.4.9: Comparison of measured and calculated nutrient loadings in the period 1998-2000.

Since the model has already been now for three study periods (1983-1987, 1993-1997 and 1998-2000) with the above shown differing levels of nutrient emissions in individual catchments, it is also interesting, from a scientific point of view, to test whether the retention estimations which now supplement the retention of total nitrogen, can also describe the changes of loadings.

Figures 4.9 to 4.11 show the comparison of loadings of total phosphorus (TP), inorganic dissolved nitrogen (DIN) and total nitrogen made from measurements with those made from nutrient emissions with consideration of retention functions. Comparisons are shown separately for the three studied time periods.

In general, from the figure it can be concluded that on the basis of a combined model, and despite the large range of loadings (more than 4 orders of magnitude) loading emissions as well as nutrient emissions are possible. The combined model also reflects the changes in individual catchments over the 15 year period of a factor of 0.2 to 0.5 for phosphorus and 0.4 to 0.8 for nitrogen.

While for the two nitrogen components, the changes in loadings in the study periods show no clear trend, for phosphorus, the calculated loadings show a tendency for an increasing proportion to lie below the 1:1 line from 1983-1987 to 1998-2000. This indicates an underestimate in the calculated TP loadings.

One can conclude that for phosphorus, emissions are not underestimated. The cause of the deviation from a 1:1 relationship is above all the retention formulae of BEHRENDT & OPITZ (1999) which calculated too high P-retention for these catchments. Since this relationship only applies to catchments such as the Havel containing shallow lakes in addition to rivers within the waterway network, there must be an additional P-source, namely the release of phosphorus from lake sediments. Up to now, this process was not considered in the model calculations since no general formula was available. On the basis of a constant release rate, one can use a correction factor for individual study periods. However, this does not solve the problem since as shown for the Havel catchment in Table 4.35, the release rate changes depending on external loadings. With the use of a constant release rate, the deviation of

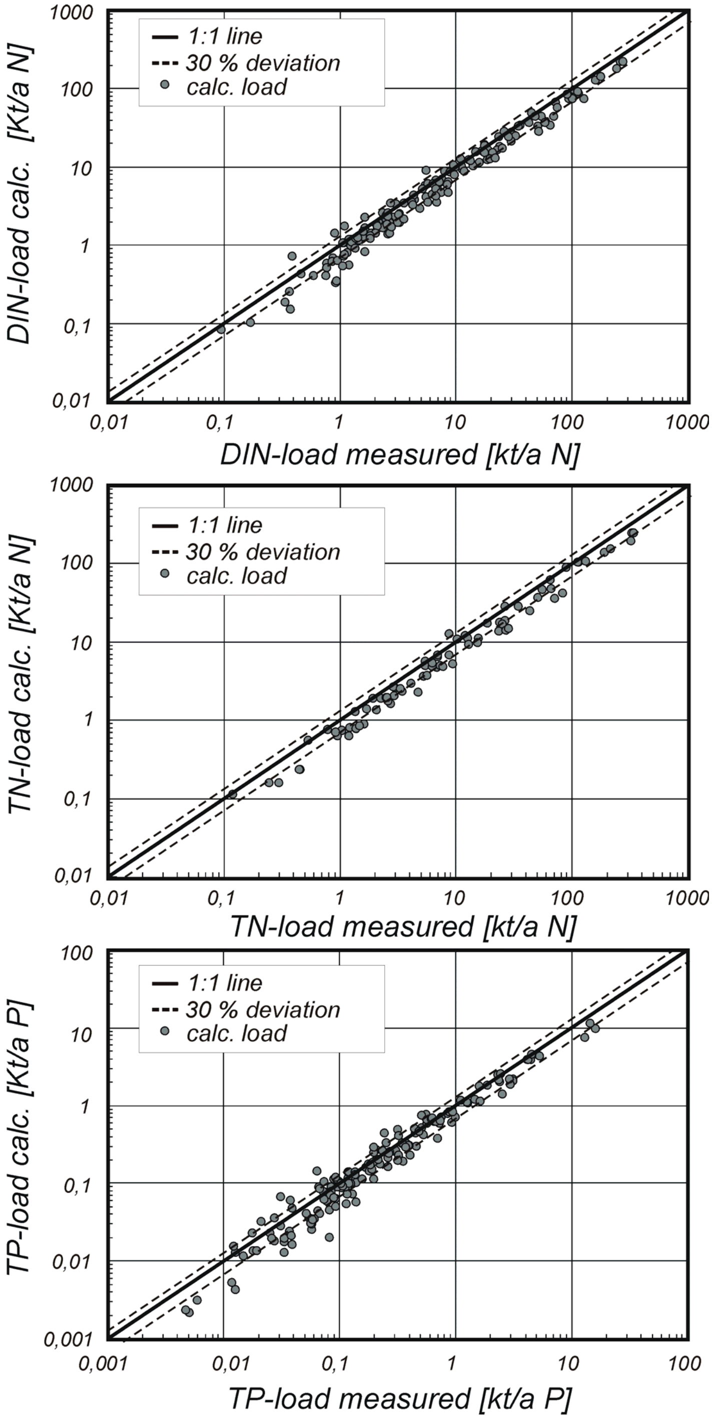


Figure 4.10: Comparison of measured and calculated nutrient loadings in the period 1993-1997.

measured and calculated loadings must increase. The relative deviations however remain nearly constant with a four fold reduction in loadings. If one compares particular calculated loadings with measured loadings of particular following periods, a better agreement between the observed and calculated loads can be estimated. In other words, the P-release is delayed in relation to loading.

For the Havel catchment, this delay is likely about 4 to 10 years and therefore probably longer than the retention time for phosphorus for all surface waters in the river network. Through the production of an effective retention time for phosphorus in water networks containing polymictic lakes, it is possible in the future that the P-retention will be described better. For the formation of such an effective retention time, one must, however, study the long-term behaviour of such catchments more detailed.

For nitrogen, too, the comparison of calculated and measured loadings shows that out of the 21 catchments, only that of the Havel shows a large deviation for all three study periods. Overall, the calculated nitrogen loadings are greatly underestimated in this catchment in a manner reminiscent of that for phosphorus. The polymictic and highly eutrophic lakes generally have a clearly higher denitrification potential than most other inland lakes and rivers. This potential is, however, also strongly dependent on external loading. The nitrogen behaviour could be solved through the determination of an effective retention time.

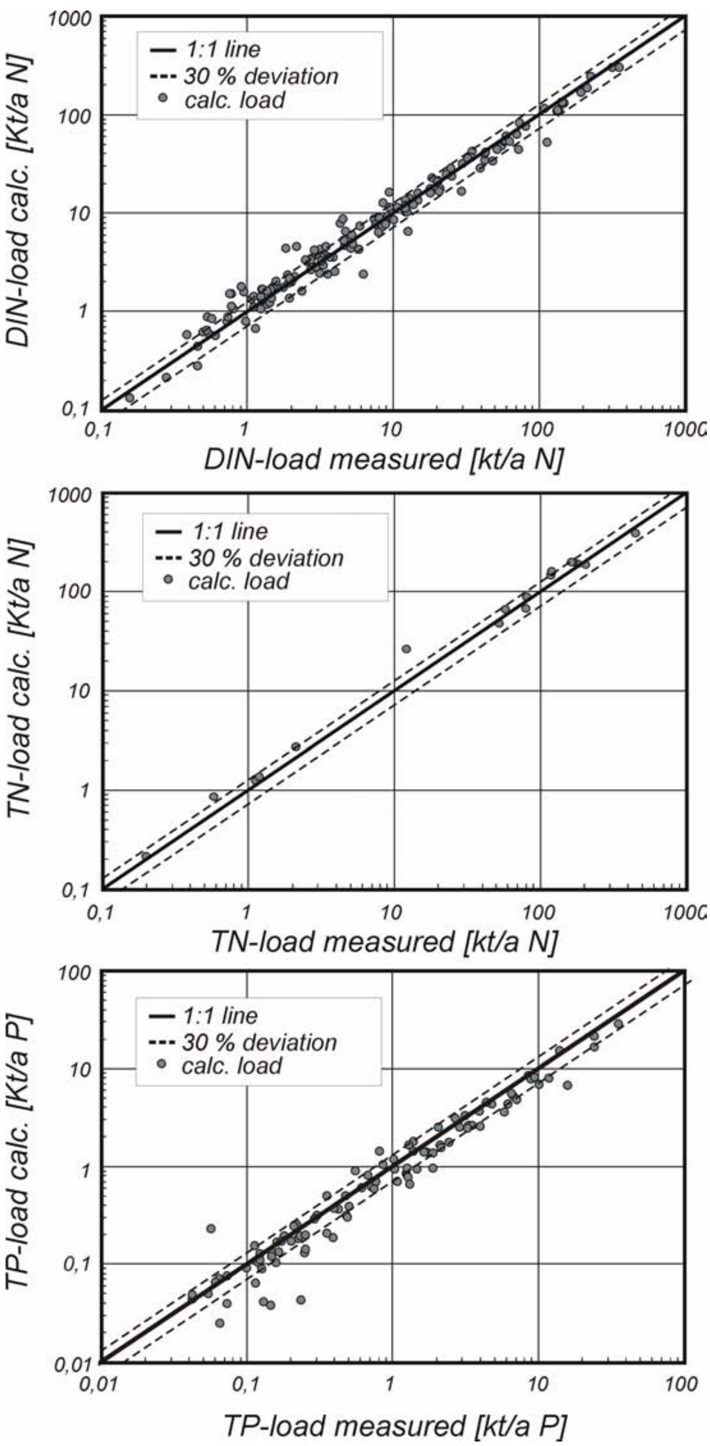


Figure 4.11: Comparison of measured and calculated nutrient loadings in the period 1983-1987.

In the other catchments included in Tables 4.35 to 4.37, the deviations from linearity are higher for individual study periods but in none for all three, it is the case for the Havel. This relates to the loading measurements. For example, in the Lippe catchment in 1993-1997, only monthly observational data was collected for part of the period (1993-1995).

A summary of all comparisons of measured and calculated nutrient loadings for all catchments and time periods is given in Table 4.38. For phosphorus, there is a mean deviation for all time periods of 27 % ranging from 25 to 30 % for the three individual periods. The differences are not statistically significant. The cause of the increase in 1998-2000 could be related to the shorter three year study period or a general increase in the deviation related to an increase in variation related to increase in the proportion of diffuse P-emissions. Of the total

Table 4.35: Comparison of measured (LP_{meas}) and calculated (LP_{cal}) loadings of total phosphorus in selected German catchments for the periods 1983-1987, 1993-1997 and 1998-2000.

CATCHMENT	**1998-2000**			**1993-1997**			**1983-1987**		
	LP_{meas}	**LP_{cal}**	**Dev.**	**LP_{meas}**	**LP_{cal}**	**Dev.**	**LP_{meas}**	**LP_{cal}**	**Dev.**
	[t/a P]	**[t/a P]**	**[%]**	**[t/a P]**	**[t/a P]**	**[%]**	**[t/a P]**	**[t/a P]**	**[%]**
Naab	286	155	46	261	168	35	504	399	21
Isar	455	500	10	443	526	19	1890	1388	27
Inn	1784	2723	53	2417	2113	13	2692	3181	18
Danube	4157	5206	25	5042	4742	6	8524	8688	2
Upper Rhine	6634	4312	35		4445			6952	
Neckar		1064		1007	1180	17	3114	3408	9
Main		1489		2520	1437	43	5867	3694	37
Mosel	4442	1541	65	3126	2255	28	6133	4405	28
Ruhr		425		300	449	50	1019	1203	18
Lippe		333		188	357	90	1252	979	22
Rhine	12449	10796	13	14454	11951	17	35326	29113	18
Ems		822		872	858	2	967	1562	61
Werra		359		348	333	4	1071	713	33
Fulda		337		392	315	20	1300	677	48
Aller		802		944	865	8	1984	1951	2
Weser	2888	2229	23	2349	2196	7	7136	4918	31
Schwarze Elster	60	73	22	73	108	47		277	
Mulde	295	344	16	244	455	87		734	
Saale	896	955	7	1110	1212	9	3961	2610	34
Havel	473	197	58	702	393	44	1898	973	49
Elbe	3808	3675	4	4551	4700	3	9432	8304	12

369 compared values, more than two thirds have a deviation of less than 30 %. For about 10 % of the catchments, however, deviations of more than 50 % were found.

For inorganic dissolved nitrogen (DIN), Table 4.38 gives a mean deviation of measured and calculated values of 23 %. This is 2 % less than with phosphorus. The proportion of compared values with a difference of less than 30 % is 7 % higher than with phosphorus.

For phosphorus, one must conclude that in about 10 % of the catchments, the deviations are greater than 50 %. For 1993-1997 this figure is less than 5 %, likely due to the fact that the model coefficients for drainage and groundwater emissions were based on actual data.

For total nitrogen, the relationships are similar to those for DIN. But it has to be considered

Table 4.36: Comparison of measured (L_{DINmea}) and calculated (L_{DINcal}) loads for inorganic dissolved nitrogen in selected German catchments for the periods 1983-1987, 1993-1997 and 1998-2000.

VORFLUT	1998-2000			1993-1997			1983-1987		
	L_{DINmea}	L_{DINcal}	Dev.	L_{DINmea}	L_{DINcal}	Dev.	L_{DINmea}	L_{DINcal}	Dev.
	[t/a N]	[t/a N]	[%]	[t/a N]	[t/a N]	[%]	[t/a N]	[t/a N]	[%]
Naab	7170	5660	21	6890	5370	22	7610	7830	3
Isar	16360	14010	14	16680	16470	1	21050	18210	13
Inn	24560	32790	34	29670	28740	3	29610	32460	10
Danube	100480	102680	2	103300	100460	3	108080	118760	10
Upper Rhine	100970	64600	36	74540	59330	20	81190	77620	4
Neckar		24980		25720	29700	15	34150	37380	9
Main	41250	31730	23	50410	34310	32	51260	45050	12
Mosel	56160	41850	25	42360	37980	10	58110	54310	7
Ruhr		8170		14970	9260	38	12160	10520	13
Lippe		9280		12280	11270	8	13750	12420	10
Rhine	270870	227430	16	274930	231200	16	355190	308340	13
Ems		16770		25070	17840	29	20580	17140	17
Werra	7670	7580	1	7210	6650	8	9100	9530	5
Fulda	10420	9710	7	8830	8940	1	12050	11370	6
Aller		13900		20500	15650	24	30700	24200	21
Weser	76640	44520	42	54120	45080	17	70050	64470	8
Schwarze Elster	2300	2090	9	2600	2700	4	3480	4680	34
Mulde	13740	11290	18	13190	12550	5		16980	
Saale	20290	18910	7	28250	25010	11	47940	34390	28
Havel	3260	5670	74	5520	9290	68	9430	16610	76
Elbe	89540	82540	8	111710	93690	16	145060	137810	5

that the total number of loading values available for the comparison was about 60 % less than for DIC.

In general, for further studies of emissions and loadings in catchments it is necessary to make a detailed differentiation between catchments with and without lakes. This way, the specifics of particular lake types can be considered better. This can, however, only be done in association with a reworking of the studied catchments that clearly considers the size of catchments in relation to water quality guidelines. These catchments are, as a rule, clearly smaller than the up to now used lower limit of 500 km² for the use of MONERIS. It still has to be determined if this model on the basis of available data is applicable to these smaller catchments as well.

Table 4.37: Comparison of measured (**L_{TNmea}**) and calculated (**L_{TNcal}**) loadings for total nitrogen in selected German catchments for the periods 1983-1987, 1993-1997 and 1998-2000.

CATCHMENT	1998-2000			1993-1997			1983-1987		
	L_{TNmea}	L_{TNcal}	Dev.	L_{TNmea}	L_{TNcal}	Dev.	L_{TNmea}	L_{TNcal}	Dev.
	[t/a N]	[t/a N]	[%]	[t/a N]	[t/a N]	[%]	[t/a N]	[t/a N]	[%]
Naab		6043			5916			10030	
Isar		16230			18583			24752	
Inn		36522			30168			39046	
Danube		116506		113625	109148	4	118892	150426	27
Upper Rhine		70265		65119	64836	0		100422	
Neckar		27305			30880			45257	
Main		36442		50297	37913	25		58801	
Mosel	65237	46654	28	96487	41004	58	58111	67842	17
Ruhr		8629		16861	9665	43		12827	
Lippe		10070		15488	12026	22		15804	
Rhine	297956	251612	16	335931	252514	25	449407	397294	12
Ems		18228		26296	19382	26		22396	
Werra		7792			6912			11527	
Fulda		10207			9550			14134	
Aller		15585		24879	17597	29		32169	
Weser		47547		65673	49152	25		82408	
Schwarze Elster	2673	3160	18	1261	3642	189		7394	
Mulde	14386	12452	13	10568	13613	29		21834	
Saale	25562	23159	9	26480	29566	12	52667	48683	8
Havel	5356	9059	69	8676	13050	50	12145	26988	122
Elbe	112664	106145	6	109691	115977	6	163515	204686	25

Table 4.38: Deviations between measured and calculated nutrient loads for all catchments for which data was available for the individual time periods.

		Mean dev.	Total number	Dev. <30%	>30%Dev.<50%	Dev. >50%
		[%]	[Number]	[Number]	[Number]	[Number]
TP						
1983-2000		27.2	369	251	82	36
	Prop. [%]		100.0	68.0	22.2	9.8
1998-2000		29.8	109	66	28	15
	Prop. [%]		100.0	60.6	25.7	13.8
1993-1997		25.1	166	121	30	15
	Prop. [%]		100.0	72.9	18.1	9.0
1983-1987		27.7	94	64	24	6
	Prop. [%]		100.0	68.1	25.5	6.4
DIN						
1983-2000		22.5	420	314	72	34
	Prop. [%]		100.0	74.8	17.1	8.1
1998-2000		23.1	111	78	22	11
	Prop. [%]		100.0	70.3	19.8	9.9
1993-1997		21.8	160	120	33	7
	Prop. [%]		100.0	75.0	20.6	4.4
1983-1987		22.7	149	116	17	16
	Prop. [%]		100.0	77.9	11.4	10.7
TN						
1983-2000		23.1	152	99	45	8
	Prop. [%]		100.0	65.1	29.6	5.3
1998-2000		21.2	58	36	17	5
	Prop. [%]		100.0	62.1	29.3	8.6
1993-1997		23.9	76	50	25	1
	Prop. [%]		100.0	65.8	32.9	1.3
1983-1987		26.0	18	13	3	2
	Prop. [%]		100.0	72.2	16.7	11.1

4.4 Model use for small catchments

Table 4.39 provides an overview on studies carried out within the framework of contracts from various state offices (LfU Baden-Württemberg, LUA Brandenburg, LUNG Mecklenburg-Vorpommern), for catchments of Germany as a whole (BEHRENDT et al., 2001, 2002a) or for individual catchments (Warnow; PAGENKOPF, 2002). The Table also includes student dissertations which employed the MONERIS model for the quantification of nutrient emissions in small catchments (VENOHR, 2000; GEISLER, 2001; THOMAS, 2001; SCHMIDT 2002). All studies were carried out on the basis of catchment partitioning using available digital data. The size of the catchments studied was clearly smaller than that for which the model was developed. Only a part of the database used provides a better spatial resolution.

The results of the studies of the Stör catchment led VENOHR et al. (2003) to conclude already that the MONERIS model can be used for the quantification of nutrient emissions in catchments with an area of only 50 km². For an analysis of smaller catchments, a better spatial resolution of data must be made available in the form of maps and statistics. Such a fine resolution i.e. sufficient quality and density of measurements, is often not available for an adequate estimation of loadings.

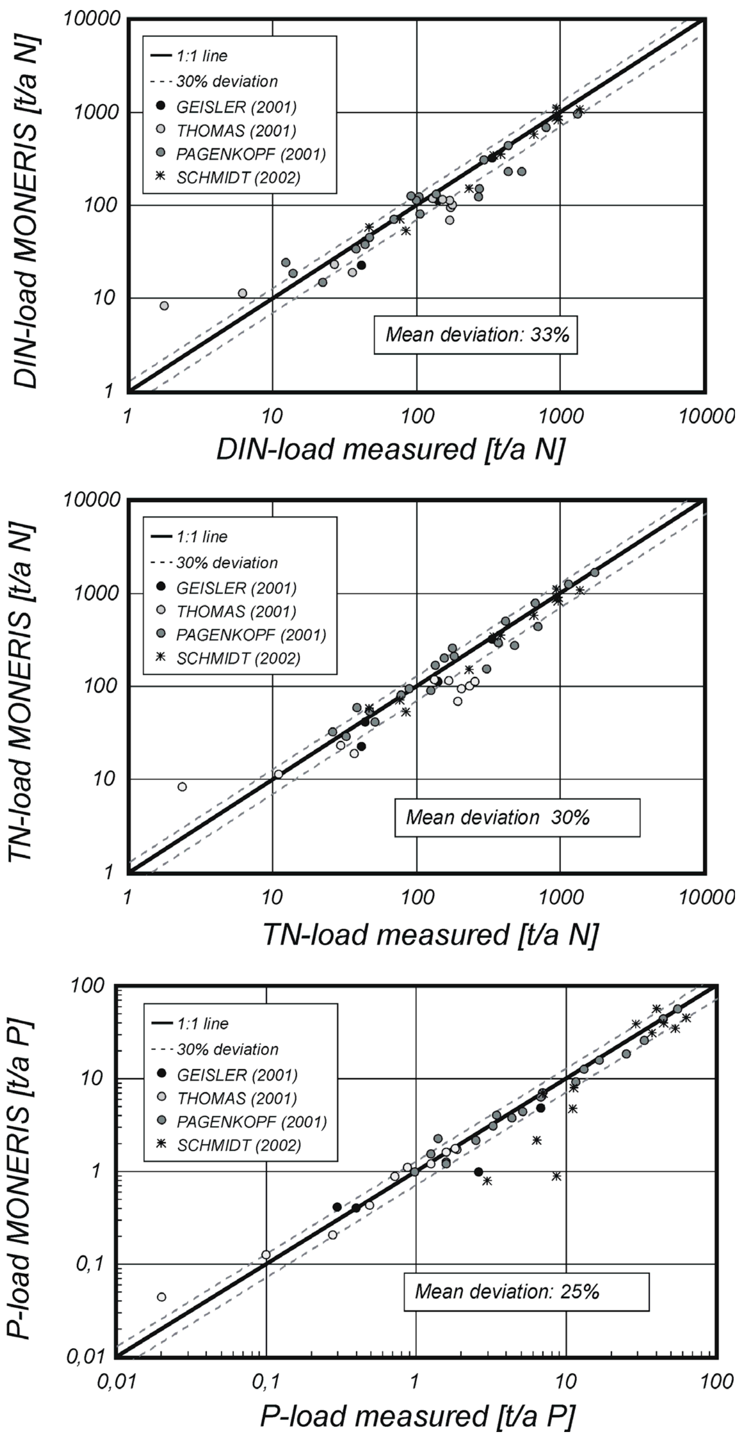


Figure 4.12: Comparison of measured and calculated nutrient loadings in small catchments. From GEISLER (2001), PAGENKOPF (2001), THOMAS (2001) and SCHMIDT (2002).

Whether the results for the Stör catchment are applicable in general to small German catchments should be determined by studies on the Dhünn (sub-catchment of the Wupper), Linde (sub-catchment of the Tollense or Peene), Helme (sub-catchment of the Saale) and Warnow catchments not carried out by the model developers.

These studies suggest that the model can be applied without the participation of the model development team.

Figure 4.12 present a comparison of studies of calculated and measured loadings in catchments of total phosphorus, inorganic dissolved nitrogen and total nitrogen. Although the average catchment size is clearly less than 500 km², the mean deviations between calculated and measured loadings for nitrogen only insignificantly larger and for phosphorus smaller than for the larger German catchments described in the previous section. Deviations of more than 100 % were only found for nitrogen in some of the sub-catchments of the Linde and for phosphorus only Linde and Helme sub-catchments.

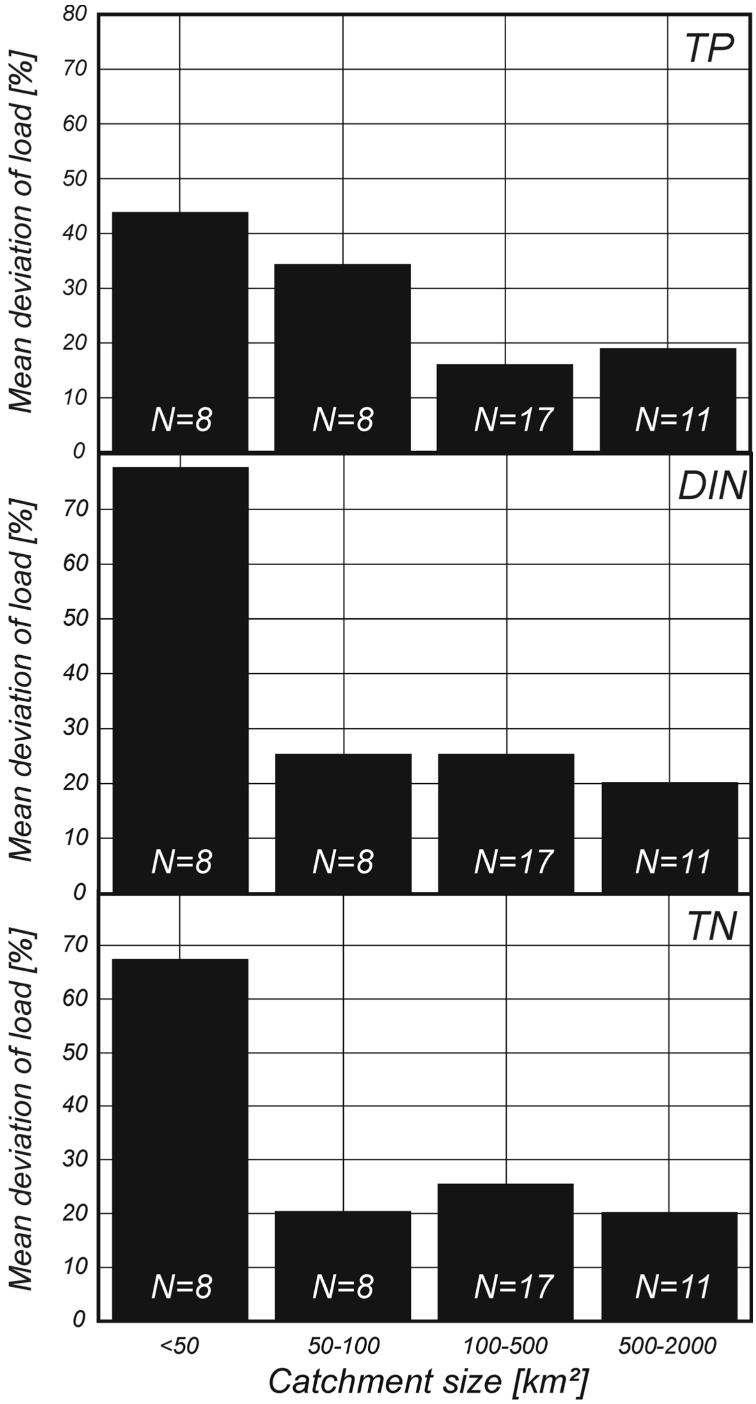


Figure 4.13: Mean deviations of measured and calculated nutrient loadings for catchments of various size ranges on the basis of studies of Geisler (2001),

A summary of the study results according to catchment size is given in Figure 4.13. For nitrogen, this shows clearly that the mean deviation between measures and calculated loadings are 25 % and 20 % for inorganic dissolved nitrogen and total nitrogen respectively for catchments of 50 to 100 km².These values are the same as found for the larger German catchments (see

Table 4.39: River basins and regions with MONERIS applications for smaler catchments.

Catchment/Region	Number of catchments	Mean catchment area [km²]	Reference
Brandenburg	187	210	Behrendt et al. (2002a)
Baden-Württemberg	212	205	Behrendt et al. (2001)
Stör	125	9	Venohr (2000)
Linde	10	16	Thomas (2001)
Dhünn	4	33	Geisler (2001)
Helme	7	92	Schmidt (2002)
Warnow	20	118	Pagenkopf (2002)

Table 4.38). Only for catchments of less than 50 km² the mean deviation is greater than 70 %. This high figure is due to the deviation of 300 % for the Linde catchment with an area of only 7 km². If one excludes this catchment, the mean deviation falls to 34 % for DIN and 30 % for TN in the catchments of less than 50 km². These figures remain clearly higher than for the other catchment size classes. As a result of this analysis, one can conclude that for nitrogen, MONERIS can be used for catchments as small as 50 km².

For phosphorus, the mean deviation in catchments of less than 50 km² and of 50 to 100 km² is clearly higher than for those in Table 4.38. In contrast, for catchments in the two larger size classes, the mean deviation is less than the mean in Table 4.38. This is probably because in the catchments studied (Warnow, Linde), erosion and linked P-emissions play a smaller role than the average for German catchments. On the other hand, the comparatively high mean deviation (36 %) for catchments of 50 to 100 km² is probably related to the fact that the data used for loading calculation was partly for periods of less than 12 measurements per month.

This low frequency of measurements does not apply to the given catchment sizes marked by very variable P-transport with high discharges. Consequently, a large part of the deviation for these catchment size classes is attributable to inaccurate loading determination. In contrast to nitrogen, for phosphorus one can say with some certainty that the model use is possible for catchments of 100 km² or larger. The study of VENOHR et al. (2003) on the Stör catchment indicates that is also possible to use the model for catchments of 50 km². A clearer recommendation requires further studies, in particular with use of a higher intensity of phosphorus measurements.

4.5 Comparison with results of other methods for quantification of nutrient emissions

One task of this study is to test the applicability of the model to catchments outside Germany and also to compare the results with those using other methods, particularly for catchments within Germany. It is important that the methods compared, for the quantification of diffuse emissions should have harmonised procedures.

Such a harmonisation does exist for the quantification of emissions from urban areas and for nutrient retention (HARP, 2002). However, there is no such harmonisation yet for emissions related to agriculture. Within the EU project EUROHARP, a comparison should be made between a total of 7 models for nitrogen and phosphorus emissions to determine which provide suitable information for harmonised action. Although results are expected in one or two years, one can already say that on practical grounds, no completely harmonised method for the quantification of nutrient emissions to European catchments will be found and this, from a scientific point of view, is undesirable. Presumably, no model can be constructed for reactions in the catchments on the possible variability of the natural and socio-economic conditions without further changes or limitations. One knows the reactions of various models from boundary conditions which lye outside the development area. Therefore, it is really wishful thinking that a particular model can be applied universally.

With regard to the use of the MONERIS model outside Germany, it can be said that for this the proof has already been made in other studies. The studies on the catchment differentiated nutrient and heavy metal emissions in the Odra basin (46 sub-catchments) have clearly established that the model in its 1999 version can generally simulate the emission and loading situation in other mid-European catchments (BEHRENDT et al., 2002b). In addition the available databases are comparable for those of the German catchments and allow the application of the model.

Figures 4.14 and 4.15 show a summary of some real results of the Odra study. According to the studies of BEHRENDT et al. (2002a), emissions in the period 1993-1997 were 12200 t/a P for phosphorus and 119000 t/a N for nitrogen. The equivalent loadings were 5100 t/a P and 71200 t/a N. The derivable very high N and P retentions in the Odra basin is also reflected in the model calculations in which the loadings, calculated from the emissions, were 4800 t/a P for phosphorus and 70800 t/a N for nitrogen (see also Figure 4.15).

The deviation of the calculated from the measured values of 29 % (n = 40) for phosphorus is only insignificantly above the average for German catchments (Table 4.38). For inorganic dissolve nitrogen, the deviation of the calculated from the measured values was 25 % and for total nitrogen 21 %.

As with the relationship between calculated and measured phosphorus concentrations in the German catchments (see Figure 4.9), one can also discern an underestimate in the calculated

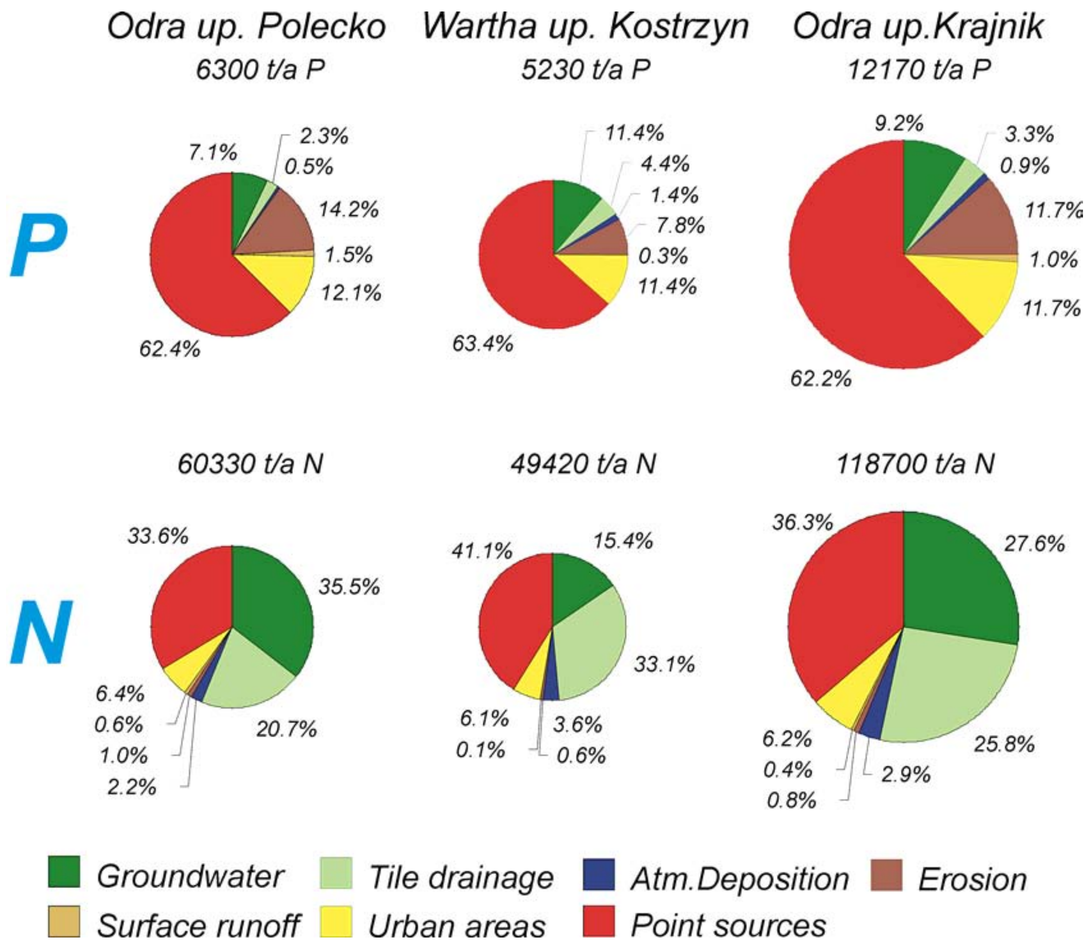


Figure 4.14 Nutrient emissions via the various pathways for the Odra basin above Krajnik Dolny and the main sub-catchments in the period 1993-1997.

model loadings (see Figure 4.15). Within the Odra basin, the Wartha catchment in particular contains many eutrophic lakes.

In relation to the proofing of the MONERIS model for catchments outside Germany, the Odra study shows two other important aspects:

- Through the international collaboration of scientists in the countries involved, for the first time it was possible to employ the same methods and similar data-bases in a multinational river basin.

- Essential data bases and the methodological approaches for the quantification of nutrient emissions in a river basin are also suitable for the estimation of emissions of other substances as for heavy metals in the Odra basin.

The use of essential model emissions of MONERIS for other materials has already been carried out for German catchments (Scherer et al., 2001) and in particular for the Elbe and Rhine catchments (VINK & BEHRENDT, 2001, 2002; GANDRASS et al., 2001). In these studies, the main hindrance to a river-differentiated analysis with a similar spatial scale as for nutrients is the, as yet, inadequate database for concentrations of substances in ground-water and smaller rivers.

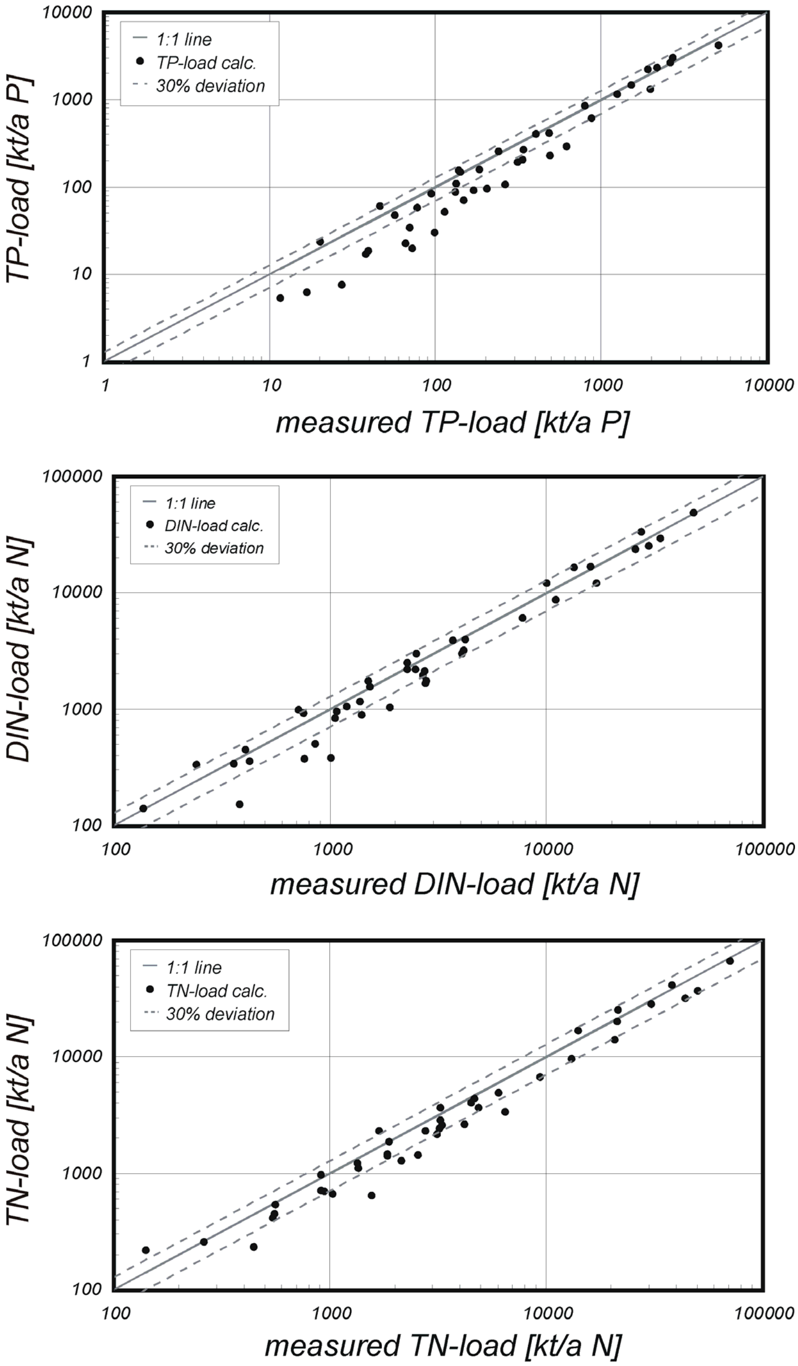


Figure 4.15: Comparison of measured and calculated nutrient loadings in the Odra basin in the period 1993-1997.

Tables 4.40 and 4.41 provide an overview on the quantification of phosphorus and nitrogen emissions in catchments used in MONERIS and other models. Out of the total of 38 catchments, methods were used in 11 which at the moment represent the standard behaviour in Austria (KROIß, 1997), Switzerland (PRASUHN et al., 1996; PRASUHN, et al. 1999) and the Czech Republic (NESMERAK et al., 1994). Out of these, the studies of Prasuhn for the German catchments of the Lake Constance basin are particularly interesting since the model emissions are as detailed as with MONERIS. For the nutrient emissions to the Argen, Radolfzeller Aach, Rotach, Seefelder Aach und Stockacher Aach, the MONERIS values for Baden Württemberg catchments are used (BEHRENDT et al., 2001). If one considers the studies for the periods 1985/86 (PRASUHN et al., 1996) and 1996/97 (PRASUHN et al., 1999) together, one can find a mean deviation of 22 % for diffuse P-emissions and 26 % for diffuse N-emissions. Only for the Argen catchment the deviations are exceptionally high (90 %). Although the model is used for the considered time periods with differing discharge conditions, one can conclude that with both methods, almost identical results are found.

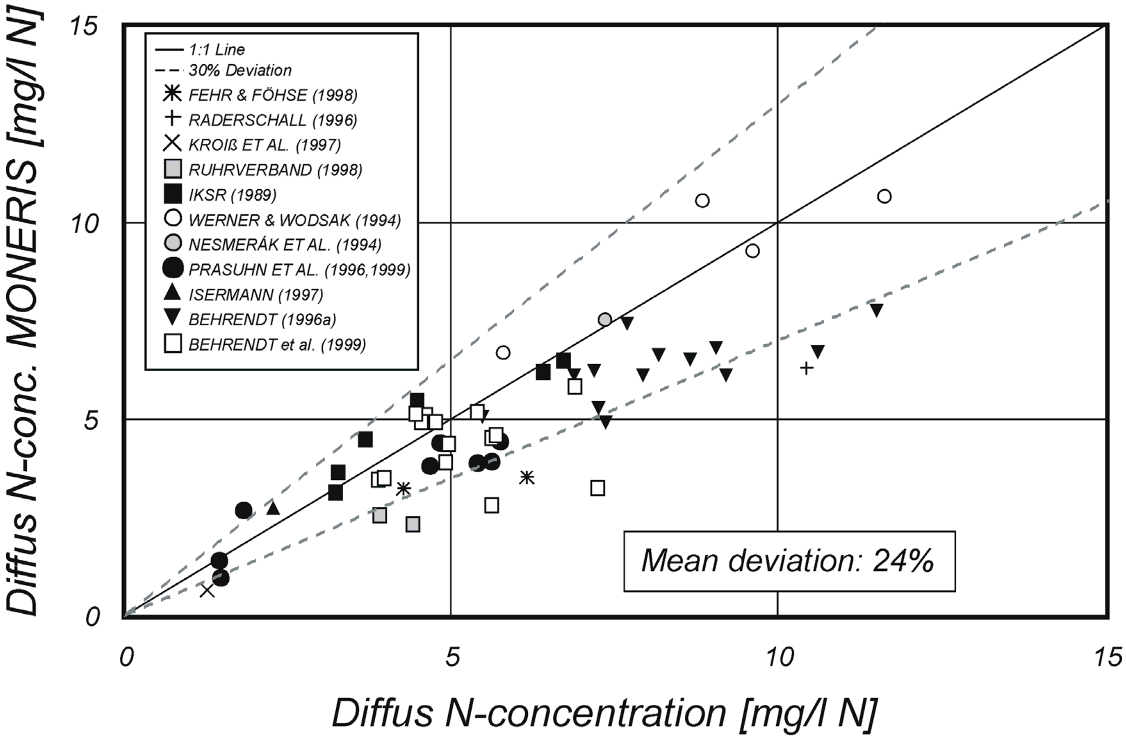
Table 4.40: Comparison of estimated total P-emissions and diffuse P-emissions for various catchments with MONERIS and in other studies.

River	Water quality measuring station	MONERIS results		Results of other authors		Reference
		Total	Diffuse sources	Total	Diffuse sources	
		[t/a P]				
Inn	Kirchdorf	1,271	1,034	710	350	KROIß ET AL. (1997)
Donau	Jochenstein	7,172	5,187	10,900	8,940	ISERMANN (1997)
Rhine	Oehningen	1,385	902	2,370	1,696	PRASUHN ET AL. (1996)
Schussen	Meckenbeuren	112	58	190	104	PRASUHN ET AL. (1996)
Rhine	Oehningen	1,100	904	1,526	1,344	PRASUHN ET AL. (1999)
Schussen	Meckenbeuren	67	53	74	56	PRASUHN ET AL. (1999)
Stockacher Aach	Wahlwies	14	13	15	13	PRASUHN ET AL. (1999)
Seefelder Aach	Mühlhofen	23	20	18	16	PRASUHN ET AL. (1999)
Argen	Gießen	80	75	84	75	PRASUHN ET AL. (1999)
Rotach	Friedrichshafen	12	11	10	9	PRASUHN ET AL. (1999)
Radolfzeller Aach	Rielasingen	34	34	31	28	PRASUHN ET AL. (1999)
Neckar	Mannheim	5,458	978	4,790	1,410	IKSR (1989)
Main	Kahl am Main	4,785	1,702	4,940	2,360	IKSR (1989)
Main	Bischofsheim	7,210	2,022	7,370	2,750	IKSR (1989)
Mosel	Koblenz	7,021	1,727	6,400	2,110	IKSR (1989)
Rhine	Koblenz	30,008	8,444	28,160	8,830	IKSR (1989)
Rhine	Kleve-Bimmen	50,341	11,844	45,560	12,890	IKSR (1989)
Ruhr	Villigst	189	122	180	90	RUHRVERBAND (1998)
Ruhr	Essen	576	313	480	270	RUHRVERBAND (1998)
Hunte	Tungeln	213	195	260	200	RADERSCHALL (1996)
Mulde	Dessau	2,329	866	3,000	800	WERNER & WODSAK (1994)
Saale	Gr. Rosenburg	7,239	2,364	7,700	2,400	WERNER & WODSAK (1994)
Havel	Toppeln	3,904	960	5,100	1,700	WERNER & WODSAK (1994)
Elbe	Schnackenburg	24,111	9,044	29,600	12,000	WERNER & WODSAK (1994)
Elbe	Schmilka	6,667	3,752	5,250	2,110	NESMERAK ET AL. (1994)
Elde	Doemitz	120	96	190	140	BEHRENDT (1996a)
Stepenitz	Dassow	41	37	66	54	BEHRENDT (1996a)
Warnow	Kessin	133	115	250	210	BEHRENDT (1996a)
Recknitz	Ribnitz	36	33	50	39	BEHRENDT (1996a)
Peene	oh. Anklam	198	170	370	300	BEHRENDT (1996a)
Trebel	oh.Wotenick	30	26	71	55	BEHRENDT (1996a)
Tollense	Demmin	80	69	133	106	BEHRENDT (1996a)
Zarow	Grambin	26	24	56	47	BEHRENDT (1996a)
Randow	Eggesin	24	22	42	38	BEHRENDT (1996a)
Sude	Bandekow	128	122	160	140	BEHRENDT (1996a)
Uecker	Ueckermuende	96	81	160	100	BEHRENDT (1996a)
Böhme	Boehme	38	18	39	28	FEHR & FÖHSE (1998)
Illmenau	Rote Schleuse	66	55	90	67	FEHR & FÖHSE (1998)

Table 4.41: Comparison of estimated total N-emissions and diffuse N-emissions for various catchments with MONERIS and in other studies.

Water body	Water quality measuring station	MONERIS results		Results of other authors		Reference
		Total	Diffuse sources	Total	Diffuse sources	
		[t/a N]				
Inn	Kirchdorf	8,890	6,470	10,330	8,060	KROIß ET AL. (1997)
Danube	Jochenstein	151,800	121,840	123,000	102,500	ISERMANN (1997)
Rhine	Oehningen	21,010	15,720	23,830	18,270	PRASUHN ET AL. (1996)
Schussen	Meckenbeuren	2,380	1,410	2,500	1,900	PRASUHN ET AL. (1996)
Rhine	Oehningen	16,300	11,940	18,690	15,060	PRASUHN ET AL. (1999)
Schussen	Meckenbeuren	2,350	1,790	1,690	1,310	PRASUHN ET AL. (1999)
Stockacher Aach	Wahlwies	327	270	240	232	PRASUHN ET AL. (1999)
Seefelder Aach	Mühlhofen	530	430	470	445	PRASUHN ET AL. (1999)
Argen	Gießen	1,980	1,828	1,100	952	PRASUHN ET AL. (1999)
Rotach	Friedrichshafen	346	310	280	255	PRASUHN ET AL. (1999)
Radolfzeller Aach	Rielasingen	1,460	1,456	1,320	1,310	PRASUHN ET AL. (1999)
Neckar	Mannheim	60,440	29,791	46,310	24,180	IKSR (1989)
Main	Kahl am Main	55,670	39,400	59,630	40,450	IKSR (1989)
Main	Bischofsheim	81,740	45,670	78,230	47,010	IKSR (1989)
Mosel	Koblenz	103,110	58,970	96,400	45,880	IKSR (1989)
Rhine	Koblenz	341,590	186,450	346,910	188,620	IKSR (1989)
Rhine	Kleve-Bimmen	573,300	290,010	562,300	258,700	IKSR (1989)
Ruhr	Villigst	4,360	2,870	4,420	2,580	RUHRVERBAND (1998)
Ruhr	Essen	12,650	6,630	13,330	8,130	RUHRVERBAND (1998)
Hunte	Tungeln	3,640	3,340	3,650	3,270	RADERSCHALL (1996)
Mulde	Dessau	34,350	21,510	33,000	16,000	WERNER & WODSAK (1994)
Saale	Gr. Rosenburg	82,280	44,050	92,000	51,000	WERNER & WODSAK (1994)
Havel	Toppeln	47,020	24,030	46,000	20,000	WERNER & WODSAK (1994)
Elbe	Schnackenburg	310,670	194,940	365,000	230,000	WERNER & WODSAK (1994)
Elbe	Schmilka	105,270	72,480	87,380	56,170	NESMERÁK ET AL. (1994)
Elde	Doemitz	2,360	1,870	2,750	2,210	BEHRENDT (1996a)
Stepenitz	Dassow	1,250	1,210	2,050	1,950	BEHRENDT (1996a)
Warnow	Kessin	2,920	2,730	3,980	3,660	BEHRENDT (1996a)
Recknitz	Ribnitz	930	900	1,070	950	BEHRENDT (1996a)
Peene	oh. Anklam	4,930	4,310	6,410	5,740	BEHRENDT (1996a)
Trebel	oh.Wotenick	990	930	1,550	1,470	BEHRENDT (1996a)
Tollense	Demmin	1,680	1,430	2,310	1,920	BEHRENDT (1996a)
Zarow	Grambin	460	450	650	590	BEHRENDT (1996a)
Randow	Eggesin	320	310	350	330	BEHRENDT (1996a)
Sude	Bandekow	3,090	3,030	2,710	2,580	BEHRENDT (1996a)
Uecker	Ueckermuende	1,610	1,460	1,870	1,570	BEHRENDT (1996a)
Böhme	Boehme	950	660	1,290	1,110	FEHR & FÖHSE (1998)
Illmenau	Rote Schleuse	1,330	1,020	1,340	1,120	FEHR & FÖHSE (1998)

To exclude the influences the different discharge conditions in the particular study periods have on the model results, they were at least partially eliminated by calculation of mean diffuse emission concentrations. For this, the calculated sum of the diffuse emissions was divided by the total discharge of the catchment. The results are shown in Figure 4.16.



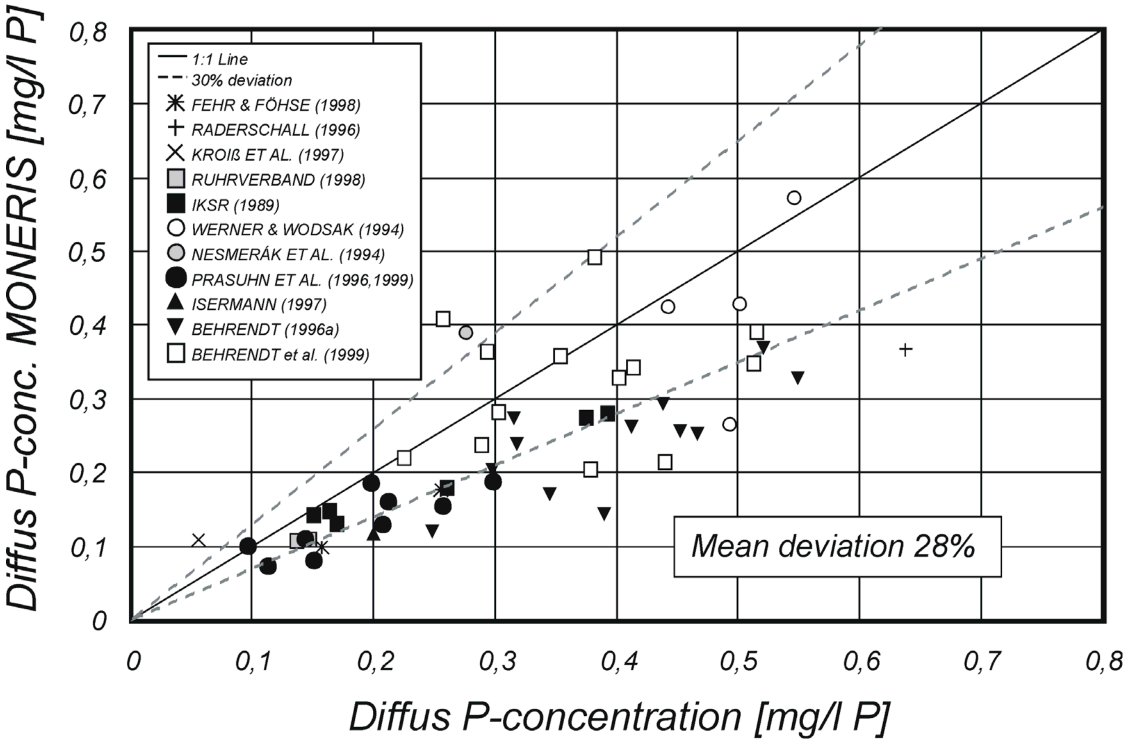


Figure 4.16: Comparison of flow weighted concentrations of the total diffuse nutrient emissions to catchments with results of other authors using different methods.

Overall, with this comparison one can conclude that the mean deviations of 28 % for phosphorus and 24 % for nitrogen are not larger than the overall figure for total diffuse emissions of at least 30 % determined by BEHRENDT et al. (1999). However, for phosphorus, on the basis of Figure 4.16 one can presume that MONERIS gives a slight underestimate for diffuse emissions, particularly in comparison to the results of PRASUHN et al. (1999). The cause of this not clear yet.

In connection with the studies on emissions to the Odra (BEHRENDT et al., 2002b) and Elbe (BECKER et al., 2001, WENDLAND & KUNKEL, 1999) basins, it was also possible to compare the results for concentrations of nitrate in groundwater emissions from the conceptual model MONERIS with those of the mechanistic models MODEST and WAKU. The results of these comparisons are shown in Figures 4.17 and 4.18. and have already been discussed in detail in BEHRENDT et al. (2002b) and BEHRENDT et al. (2003).

In summary, one can make the following statements:

- The mean nitrate concentrations in rivers with low discharges and at low temperatures show a deviation from the measured nitrogen concentrations in groundwater of around 40 %.
- This is a better measure for the characterisation of mean nitrogen concentrations in

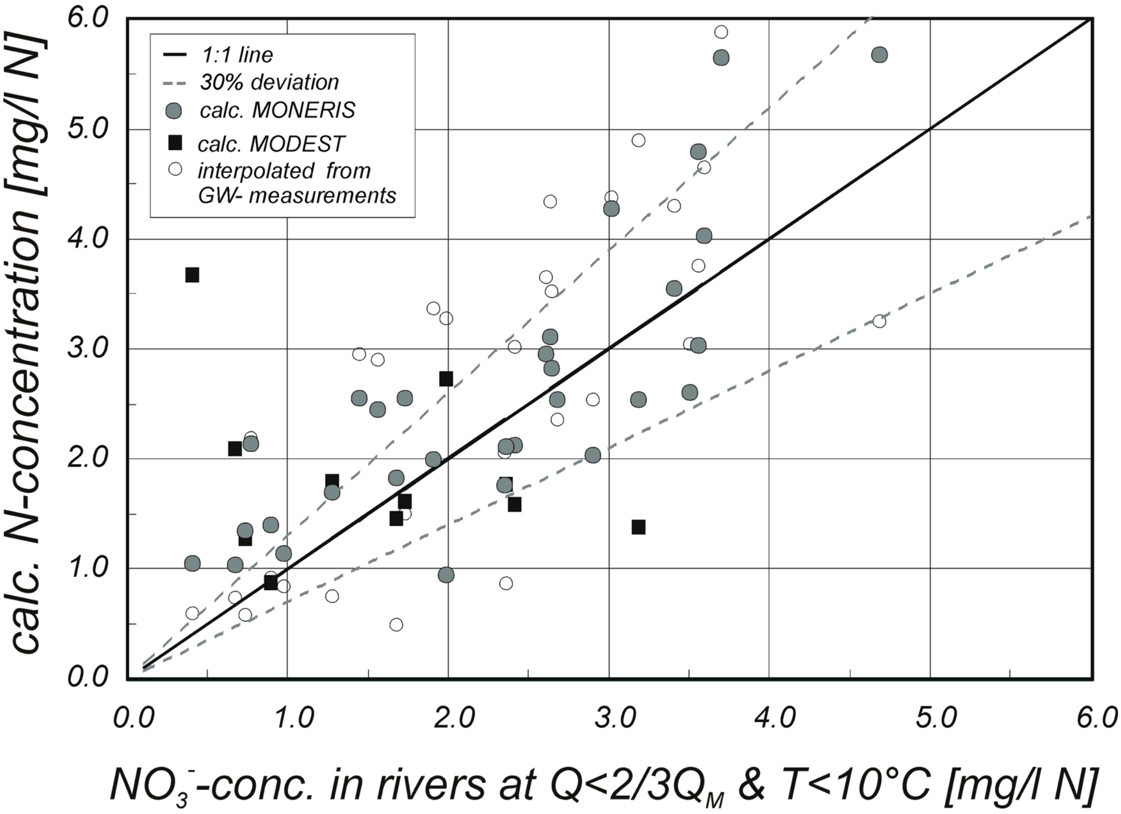


Figure 4.17: Comparison of calculated groundwater emission nitrogen concentrations using WEKU and MONERIS in the Odra basin with the regionalised groundwater concentration measurements and nitrate concentrations in rivers when discharges and temperatures are low (after Behrendt et al., 2002b).

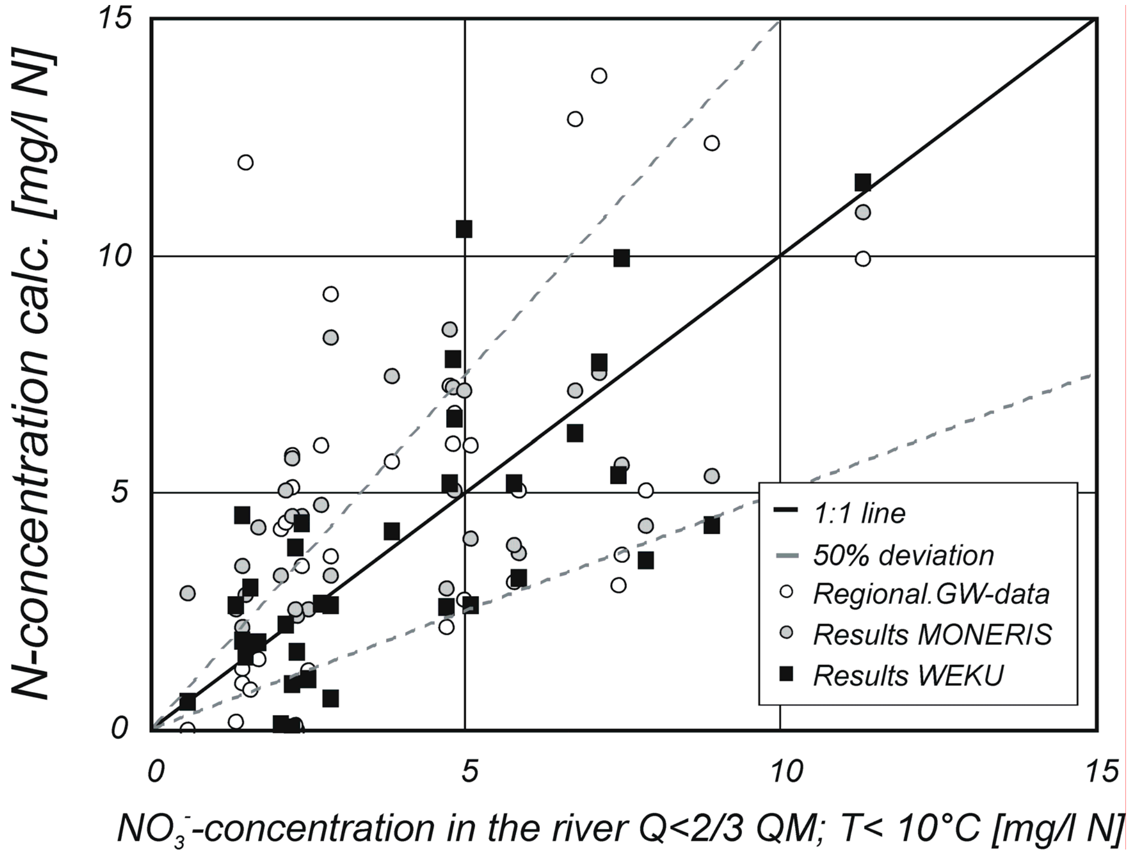


Figure 4.18: Comparison of calculated nitrogen concentrations in Elbe groundwater emissions from the WEKU and MONERIS models with the regionalised measured nitrate concentrations in rivers with low discharges and temperatures (after BEHRENDT et al., 2003)

catchment groundwater emissions where the intensity of measurements is low.

- The deviations using MONERIS of about 40 % for the MODEST and WAKU models using the same emission data for catchment nitrogen surpluses. This is not larger than with the two indicators derived from measurements.
- Without a better measurement-based characterisation of nitrogen concentrations in groundwater emissions to catchments and better regional differentiation of emission data, the deviation between the model results and measurements can not be reduced in the future.
- Deviations of much less than 40 % between model results and indicator measurements are unlikely to be realised in the future, in particular for the northeast German plain. This is due to the fact that N-retention is around 80 to 99 % and therefore calculated groundwater emissions are very small in comparison to the nitrogen surpluses and retention.
- The various models can be applied for a nested approach, since digitalised and therefore more detailed area-based analyses are used.

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Acknowledgements

This research project was founded and supported by the German Federal Environmental Agency. We owe special thanks to Dr. Herata (Mrs.) and Mr. Mehlhorn who accompanied the project with great interest and gave numerous hints in their expert capacity during the entire project.

Our particular thanks go to the Federal Institutes, Ministries, Federal State Agencies and regional authorities for their friendly support and providing the basic data for the estimation of the nutrient emissions into the German surface waters. Without their assistance this project could not have been implemented.