Research Report

on the joint international project

(FKZ: 298 28 299)

Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Phase III

Point and diffuse emissions of pollutants, their retention in the river system of the Odra and scenario calculations on possible changes

by

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Berlin, December 2001

Berichts-Kennblatt

1. Berichtsnummer
UBA-FB

2.

3.

4. Titel des Berichts

Quantifizierung diffuser Stoffeinträge in die Gewässer im Einzugsgebiet der Oder und der Pommerschen Bucht mit dem Ziel der Erarbeitung von Entscheidungshilfen für den integrierten Gewässerschutz
Phase III

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8. Abschlußdatum
30.06.2001

9. Veröffentlichungsdatum
31.12.2001

10. UFOPLAN - Nr.
298 28 299

6. Durchführende Institution

Institut für Gewässerökologie und Binnenfischerei im Forschungsverbund Berlin e.V.
Müggelseedamm 310
12561 Berlin

11. Seitenzahl
271 Seiten

12. Literaturangaben
86 Quellen

13. Tabellen
110 Tabellen

7. Fördernde Institution

Umweltbundesamt
Bismarckplatz 1
14193 Berlin

14. Abbildungen und Karten
67 Abbildungen
57 Karten

15. Zusätzliche Angaben

16. Kurzfassung

Für 45 Teilgebiete der Oder wurden mit Hilfe der Modelle MONERIS, MODEST und NIIRS die Nährstoff- und Schwermetallemissionen von punktuellen und diffusen Quellen für den Zeitraum 1993-1997 quantifiziert. Insgesamt wurde zwischen 6 verschiedenen diffusen Eintragspfaden unterschieden und darüber hinaus die Einträge aus kommunalen Kläranlagen und durch industrielle Direkteinleiter berücksichtigt. Für Stickstoff konnten für den Zeitraum 1993-1997 Einträge von insgesamt ca. 124 kt N/a davon 64% aus diffusen Quellen für die Oder ermittelt werden. Für Phosphor betrugen die Einträge im gleichen Zeitraum 12,8 ktP/a, wozu diffuse Eintrage nur zu 38% beitrugen. Ein Vergleich der abgeschätzten Nährstofffrachten zeigt für die untersuchten Flussgebiete mittlere Abweichungen von 22% für Stickstoff und 32% für Phosphor. Die regionale Auflösung des Eintragsberechnungen erlaubt die Identifikation von Schwerpunkten der Nährstoffbelastung und die Ableitung gebietsspezifischer Maßnahmen. Für die Schermetalle konnten Einträge von 10,8 t/a (Cd), 175 t/a (Cu), 113 t/a (Pb) und 1190 t/a (Zn) ermittelt werden.

17. Schlagwörter

Oder-Einzugsgebiet, Nährstoffeinträge, Schwermetalleinträge, Emissionsmethode, MONERIS, MODEST, NIIRS, Immissionsmethode, Punktquellen, diffuse Quellen, Flussgebiete, Nährstofffrachten, Retention, kommunale Kläranlagen, industrielle Direkteinleiter, atmosphärische Deposition, Abschwemmung, Erosion, Dränage, Grundwasser, urbane Flächen

18. Preis

19.

20.

Report No. 1. UBA-FB	2.	3.

4. Report Title

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8. Report Date
30.06.2001

9. Publication Date
31.12.2001

10. UFOPLAN - Ref.No.
298 28 299

6. Performing Organisation

Institute of Freshwater Ecology and Inland Fisheries
Müggelseedamm 310
D-12561 Berlin

11. No. of Pages
271 pages

12. No. of References
86 references

13. No. of Tables
110 tables

7. Founding Agency

Umweltbundesamt
Bismarckplatz 1
14193 Berlin

14. No. of Figures and Maps
67 figures
57 maps

15. Supplementary Notes

16. Abstract

The nutrient and heavy metal emissions by point and diffuse sources were estimated for 45 sub catchments of the Odra basin for the period 1993-1997 by means of the Models MONERIS, MODEST and NIIRS. The approach distinguish between 6 different diffuse pathways and the point discharges from municipal waste water treatment plant and industry. For nitrogen total emissions of 124 ktN/a were estimated for the Odra basin. 64% of these emissions were caused by diffuse sources (mainly groundwater and tile drainage). For Phosphorus the emission was 12.8 ktP/a, with a contribution of diffuse sources to this sum of 38%. The comparison of calculated and observed loads shows that the mean deviation for the investigated sub catchments of Odra is 22% for nitrogen and 32% for phosphorus. The spatial resolution of the emission calculations allows the identification of regional hot spots and the derivation of specific regional measures to reduce the emissions into the Odra. For the heavy metals emissions of 10,8 t/a (Cd), 175 t/a (Cu), 113 t/a (Pb) and 1190 t/a (Zn) were estimated.

17. Keywords

Odra river, nutrient and heavy metal inputs, emission method, MONERIS, MODEST, NIIRS, 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

18. Price	19.	20.

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Abbreviations

ATV	German Association for Water, Wastewater and Waste (Abwassertechnische Vereinigung)
BB	Brandenburg
BfG	Federal Agency for Hydrology (Bundesanstalt für Gewässerkunde)
BGR	Federal Institute for Geosciences and Natural Ressources (Bundesanstalt für Geowissenschaften und Rohstoffe)
BOD	biological oxygen demand
BÜK	general soil map of Germany
Cd	Cadmium
CHMU	Czech Hydrometeological Institute
CLC	CORINE-Landcover
COD	cemical oxygen demand
Cu	Copper
CZ	Czech Republic
DEM	digital elevation model
DIN	dissolved inorganic nitrogen
DNMI	Det Norske Meteorologiske Institutt
DOC	dissolved organic carbon
DVWK	German Association for Water Resources and Land Improvement (Deutscher Verband für Wasserwirtschaft und Kulturbau)
DWD	German Weather Service (Deutscher Wetterdienst)
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
ESRI	Environmental Research Systems Institute
FEA	Federal Environmental Agency
GER	Germany
GDR	German Democratic Republic
GIS	Geographic Information System
HSP	Hydrogenetic subprovinces
HYKA	hydrogeological map
IFEIF	Institute of Freshwater Ecology and Inland Fisheries
IMGW	Institute for Metrology and Water Management
IMUZ	Institute for Land Reclamation and Grassland Farming
IUNG	Institute of Plant Nutritation and Soil Science
LAWA	State Water Working Group (Länderarbeitsgemeinschaft Wasser)
MMK	medium-scale agricultural site mapping in Germany
MODEST	MOdelling Diffuse Nitrogen Entries via Subsurface Trails
MONERIS	MOdelling Nutrient Emissions in RIver Systems
N	nitrogen
NH_4	ammonia
NIIRS	Nutriant input into the River Systems
NO_3	nitrate
NO_x	nitric oxides

OSPARCOM	Oslo-Paris Commission (on the Protection of the North-east Atlantic)
P	phosphorus
PAN	Polish Academy of Sciences
Pb	Lead
PIG	Polish Geological Institute
PO_4	phosphate
QD	domestic wastewater
QCOM	commercial wastewater
QEX	external wastewater
QU	urban wastewater
QST	storm wastewater
QTOT	total wastewater
RIVM	National Institute of Public Health and the Environment
RU	rate of utilisation
SMS	State Administration of Land Reclamatin and Improvement
SRP	soluble reactive phosphorus
SS	suspended solids
TN	total nitrogen
TOC	total organic carbon
TP	total phosphorus
TPE	treated population equivalents
TPE_{IN}	treated population equivalents (inhibitants)
TPE_{IID}	treated population equivalents (indirect industrial discharges)
UBA	German Federal Environmental Agency
U.S.	United States
USGS	United States Geological Survey
USLE	uniformed soil loss equation
VSEU	Valuatet Soil Ecological Unit
VUMOP	Research Institute of Soil and Water Conservation
VURV	Research Institute of Plant Production
WWTP	wastewater treatment plant
ZALF	Center for Agriculture Landscape and Land Use Research
Zn	Zinc

Abbreviations used in Formulas

$v_a(k)$	Long-term mean groundwater flow velocity within cell k
$v_a(i,j)$	Mean groundwater flow velocity in grid cell (i,j)
$v_T(i,j)$	Long-term mean vertical percolating velocity in grid cell (i,j)
a	Grid cell area
A_{AL}	Arable Land
A_{AR}	area of arable land from CLC
A_{AG}	agricultural area
E_{AUN}	heavy metal input from paved urban areas connected neither to sewers nor to wastewater treatment plants
A_{CA}	catchment area
a_{COM}	proportion of total urban area in commercial use
A_{DR}	drained area
A_{DRB}	area of drained bog soil
A_{DRL}	area of drained loams
A_{DRF}	area of drained fen soil
A_{DRS}	area of drained sandy soil
E_{EWN}	inhabitants connected neither to sewers nor to wastewater treatment plants
AF	field capacity
AG_E	inhabitant specific metal load
AG_{EG}	inhabitant specific load of dissolved heavy metals
AG_{EG}	inhabitant specific load of dissolved heavy metals
A_{GRAS}	grassland area
A_{HM}	area of bog soil
A_{HRT}	area of different hydrogeologically rock types
A_{IMP}	impervious urban area
A_{IMPC}	impervious urban area connected to combined sewer system
A_{IMPN}	impervious urban area connected neither to a sewer nor to a wastewater treatment plant
A_{IMPS}	impervious urban area connected to separated sewer system
a_{IMP}	share of precipitation realized as surface runoff from impervious urban areas
A_{IMPSO}	urban area connected only to sewers
A_L	area of loamy soil
A_{LN}	agricultural area
A_M	mountain area
A_F	area of fen soil
A_{OPEN}	open area
A_{ro}	areas relevant for surface runoff
AS	specific metal input from impervious urban areas
A_S	area of sandy soil
AS_{URB}	specific heavy metal input from impervious urban areas
AU	Animal Units
A_{URB}	total 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_{WCLC}	water surface area from CORINE-Landcover
A_{WOOP}	woodland and open area
C	*cover-management factor* – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow
C_{B}	concentration of heavy metals in topsoil
$C_{COM_{N,P}}$	nutrient concentration in commercial wastewater
$C_{C_{N,P}}$	nutrient concentration in combined sewers during overflow
$C_{D_{N,P}}$	mean concentration of the diffuse emissions
$C_{DRB_{N,P}}$	drainage water nutrient concentration for bog soil
$C_{DRL_{N,P}}$	drainage water nutrient concentration for loamy soil
C_{DR}	heavy metal concentration in drainage water
$C_{DR_{N,P}}$	drainage water nutrient concentration
$C_{DR_{NO3-N}}$	nitrate concentration in drainage water
$C_{DRF_{N,P}}$	drainage water nutrient concentration for fen soil
$C_{DRS_{N,P}}$	drainage water nutrient concentration for sandy soil
C_{GEW}	metal concentration in industrial-commercial wastewater
$C_{GEW_{N,P}}$	nutrient concentration in commercial wastewater
C_{GW}	heavy metal concentration in springs
$C_{GWAG_{SRP}}$	groundwater SRP concentration for agricultural land
$C_{GWB_{SRP}}$	groundwater SRP concentration for bog soil
$C_{GWF_{SRP}}$	groundwater SRP concentration for fen soil
$C_{GWL_{SRP}}$	groundwater SRP concentration for loamy soi
$C_{GWS_{SRP}}$	groundwater SRP concentration for sandy soil
$C_{GW_{TP}}$	TP-concentration in groundwater
$C_{GW_{NO3-N}}$	nitrate concentration in groundwater
$C_{GW_{SRP}}$	SRP-concentration in groundwater
$C_{GW_{N,P}}$	nutrient concentration in groundwater
$C_{GW_{SRP}}$	SRP-concentration in groundwater
$C_{GWWOOP_{SRP}}$	groundwater SRP concentration for woodland and open areas
c_{i}	measured concentration
CLS	correction factor for the long-term changes in surpluses
$C_{LWPOT_{NO3-N}}$	potential nitrate concentration in leakage water for the total area at base flow
$CNF_{N,P}$	content of nutriants in feed
$c_{N}(i,j)$	Concentration of dissolved N entering resp. leaving a certain compartment of the subsurface pathway related to cell (i,j)
$c_{N1}(i,j)$	N concentration at the top soil bottom (cell i,j)
$c_{N2}(i,j)$	N concentration entering groundwater in grid cell (i,j) ("N entry")
$c_{N3}(i,j)$	N concentration entering the receiving water from grid cell (i,j) ("N charge")
$CNON_{N,P}$	content of nutriants in organisms

$C_{ROAR_{N,P}}$	nutrient concentration in surface runoff from arable land
$C_{ROCROP_{N,P}}$	nutrient concentration in surface runoff from arable land
$C_{ROGRAS_{N,P}}$	nutrient concentration in surface runoff from grassland
$C_{RO_{N,P}}$	nutriant concentration in surface runoff
$C_{ROOPEN_{N,P}}$	nutrient concentration in surface runoff from open land
$C_{SW_{N,P}}$	nutrient concentration in leakage water
CWW_{DIN}	concentration of dissolved inorganic nitrogen in wastewater
CWW_{NORG}	concentration of organic nitrogen in wastewater
CWW_{P}	concentration of phosphorus in wastewater
D	atmospheric deposition rate of heavy metals
$D_{max}(i,j)$	Denitrification potential (cell *i,j*)
$DEP_{N,P}$	area specific deposition
$DGT(i,j)$	Depth to the groundwater table (cell *i,j*)
DR	exponent for denitrification
$EAD_{N,P}$	nutrient input via atmospheric deposition
E_{D}	input of heavy metals via atmospheric deposition
$ED_{N,P}$	nutrient input via diffuse sources
E_{DR}	input of heavy metals via tile drainage
$EDR_{N,P}$	nutrient emissions via tile drainage
E_{ER}	input of heavy metals via erosion
$EER_{N,P}$	nutrient input via erosion
E_{EWK}	inhabitants connected only to sewers
$EFI_{N,P}$	nutriant emissions from fish farms
E_{GW}	input of heavy metals via groundwater
E_{GEWK}	input from industrial-commercial wastewater
$EGW_{N,P}$	nutrient input via groundwater and natural interflow
$EIN_{D_{N,P}}$	inhabitant specific output of dissolved nutrients
EIN_{N}	inhibitant specific nitrogen output
$EIN_{N,P}$	inhabitant specific nutrient output
EIN_{p}	inhibitant specific phosphorus output
E_{KA}	inhabitants connected to waste water treatment plants
$EP_{N,P}$	nutrient input via point sources
ER	enrichment ratio
ER_{N}	enrichment ratio for nitrogen
$ER_{N,P}$	enrichment ratio for nutrients
ER_{P}	enrichment ratio for phosphorus
$ERO_{N,P}$	nutrient input via surface runoff
ES_{IMP}	specific nutrient emissions from impervious urban areas
$ET_{N,P}$	total nutrient input
ETR	evapotranspiration
ETR_{MAX}	maximum annual evapotranspiration
E_{UAK}	input from urban areas connected only to sewers
$EUC_{N,P}$	nutrient emission via combined sewer overflows
E_{UK}	heavy metal input via sewers not connected to WWTP`s
E_{UM}	input of heavy metals via combined sewer overflows

E_{UN}	heavy metal input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants
$EUN_{N,P}$	nutrient input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants
$EUS_{N,P}$	nutrient inputs via separate sewers
$EUSO_{N,P}$	nutrient input via impervious urban areas and from inhabitants connected only to sewers
E_{UT}	heavy metal input via separate sewers
EWW_N	nitrigen emission from wastewater treatment plants
EWW_P	phosphorus emission from wastewater treatment plants
$FC_{sub}(i,j)$	Field capacity of the subsoil (cell i,j)
HL	hydraulic load
h_M	mean elevation of the catchment
$I(i,j)$	Hydraulic gradient (cell i,j)
IN_C	number of inhabitants connected to combined sewer system
IN_{CON}	conectet inhibitants
IN_N	inhabitants connected neither to sewers nor to wastewater treatment plants
IN_{SO}	inhabitants connected only to sewers
K	*soil erodibility factor* – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 22.1 m length of uniform 9 % slope in continuous clean-tilled fallow
k	Number of a grid cell along with the groundwater flow path
$K(i,j)$	MICHAELIS-MENTEN reaction constant (cell i,j), in mg N per kg soil per year
$k_f(i,j)$	Saturated hydraulic conductivity (cell i,j)
k_v	Reduction constant
L	*slope length factor* – the ratio of soil loss from the field slope length to soil loss from a 22.1 m length under identical conditions
$L0_{N,P}$	hypothetic load [t/a] at a discharge 0
$l_a(k)$	Flow length within cell k
$LD_{N,P}$	nutrient load from diffuse sources
l_{CSO}	length of the combined sewer overflows
$L_{N,P}$	nutrient load
L_P	average annual nutrient load in the studied period
$LP_{N,P}$	Nutrient load from point sources
l_{SAS}	length of the sanitary sewers
LW	leakage water quantity
L_y	annual load
n	number of data
$N_0(i,j)$	Specific N input at the soil surface (cell i,j)
N_{DEP}	atmospheric nitrogen deposition
$N(i,j)$	Specific N load entering resp. leaving a certain compartment of the subsurface pathway related to cell
$N_1(i,j)$	Specific N load released from the root zone in grid cell (i,j) (“N leaching”)
$n_f(i,j)$	Effective yield of pore space (cell i,j), derived from $k_f(i,j)$
N_{SOIL}	nitrogen content of soil
N_{SUR}	nitrogen surplus of agricultural areas

N_{TSUR}	total nitrogen surplus
N_{tot}	unit load of nitrogen
$NU_{D,H,S}$	specific agricultural N input from mineral fertiliser, organic manure, and silage saps, in kg/ha/a
NU_{in}	specific agricultural N input
NU_{min}	mineral fertilizer
NU_{org}	organic manure
NU_{P}	specific N output via main crop production, in kg/ha/a
$NU_{sur,F}$	specific agricultural N surplus at farm level
NU_{S90g}	nutrient surplus in the same gmina in 1989/1990 [kg/ha],
NU_{S90w}	average surplus in the same voivodship in the year 1989/1990
NU_{Sxg}	nutrient surplus in the certain gmina in the year **x** [kg/ha],
NU_{Sxw}	average surplus in the voivodship in the year **x**
$N_{\ddot{U}GES}$	total nitrogen surplus
NU_{up}	specific agricultural N uptake
$n_{tot}(\mathbf{W})$	Total N load entering the water *w* in a certain reference year
P	*support practice factor* – the ratio of soil loss with a support practice like contouring, stripcropping, or terracing, to soil loss with straight-row farming up and down the slope
p	number of years with measuring data in the study period
PF	production
POP_{DEN}	population density
P_{SU}	average precipitation in the summer half year
P_{SOIL}	phosphorus content of soil
P_{tot}	unit phosphorus load
P_{WI}	average precipitation in the winter half year
P_{Y}	average annual precipitation
Q	average runoff
q	specific runoff
Q_{AD}	atmospheric input flow
q_{COM}	specific runoff from commercial areas
Q_{COMC}	runoff from commercial areas connected to combined sewers
Q_{COMSO}	annual runoff from commercial areas only connected to sewers
Q_{DR}	tile drainage flow
q_{DR}	specific drain water flow
q_{G}	average yearly specific runoff
Q_{GEWM}	specific runoff from commercial areas
Q_{GW}	base flow and natural interflow
q_{i}	measured flow
q_{IN}	daily wastewater output per inhabitant
q_{IMP}	specific surface runoff from impervious urban areas
Q_{IMPC}	storm water runoff from combined sewer system
Q_{MIN}	minimum discharge
Q_{P}	discharge from point sources
q_{R}	rainfall runoff rate
Q_{RO}	surface runoff from non-paved areas
q_{RO}	specific surface runoff

Q_{URB}	surface runoff from urban areas
QWW	water discharge of the wastewater treatment plants
Q_y	mean annual flow
R	*rainfall-runoff erosivity factor* – the rainfall erosion index plus a factor for any significant runoff from snowmelt
$R(i,j)$	Mean groundwater recharge from ABIMO (cell i,j)
RE	discharge rate of combined sewer overflows
$RET(i,j)$	overall N retention potential
$R_{L_{N,P}}$	load weighted nutrient retention
$R_{N,P}$	loss or retention of nutrients
RR_N	nitrogen removal rate
RR_P	phosphorus removal rate
$R_{S_{N,P}}$	nutrient retention in soil (80% for nitrogen and 90% for phosphorus)
S	*slope steepness factor* – the ratio of soil loss from the field slope gradient to soil loss from a 9 % slope under otherwise identical conditions
SDR	sediment delivery ratio
SED	sediment input
SER	sewage system ratio
SL	mean slope
SL_{CA}	mean slope of the catchment from USGS-DEM
SOL	average soil loss on arable land calculated with USLE
SW	leakage water quantity
$t_a(k)$	Elementary residence time within cell k
TE	mean time of discharge via combined sewer overflow
$t_{½}$	Half life of denitrification along the lateral path
$t_{tot}(i,j)$	Total long-term mean groundwater residence time between any grid cell (i,j) and the receiving water
$t_T(i,j)$	Long-term mean vertical travelling time in grid cell (i,j)
V_S	storage volume
$\mathbf{W}$	Set of the grid cells defining the catchment area of water w
W_{TR}	proportion of dissolved human nutrient output transported to wastewater treatment plants [%]
Z_{NST}	effective number of storm water days

Summary

Different models (**MONERIS, MODEST and NIIRS**) were applied to estimate the nutrient inputs by point sources and various diffuse pathways into river basins of Odra. The models are 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 within the MONERIS model:

- point sources
- atmospheric deposition
- erosion (NIIRS)
- surface runoff
- groundwater (MODEST)
- tile drainage
- paved urban areas

For erosion and groundwater emissions additionally the Models NIRRS and MODEST were applied.

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.

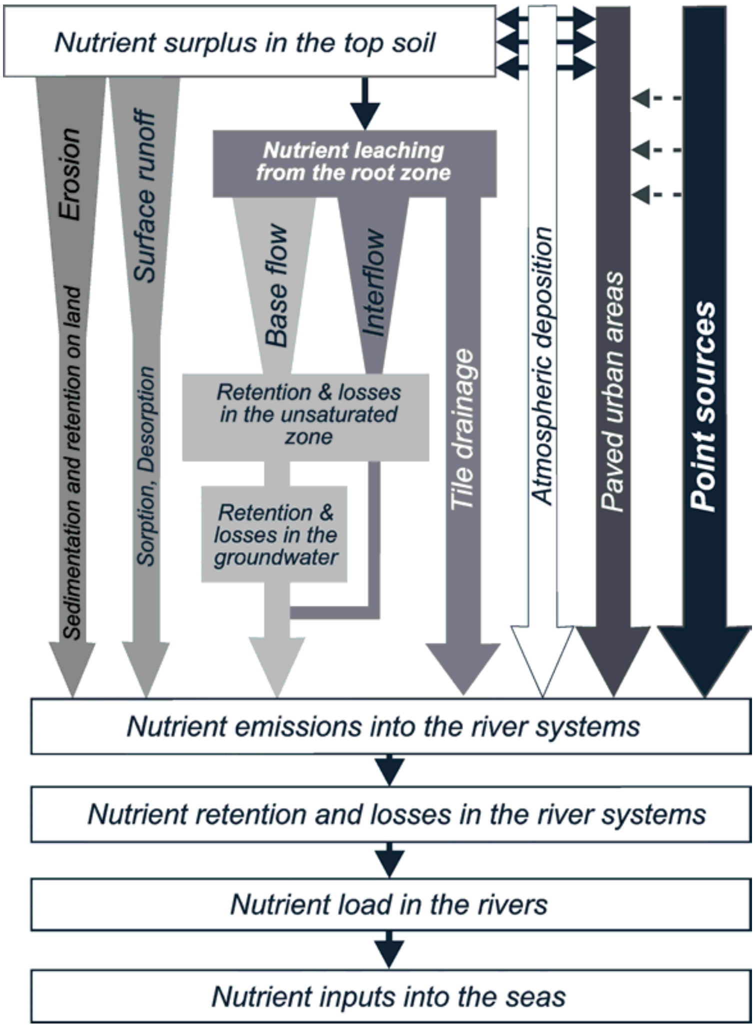


Figure 1: Pathways and processes within MONERIS.

The use of a GIS allows a regional differentiated quantification of nutrient emissions into river systems. Therefore, estimates were not only carried out for large river basins. Altogether

the MONERIS model was applied to 45 different river catchments within the Odra basins for the time period 1993-1997. MODEST and NIIRS allow the estimation of nutrient emissions by groundwater and erosion by a higher spatial resolution (MODEST: 1 km grid; NIIRS: municipalties) but for the comparison of the models the results of MODEST and NIIRS were additionally aggregated to these 45 river catchments.

The results of the estimation of the nutrient emissions into the Odra and the contribution by countries and by pathway are presented in Tables 1 and 2 and in the Figures 2 to 3.

Nitrogen emissions into the river basins of Odra were about 124260 tN/a in the period 1993-1997. As the main sources of nitrogen emissions point sources (36.4%), groundwater (27.1%) and tile drainage (26.0%) were identified. The contribution of other pathways to the total nitrogen emission is only about 10%. From the total nitrogen emissions within the Odra basin 85% are caused by Poland, 11.3% by the Czech Republic and 3.7% by Germany.

The total phosphorus emissions into the Odra river basins were about 12840 tP/a in the period 1993-1997. The point sources are the dominant pathway for the phosphorus inputs into the river systems of the Odra. The point sources cause 62.1% of the total P-emissions. Erosion (11.8%), urban areas (11.7%) and groundwater (9.1%) are the main sources of the diffuse entries in the Odra basin. From the other pathways as atmospheric deposition, tile drainage and surface runoff together only about 5% of the P-emission come from. The polish part of the Odra originates 89.4% of the P-emissions.

Table1: Nutrient emissions by point and diffuse sources into the Odra basin in the period 1993-1997.

		E_{Gw}	E_{Dr}	E_{Dep}	E_{Ero}	E_{Ro}	E_{Urb}	E_{Point}	Sum
Phosphorus	tP/a	1,170	420	130	1520	130	1,500	7,970	12,840
	%	9.1	3.2	1.0	11.8	1.0	11.7	62.1	100
Nitrogen	tN/a	33650	32260	3870	1020	500	7,680	45,280	124,260
	%	27.1	26.0	3.1	0.8	0.4	6.2	36.4	100

Table2: Total and diffuse nutrient emissions into the river systems of the Odra by country in the period 1993-1997 (the percentages in bold and italic are related to the total emissions of the Odra; the other percentages are related to the total emissions of each country).

		Czech Republic		Poland		Germany		Sum	
		total	diffuse	total	diffuse	total	diffuse	Total	diffuse
Phosphorus	tP/a	1,030	500	11,480	4,220	330	150	12,840	4,870
	%	***8.0***	48.5	***89.4***	36.8	***2.6***	45.5	***100***	37.9
Nitrogen	tN/a	14,020	10,900	105,690	65,170	4,540	2,900	124,260	78,980
	%	***11.3***	77.7	***85.0***	61.7	***3.7***	63.9	***100***	63.6

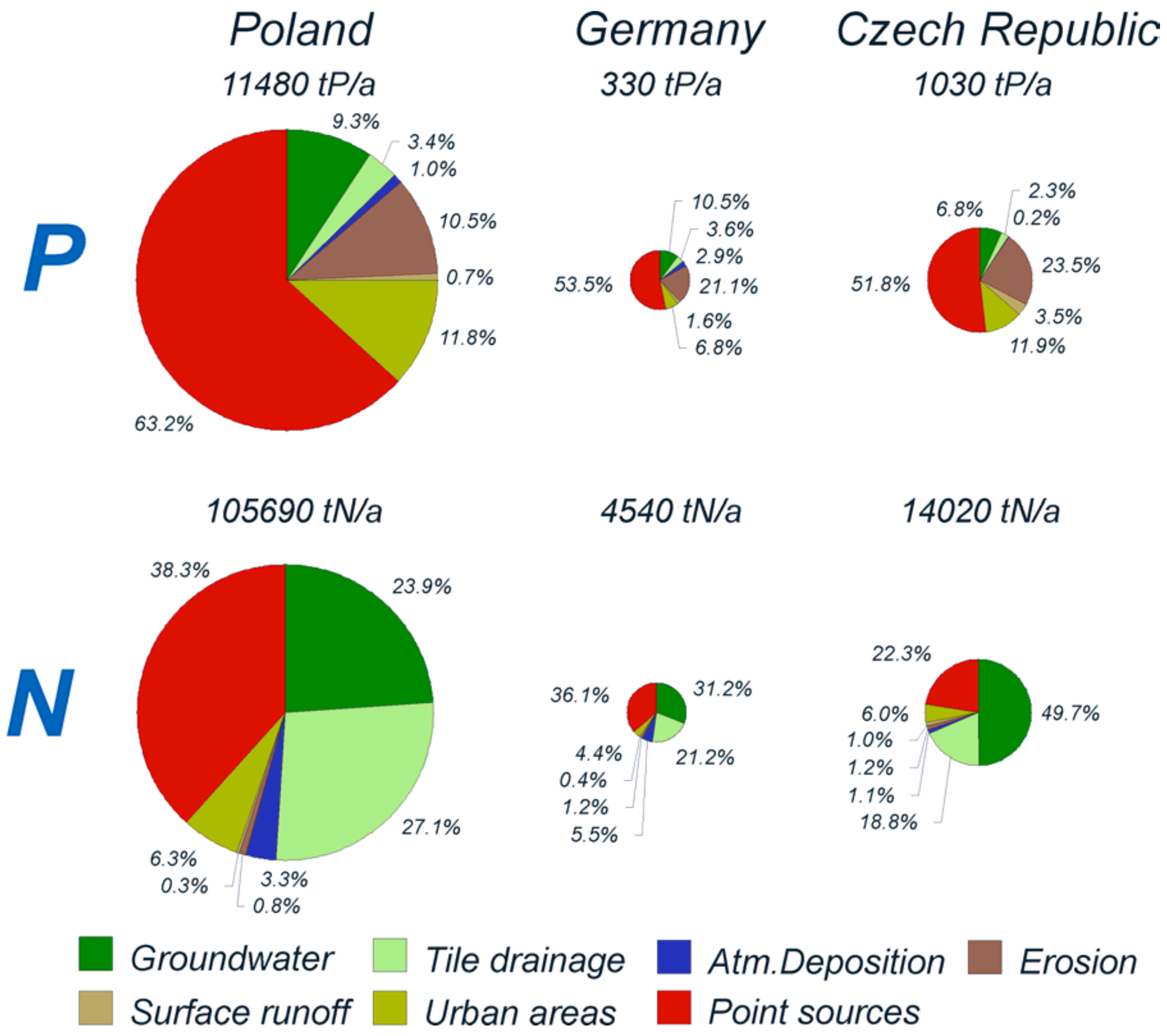


Figure 2: Nutrient inputs via the various pathways caused by the different countries within the Odra basin in the time period 1993-1997.

A percentage of 8% and 2.6% of P-emissions is caused by the Czech and German part of the Odra.

The comparison of the different models regarding nutrient inputs by erosion (NIIRS and MONERIS) shows that a mean deviation of 50% exists, mainly caused by the different approaches for the sediment delivery ratio (SDR) and enrichment ratio (ER). Further research is necessary to develop these approaches in order to describe the dependencies on the main driving forces more correctly.

The comparison of the results of the MODEST and MONERIS model could only be done for nitrogen within the unconsolidated rock region of the Odra basin. This comparison shows that the deviation between the models is lower than the deviation between the parameters which can be used as indicators for the groundwater emissions of nitrogen (nitrate concentrations in rivers at low flow conditions in winter and regionalized nitrate concentrations in groundwater). Compared to these indicators the quality of the results of the conceptual box model MONERIS, which was applied without changes of parameters, was not worse than this

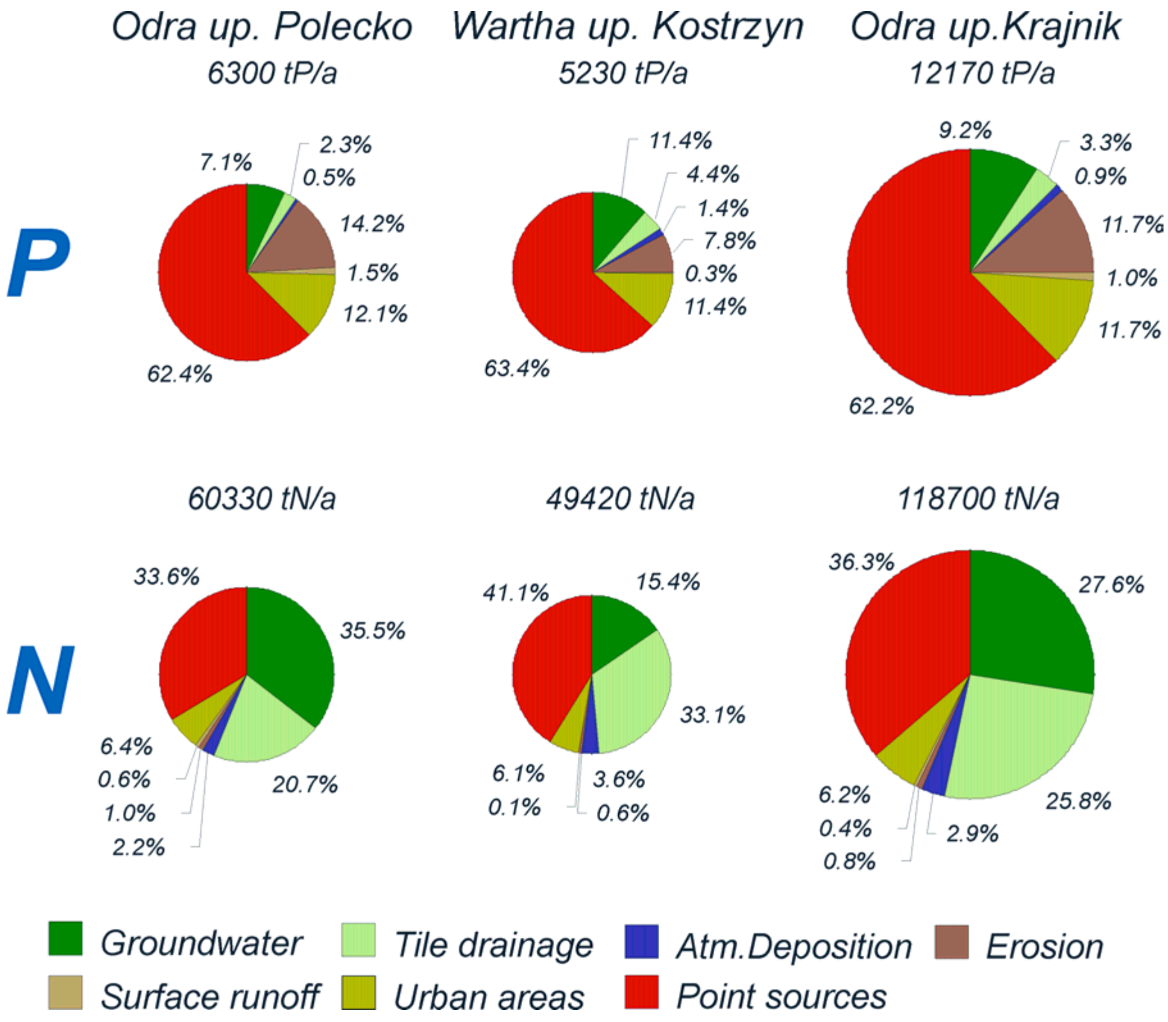


Figure 3: Nutrient inputs via various pathways within the Odra upstream Krajnik dolny and its main tributaries in the period 1993-1997.

of the mechanistic MODEST model. For the evaluation of the model results it is to consider that the error of the estimated groundwater N-inputs is up to now in a range lower than 40 %.

By application of the retention functions of MONERIS for nitrogen and phosphorus the load within the river systems could be calculated and compared with the observed loads at 41 monitoring stations within the river system of the Odra. It was found that the mean deviation between the calculated and observed nitrogen loads was 21% for dissolved inorganic nitrogen and 22% for total nitrogen. These deviations are not larger than the deviation for the observed load, which could be derived from the comparison of two independently datasets of observations for the Odra at Schwedt and Krajnik Dolny. For phosphorus a mean deviation between calculated and observed loads of 32% was estimated for the 41 stations, which is also similar to the deviation found for the loads at Schwedt and Krajnik Dolny. Additionally a systematical underestimation of the calculated load was discovered for such catchments in the Odra which have a high portion of lakes within the catchment area. This can be due to desorption of phosphorus from the sediments of the high eutrophic and polymictic lakes, because this process is up to now not involved in the retention functions of MONERIS.

Additionally to the emission models the immission approach was applied for 41 different catchments of the river system of Odra. In general, the results of the application of the immission approach support the results which were find out by means of the emission approach.

The emissions and loads of nitrogen in the Odra basin in the period 1993-1997 are low in comparison to other river system within Central Europe, which is mainly due to the high portion of unconsolidated rock region at the total catchment area of the Odra. The same can be concluded for the diffuse P-emissions in the Odra basin, but the level of point source emissions in the Odra corresponds to that of other rivers in Central Europe in the period 1983-1987.

The calculation of different scenarios shows that a reduction of phosphorus can be expected within the next years especially by implementation of phosphorus free detergents in Czech Republic and Poland and if the EU waste water directive is implemented. For this case a reduction of P-inputs by point sources to 20-25% of the value in the period 1993-1997 would be possible. If additional measures for the reduction of P-emissions by erosion and from urban areas are implemented a total reduction of the phosphorus emission and load of Odra into the Baltic Sea of 62% can be expected within the next 10 to 20 years.

For nitrogen we can expect that especially with the full implementation of the EU waste water directive a substantial decrease of point source discharges of 65% can be reached. But this reduction will be not sufficient for the 50% reduction according HELCOM targets. Additional measures for the reduction of diffuse sources are necessary.

A possible further reduction of the average nitrogen surplus on agricultural areas would lead to a decrease of the diffuse nitrogen inputs into the river system of Odra of 17 % within the next 20 years. Together with the point source reduction a decrease of 34% compared to the state in the period 1993-1997 seems to be possible. Up to now it is unclear that this reduction is sufficient to fulfil the HELCOM targets because the emission situation for the period 1983 to 1987 is unsure. But a raw estimation of the N-inputs in this periods based on calculations of N-emissions by groundwater and drainage for this time and point source discharges which are 20% higher than in 1993-1997 the reduction in 2020 would be only 44% compared to the late eighties. That means a 50% reduction of the nitrogen load of Odra into the Baltic sea can not be reached by measures focused on the decrease of the nitrogen emissions from point and diffuse sources alone. Additional measures aimed at an increased retention and losses of nitrogen in the agricultural area (re-establishing of tile drained areas) or near by as well as within the surface waters of the river system of Odra (e. g. buffer strips, establishing renaturalization of wetlands, small reservoirs) are necessary.

As presented in Figure 4 and Table 3 the total emissions of heavy metals were estimated in the period 1993-1997 to 10.8 t/a for Cadmium, 175 t/a for Copper, 113 t/a for lead and 1190 t/a for zinc. The portion of point sources to the heavy metal inputs varies between 34 % for copper and 73% for Cadmium. Within the point sources the discharges by municipal WWTP`s were the main source. For all heavy metals the dominant diffuse source was the input from urban areas. The portion of this pathway to the total emissions varies between 16% (Cadmium) and 31% (copper and lead). In general the heavy metal emissions are higher in the upper Odra than in the Warta.

Compared to other river systems the heavy metal loads in the Odra are very low, which is due to high retention of heavy metals within the river system.

The estimation of the emissions for copper and zinc could be evaluated by the comparison with measured loads and the results of the immission method.

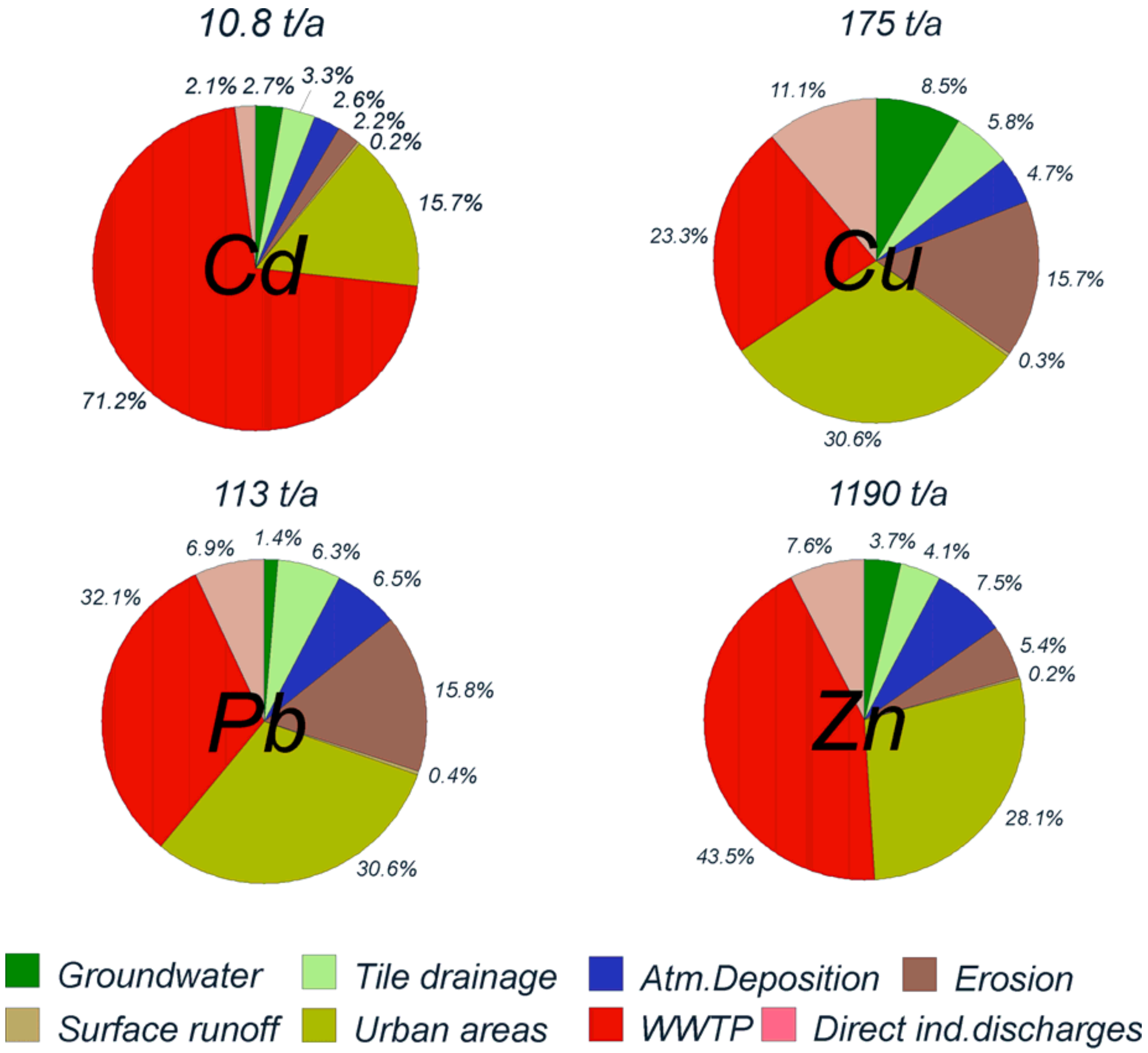


Figure 4: Inputs of heavy metals into the Odra basin in the time period 1993-1997.

Table 3: Heavy metal emissions by point and diffuse sources into the Odra basin in the period 1993-1997.

Catchment	Gw	Dr	Dep	Ero	Ro	Urb	WWTP	Ind	Sum
	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]
Cadmium	289	357	286	240	24	1701	7707	223	10826
Copper	14900	10200	8300	27500	600	53600	40800	19400	175200
Lead	1600	7100	7400	17900	400	34700	36300	7900	113300
Zinc	43300	48400	89200	63800	2700	333400	515900	90000	1186700

The observed loads for cadmium and lead were to unsure for the evaluation of these emission results.

For a further success at the estimation of heavy metal emissions into the Odra basin a more detailed database is needed.

With the increase of the elimination rates of phosphorus in the municipal WWTP`s also the inputs of heavy metals by this source will be reduced.

In relation to the HELCOM activities the results of this study give the possibility to predict the influence of possible measures on the change of the loads of nutrients and heavy metals in the future. But to control the success in relation to the targets (50% reduction) it is necessary to calculate the emissions and loads of nutrients and heavy metals also for a period within the mid 1980s. This could not be done within this study.

1 Introduction

In the middle of the last century it became obvious that in the case of many river basins the targets of the *Helsinki-Commission* (*HELCOM*) concerning a 50% reduction of nitrogen and phosphorus inputs to the Baltic Sea were not reached. Such a conclusion could be derived by observed loads. But the measurements were not sufficiently regarding the analysis what were the reasons for this development, what has to be done to fulfil this agreement and in which time the targets can be reached.

The answer to these questions can only be given, if the sources of the emissions of substances within a river system are known. Inventories of point sources were possible but the knowledge regarding the diffuse sources were not sufficiently to estimate these inputs within river systems of different size, hydrology, soil conditions and intensity of land use.

By national studies as e.g. Hamm et al. (1991) first approximations were carried out regarding the different diffuse pathways, but on this base the differences especially in the individual large river basins could not be explained. On the other hand the measurements and the application of existing models for the estimation of diffuse nutrient entries could only be applied for small catchments. Further the models were mainly focused on individual pathways and could not be summarized to a tool, which allows the estimation of all point and diffuse sources of inputs. But only the summarized view could give the possibility to combine the analysis of emissions within a certain time period with the observed loads and at the end to calculate scenarios simulating the influence of individual management measures on the emissions and loads in the future. For international river basins as the Odra the situation was much more difficult because the used methods and tools for an analysis of the sources of nutrients and other substances in the river basin were different and not harmonised.

This situation was the background for the decision of the German Environmental Agency to support different scientific projects with the aim to develop special modelling tools for the analysis of the nutrient inputs mainly by diffuse sources into individual medium and large river basins.

One of these projects was related to the “Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection - Diffuse entries in rivers of the Odra Basin“. Phase I and II of this project were focused on the development of special models for the estimation of the main diffuse pathways for diffuse nutrient entries, erosion (mainly phosphorus) and groundwater entries from the unconsolidated rock region (mainly nitrogen).

Besides the scientific tasks the special value of this project consisted in the establishment of an international group of scientists which offered the possibility to develop harmonized models at the start of the project.

With the end of phase II of this project in 1998 the models MODEST for the nitrogen emissions by groundwater and NIIRS for the nutrient emissions by erosion were developed and applied for the unconsolidated rock region of the Odra basin (see Dannowski et al, 1999).

From this phase of the project it was concluded that on the one hand a substantial progress was reached regarding the understanding of the processes occurring especially by the transformation of nutrient application in the agriculture and the entries into river systems dominated by unconsolidated rocks. This was possible with high spatial resolution, because recent GIS techniques were applied. On the other hand this analysis was not sufficient to explain the causes of the nutrient inputs into the whole Odra basin, because the consolidated rock region was not investigated and other diffuse pathways as well as the point discharges were neglected. Further the international cooperation was limited to a joint work of Polish and German scientist and the Czech part of the Odra was not analysed.

For the solution of these open tasks phase III of the project was started in 1998. This phase was focused on four objectives. At first: the developed tools and models of each source of emission are to be summarized to a system which describes the material flow from the sources to the riverine transports at the mouth. Secondly: possible changes of the nutrient state of the Odra which are based on scenarios for diffuse and point emissions should be derived. Thirdly: a spatial digital database for the whole Odra basin which can be used by the International Commission for the Protection of Odra for further analysis has to be prepared. Fourthly: scenario analyses are needed to quantify the expected changes of the diffuse and point emissions of nutrients and heavy metals on the background that Poland and Czech Republic access the European Union in the next decade. Additionally first approximations regarding the emission and load situation for heavy metals in the Odra basin should be derived.

For the solution of these objectives it was necessary to incorporate Czech scientists into the study team and to use an additional model for the estimation of further pathways. The model MONERIS, which was developed and applied for German river basins within the framework of an other research project and was funded by the German Environmental Agency (see Behrendt et al., 2000). This model is able to estimate all important pathways of point and diffuse entries within a river system. It can be applied also outside of the unconsolidated rock region and allows the calculation of the load at certain monitoring stations of a river on the base of the results of the emissions.

For this model involves also modules for the nutrient inputs from groundwater and erosion, it was possible and necessary from the scientific point of view to compare the results of the different models in relation to the present state and also for the scenarios.

The following research report shows all of these results, which may be interesting both for other scientists in this field as well as for the further work of the International Commission for the Protection of Odra.

2 Description of the Odra Basin

2.1 General information

The catchment of the Pomeranian Bay is comprised of Polish, German, and Czech parts of the Odra Haff catchment (Odra, Uecker, Zarow, Peene rivers), as well as the catchment areas of the Polish direct tributaries to the Pomeranian Bay. It covers an area of 136,528 km² in total; the Polish part encompassing 115,768 km², the Czech, 6,344 km², and the German, 14,416 km².

The upper and middle parts of the Odra catchment occupy the area of 53,536 km², of which only 9,235 km² are outside the Polish borders. In this extensive region there are lowlands, mountain-like and mountainous regions, which, together with uplands, constitute about 40% of the area comprising mainly the left side of the basin. The region is characterised by complex processes of meteorological element formation and runoff ratios. These processes result from the region's orography and high variability of meteorological factors in time and space and determine the water storage capacity and runoff ratios of the catchment. Intensive water management on storage reservoirs and on Odra River, mainly in the canalised section, are also influencing factors.

The Warta River basin, comprising 54,529 km², is located completely within Poland. The basin occupies lowland areas with a considerable share of *sandur* (sandy) areas enabling infiltration, and a large share of forest areas, balancing to a certain degree the water course supply during the year. The process is also supported by a large number of lakes in the region.

The lower Odra River catchment comprises 10,796 km², of which 3,548 km² are located in Germany. The region begins below the Warta estuary and constitutes a complex hydrographic system. For a considerable part of its area, the fluctuations and water levels in the water courses depend not only on supply conditions but also on water levels of the Baltic Sea and Szczecin Bay. Numerous locks and canals connected with the utilised waterway, as well as artificial and natural channel branches also significantly complicate the water relations in this region.

The catchments of the direct tributaries to the Pomeranian Bay comprise an area of 9,491 km²; the Rega and Parseta are the largest rivers.

The Odra River basin is very extended and exceptionally asymmetrical. Most tributaries supplying the middle Odra River are rivers of mountain type with the headwaters in the Sudety Mountains. These are the Osobłoga, Nysa Kłodzka, Oława, Ślęza, Bystrzyca, Kaczawa, Bóbr with Kwisa, and Nysa Łużycka constituting the last significant left-sided tributary of the Odra River. The Olza, the right-sided tributary, has its source in the Beskidy Mountains. The right-sided tributaries, such as Kłodnica, Ruda, Bierawka, Mała Panew, Stobrawa, Widawa and Barycz, are lowland type rivers with lower discharge. On the contrary, the Warta River, which has a length and catchment area nearly equal to the length and catchment area of the upper and middle Odra, has a significant influence on the course of the lower Odra River.

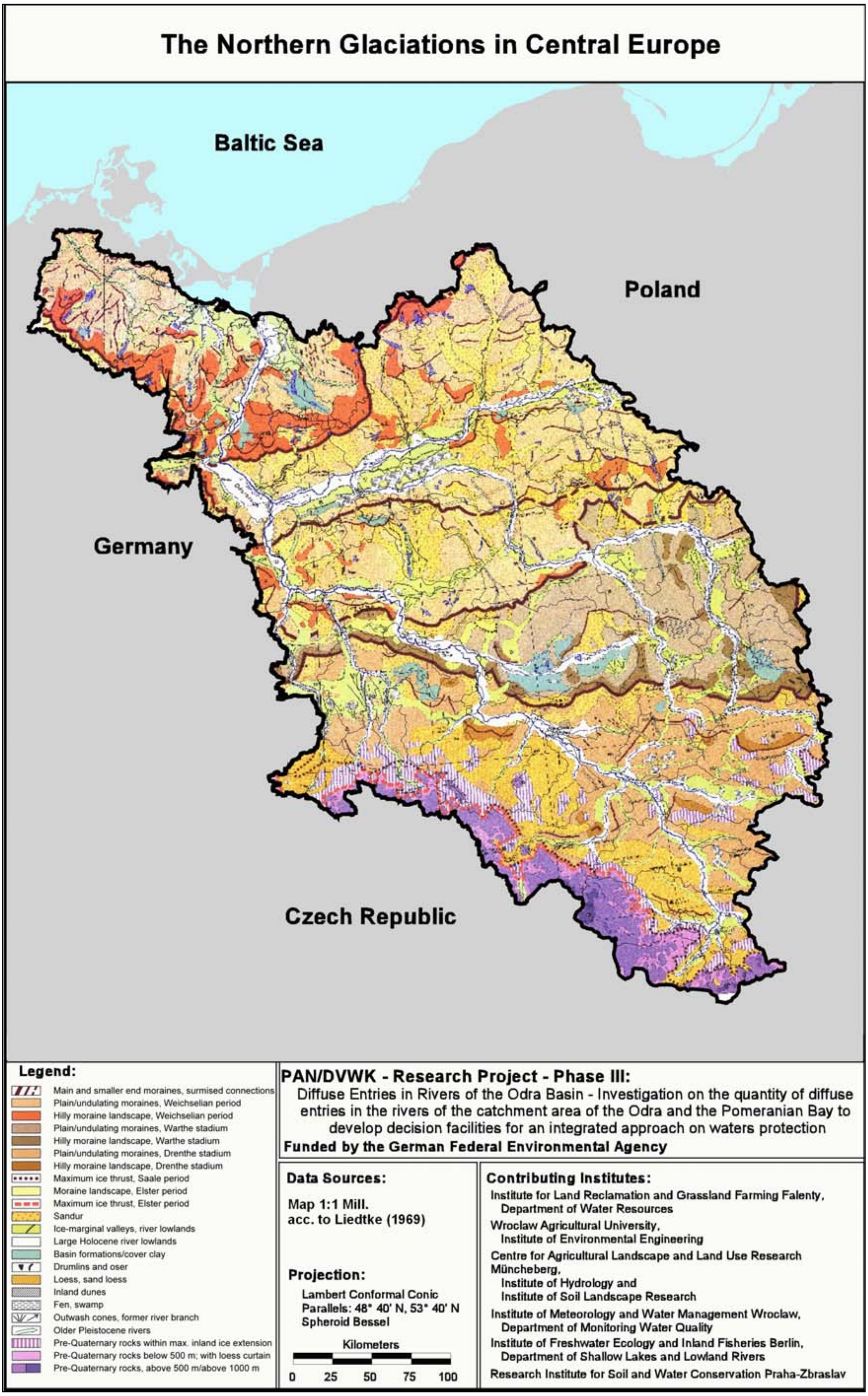
The average annual indices of water balance for the entire basin for the years 1951 to 1970 are (according to Polish evaluations): precipitation 587 mm, runoff 133 mm, runoff deficiency (actual evapotranspiration) 454 mm. The values vary depending on the particular region. The highest average precipitation values occur in the upper and middle Odra River catchment (646 mm). Lower and more similar values were measured in the two remaining regions (551 mm, 544 mm). The highest values of runoff were found in the lower Odra River basin (165 mm), and the lowest in the Warta River basin. The runoff deficiency decreases along the river course from 499 mm in its upper section and 426 mm in the Warta River basin to 386 mm in the lower Odra River basin. The average discharge flow is approximately 5.0 $l/s/km^2$, but only 2 to 3 $l/s/km^2$ in the middle section (Niziny Środkowopolskie), near the Baltic Sea – 6 to 10 $l/s/km^2$, and in the Sudety mountains more than 20 $l/s/km^2$.

There are a total of approximately 500 gminas (the smallest administration unit in Poland) in the Odra catchment. In the Czech territory, the Odra catchment comprises parts of Severoczesky Kraj, Vychodoczesky Kraj, and Severomoravsky Kraj; and in Germany – parts of Sachsen, Brandenburg, and Mecklenburg-Vorpommern federal states.

The relief directly or indirectly influences the formation of the natural environment elements. The indirect influence occurs mainly from the proportion of water on the site, in the course of soil and soil-water processes and in local climatic elements. The topography directly impacts the organisation of the agricultural production. The most supportive conditions for this production (table-plain area) occur in the northwestern part of Szczecin district, in the middle and lower Warta and Noteć valley, at the lower and middle Barycz river, in the Odra River valley in the section from Scinawa to Kostrzyn and in the left-sided Oderbruch polder region below Kostrzyn, and in the right-sided Odra valley from Krapkowice to Scinawa. The areas most suitable for agriculture (little relief) are predominately located in the catchment areas of the Pomeranian Bay, in the upper part of the Warta catchment, in the northern part of Poznan district, and in the southern part of Wrocław and Opole districts. The most inconvenient conditions for the agricultural production are in Sudety, particularly in the regions Kamienna Gora, Wałbrzych, Nowa Ruda, Kłodzko, and Bystrzyca Kłodzka.

2.2 Physical, geographic and hydrographic situation

The Odra River in terms of its drainage basin surface area (118,611 km^2) and the length of its channel (912 km) ranks – after the Vistula – as the second largest stream in Poland's hydrographic system. On its way, the Odra cuts across all the major morphological units of the country the result being that its catchment features all types of natural landscapes in Poland.



PAN/DVWK - Research Project - Phase III:

Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Data Sources:

Map 1:1 Mill.
acc. to Liedtke (1969)

Projection:

Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty,
  Department of Water Resources
Wroclaw Agricultural University,
  Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
  Institute of Hydrology and
  Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
  Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
  Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 2.1: Geomorphologic synopsis of the Odra Basin

Map 2.1 presents a clipping from a geomorphologic synopsis of Central Europe based on a map 1:1 Million according to Liedtke (1969). In the unconsolidated rock region (white and yellow to brown colours), the elements of the glacial series which are dominant for the landscape structures are evident. The large-scale correlation between geographical formations east and west of the Odra River is clearly visible. To the south, the relative small area of the solid rock region (purple colours) attracts attention.

According to the physio-geographic division of Poland (Kondracki 1998), the Odra catchment covers six sub-provinces (Map 2.2):

1. Sudety Mountains (332)
2. Niziny Sasko-Łużyckie /Saxonian-Lusatian Lowlands/ (317)
3. Wyżyna Śląsko-Krakowska /Silesian-Cracow Highlands/ (341)
4. Niziny Środkowopolskie /Central Polish Lowlands/ (318)
5. Pojezierza Południowobałtyckie /Southern Baltic Lake district/ (314)
6. Pobrzeża Południowobałtyckie /Southern Baltic Littoral / (313)

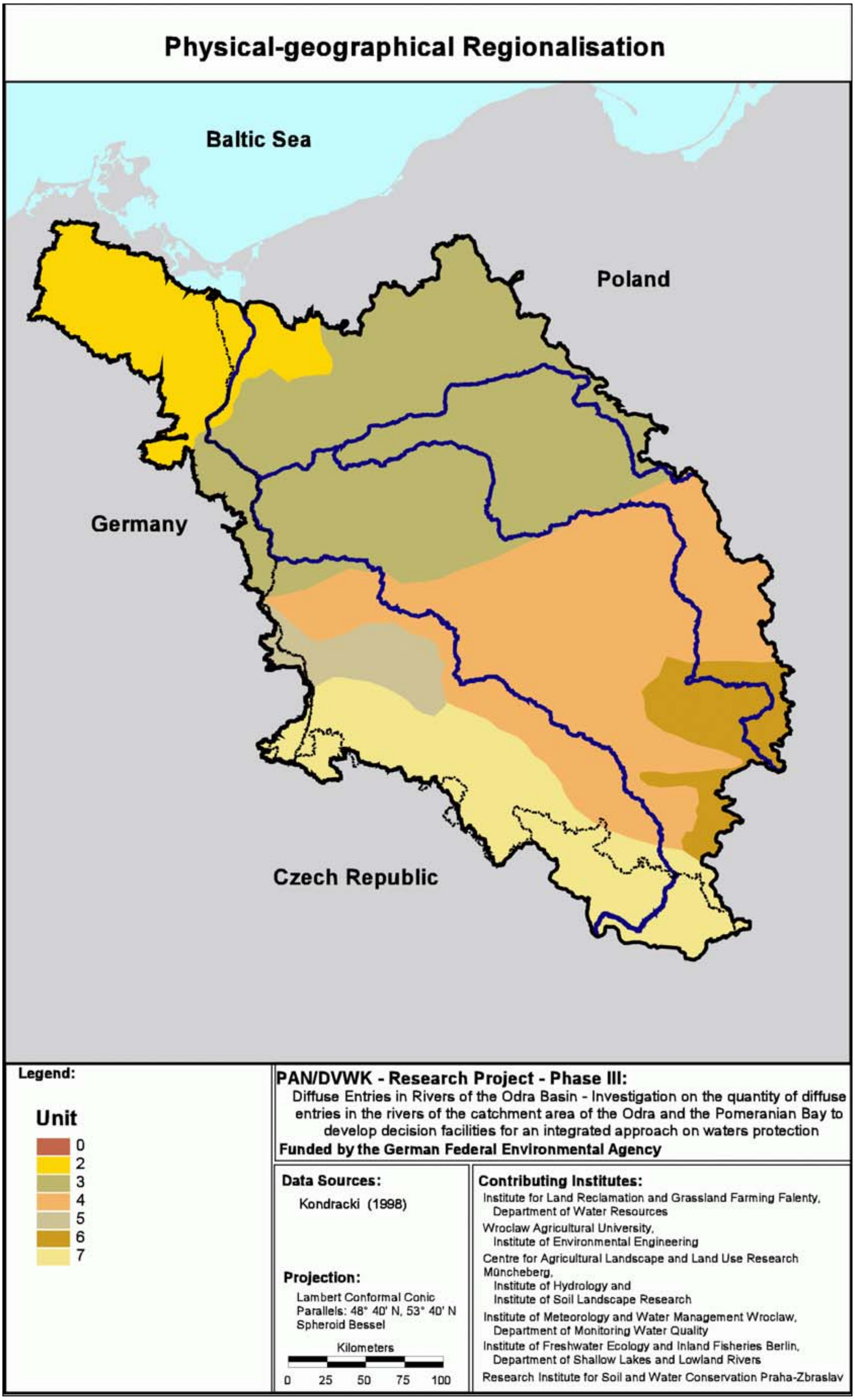
The upper course of the Odra (measured from its headwaters to the region of Wrocław) lies in three subprovinces: the headwater zone belongs to the Sudety region while the sections lower downstream form part of the Silesia-Cracow Upland (in the east) and Central Polish Lowlands (in the west).

The Sudety from the point of relief are a region of medium-high mountains. They are characterised by substantially varied geological structure which features metamorphic (gneiss, migmatites) igneous (diabase, porphyry) and sedimentary rock (sandstone, limestone, dolomite, marl). The rocks building the Sudety have a different resistance to weathering which has resulted in the development of a highly varied relief. A common sight are substantial differences in relative altitude, steep valley slopes and rises and denudation mountains.

The **Central Polish Lowlands** are bounded in the north by the range of the last glaciation and the province of the Bohemian Massif in the south. The region largely features landscapes of lakeless denudation plains with relics of kames and moraines of the Odra and the Warta glaciation, bisected by basin areas and river valleys.

The **Saxonian-Lusatian Lowlands** which correspond to the Central Polish Lowlands lie for the most part on the territory of Germany.

The **Silesia-Cracow Highland** belongs to the class of highland and low mountain landscapes. In terms of its geology it is a tectonic elevation built of Carboniferous coal deposits buried under Mesozoic sedimentary rock. Relief is on the whole uniform, the older geological formations lying under Quaternary deposits.



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Map 2.2: Physical-geographical regionalisation of the Odra Basin

The middle and lower course of the Odra flows through the subprovince of Southern Baltic Lake Districts and the Southern Baltic Littoral.

A characteristic feature of geomorphology of the **Southern Baltic Lake Districts** is that the main morphological units composing it form zones running E-W. There are two main landscape types: young glacial landscape, featuring moraine plains as well as post-lacustrine-outwash plains and valley relief with numerous terraces and dunes and flooded valley floors.

The mouth section of the Odra lies in the subprovince of **Southern Baltic Littoral**. The region has been subdivided into morphological units of zonally distributed plains. In the north of the region they are of fluvial and maritime origin, in the south their origin is glacial and dates back to the North Polish glaciation of the Pomeranian Stage. Landscape types include dunes, delta, lake and wetland, and uplands.

As already noted, the headwaters of the Odra lie on territory of the Czech Republic, Odra Highlands, 634 m above the sea level. From the headwaters to the tectonic fault rift of the Moravian Gate the Odra has the character of a mountain stream, its gradients over 7 ‰, in the remaining section its character is that of a lowland river. From Bogumin to the confluence with the Olza the Odra is the border river between Poland and the Czech Republic. At the outset it flows northward, from the mouth of the Gliwice Canal it veers northwest down to the mouth of the Nysa Łużycka. From the town of Kędzierzyn Koźle to that of Brzeg Dolny, 186 km of the river has been channelled and straightened with 23 stages of fall. In this section, the Odra receives its right-hand tributaries: the Kłodnica, Mała Panew, Strobrawa, Widawa, Barycz, Obrzyca; its left tributaries being Osobłoga, Nysa Kłodzka, Oława, Ślęza, Bystrzyca, Kaczawa, Bóbr, Nysa Łużycka. From the mouth of the Nysa Łużycka the Odra again starts to flow northward and over 179 km it is the border river between Poland and Germany. When it reaches the region of the Toruń-Eberswalde Old valley it receives its largest tributary, the Warta. Downstream of Widuchowa, some 84 km from its mouth it branches out into Odra Zachodnia (Western Odra) carrying its main stream, flowing by Szczecin and feeding into the Gulf of Szczecin. Its eastern branch, the Regalica flows through Lake Dąbie and subsequently also empties into the Gulf of Szczecin.

As far as its regime is concerned – the upper course of the Odra up to the region of Wodzisław is characterised by a pluvial-nival regime (snow and rainfall-fed) with surface and groundwater feeding (both at ca. 45 to 55%), mean specific runoff in this area is at 3 to 8 $l\,s^{-1}\,km^{-2}$; outside that area the regime is nival (snow-fed). In the stretch from its headwaters to the mouth of the Nysa Łużycka on the whole there is a balance between subterranean and surface feeding, further downstream to the confluence with the Warta there is a slight dominance of subterranean feeding (ca. 55 to 65%), the mean specific runoff ranging between 3 and 6 $l\,s^{-1}\,km^{-2}$; the lower course is characterised by a substantial prevalence of subterranean feeding of over 65%, with specific runoff of 4 to 6 $l\,s^{-1}\,km^{-2}$. On the whole in the entire basin there is a prevalence of spring meltwater high water stages (March to April), only the section from the headwaters to the region of Opole registers the occurrence of high water resulting from precipitation (May to August).

Characteristic discharge is specified by substantial differentiation with visible increase observed along the longitudinal profile of the Odra (Table 2.1), and thus, SSQ ranges from 44.3 m/s to as much as 277 m/s. Similarly, minimum and maximum stages SWQ range from 405 m/s to 835 m/s, SNQ from 9.9 m/s to 452 m/s.

Table 2.1 Characteristic discharges on the Odra at selected stations in the 1961-1990 period, m/s

Water gauge	NNQ	SNQ	SSQ	SWQ	WWQ
Chałupki	5.7	9.9	44.3	403.0	1,050
Oława Most	31.2	56.3	139.0	653.0	1,190
Ścinawa	34.8	77.9	198.0	714.0	1,670
Połęcko	81.6	118.0	277.0	835.0	1,680
Słubice*	56.3	244.0	344.0	490.0	1,820
Gozdowice*	156.0	452.0	582.0	744.0	2,170

* data from the 1951-1980 period

The German part of the study region (Table 2.2) comprises the western parts of the Odra as well as the Lausitzer Neiße (Nysa Łużycka) catchments and the catchment of the Odra Haff with Uecker, Zarow, and Peene rivers.

Table 2.2 List of German catchments

Catchment	Catchment area (km²) (Hydrogr. Atlas)	Number of sub-catchments
Oder (Odra)	4,225	87
Lausitzer Neiße (Nysa Łużycka)	1,448	31
Uecker	2,401	65
Zarow	748	21
Peene	5,110	135
Oder-Haff	484	11
German study region	**14,416**	**350**

The German part of the Odra catchment ranges to the left of the Odra river from the mouth of the Lausitzer Neiße in the south (km 542.4) towards the Widuchowa weir in the north (km 704.1) – the branching point into Western and Eastern Odra, and further along the Western Odra down to km 17.1 (near Mescherin). In this region, the middle and lower course of the Odra representing also the border between Germany and Poland transits the same types of glacially formed Southern Baltic lowland landscapes as mentioned in the Polish part. With the exceptions of the Lausitzer Neiße river and the Hohensaaten-Friedrichsthal waterway, the German tributaries are of low importance for the Odra discharge and, thus, nutrient load.

At a distance of 197 km, the Lausitzer Neiße river is forming the southern part of the Polish-German border. Its catchment is divided into Poland, Germany, and the Czech Republic. From the German territory, 14 rivers are tributary to the Lausitzer Neiße river. About 45% of the German part of the catchment area is underlain by solid rock, the maximum elevation is about 700 m above sea level.

At the Odra river, aiming at flood protection and land improvement, since the 18th century a series of polders with artificial drainage systems (Neuzelle, Ziltendorf, Oderbruch polder lowlands) has been developed which receive recharge from the Odra and the western subcatchments (ground and surface waters). As a rule they are discharging into the river, by part via pumping stations. Paralleling the lower Odra river in the west, the Hohensaaten-Friedrichsthal waterway receives excess water from the Oderbruch polder as well as the Finow and Welse river catchments (totalling 3,907 km²). In this way, on a distance of 114 km north of Frankfurt down to the mouth of the Hohensaaten-Friedrichsthal waterway into the Western Odra, no direct tributaries occur from German side.

The Oder Haff catchment (such as the Welse catchment mentioned above) is representative for the younger moraine landscape of north-eastern Germany. Because of the loamy soils, a considerable portion of the catchment area (ground moraines) is under intensive agrarian land use improved by artificial drainage. The river lowlands are widely covered with drained peat soils (degraded fens of variable thickness, fed by groundwater) under grassland use. Sandy soils as well as the steeper slopes of end moraines are commonly forested. Large parts of the Oder Haff catchment are so-called 'internal drainage areas' with a very sparse and underdeveloped surface flow system, inclosing lakes and ponded areas.

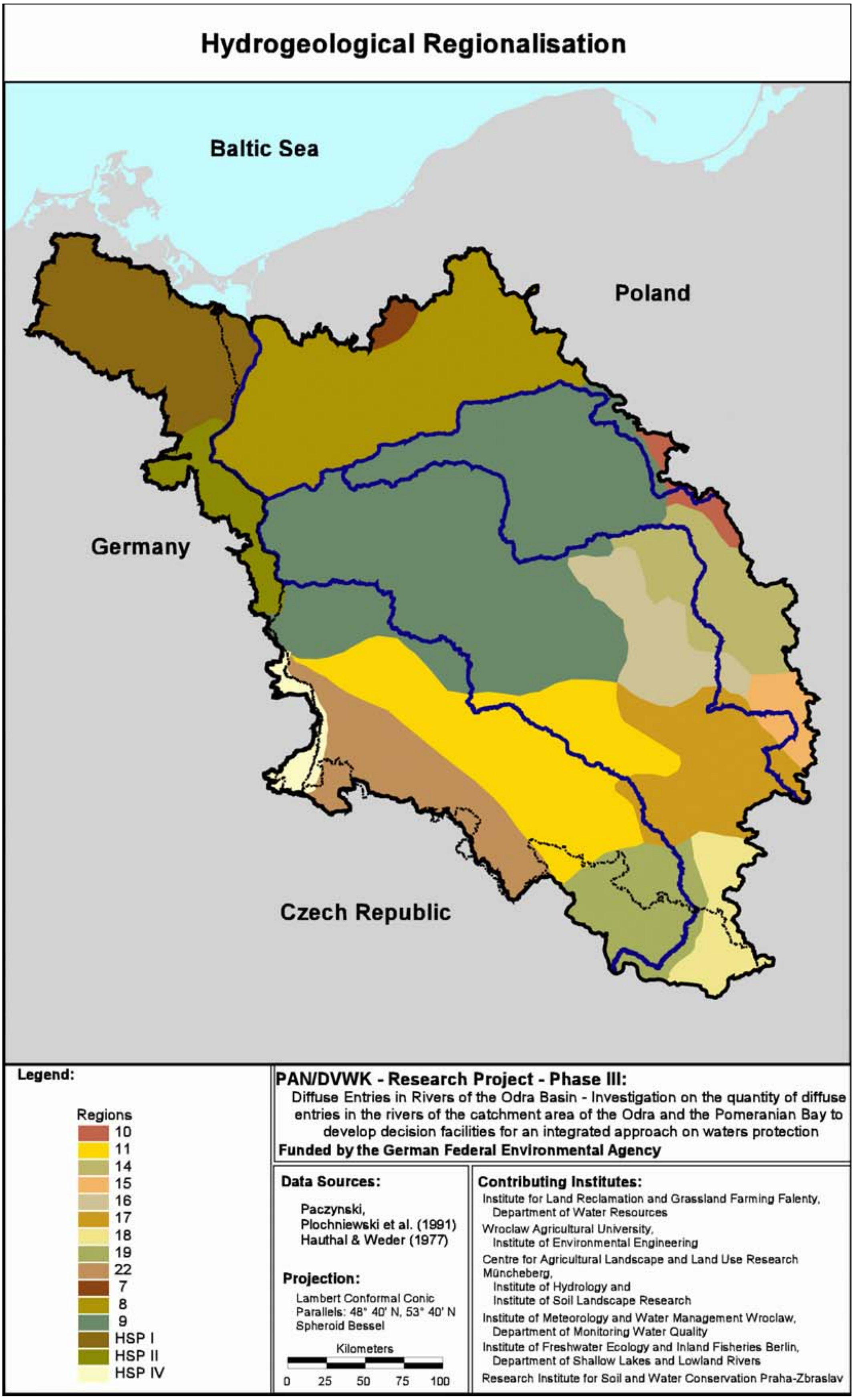
As a special characteristics of the Uecker and Peene catchments, the presence of relatively large lakes is mentionable, which are flown through in the upper sections of the rivers. The Zarow river is receiving excess water from a large deep fen area including a relic shallow lake also flown through by surface waters.

2.3 Hydrogeology

Hydrogeological regionalisation of Poland (Paczyński, Płochniewski et al. 1991) was defined on the basis of differentiation of geology and structure on the one hand and geomorphology and hydrography on the other.

According to this classification, the Odra catchment belongs to the macroregion of the Western, Southern and Central Polish Lowland (Map 2.3). The macroregions are subdivided into regions distinguished by their hydrogeological characteristics. Below a description of these regions is presented with special focus placed on the description of subsurface (mainly Quaternary) water-bearing layers.

Western Pomeranian Region (7), from the point of view of geology comprises a north-eastern section of the Pomeranian anticlinorium and a fragment of the Szczecin Basin. The area under discussion features Triassic, Jurassic, and Cretaceous water-bearing horizons as well as Quaternary formations. Tertiary formations are scattered and are nearly waterless.



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
Paczynski,
Plochniewski et al. (1991)
Hauthal & Weder (1977)

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 2.3: Hydrogeological regionalisation of the Odra Basin

The Quaternary water-bearing horizon occurs throughout the entire region. It is the main utilisation level of up to 100 m in thickness. Locally several water-bearing layers may occur of utilisation character. Well yield ranges from 30 m^3/h to, locally, 120 m^3/h. In marginal ice-valley formations, e.g. the Rega old valley, well yield exceeds 120 m^3/h. Subterranean water flow is to the north (the Baltic) and to the north-west (the Gulf of Szczecin).

Waters from this level are characterised by moderately good quality due to the excessive content of iron and manganese.

The **Southern Pomeranian Region (8)** is distinguished by various hydrogeological conditions. There are four water-bearing horizons: Jurassic, Cretaceous, Tertiary, and Quaternary. Almost the entire region is dominated by Quaternary formations. In such formations there are 1 to 4 water-bearing horizons, which are found from a few to several meters deep. Well yield is relatively large from 20 m^3/h to 140 m^3/h, locally 200 m^3/h.

The **Wielkopolska (Great Polish Plain) Region (9)** is characterised by a visible relationship of geomorphological units with Quaternary water-bearing structures.

The region is distinguished by varied hydrogeological conditions and presence of three water-bearing horizons: Cretaceous, Tertiary and Quaternary, differing in water capacity.

The presence of the Quaternary water-bearing horizon was determined throughout the entire region; owing to its substantial differentiation it was subdived into subregions – units of a lower order.

In the Wielkopolska fossil valley subregion the Quaternary horizon is formed by fluvial sediment with a high admixture of gravel overlain by tills of the last glaciation. Well yield is 70 to 120 m^3/h.

In the Lubusz Heights (subregion **Wysoczyzna lubuska)** the Quaternary level occurs at the depth of 15 to 50 m. The thickness of the water-bearing formations ranges between 10 and 20 m, with well yield at 30 to 70 m^3/h.

In the Poznań Lake District (subregion **Pojezierze Poznańskie)** Quaternary formations occur at the depth of 15 to 50 m ranging in thickness from 5 to 20 m, with well yield at 30 to 70 m^3/h. The water occurs under hydraulic pressure of 150 to 300 kPa.

In the Mogilno Basin (subregion **Niecka mogileńska)** the Quaternary forms a subordinate water-bearing horizon with water-bearing formations occurring in the valleys of rivers and in some lakes, reaching in thickness only some 10 m, with yields reaching 30 m^3/h.

In the southern area of the region, within the Warsaw-Berlin Old valley subregion the water-bearing layer ranges in thickness from several to a dozen odd metres, ranging substantially in yield i.e., from 30 to 120 m^3/h. The level is linked hydraulically with surface waters.

The **Barycz-Głogów Pradolina** subregion is characterised by highly varied hydrogeological conditions. The Żmigród and Odolany basins feature two water-bearing levels divided by clays and loams of marginal lake origin. The upper level reaches the thickness of 25 to 30 m, its yield reaching up to 50 m^3/h. The lower occurs at a depth of a dozen odd up to 35 m, reaching in places 70 m. The thickness of this layer may be as much as 40 m, its yield, 60 to 90 m^3/h. In the Odra section one of the most productive water-bearing structures is found. It is built of a sandy-gravel complex some 20 to 60 m thick. Its productivity ranges between 80 and 250 m^3/h.

In the **Zielona Góra-Leszno Heights** subregion two water-bearing levels are in evidence. The first is formed of glaci-fluvial sandy-gravel sediments of the end moraine which are divided by Tertiary clays into a number of aquifers. The thickness of the water-bearing layer is 20 to 60 m, its productivity at 50 m^3/h.

The other level occurs at the foot and on the slopes of the heights; it is formed of sandy-gravel kame-outwash sediments of 20 to 30 m thickness. The productivity of this layer is 100 m^3/h.

In the **Żary-Trzebnica-Ostrzeszów Heights** subregion Quaternary waters occur in sandy-gravel layers with a small up to a dozen odd meters' thickness. Productivity of the level is low, from several to a dozen odd m^3/h.

The **Wrocław Region (11)** is found at the junction of the pre-Sudety bloc built of crystalline Palaeozoic and Precambrian rock and the Pre-Sudety monocline represented by Permian-Triassic deposits. These forms are overlain by upper Cretaceous and Tertiary formations (Dyjor & Kuszel 1975). The principal water-bearing levels occur in Cainozoic, Mesozoic, Palaeozoic and crystalline formations.

The Quaternary water-bearing horizon in the region is highly varied and may be distinguished into three types of water-bearing levels:

- water-bearing levels in fossil valleys associated with the old Pleistocene river network
- water-bearing levels associated with river valleys developed primarily during the maximum stadial of the Middle Polish glaciation. They occur in the valleys of the Odra, Nysa Kłodzka, Strobrawa, Oława and Widawa
- levels formed by fluvio-glacial formations with a diluvial or inter-moraine character. They are encountered mainly in the northern part of the region

Generally the thickness of the water-bearing formations is some 20 m, only within some fossil structures reaching 80 m, their productivity ranging from 10 to 70 m^3/h.

In the region of the **Łódź Basin (14)** the water divide runs between the catchment of the Odra and the Vistula. As compared to the rest of the country the region is rich in subterranean water featuring water-bearing levels from the Cretaceous, Tertiary and Quaternary period.

Quaternary formations cover most of the area and are formed largely of fluvio-glacial sediments reaching 30 m in thickness, occasionally more. Productivity of the formations may be up to 100 m^3/h.

Only a small fragment of the **Miechów Basin Region (15)** lies in the Odra catchment. The principal water-bearing level occurs in Quaternary formations built of sandy and sandy-gravel formations of fluvio-glacial origin, more rarely fluvial and eolian, their thickness seldom exceeding 15 m, productivity reaching 30 m^3/h.

The **Kalisz Region (16)** lying on the northern margin of the Śląsk-Wieluń mono cline is relatively little defined. It is known to feature Jurassic, Tertiary and Quaternary water-bearing levels.

The Quaternary covers much of the region and is formed by glaci-fluvial formations of the Middle Polish and Southern Polish glaciation, reaching in thickness up to 100 m, in well yield up to 50 m^3/h.

The **Cracow-Śląsk Region (17)** greatly varied in terms of hydrogeology, is characterised by multi-storey structure. Of significance for use are tectonic Alpine structures: the Śląsk-Cracow and the pre-Sudety monocle. They are built by Triassic and Jurassic formations buried under Cretaceous and Tertiary deposits.

The Quaternary horizon is formed by Pleistocene and Holocene sands and gravels. Its thickness is negligible, there is usually only a single water-bearing level. Slightly more favourable hydrogeological conditions may be observed in valleys of rivers, both fossil and contemporary. Well yield may be as much as 25 m^3/h.

The **Kędzierzyn Region (19)** is situated in the southern area of the Tertiary depression of the Upper Odra. It features Tertiary and Quaternary water-bearing levels.

The latter is formed by sandy fluvial, glaci-fluvial sediments and intermoraine sands ranging in thickness between several up to 100 m. Well yield reaches 60 m^3/h.

The **Sudety Region (22)** is greatly varied in terms of hydrogeology. Two main types of hydrogeological units may be distinguished in the area: areas of outcropping crystalline platform lacking in distinct water-bearing levels featuring a system of hydraulically related water-bearing fissure layers characterised by negligible yield of 2 to 3 m^3/h. The other unit are Palaeozoic-Mesozoic pools which may be distinguished into lithostratigraphic levels richer in fissure water.

Best investigated and utilised is the Quaternary water-bearing level. It may occur in three ways:

1. As old Pleistocene fossil valleys, e. g. the fossil valley of Nysa Kłodzka

2. As young Pleistocene river valleys, e. g. that of the Nysa Kłodzka, Kaczawa, Bóbr, Nysa Łużycka

3. In upland areas – western area of the Sudety.

In the German part of the study region, only the Quaternary deposits are of importance to characterise the hydrogeologic conditions in the given context. This is caused by the nearly area-wide presence of the so-called Rupel clay formation dividing the Cainozoic (Quaternary) deposits bearing fresh groundwater off the salty Tertiary waters from deeper levels. Its thickness ranges between 15 to 20 m in the southern Lausitzer Neiße catchment up to 60 to 160 m in the middle and lower Odra and the Oder Haff catchments.

The typology of Hydrogenetic Subprovinces (HSP) according to Hauthal & Weder (1977) seems to be adequate to characterise the hydrogeologic conditions within the German part. From the south to the north, three subprovinces are of relevance (Map 2.3):

HSP IV: Subprovince of geosynclinale rocks

This subprovince comprises the southern (solid rock) part of the Lausitzer Neiße catchment. The presence of groundwater is highly restricted due to the heavy hardening and small fissure volume of the bedrock. Casually, fissure zones may occur with increased but very anisotropic permeability. Weathered rock material overlaying the bedrock can act as a relatively shallow water-bearing layer of local importance.

HSP II: Subprovince of predominantly Quaternary unconfined groundwater occurrence

The lower Lausitzer Neiße/middle Odra sections as well as their catchments are occupied by this subprovince that is very typical for the unconsolidated rock region. It comprises widespread sandur (sandy) areas south of the Pomeranian Stage end moraine and north of the extreme Quaternary ice thrust, the 'uplands' (ground moraines) of the Brandenburg glacier stadium, as well as the Old (ice-marginal) valleys. The typically unconfined groundwater is covered at the most by ground moraine deposits in the upland plates between the great valleys. Sandur areas mostly hold regionally spread water-bearing horizons of 10 to 50 m in thickness. The glaci-fluviatile and fluviatile deposits of the Old valleys mostly form a single aquifer along the direction of the bottom of the valley. Mean thickness is about 25 m with extremes of less than 5 m at the edges and up to 80 m in the centre of the valley. The ground moraine plates between the Old valleys are characterised by thicknesses of the covering layers as well as the water-bearing horizons decreasing from south to the north from 20 m to about 10 m. In upland sand deposits often two, as a rule hydraulically connected water-bearing layers occur.

HSP I: Subprovince of predominantly Quaternary confined groundwater occurrence

This subprovince occupies the lower Odra and Oder Haff catchments. Its southern border is marked overall by the end moraine of the Pomeranian Stage which is also forming the south-western water divide of the Uecker and Peene catchments. The groundwater is confined by relatively thick (between 10 and 70 m), more or less impermeable layers of glacial deposits. The water-bearing horizon is about 10 m in thickness. Because of the confining layer, the groundwater surface is characterised by a relatively high pressure potential. At the same time, the groundwater recharge is hardly restricted. In the northern part, the interface between geogenetic salinity and fresh upper groundwater is raising up to about 20 m below sea level.

2.4 The climate

The climate in the headwaters region of the Odra (Eastern Sudety in the Odra Highlands) is of the mountain type, characterised by presence of vertical climatic zones. Increase in altitude is accompanied by greater precipitation, humidity and declining temperatures. Temperature inversion is typical. The fact that the mountain ranges run from the SW to the NE in association with the prevailing westerly and south-westerly winds is responsible for higher precipitation on southern slopes. Average annual precipitation (with probability of occurrence of 90%) in this area ranges from 700 to over 1500 mm, the average number of days with snowfall is over 60. Average annual air temperature may reach 3 to 5 ºC. Average temperatures are ca. 15 ºC in July, in January falling to -6 ºC. The duration of the period of occurrence of average 24-hour air temperature of below 0 ºC is between 75 and 95 days. The duration of snow cover is over 100 days per year. The vegetation period is relatively short, i.e. less than 190 days.

The basin of the Upper Odra receives an average of 450 to 550 mm precipitation, that of the Middle Odra slightly less, i.e. ca. 400 to 500 mm, while the Poznań area lies in the rain shadow and average less than 400 mm precipitation annually (values uncorrected). Average number of days with snowfall ranges from 40 to 50, only in the Poznań region being less than 30 days. Average July temperature is ca. 18.5 ºC, in January being -1.5 ºC. The period with average 24-hour temperatures below 0 ºC lasts from 55 to 75 days, that with over 15 ºC temperature, more than 100 days per year. The duration of snow cover is 40 to 60 days. The vegetation season lasts ca. 220 days, in the Silesia Lowland being longest, i.e. 230 days.

The mouth section of the Odra is influenced by masses of sea air resulting in increased precipitation of over 450 to 550 mm, the number of days with snowfall is 30 to 40. Winters are mild (with average January temperature at -0.5 ºC) and cool summers (average July temperature of 17.5 ºC). The period with below 0 ºC temperatures is 55 to 75 days, that with more than 15 ºC between 80 and 100 days in a year. Snow cover on the ground stays on the average for 40 to 60 days. The vegetation season lasts from 210 to 220 days.

The climatic conditions in the German and Czech parts, due to the generally small distance from the border, are very close to those in Poland.

The hydroclimatic conditions (precipitation and evapotranspiration) are characterised more in detail in the following chapters.

Database

Spatial input data

The following data were made available as geo-referenced datasets and could be implemented into the GIS. For GIS presentation of these data and the calculation results, the Lambert Conformal Conic Projection based on the Bessel Ellipsoid was used with the parallels 48°40’N and 53°40’N.

- The **River Network** and the **catchment borders** were digitised from the Atlas Hydrologiczny Polski, Basic Water Management Maps of the Czech Republic (digitised by *TGM Water Management Research Institute, Prague*), and the atlas Hydrographisches Kartenwerk der DDR 1:200,000. Map 3.1 and Table 3.1 give an overview of the 46 investigated catchments, which have been selected according to the position of the river monitoring stations. The size of the subcatchments, between two monitoring stations, is normally more than 600 km², only the subcatchment at the Czech/Polish border at station Bohumin/Chałupki is smaller. The largest subcatchment is the Warta at Poznań occupying more than 11,000 km². The overall catchment size of the Odra is 118,861 km². The catchments of rivers directly entering the Odra Haff cover an area of 8,885 km².

- For **land use** classification, data from CORINE Landcover (CLC) (Data on German soil cover, *Federal Statistical Agency*, 1997; Phare Natural Resources, Land Cover, *European Commission*, 1996) were used. The original classes were aggregated for calculation. The remaining 8 classes are shown in Map 3.2. An overview of the land use distribution in the investigated catchments is given in Table 3.2. In the Odra catchment, according to CLC, 47 % of the area are under agricultural use, 31 % are covered by forest, 4 % by urban areas, and 1.2 % by open waters. The portions differ between the subcatchments, e. g. for agricultural land between 19 % in the Ostravice and 73 % in the Oława, and for forest between 10 % in the Oława and 54 % in the Drawa catchments. In the catchments of Kłodnica, Nysa Łużycka at Zgorzelec, and Ostravice rivers, more than 10 % are occupied by urban area.

- The **Soil Map** is composed from different soil maps of the three countries in the Odra Basin. For Poland, a new digitised soil map 1:500,000 was made available with the aid of the IMUZ group from *Institute of Plant Nutrition and Soil Science* (*IUNG*), *Pulawy*. For the German part, the Medium-scale agricultural site mapping (MMK 100, *State Geological Offices of Brandenburg, Mecklenburg-Vorpommern,* and *Sachsen*) has been used. For the agricultural areas in the Czech part of the Odra basin, the Research Institute of Soil and Water Conservation (*VUMOP*) provided the digital map 1:5,000 of Site valuation units (BPEJ). Map 3.3, by means of the available field capacity, gives an overview of the soils in the Odra Basin. – For detailed spatial modelling, the themes: field capacity (root zone, subsoil), denitrification potential (top soil), and

Michaelis-Menten denitrification constant (top soil) were assigned to soil types according to the national soil classifications. The nitrogen and phosphorus contents (Maps 3.4; 3.5) in the upper soil layer are used as described in Phase II.

- The **Digital Elevation Model** (DEM) GTOPO30 from *U. S. Geological Survey* (*USGS*), with a resolution of 30 arcsec (about 925 m × 570 m, resampled to 500 m × 500 m), is available for the entire Odra catchment (Map 3.6). In general, this DEM is not very useful for any process-oriented calculations, unless additional information (e. g. groundwater exposure from the soil type in the case of the depth to groundwater) is available. Especially this applies to estimating surface runoff and water erosion.

- The **Depth to the groundwater table** (Map 3.7) is available for the German part from the free market (*WASY Ltd.*), additional information of groundwater-exposed soil types resulted from MMK 100. For Poland, appropriate data were obtained at ZALF from digitising a hydrogeological map 1:300,000 originating from the late 1950s. By means of Image Processing and Desktop Mapping Software (ERDAS-IMAGINE), classified grid-based information of the depth to the groundwater table was gathered from differently coloured polygons of the scanned original map sheets. This offered the opportunity to close the gap in basic data related to the unsaturated zone, which impeded more realistic subsurface nitrogen transport calculations before. For the Czech part, information of the groundwater depth was finally not required (see below).

- A **Hydrogeological map** of Europe from the *National Institute of Public Health and the Environment (RIVM)* was used for the differentiation of solid and unconsolidated rocks within the catchment areas (Map 3.8). In total, 87 % of the Odra catchment and 100 % of the catchments directly entering the Odra Haff belong to the unconsolidated rock region. – For subsurface N transport calculations, additional information of the extent of the unconsolidated rock region was obtained from the geological/geomorphological map 1:1 Million of Quaternary formations (LIEDTKE 1969 – Map 2.1). The maximum stadial during the Saale glaciation has been assumed to be the border between unconsolidated and solid rocks. In the Czech part, the unconsolidated rock portion is very small (limited to the Odra valley itself) and has been omitted. From the hydrogeological map 1:200,000 of Poland (*Polish Geological Institute, PIG*), groundwater contour lines have been digitised, supplemented by groundwater levels from several hundreds observation points (*IMGW*), surface water levels in gauging stations, as well as water table and surface elevations in the vicinity of selected waterways. The hydraulic conductivity of the Polish aquifers was digitised based on a hydrogeological map 1:500,000. The same groundwater-related information was available for the German part from the hydrogeological map 1:50,000 (HYKA 50). The hydrogeological themes are presented in Maps 3.9 and 3.10.

- As **hydrometeorological** input data (Map 3.11 and 3.12), the interpolated distributions of corrected **precipitation** as well as **potential evapotranspiration** (Penman) were obtained from long-term meteorological data as described in Phase II.

- Results on **atmospheric deposition** of nitrogen oxides and ammonium with a resolution of 50 km for 1996 from the EMEP programme of the *Norwegian Meteorological Institute* (*DNMI*) were used for calculating the total nitrogen deposition in the investigated area (Map 3.13).

- Results on **atmospheric deposition** of cadmium and lead with a resolution of 50 km for 1999 from the EMEP MSC-East Moscow (http://www.msceast.org/EMEP.html) were used for calculating the total cadmium and lead deposition in the investigated area (Map 3.14 and Map 3.15).

- The borders of the **administrative areas** (municipalities, districts, regions, and countries) in Poland, the Czech Republic, and Germany are available for the year 1999 from "Maps and data professional sets – Europe" (MACON 2000) (Map 3.16).

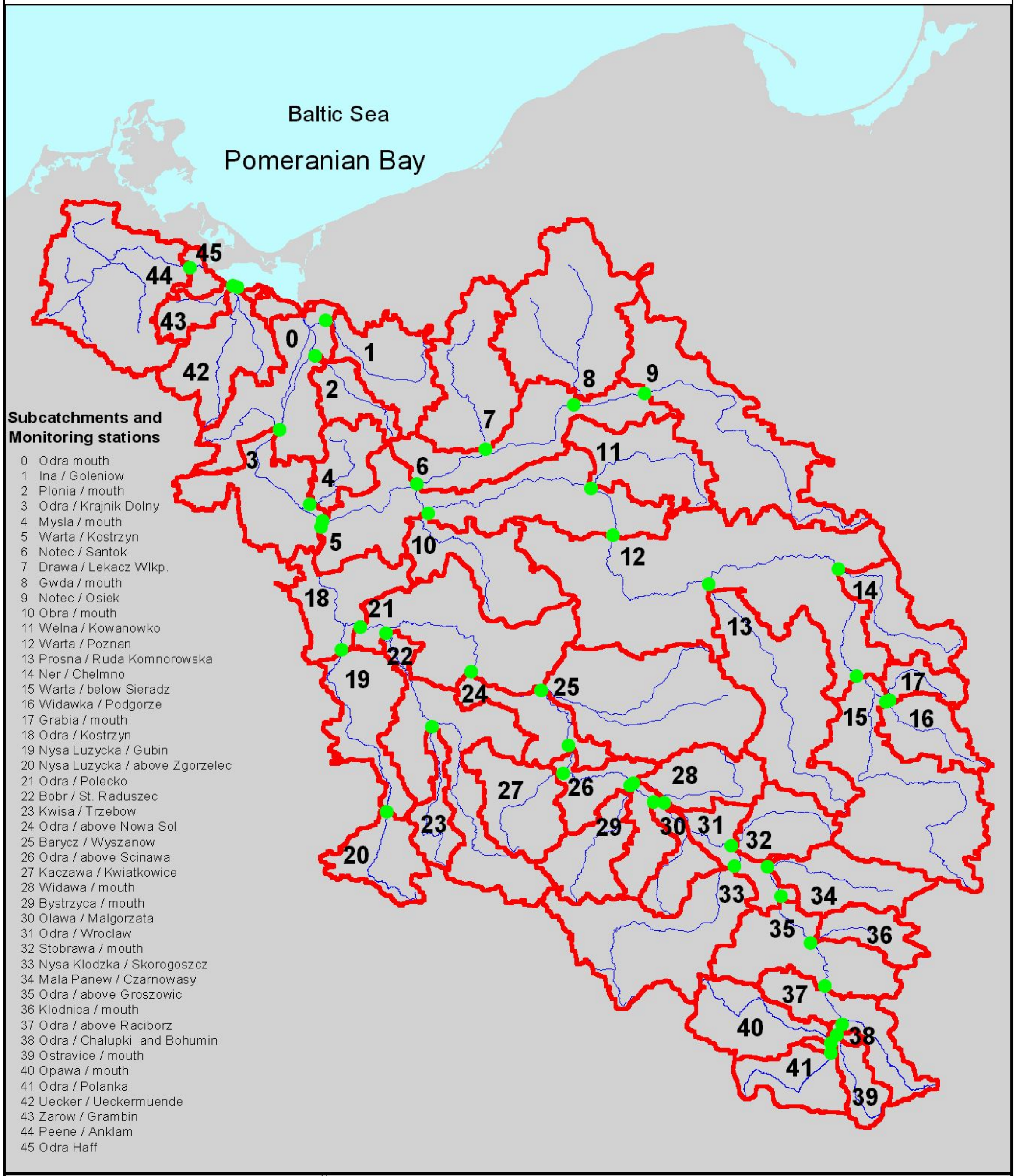
Table 3.1: Selected catchments, total catchment area, percentage of total catchment area in the different countries, and area of the sub catchments.

River	**Station**	**Short name**	**Area**				
			Catchment	**Czech Rep.**	**Germany**	**Poland**	**Subcatchment**
			km²	**%**			**km²**
Odra	Polanka	Odra-Pola	1,569.8	100.0			1,569.8
Opava	Mouth	Opava	2,091.2	93.0		7.0	2,091.2
Ostravice	Mouth	Ostravice	824.3	100.0			824.3
Odra	Chałupki	Odra-Chal	4,666.0	96.8		3.2	180.7
Odra	above Raciborz	Odra-Raci	6,684.0	78.2		21.8	2,018.0
Kłodnica	Mouth	Kłodnica	1,084.8			100.0	1,084.8
Odra	above Groszowic	Odra-Gros	10,989.0	51.1		48.9	3,220.2
Mala Panew	Czarnowasy	Mala Panew	2,122.5			100.0	2,122.5
Nysa Kłodzka	Skorogoszcz	Nysa Kłod	4,514.5	19.4		80.6	4,514.5
Stobrawa	Mouth	Stobrawa	1,601.2			100.0	1,601.2
Odra	Wrocław	Odra-Wroc	20,397.0	31.5		68.5	1,169.8
Oława	Małgorzata	Oława	1,167.4			100.0	1,167.4
Bystrzyca	Mouth	Bystrzyca	1,760.0			100.0	1,760.0
Widawa	Mouth	Widawa	1,716.1			100.0	1,716.1
Kaczawa	Kwiatkowice	Kaczawa	2,261.3			100.0	2,261.3
Odra	above Scinawa	Odra-Scin	29,584.0	21.7		78.3	2,282.2
Barycz	Wyszanow	Barycz	5,534.5			100.0	5,534.5
Odra	above Nowa Sól	Odra-Nowa	36,780.0	17.5		82.5	1,661.5
Kwisa	Trzebów	Kwisa	1,026.3	2.7		97.3	1,026.3
Bóbr	St. Raduszec	Bóbr	5,869.4	0.7		99.3	5,869.4
Odra	Połecko	Odra-Połe	47,152.0	13.7		86.3	3,476.3
Nysa Łużycka	above Zgorzelec	Ny Łu-Zgor	1,609.2	47.8	31.1	21.1	1,609.2
Nysa Łużycka	Gubin	Ny Łu-Gubi	3,973.6	19.2	26.1	54.7	2,364.4
Odra	Kostrzyń	Odra-Kost	53,532.0	13.5	3.8	82.7	2,406.0
Grabia	Mouth	Grabia	813.4			100.0	813.4
Widawka	Podgorze	Widawka	2,354.5			100.0	2,354.5
Warta	below Sieradz	Warta-Sier	8,139.6			100.0	5,785.1
Ner	Chełmno	Ner	1,866.5			100.0	1,866.5
Prosna	Ruda Komnorowska	Prosna	4,825.0			100.0	4,825.0
Warta	Poznań	Warta-Pozn	25,911.0			100.0	11,079.9
Welna	Kowanowko	Welna	2,621.1			100.0	2,621.1
Obra	Mouth	Obra	2,757.7			100.0	2,757.7
Noteć	Osiek	Noteć-Osie	5,508.0			100.0	5,508.0
Gwda	Mouth	Gwda	4,942.8			100.0	4,942.8
Drawa	Łekacz Wlkp.	Drawa	3,296.4			100.0	3,296.4
Noteć	Santok	Noteć-Sant	17,330.0			100.0	3,582.8
Warta	Kostrzyń	Warta-Kost	54,518.2			100.0	5,898.4
Mysła	Mouth	Mysła	1,334.0			100.0	1,334.0
Odra	Krajnik Dolny	Odra-Kraj	110,074.0	6.5	3.7	89.9	689.8
Płonia	Mouth	Płonia	1,101.0			100.0	1,101.0
Ina	Goleniów	Ina	2,162.7			100.0	2,162.7
Odra	Mouth	Odra-Mout	118,861.0	6.1	4.7	89.2	5,523.3
Peene	Anklam	Peene	5,110.0		100.0		5,110.0
Zarow	Grambin	Zarow	748.0		100.0		748.0
Uecker	Ueckermünde	Uecker	2,401.0		99.4	0.6	2,401.0
Odra Haff		Odra Haff	8,885.1		97.5	2.5	626.1

Table 3.2: Land use distribution in the investigated catchments.

Short name	Urban area	Arable land	Grassland	Forest	Water	Exploitation area	Open land	Wetlands
	%							
Odra-Pola	7.6	48.4	1.4	26.2	0.5	0.2	4.4	0.0
Opava	4.9	42.4	2.5	34.0	0.2	0.1	4.0	0.0
Ostravice	12.0	19.5	0.1	44.4	0.8	0.8	3.0	0.0
Odra-Chal	8.2	39.7	1.6	32.4	0.4	0.3	3.8	0.0
Odra-Raci	8.7	42.9	1.8	27.6	0.5	0.4	2.9	0.0
Kłodnica	21.5	37.9	4.4	23.8	1.0	1.5	2.0	0.0
Odra-Gros	9.9	44.5	3.1	26.9	0.6	0.5	2.3	0.0
Mala Pa-	4.9	25.6	7.5	50.5	1.0	0.2	1.8	0.1
Nysa Kłod	3.5	46.5	5.1	31.3	0.8	0.2	2.1	0.1
Stobrawa	2.4	38.5	8.8	43.8	0.5	0.0	1.7	0.0
Odra-Wroc	7.0	42.8	4.9	31.9	0.7	0.4	2.0	0.1
Oława	4.4	73.3	5.8	9.6	0.1	0.2	0.1	0.0
Bystrzyca	6.7	60.4	3.4	19.5	0.4	0.2	0.1	0.1
Widawa	2.7	60.3	10.0	21.4	0.1	0.0	0.4	0.0
Kaczawa	2.8	57.1	5.6	24.0	0.7	0.2	1.5	0.0
Odra-Scin	6.3	49.3	5.1	27.6	0.6	0.3	1.6	0.1
Barycz	2.7	52.8	11.0	28.5	1.3	0.0	0.1	0.1
Odra-Nowa	5.6	50.1	6.1	27.7	0.8	0.3	1.3	0.1
Kwisa	1.2	39.2	4.7	31.0	0.2	0.4	10.0	0.0
Bóbr	2.4	34.4	6.2	41.3	0.5	0.3	5.1	0.6
Odra-Pole	4.9	47.0	6.5	31.1	0.8	0.3	1.6	0.1
Ny Łu-	11.5	40.2	2.2	29.0	0.2	2.7	4.0	0.0
Ny Łu-	6.7	33.0	4.7	44.1	0.3	1.3	4.0	0.0
Odra-Kost	5.1	45.0	6.3	33.2	0.8	0.3	1.8	0.1
Grabia	2.7	44.0	10.5	22.6	0.1	0.1	0.1	0.0
Widawka	2.8	39.7	13.7	25.2	0.3	1.4	0.9	0.3
Warta-Sier	3.7	39.7	11.3	27.4	0.2	0.5	0.5	0.3
Ner	8.5	53.3	9.8	13.5	0.2	0.1	0.1	0.7
Prosna	2.7	59.7	8.1	19.9	0.1	0.0	0.1	0.1
Warta-	3.7	53.9	9.5	20.5	0.5	0.4	0.3	0.3
Welna	1.9	66.1	5.1	21.5	1.7	0.0	0.0	0.0
Obra	1.4	39.9	10.2	41.3	1.6	0.0	0.1	0.3
Noteć-Osie	1.7	62.2	7.7	17.8	2.3	0.2	0.2	0.7
Gwda	1.5	38.8	5.2	46.7	2.6	0.1	2.2	0.1
Drawa	1.2	29.0	4.9	54.4	3.8	0.0	2.6	0.1
Noteć-Sant	1.4	42.9	8.6	38.4	2.4	0.1	1.3	0.3
Warta-Kost	2.7	49.0	8.9	29.4	1.3	0.2	0.7	0.3
Mysła	1.7	46.8	7.8	36.5	2.2	0.0	0.0	0.2
Odra-Kraj	4.0	47.0	7.6	31.4	1.1	0.3	1.2	0.2
Płonia	2.6	59.8	11.0	14.0	5.1	0.0	0.8	0.0
Ina	2.2	57.7	8.5	23.6	1.4	0.1	0.4	0.1
Odra-Mout	4.0	47.1	7.7	31.1	1.2	0.3	1.2	0.3
Peene	5.9	51.9	17.1	20.5	2.1	0.1	0.1	0.4
Zarow	5.8	42.2	23.3	25.7	1.2	0.1	0.0	0.4
Uecker	5.7	48.9	13.9	24.5	3.2	0.0	1.5	0.7
Odra Haff	5.7	47.8	17.1	23.9	2.4	0.1	0.5	0.7

Investigated Catchments and Monitoring Stations



Subcatchments and Monitoring stations

0	Odra mouth
1	Ina / Goleniow
2	Plonia / mouth
3	Odra / Krajnik Dolny
4	Mysla / mouth
5	Warta / Kostrzyn
6	Notec / Santok
7	Drawa / Lekacz Wlkp.
8	Gwda / mouth
9	Notec / Osiek
10	Obra / mouth
11	Welna / Kowanowko
12	Warta / Poznan
13	Prosna / Ruda Komnorowska
14	Ner / Chelmno
15	Warta / below Sieradz
16	Widawka / Podgorze
17	Grabia / mouth
18	Odra / Kostrzyn
19	Nysa Luzycka / Gubin
20	Nysa Luzycka / above Zgorzelec
21	Odra / Polecko
22	Bobr / St. Raduszec
23	Kwisa / Trzebow
24	Odra / above Nowa Sol
25	Barycz / Wyszanow
26	Odra / above Scinawa
27	Kaczawa / Kwiatkowice
28	Widawa / mouth
29	Bystrzyca / mouth
30	Olawa / Malgorzata
31	Odra / Wroclaw
32	Stobrawa / mouth
33	Nysa Klodzka / Skorogoszcz
34	Mala Panew / Czarnowasy
35	Odra / above Groszowic
36	Klodnica / mouth
37	Odra / above Raciborz
38	Odra / Chalupki and Bohumin
39	Ostravice / mouth
40	Opawa / mouth
41	Odra / Polanka
42	Uecker / Ueckermuende
43	Zarow / Grambin
44	Peene / Anklam
45	Odra Haff

Legend:

● Station
— River
— Catchment border

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Funded by the German Federal Environmental Agency

Data Sources:
Atlas Hydrologiczny Polski
Hydrographisches Kartenwerk der DDR
Topographic Maps of the Czech Republic

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Kilometers
0 25 50 75 100

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
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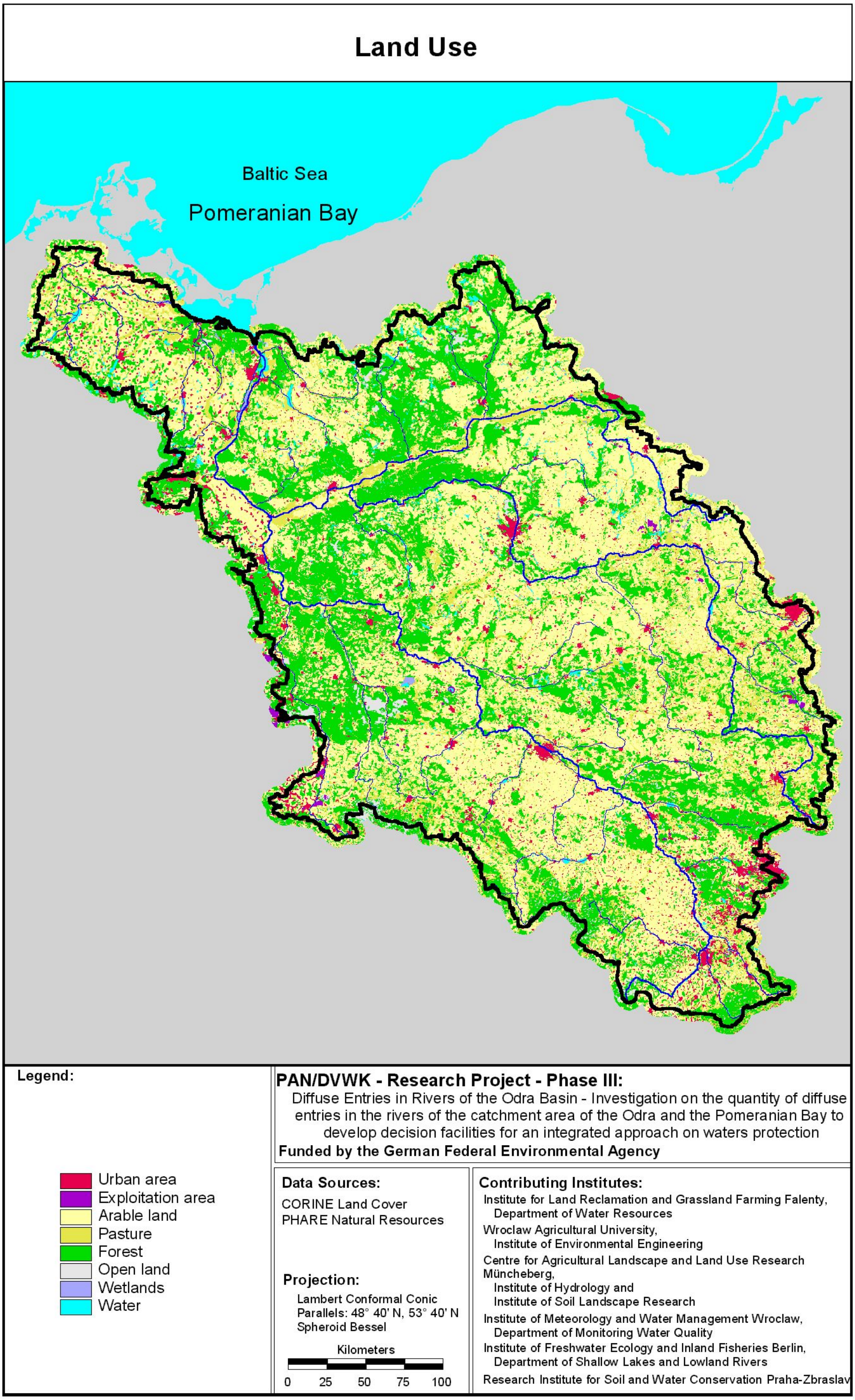
Map 3.1: *Investigated catchments and monitoring stations.*



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Funded by the German Federal Environmental Agency

Data Sources:

CORINE Land Cover
PHARE Natural Resources

Projection:

Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:

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Institute of Hydrology and
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Institute of Meteorology and Water Management Wroclaw,
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Institute of Freshwater Ecology and Inland Fisheries Berlin,
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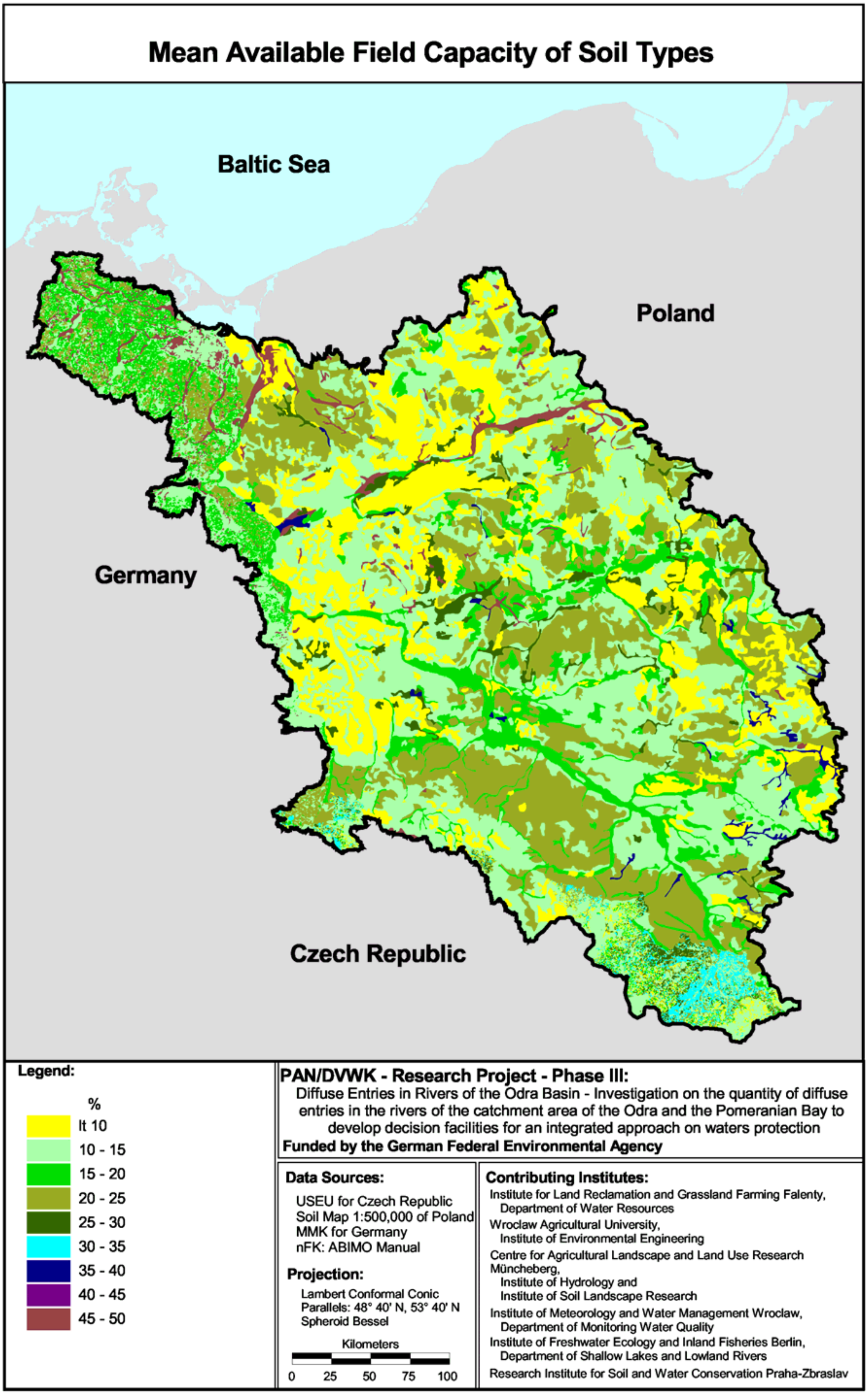
Map 3.2: Land use.



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Funded by the German Federal Environmental Agency

Data Sources:

USEU for Czech Republic
Soil Map 1:500,000 of Poland
MMK for Germany
nFK: ABIMO Manual

Projection:

Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty,
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Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
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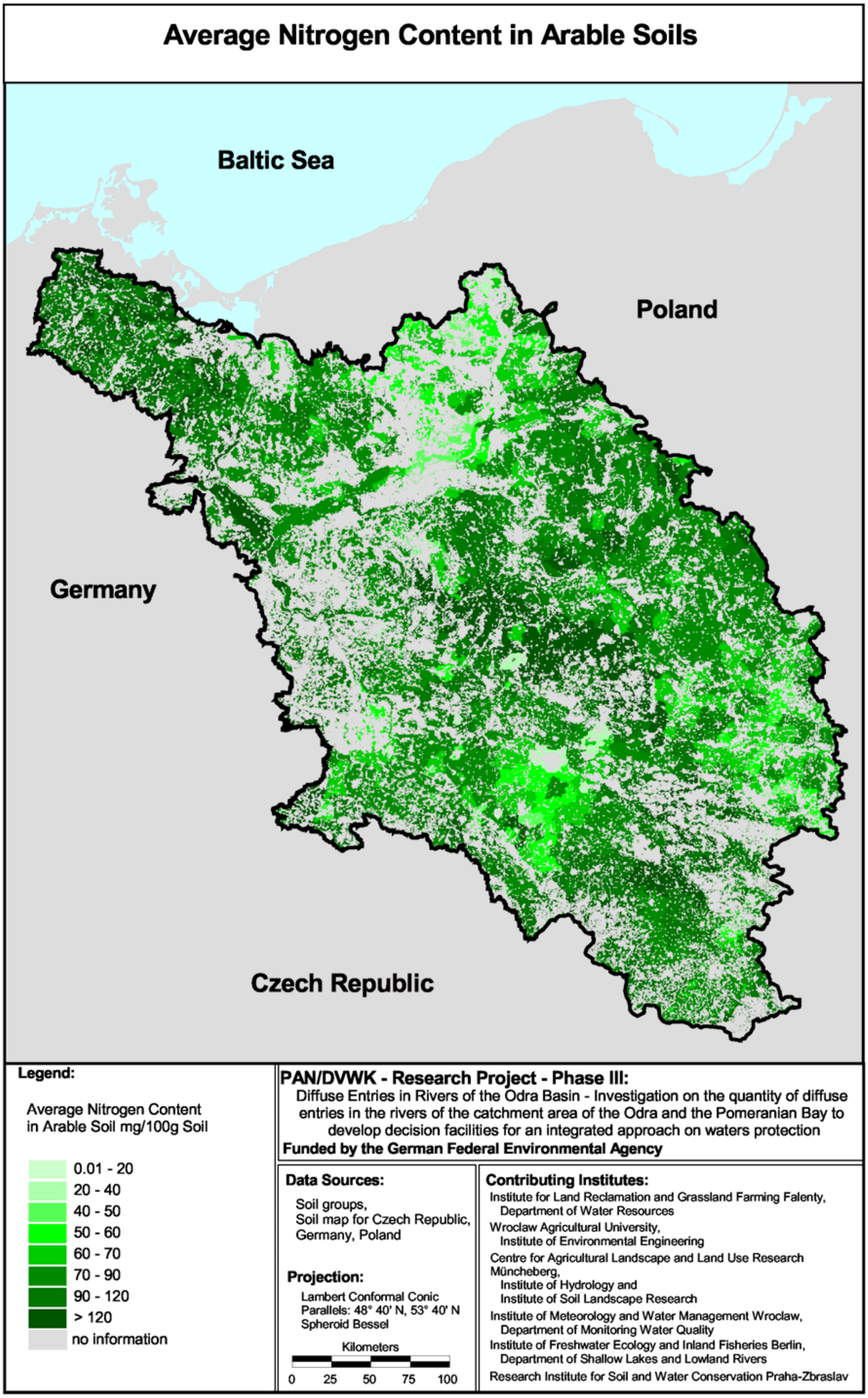
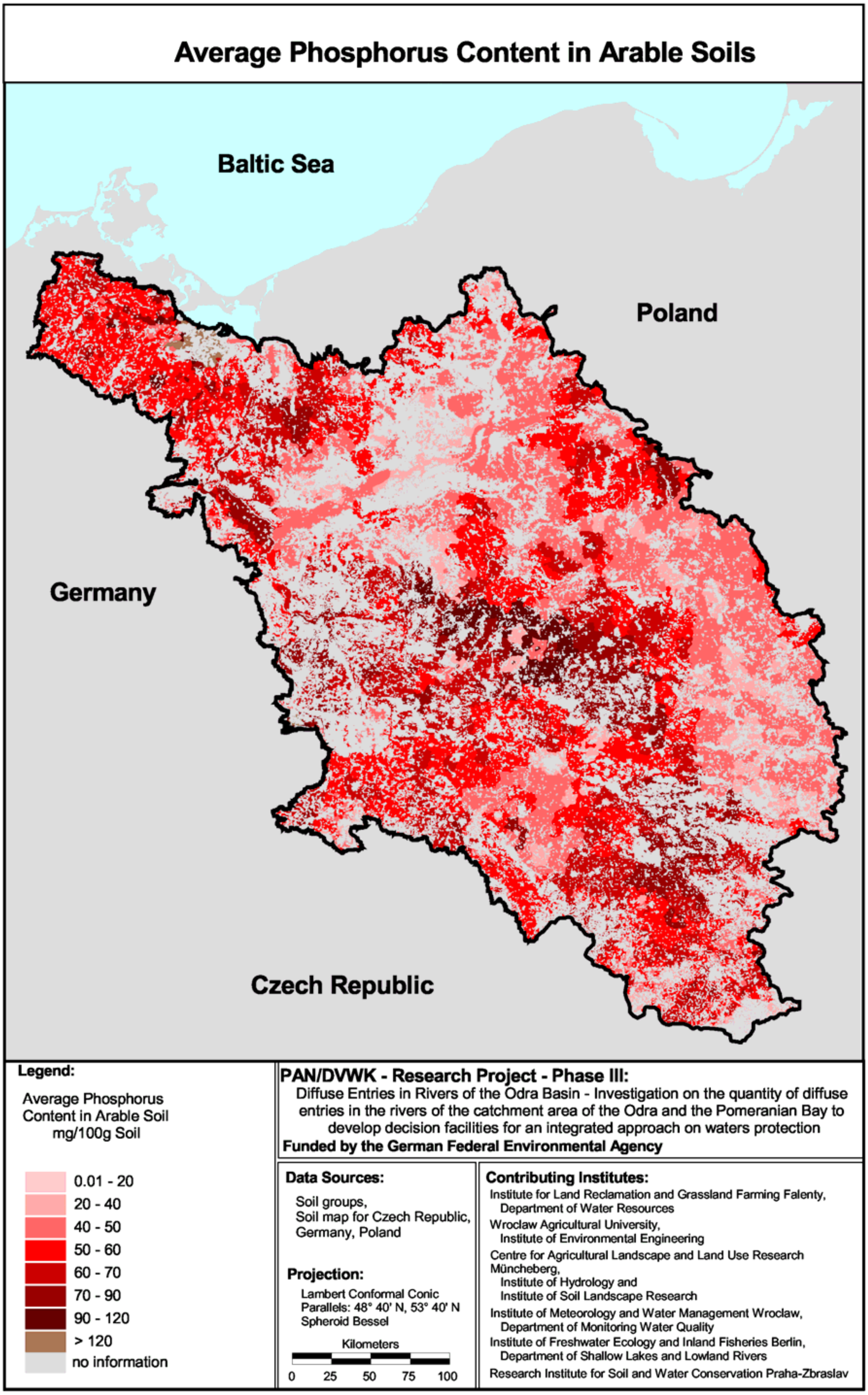
Map 3.3: Soils.



Map 3.4: Topsoil N content.



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Data Sources:
Soil groups,
Soil map for Czech Republic, Germany, Poland

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
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Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
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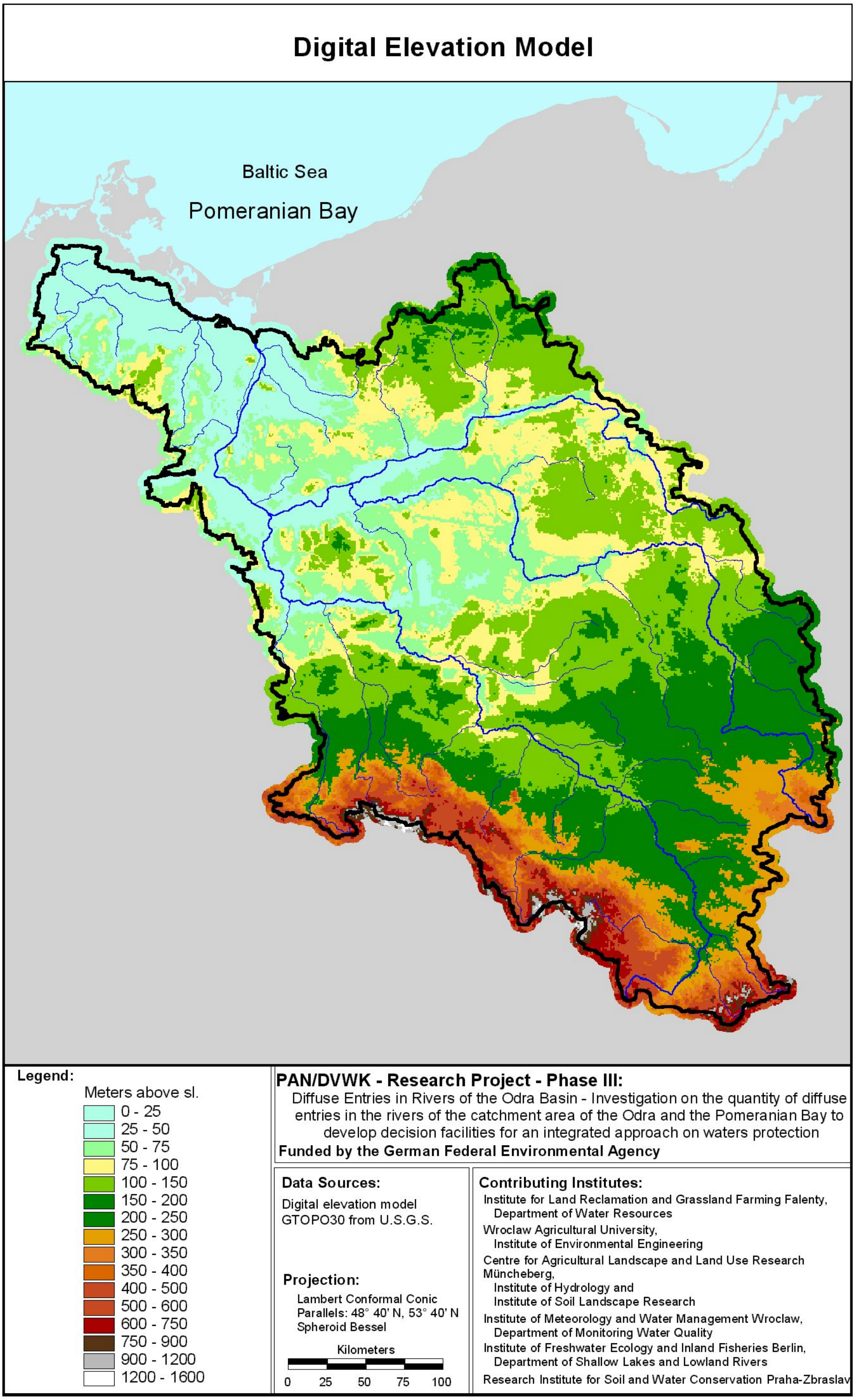
Map 3.5: Topsoil P content.



PAN/DVWK - Research Project - Phase III:

Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Data Sources:

Digital elevation model GTOPO30 from U.S.G.S.

Projection:

Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
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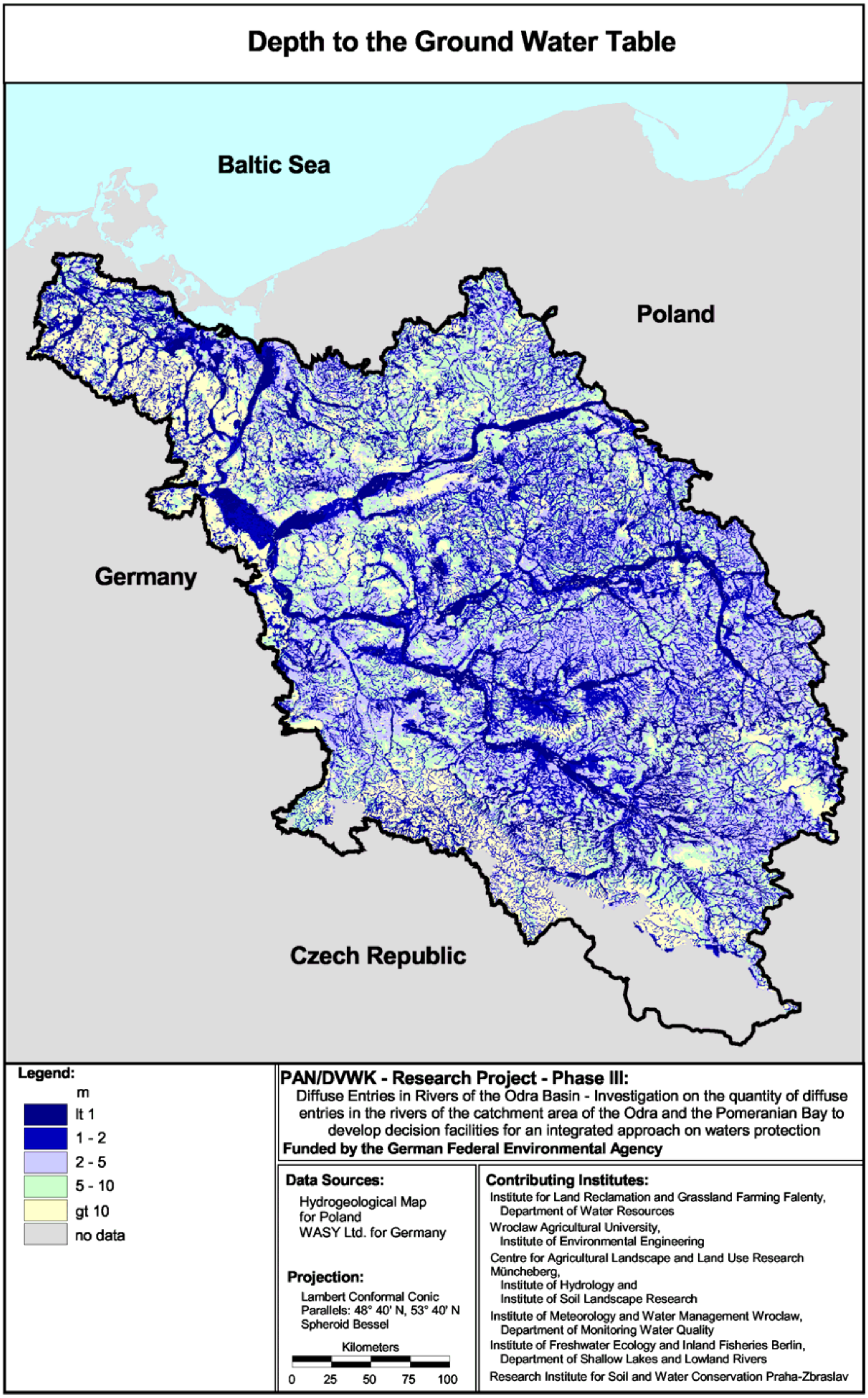
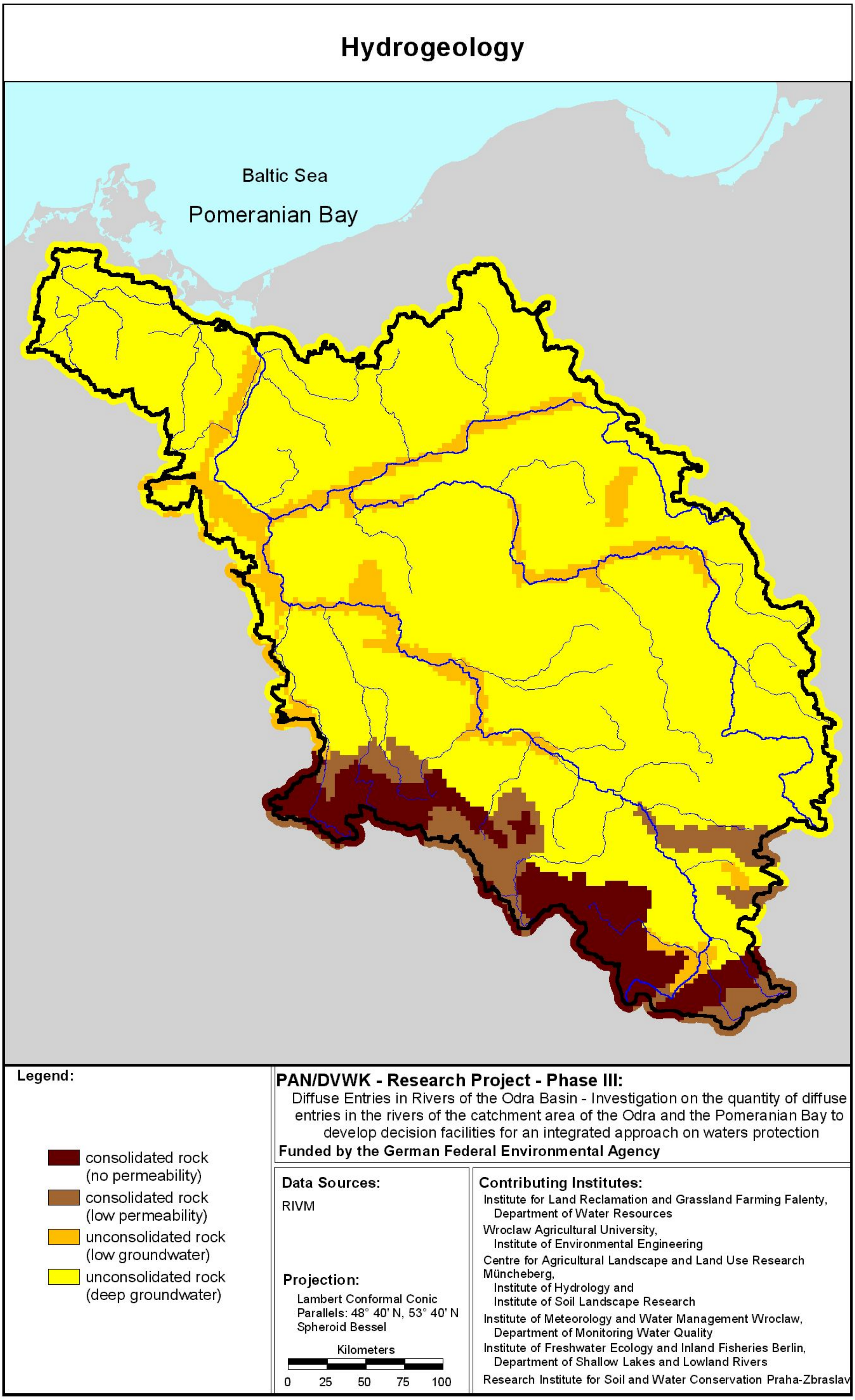
Map 3.6: Digital elevation model (USGS GTOPO30).



Map 3.7: Depth to the groundwater table.



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Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
RIVM

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
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Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
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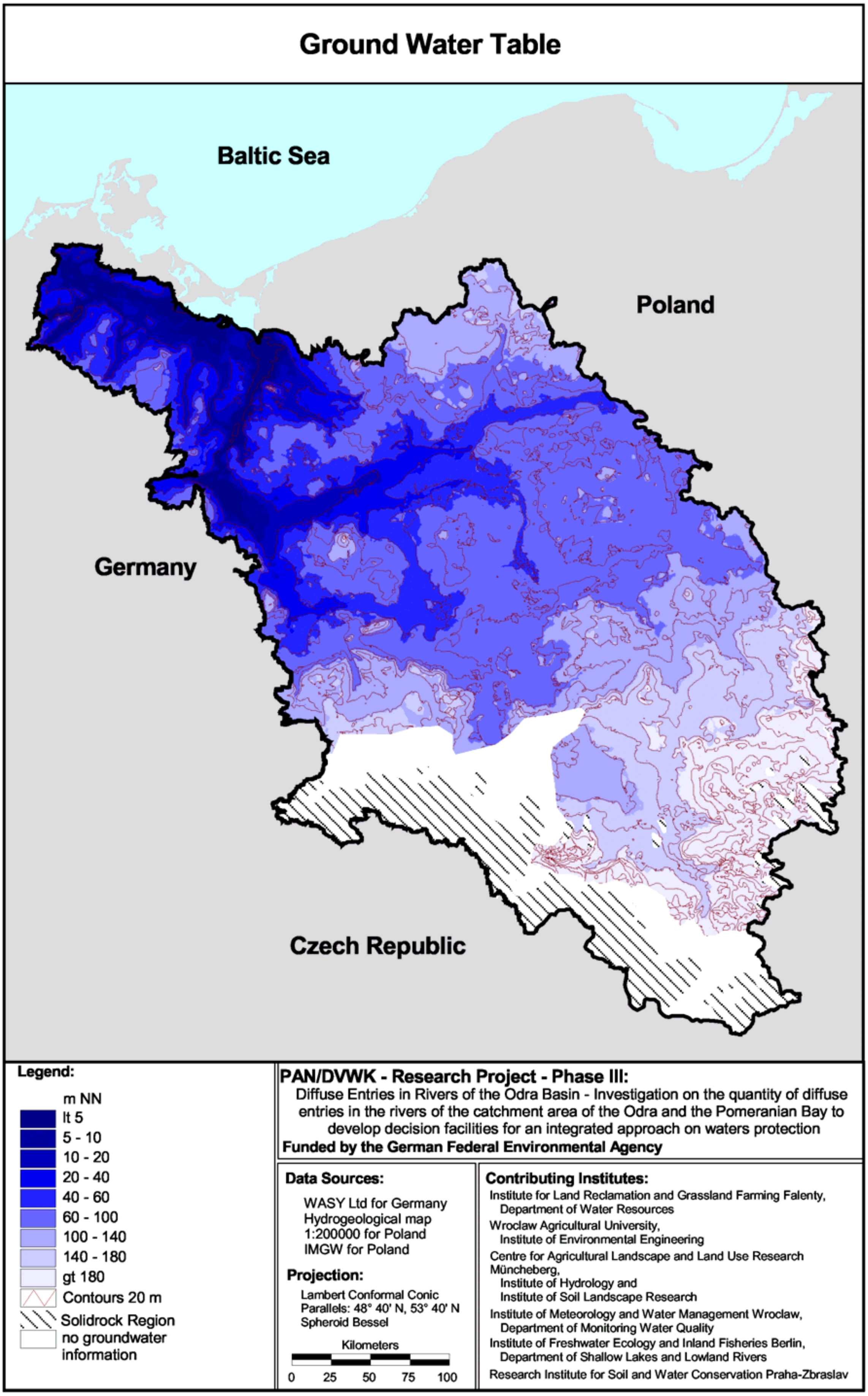
Map 3.8: *Hydrogeological map.*



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Funded by the German Federal Environmental Agency

Data Sources:
WASY Ltd for Germany
Hydrogeological map
1:200000 for Poland
IMGW for Poland

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
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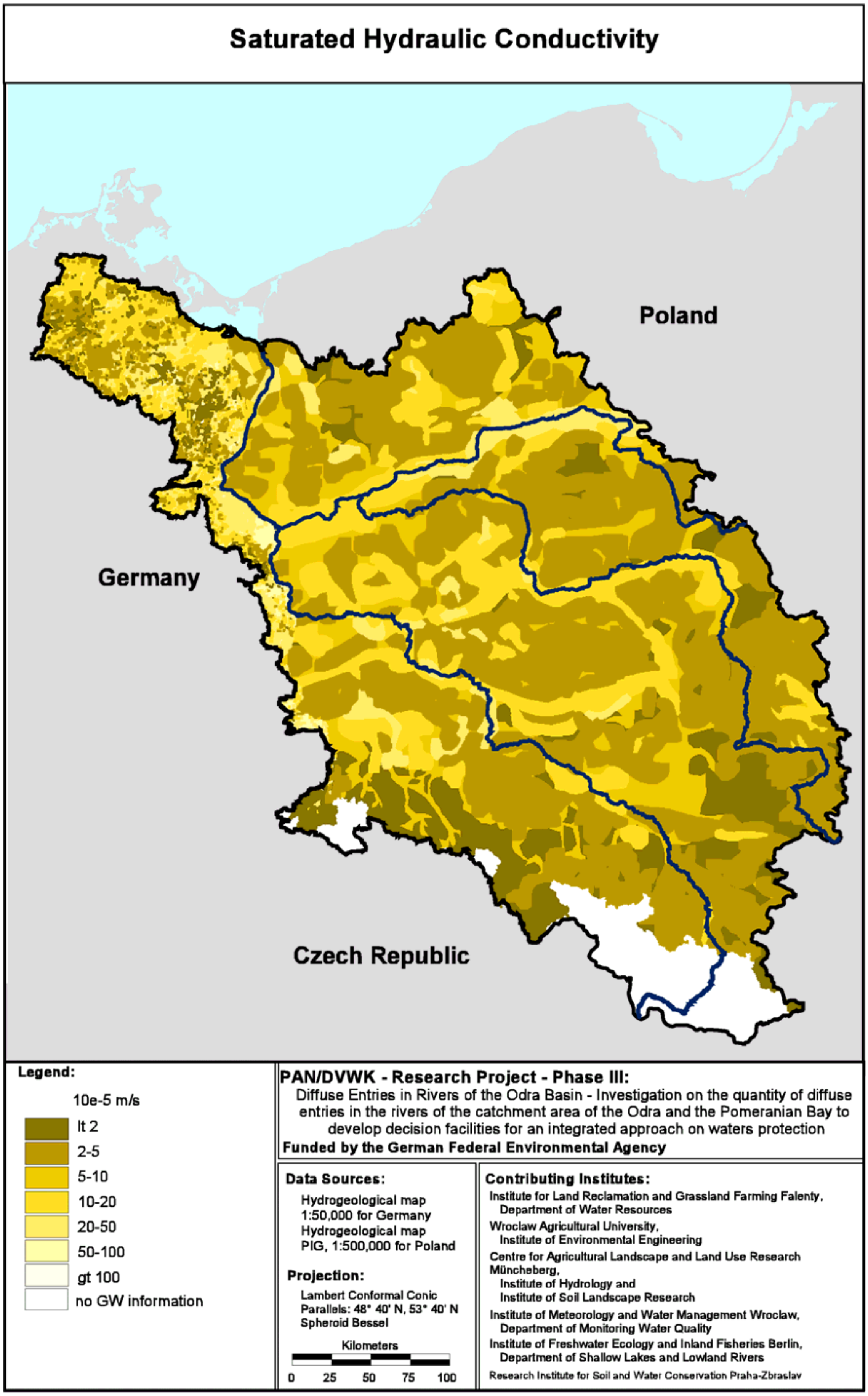
Map 3.9: Groundwater table.



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
Hydrogeological map
1:50,000 for Germany
Hydrogeological map
PIG, 1:500,000 for Poland

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
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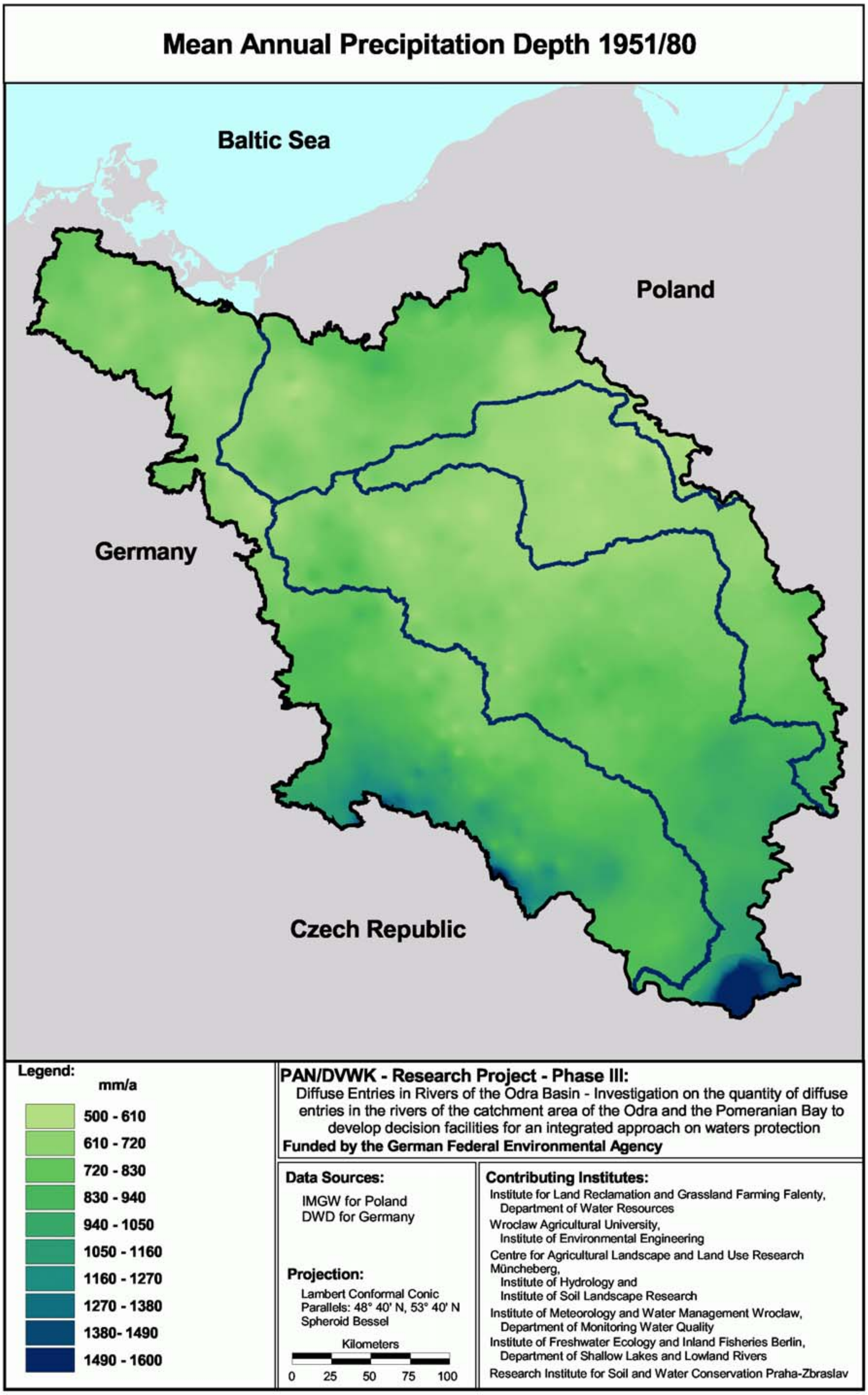
Map 3.10: Hydraulic conductivity (upper groundwater-bearing layer).



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IMGW for Poland
DWD for Germany

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
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Institute of Freshwater Ecology and Inland Fisheries Berlin,
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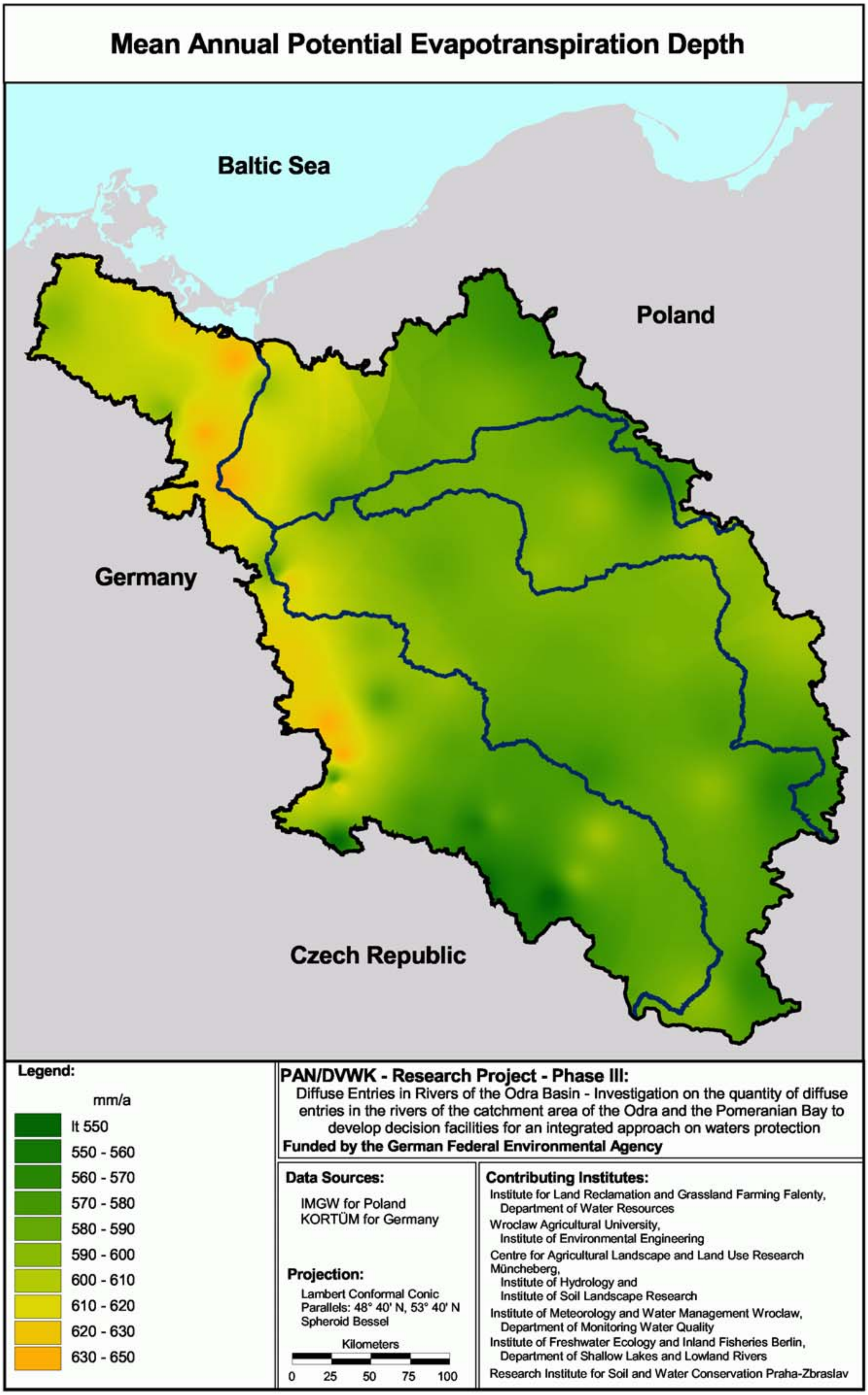
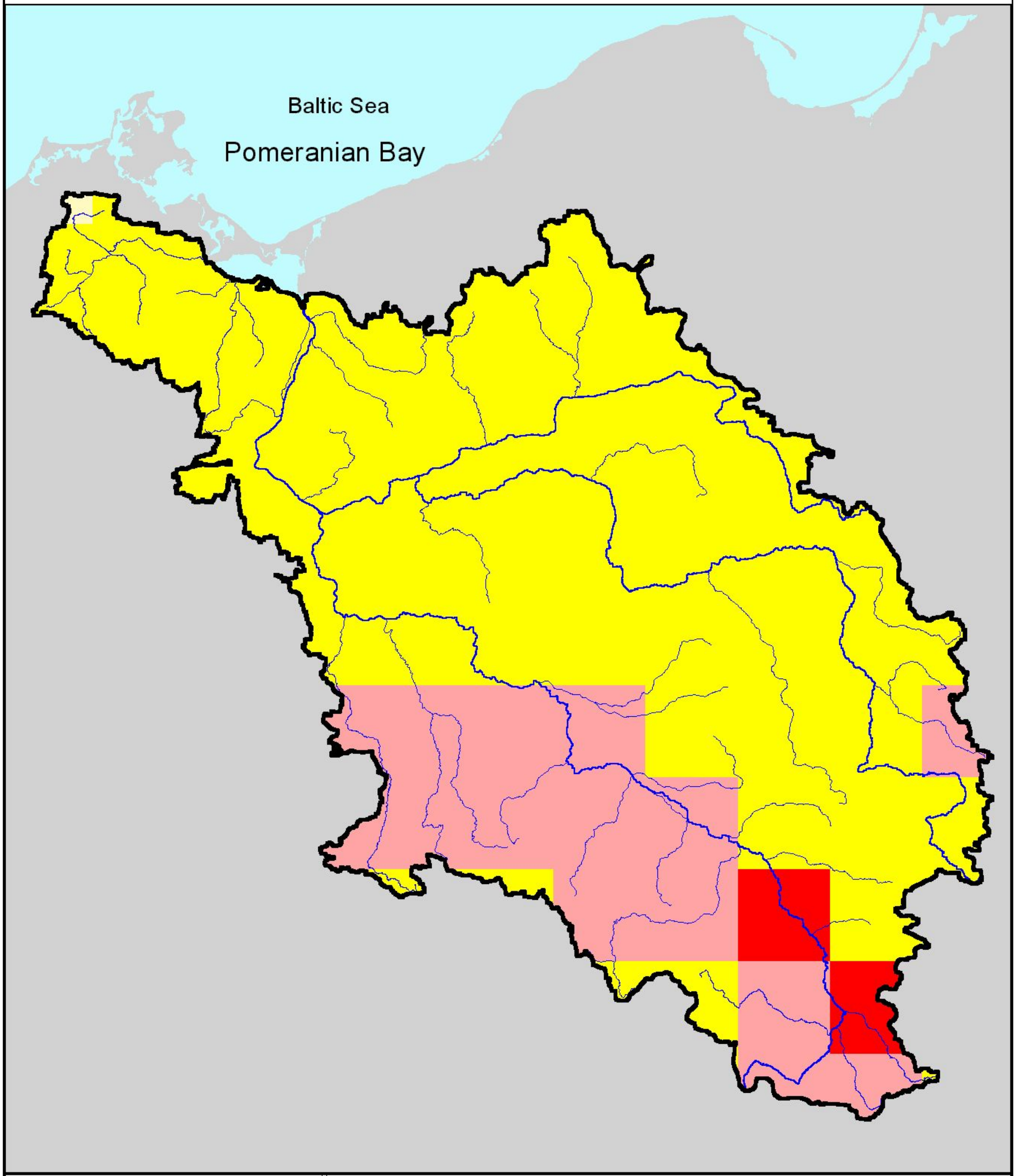
Map 3.11: Long term average of annual precipitation.



Map 3.12: Potential evapotranspiration.

Atmospheric Nitrogen Deposition 1996



Legend:

kg N/ha
- ▢ <10
- 🟨 10-15
- ▨ 15-20
- 🟥 >20

PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Data Sources:
Norwegian Meteorological Institute

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Kilometers
0 25 50 75 100

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
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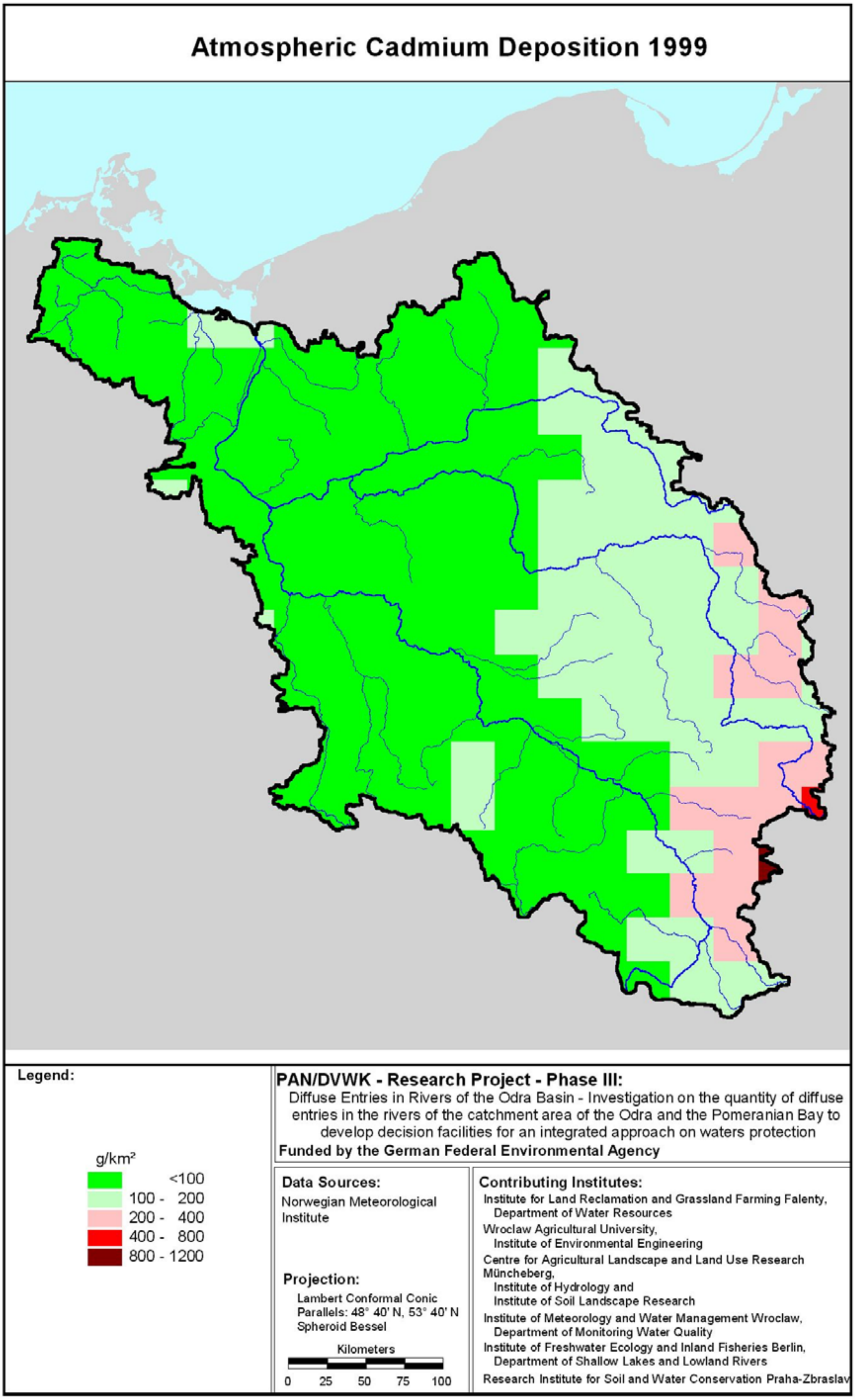
Map 3.13: *Atmospheric nitrogen deposition.*



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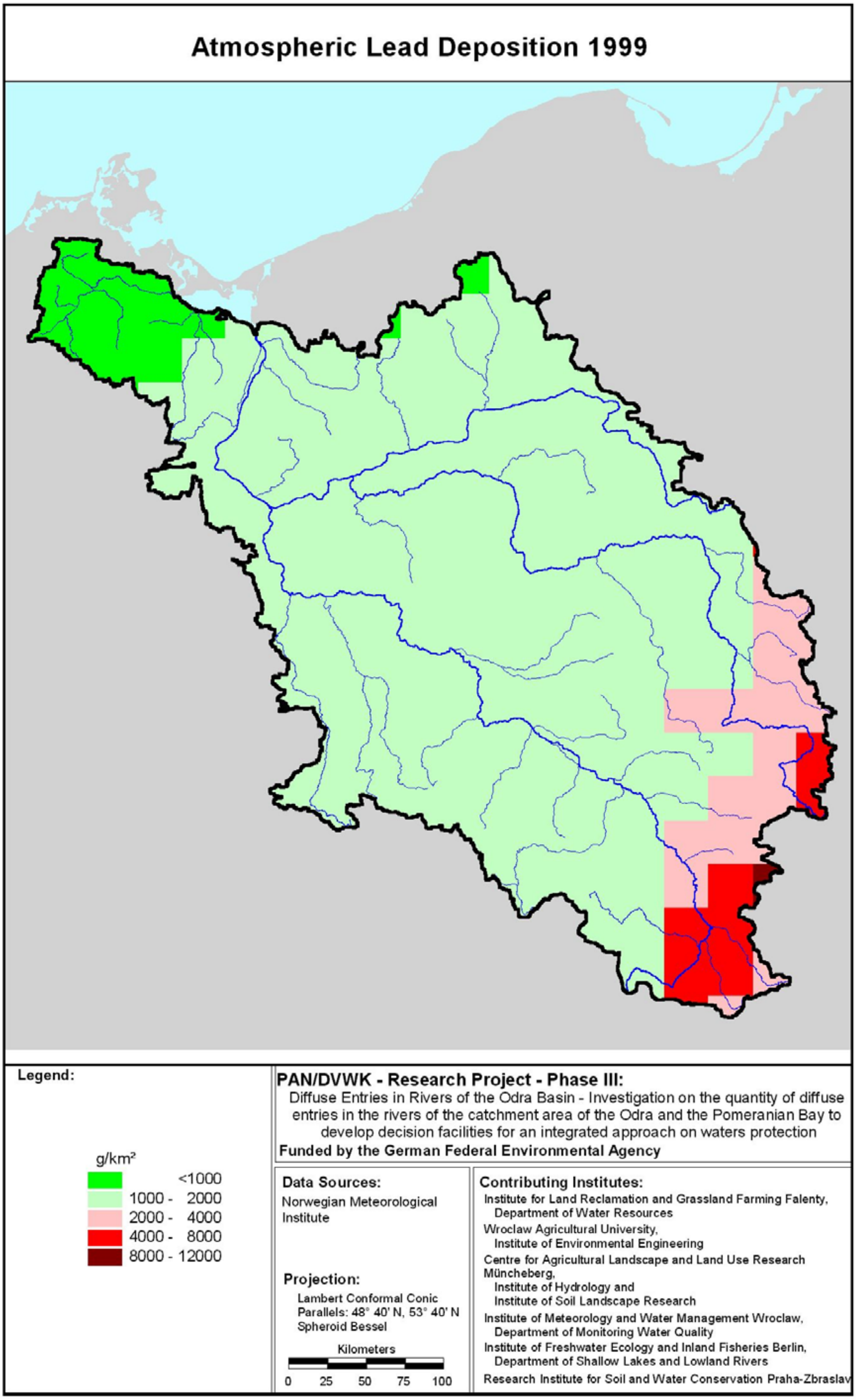
Funded by the German Federal Environmental Agency

Data Sources:
Norwegian Meteorological Institute

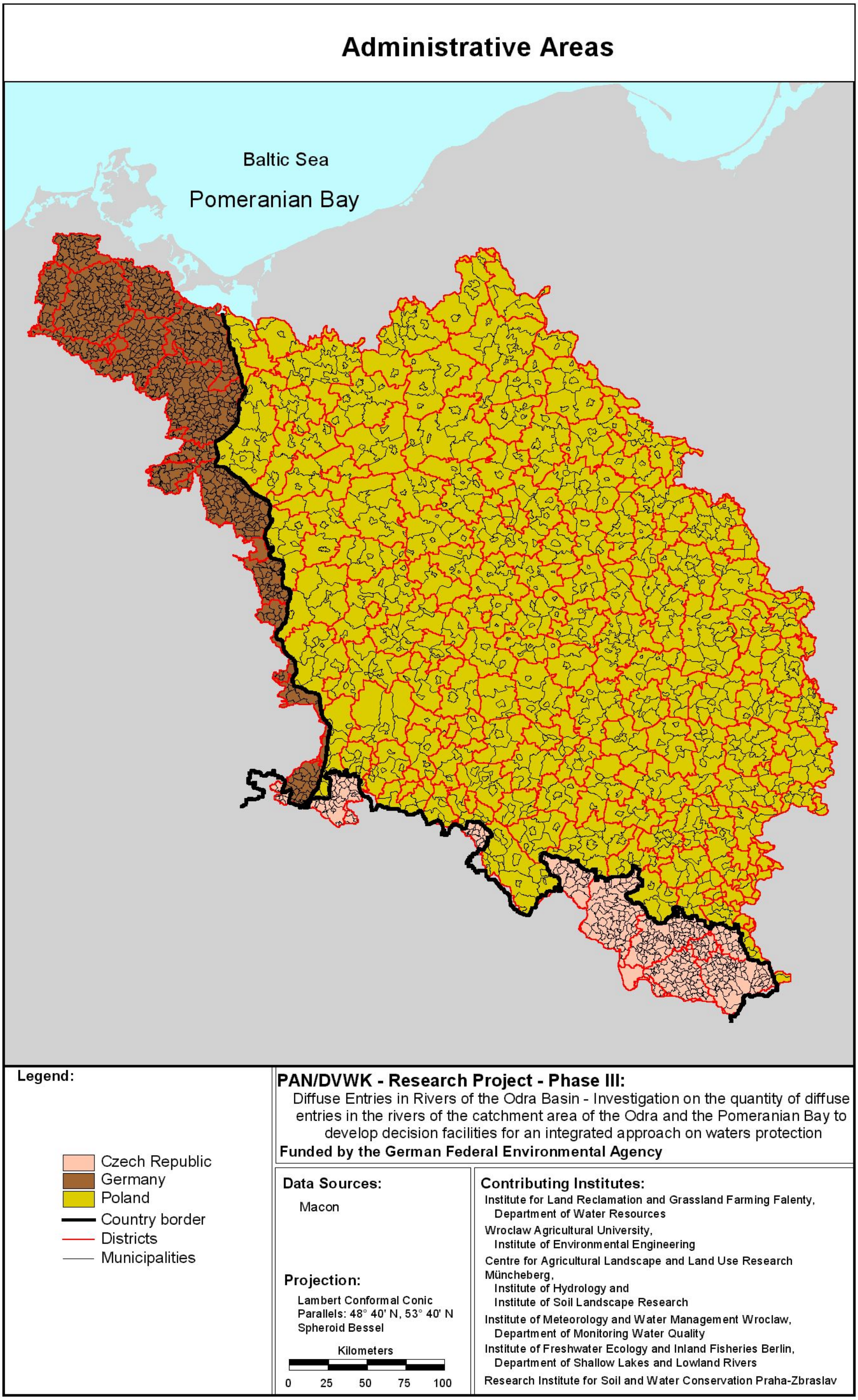
Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 3.14: *Atmospheric cadmium deposition.*



Map 3.15: *Atmospheric lead deposition.*



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Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
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Data Sources:
Macon

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
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Map 3.16: Administrative areas.

Data for calculating point source emissions

Czech Republic

Data for emissions from point sources in the Czech part of the Odra Basin during the years 1996-1997 were supplied by *Povodi Odry*. Data for the whole investigation period, however, are not available. For calculating emissions from municipal sewage treatment plants, data could be used only for the major wastewater treatment plants in the Odra Basin. Table 3.3 presents an overview of the data available.

Table 3.3: Available data for calculating emissions from WWTPs, Czech part of the Odra Basin.

River subbasin	WWTP	Q	N-NH4	N-NO3	N-NO2	TP	Zn	Cd	Cu	Pb
Opava	Opava	X	X	X	X	X	X			
Ostravice	Frýdek-Místek	X	X	X	X	X	X	X	X	X
	Havířov	X	X	X	X	X				
Odra-Chałupki	Ostrava	X	X	X	X	X				
Odra-Racibórz	Třinec	X	X	X	X	X	X	X	X	X
	Karviná	X	X	X	X	X	X	X	X	X
Nysa Łużycka-Zgorzelec	Liberec/Jablonec n.N.	X	X	X		X	X	X	X	X
	Hrádek n.N.	X	X	X						
	Frýdlant v Č.	X	X	X	X	X	X	X	X	X

Emissions of nutrients and heavy metals from industrial sources are available, altogether for 53 sources, aggregated for the different subbasins in t/a for nutrients and in kg/a for heavy metals (Table 3.4).

Table 3.4: Emissions from direct industrial discharges, Czech part of the Odra Basin.

River subbasin	Number of industrial sources	TN	TP	Zn	Cd	Cu	Pb
		t/a		kg/a			
Odra-Polanka	7	15.1	1.6	184.2	56.5	23.7	36.5
Opava	11	15.1	1.4	52.3	9.0	9.5	11.9
Ostravice	12	156.7	15.4	143.4	49.7	20.7	65.4
Odra-Chałupki	8	132.0	0.6	114.9	113.7	177.0	66.9
Odra-Racibórz	4	80.6	1.0				
Nysa Łużycka-Zgorzelec	11	27.0	0.9	428.1	61.3	5.7	33.0

Germany

For emissions from point sources in the German part of the Odra Basin in the period 1993-1997, data collected for the project "Nutrient Emissions into river basins of Germany" (BEHRENDT et al. 2000) were used (Table 3.5). Altogether, 149 municipal sewage treatment plants in the German part of the Odra Basin were considered.

Table 3.5: Emissions from WWTPs, German part of the Odra Basin.

River subbasin	Number of WWTPs	TN	TP
		t/year	
Nysa Łużycka-Zgorzelec	19	143.7	7.9
Nysa Łużycka-Gubin	10	376.8	40.9
Odra-Kostrzyn	11	790.8	93.4
Odra-Krajnik	18	240.4	26.5
Odra-mouth	12	87.5	8.1
Peene	43	585.6	27.6
Zarow	2	16.2	2.2
Uecker	33	153.6	15.2
Odra Haff	1	48.0	1.5

Data on nutrient emissions from direct industrial discharges in the German part of the Odra Basin are not available.

Table 3.6: Substances concentration in the mining water.

Substance	Concentration in mg/l
TP	0.062
NH4-N	0.76
Cd	<0.005
Cu	<0.02
Pb	<0.05
Zn	0.007

For emissions from coal mining in the German part of the Odra Basin, some data were supplied by the Landesumweltamt Brandenburg. From sewage treatment plants for mining waters, on average in the period 1993-1997, 0.356 m^3/s were emitted into the subcatchment Nysa Łużycka-Gubin. The concentrations for nutrients and heavy metals are available for the year 1997 only, originating from the self-monitoring of the mining industry (Table 3.6). The values were used for calculating the emissions from coal mining. If the measured concentrations were below the detection limit, half of the detection limit was used for calculation.

Poland

Waste water treatment plants and direct industrial discharges

The point sources database was established by the Wrocław Branch of the *Institute of Meteorology and Water Management* in 1992-1994 to provide information about municipal and industrial wastewater treatment plants. The data stored there originate primarily from "Prefeasibility Study of the Odra River Basin" (BCEOM) and have been verified on the basis of relevant data published by the National Statistical Office:

- results from point source monitoring, partly included into the Multipurpose Informatic System of Water Management, developed by the Katowice Branch of *IMGW*,

- yearly assessment of environmental conditions at the voivodship level (publication available through Environmental Monitoring Library), and
- information provided by District Inspectorates for Water Management.

Characteristic values are

- the daily volume of wastewater discharge,
- the equivalent number of inhabitants,
- the loads of Total Nitrogen and Total Phosphorus in untreated wastewater,
- Total Nitrogen and Total Phosphorus loads in treated wastewater.

The database does not go beyond December 1997 and includes 1,526 point sources. As an example, Table 3.7 shows the point source database for theriver Kłodnica.

Table 3.7: Characterisation of point sources in the Kłodnica subbasin.

No	Monitoring point	River (receiver)	Equivalent number of in-habitants	Total nitrogen	Total phosphorus
				in treated wastewater in kg/day	
1	Szkoła, Sławięcice	Kłodnica, Odra	64	0.6	0.1
2	Gliwice	Kanał Gliw., Odra	91	0.8	0.2
3	Huta Łab. Gliwice	Kanał Gliw., Odra	95	0.9	0.2
4	Ujazd	Kłodnica, Odra	189	1.7	0.4
5	Toszek	Kłodnica, Odra	8,437	76.5	17.2
6	Ruda Śląska	Kłodnica, Odra	12,863	149.6	29.6
7	Bytom	Bytomka,Kłodnica, Odra	22,700	205.8	46.2
8	Pyskowice	Kłodnica, Odra	24,100	218.5	49.0
9	Ruda Śląska	Kłodnica, Odra	33,293	301.8	67.8
10	Mikołów	Kłodnica, Odra	49,032	444.5	99.8
11	Katowice	Kłodnica, Odra	58,000	520.0	45.0
12	Kędzierzyn-Koźle	Kłodnica, Odra	70,000	480.0	38.0
13	Gliwice	Kanał Gliw., Odra	122,050	1,106.5	248.4
14	Zabrze	Bytomka, Kłodnica, Odra	266,000	1,000.0	128.0
15	Bytom	Bytomka, Kłodnica, Odra	354,903	3,217.6	722.3

Data on fish farming

For 13 fish farming enterprises within the Polish part of the Odra Basin, data on the surface water area and the amount of production were available. This small database was used for calculating the nutrient emissions by fish farming. From fish farms in the Czech or German part of the Odra Basin no data could be obtained.

Monitoring data

Surface water

The **water quality** database for the Polish stations comprises over 45,000 concentration and discharge values in the period 1993-1997, established during investigations carried out by the *National Environmental Monitoring System*, by the *District Inspectorate for Environmental Pollution Control*, and by the *Institute of Meteorology and Water Management*. Water quality data for the Odra River Basin were collected under three Polish programs – the Bench-Mark Monitoring Program (BMMP), the Basic Monitoring Program (BMP), and the Regional Monitoring Program (RMP). The BMMP sites (Chałupki, Wrocław, Krajnik, Gubin and Poznań) were monitored once a week, whereas the BMP and RMP sites were monitored twice a month and once a month, respectively, throughout the period of investigation. The data under analysis come from 37 sampling points (covered by the national or regional network). Of these, 9 are situated on the Odra River and 28 on the tributaries of the Odra.

Investigated pollutants which were determined according to Polish Standards are Ammonia (NH_4), Nitrite as Nitrogen (NO_2), Nitrate as Nitrogen (NO_3), Total Nitrogen (TN), Phosphates (PO_4), Total Phosphorus (TP), Zinc (Zn), Cadmium (Cd), Copper (Cu), Lead (Pb).

For the 3 Czech stations data on water quality were provided by *Povodi Odry* in Ostrava. The data were monitored once a month (nutrients) and bimonthly (heavy metals).

For the river basins in Germany the monitoring data for the 3 stations were supplied from the *State Office for Environment, Nature Conservation and Geology Mecklenburg-Vorpommern*. The nutrient concentrations were measured biweekly. The heavy metal concentrations are available for the Peene and Uecker rivers only and were measured irregularly.

Map 3.1 shows the location of the monitoring sites and the division into sub-basins.

The mean annual **water flow** data of the analysed Polish cross-sections were obtained from the *Institute of Meteorology and Water Management* in Poland (partly unpublished) and for the Czech stations from *Povodi Odry*. For the German stations, the daily discharge measurements were provided by the *State Office for Environment, Nature Conservation and Geology Mecklenburg-Vorpommern*.

Groundwater

Czech Republic

Data of 11 groundwater sampling points for the period 1993-1997 from the monitoring program of the *Czech Hydrometeorological Institute* (*CHMU*) were available. The investigated pollutants are Nitrate, Nitrite, Ammonium, Phosphate, Total Iron, Zinc, and Copper.

Germany

The database consists of data on 60 sampling points within or not more than 50 km apart from the Odra catchment collected by the *State Environmental Offices of Brandenburg, Mecklenburg-Vorpommern* and *Sachsen*. For the period 1993-1995, data on Nitrate, Nitrite and SRP concentration are available.

Poland

The database consists of 400 values from 31 sampling points near the Odra river covered by the *National Groundwater Monitoring Network*. The sources from which relevant data have been drawn are the results obtained by the *National Geological Institute* (PRZYTUŁA 1997). The investigated pollutants in the period 1993-1994 are Ammonia, Nitrite as Nitrogen, Nitrate as Nitrogen, Phosphates, Zinc, Cadmium, Copper, and Lead.

Atmospheric Deposition

A database of 14 stations in the Polish part of the Odra basin with wet deposition values collected by the Wrocław Branch of the *IMGW* (TWAROWSKI 1998, TWAROWSKI 2000) and of 8 stations from the monitoring program of the *CHMU* in the Czech part was available. For the Polish stations, values for Phosphorus, Copper, Zinc, Lead, and Cadmium in the period October 1998 to September 1999 and for the Czech stations of Lead and Cadmium in the period 1993-1997 were used for interpolation.

For nitrogen deposition, a map (Map 3.13.) of the *Norwegian Meteorological Institute (DNMI)* was used (see Chapter 3.1).

Precipitation

Czech Republic

Data on monthly precipitation in the period 1993-1997 for 24 gauging stations in the Czech Republic were supplied from the *CHMU* in Prague, furthermore taken from the STATISTICAL YEARBOOKS OF THE CZECH REPUBLIC (1994-1998).

Germany

For the period 1993-1997 data on monthly precipitation from the *German Weather Service (DWD)* for 55 stations in or close to the German part of the Odra Basin were used.

Poland

The database includes measured precipitation values from 69 stations of the *IMGW* monitoring program located throughout the Odra Basin in the period 1993-1997. Averages of the winter and summer half-years were used for interpolation.

Statistical data

Administrative data

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

Czech Republic

Data on population, connection to the sewage system and to wastewater treatment plants were available on the basis of regions only.

Germany

Data on population, land use, cultivation, and livestock numbers for municipalities or districts for the year 1995 were available in tabular form. Data were supplied by the State Statistical Offices.

Poland

The database provides information about land use, population, and the number of users of the sewerage system in the municipalities. Datasets have been established on the basis of bulletins issued by relevant District Statistical Offices.

Information was collected about

- type of community (typical town, village, or town-village)
- area of community,
- number of inhabitants,
- area of agricultural land subdivided into arable land and pasture,
- area of forest,
- discharge of sewage and
- number of people in town using the sewer system.

Agricultural data

The top soil **nutrient surplus** at the agricultural area for the German part of the Odra Basin has been taken for 1995 from BACH et al. (1998) and for the period 1950-1995 from BEHRENDT et al. (2000). For the Czech part, the nutrient surplus was calculated for 1995 on a district basis and for 1950-1995 on a country basis according to the OECD methodology (OECD 1997) by the *Research Institute of Plant Production (VURV)*. The nutrient surplus for the Polish part was calculated by the AR Wroclaw group within the project from statistical data at the level of municipalities.

The area of **drained lands** within the Odra catchment in the Czech Republic was supplied from the database of drainage systems of the *State Administration of Land Reclamation and Improvement (SMS)* in Prague at the level of the fourth-order catchments. For the German part it was taken from BEHRENDT et al. (2000). For Poland, information of the drained lands on the basis of gmina areas is available (STELMACH et al. 1990, GUS yearbooks).

For Poland the **nitrogen content in the top soil** was already estimated during Phase II of the project (DVWK 1999). The nitrogen content in the top soil for Germany is available within the German soil map 1:1 Million (BÜK 1000). For the Czech part, 33 values of the nitrogen content in the topsoil were available from measurements by *VUMOP* in the 1960s and 1970s, accessible from the Comprehensive Soil Survey database. Measurements of the C-content in the soil from the same database supplied for 280 sampling sites are used for calculating the nitrogen content (Chapter 4.1.2.4).

Data on sewer systems in urban areas

Czech Republic

From *Povodi Odry*, data on the sewage systems in 11 Czech towns located in the Odra basin were provided. The data included the kind and length of the sewage net, the number of connected people and the percentage of people connected. The values are related to the year 1994. For the towns in the sub-basin Nysa Łużycka, the length of the sewers is not available. The aggregated values for the investigated sub-basins are shown in Table 3.8. In all the towns analysed, a combined sewer system is used.

Table 3.8: Available data on the sewage systems in the towns in the Czech part of the Odra Basin.

River subbasin	**Kind of sewage system**	**Length**	**Number of connected people**	
		km	**people**	**%**
Opava	Combined	139.00	54,827	94.9
Ostravice	Combined	248.90	151,355	96.2
Odra-Chałupki	Combined	715.50	324,362	92.9
Odra-Racibórz	Combined	159.00	98,220	87.0
Nysa Łużycka-Zgorzelec	Combined	no data	117,140	72.1

Poland

IMGW collected data on the sewage systems for 35 Polish towns in the Odra Basin. These data include the number of inhabitants and the length of the combined and separate sewer systems (Table 3.9).

Table 3.9: Data on sewer systems for some Polish towns.

Town	Number of inhabitants	Total length of sewage system in km		
		Combined sewage system	Storm sewer	Sanitary sewer
Wrocław	625,121	411.0	51.0	332.0
Poznań	563,489	159.4	367.0	461.0
Szczecin	406,165	226.8	164.9	164.2
Częstochowa	256,016	355.4	0.0	0.0
Wałbrzych	138,638	0.0	47.0	100.9
Opole	125,550	30.9	150.0	102.6
Gorzów Wielkp.	125,017	0.0	131.0	134.5
Zielona Góra	115,255	102	0.0	57.7
Kalisz	106,970	44.6	54.3	70.0
Jelenia Góra	93,865	57.4	60.7	84.7
Konin	83,819	0.0	108.9	112.5
Ostrów Wlkp.	74,757	0.0	82.4	119.4
Leszno	61,801	0.0	52.1	68.8
Zduńska Wola	46,119	5.4	32.0	97.9
Sieradz	45,525	5.9	31.3	45.4
Bolesławiec	44,796	82.4	7.0	8.2
Zgorzelec	36,756	3.3	9.0	53.7
Turek	31,004	0.0	35.0	21.2
Jarocin	26,061	0.0	22.2	48.8
Lubań	24,639	16.6	27.1	35.4
Koło	24,258	0.0	23.3	37.5
Rawicz	21,702	0.0	10.0	44.1
Gostyń	20,940	0.0	74.9	35.1
Kępno	15,082	7.7	6.2	29.4
Słupca	14,909	0.0	41.0	24.0
Kłobuck	14,047	18.4	0.0	0.0
Poczesna	12,325	6.3	0.0	0.0
Blachownia	10,191	22.1	0.0	0.0
Kłodawa	7,291	0.0	17	12.0
Śmigiel	5,399	2.4	0.0	0.0
Zawidów	4,883	12.3	2.5	8.3
Warta	3,642	0.0	5.5	4.2
Węgliniec	3,434	4.0	0.0	1.0
Złoczew	3,349	0.0	4.6	3.8
Stawiszyn	1,568	1.5	0.0	0.0

Germany

For Germany, data on sewer systems and connected inhabitants at the level of three star code for the river basins of the *State Water Working Group* (*LAWA*) from the State Statistical Offices were used and aggregated for the German part of the investigated sub-basins.

4. Methodology

4.1 Nutrient Emissions

The GIS oriented Model MONERIS (**MO**deling **N**utrient **E**missions in **RI**ver **S**ystems) was developed for the estimation of nutrient inputs by various point and diffuse sources into the German river basins larger than 1000 km² for the periods 1983 to 1987 and 1993 to 1997 (BEHRENDT et al. 2000). Within this project this model was applied to 42 sub-basins of the Odra river and 4 sub-basins of German rivers directly discharging into the Odra Haff. The estimations were done for the period 1993 to 1997.

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

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

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

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

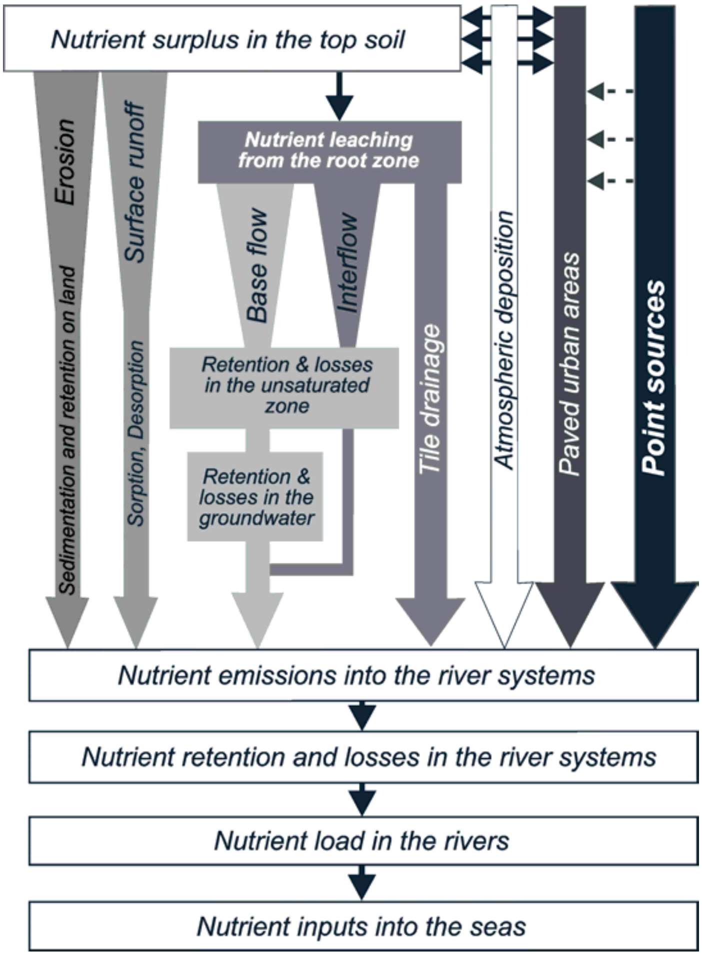


Figure **4.1:** Pathways and processes in MONERIS.

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

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

The use of a Geographical Information System gives the possibility for a regionalized estimation of nutrient inputs. The estimations were done with the same methodology for 46 different river basins. The calculation was done for the time period 1993 to 1997.

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

4.1.1 Nutrient Emissions from Point Sources

4.1.1.1 Municipal sewage treatment plants and direct industrial discharges

Czech Republic

The loads from the known wastewater treatment plants were calculated as the product of the mean nutrient concentration and the mean discharge in the years 1996 and 1997. Because of the fact that only the concentration of the inorganic nitrogen is given and the emissions of total nitrogen have to be calculated a mean value of 2.5 mg N/l is used for the concentration of organic nitrogen.

$$EWW_N = a \cdot Q_{WW} \cdot (CWW_{DIN} + CWW_{NORG}) \quad (4.1)$$

with EWW_N = nitrogen emission from wastewater treatment plants [t/a],
a = unit conversion factor,
Q_{WW} = water discharge of the wastewater treatment plant [m³/s],
CWW_{DIN} = concentration of dissolved inorganic nitrogen in wastewater [mg/l] and
CWW_{NORG} = concentration of organic nitrogen in wastewater [2.5 mg/l]

$$EWW_P = a \cdot Q_{WW} \cdot CWW_P \quad (4.2)$$

with EWW_P = phosphorus emission from wastewater treatment plants [t/a],
a = unit conversion factor and
CWW_P = concentration of phosphorus in wastewater [mg/l]

Detailed data for the emissions from Czech municipal wastewater treatment plants where available for some sources only. Therefore the emissions for the population not connected to the known WWTP's had to be calculated. From the total population in each subbasin, derived from the administrative data the population in the towns for which the emissions where available is subtracted. For the rest of the population the nutrient emissions are calculated with the assumption that about 50% of this population is connected to wastewater treatment plants and that the removal rate in these WWTP's is 30% for phosphorus and 20% for nitrogen. The inhabitant specific outputs of nitrogen and phosphorus used for the calculations are 11 g N/person/day respectively 2.5 g P/person/day (Kovarova, pers. comm.).

$$EWW_N = a \cdot IN_{CON} \cdot EIN_N \cdot RR_N \tag{4.3}$$

with a = unit conversion factor,
IN_{CON} = connected inhabitants,
EIN_N = inhabitant specific nitrogen output [11 g N/(inh.·day)] and
RR_N = nitrogen removal rate [20%]

$$EWW_P = a \cdot IN_{CON} \cdot EIN_P \cdot RR_P \tag{4.4}$$

with a = unit conversion factor,
IN_{CON} = connected inhabitants,
EIN_P = inhabitant specific phosphorus output [2.5 g N/(inh..·day)] and
RR_P = phosphorus removal rate [30%]

Germany

The regionalized estimation of nutrient inputs from municipal wastewater treatment plants (WWTP's) is based GIS-supported inventory. It comprises the following information:

- rate of utilisation (RU),
- treated population equivalents (TPE),
- treated population equivalents (inhabitants) (TPE_{IN}),
- treated population equivalents (indirect industrial discharges) (TPE_{IID}).

The yearly quantity of treated water is separated into domestic wastewater (QD), industrial and commercial wastewater (QCOM), external water (QEX), urban wastewater (QU), storm wastewater (QST) and total wastewater (QTOT). The N- and P-emissions of a WWTP were estimated based on different methods for each plant depending on the available data of this plant. For all WWTP's the emissions could be estimated on

Table 4.1: N-removal performance for various types of treatment plants (see Behrendt et al., 2000).

Plant type	N-removal
Wastewater pond (unaerated)	50%
Wastewater pond (aerated)	30%
Activated sludge plant	30%
Mechanical treatment	10%
Submerged trickling filter/Percolating filter	25%
Treatment using plants	45%
Nitrification	45%

the basis of inhabitant specific nutrient emissions and the treatment efficiency for different types of wastewater treatment (see Table 4.1). The inhabitant specific N-emission was 11 g N/d. According to the investigations of SCHMOLL (1998) it was assumed that the specific P-emission was 1.8 g P/d. For nitrogen it was further assumed that the emission of indirect industrial discharges was 6.5 g N/(d PEI).

The population, which is connected to a WWTP, was estimated depending on the size of the WWTP according to the sewage statistics for the rivers.

Poland

Nutrient loads entering the watercourse from point sources were specified according to the available information. Thus, for pollution sources with determined nitrogen and phosphorus content in the effluents, nutrient emission was calculated in terms of the product of concentration multiplied by discharge volume; for the other pollution sources (both municipal and industrial), calculations of nutrient emission were carried out in terms of equivalent parameters (PRZEWŁOCKI et al. 1995).

For point sources where BOD of raw sewage alone had been measured, Total Nitrogen and Total Phosphorus were established in terms of the formula derived to describe the conditions encountered in Poland, with respect to the equivalent number of inhabitants (1 inhabitant-60 g BOD/day). Hence, the unit load of phosphorus becomes

$$P_{tot} = -0.2532 \cdot Ln(IN_{CON}) + 3.2632 \tag{4.5}$$

with P_{tot} = unit phosphorus load [g P/(inh.·day)]

the unit load of nitrogen becomes

$$N_{tot} = -0.9266 \cdot Ln(IN_{CON}) + 15.95 \tag{4.6}$$

with N_{tot} = unit load of nitrogen [g N/(inh·day)]

For the investigated towns where sewage had not been analyzed for its composition, nutrient emission was calculated in terms of the discharged wastewater volumes included in relevant yearbooks of the National Statistical Office, as well as in terms of the parameter values determined during investigations of the effluents from the wastewater treatment plants of 115 municipalities (Table 4.2).

The decrease of nutrient emissions according to the wastewater treatment method applied was calculated on the basis of empirical data (Table 4.4).

Point sources were inventoried in each of the investigated sub-basins. The data sets provide information about the volume of wastewater discharge, Total Nitrogen and Total Phosphorus load (Table 4.4). Analyses of these data show that in the period of 1993 to 1997 new wastewater treatment plants were constructed and those under operation were retrofitted. This resulted in a decrease of nutrient emissions from point sources in the investigated sub basins.

Table 4.2: Parameters of municipal sewage pollution for two differently populated towns.

Parameter	**Unit**	**Average concentration**	**Average standard deviation**	**Average concentration**	**Average standard deviation**
		Towns with ≤15 000 inhabitants		**towns with ~170 000 inhabitants**	
BOD	mg O_2/l	228	74	225	91
COD	mg O_2/l	459	145	528	170
TN	mg N/l	49	14.3	41	24
TP	mg P/l	9.7	3.4	7.4	2.7
SS	mg /l	236	80	249	100

Table 4.3: Efficiencies of Total Nitrogen and Total Phosphorus removal related to treatment method.

Method of treatment	**Decrease of nutrient emission**	
	Total Nitrogen	**Total Phosphorus**
Mechanical	10%	10%
Biological	30%	20%
Chemical	30%	20%

4.1.1.2 Nutrient Emissions from Fish Farming

The nutrient emissions from fish farms are calculated according to the HELCOM recommendation “Quantification of nutrient discharges/losses from aquaculture plants” (HELCOM 1999). Because only the production of the Polish fish farms and no data about the food are available, the values for the content of nitrogen and phosphorus in the dry feed and in the produced organisms given by HELCOM (1999) are used (Table 4.4). For the feed conversion ratio a standard value of 1.2 is used (HELCOM 1999). The following formula is used for calculation:

$$EFI_{N,P} = 0.01 \cdot (PF \cdot 1.2 \cdot CNF_{N,P} - PF \cdot CNO_{N,P}) \qquad (4.7)$$

with EFIN,P = nutrient emissions from fish farms [t/a],
CNFN,P = content of nutrients in feed [%],
PF = production [t/a] and
CNON,P = content of nutrients in organisms [%].

Table 4.4: Nutrient contents in dry feed and fish

	TP content [%]	**TN content [%]**
Dry feed	1.20	7.5
Fish	0.45	3.0

4.1.2 Nutrient Emissions from Diffuse Sources

4.1.2.1 Nutrient Balances

Germany

Nutrient balances for nitrogen and phosphorus in the former GDR/the new German states were made up as part of an UBA project for the year 1989/90 (DANNOWSKI & FRITSCHE 1992). The spatial distribution of N surplus as calculated within that project was based on statistical data stored in a special database (LBW), which annually had been assembled directly from plant production farms. 159 farms with a mean agricultural area of 4,967 ha were situated in the present study region (by part at least) and could be evaluated.

Besides the farm data: partial areas of the main crops, mineral fertiliser – in total and related to the main crops –, and yield of the main crops, statistical data at the districts level (livestock numbers) were evaluated to derive the N surplus from organic manure as documented in NOLTE & WERNER (1991). Ammonia volatilisation has been taken into consideration. According to the standard of knowledge at that time, atmospheric deposition + symbiotic N accumulation and denitrification were considered to be equal and left out from the balance calculations. Thus, the balance equation could be established for the farms considered:

$$NU_{sur,F} = NU_{in} - NU_{up} = NU_{D,H,S} - NU_{P} \qquad (4\text{-}1)$$

with $NU_{sur,F}$ – Specific agricultural N surplus at farm level, in kg/ha/a
NU_{in} – Specific agricultural N input, in kg/ha/a
NU_{up} – Specific agricultural N uptake, in kg/ha/a
$NU_{D,H,S}$ – Specific agricultural N input from mineral fertiliser, organic manure, and silage saps, in kg/ha/a
NU_{P} – Specific N output via main crop production, in kg/ha/a

N uptake coefficients for the main crops were specified according to the following Table 4.5.

The specific agricultural N surplus as calculated at farm level for 1989/90 served as a reference for including information of the N surplus from agriculture into the present study. BEH-

Table 4.5: Specific N uptake by main crops.

Crop	Basis for yield evaluation	Specific N uptake in kg/dt
Cereals with straw	Grains	2.7
Winter rape with straw	Grains	5.5
Peas, beans with straw	Grains	6.0
Potatoes with herb	Tubers	0.5
Sugar beets with leaves	Beets	0.45
Maize	Fresh mass	0.3
Lucerne, clover	Fresh mass	0.5
Field grass, meadow, pasture	Fresh mass	0.4

RENDT et al. (1999) analysed the development of the N surplus in the time period between 1950 and 1995 as summarised for all the districts in the eastern part of Germany. The particular N surplus for each farm and year was calculated – using the 1989/90 specific agricultural N surplus as described above – from the relation between the district-based N surplus for the particular year and for the year 1989/90 with a time step of five years. The agricultural N surplus before 1945 was assumed to be the same as for the period of 1945/50. For the time period 1995/2000 no further increase of N surplus was supposed.

To include these calculations into the GIS, the borders of the farms were digitised and intersected with the land use coverage. The area evaluated within the cited N surplus study (DANNOWSKI & FRITSCHE 1992) amounted to about 90 % compared with the agricultural area listed in the Statistical Yearbook of the GDR (1990). In order to handle the differences in area between the GIS data and the statistical data, the specific N surplus values were adjusted in such a way that the total N surplus calculated from the specific N surplus and the agricultural GIS area (CORINE) of each farm finally corresponded with the total N surplus based on the statistical data only.

Atmospheric deposition has been introduced as an averaged growth function between 1950 and 1995, starting with 10 kg/ha/a in 1950 (corresponding to 62 % of the 1995 level) and targeting the known (BEHRENDT et al. 1999) N deposition values and spatial distribution in 1995. Between 1995 and 2000, further increase was assumed by 2 %, followed by retaining the N deposition unchanged at this level up to the end of the scenario period (2020). The sum from the agricultural N surplus and N deposition is used as “N surplus” for the present study. As related to the year of pouring out into any surface water body after subsurface transport and depletion, N surplus is referred to in the MODEST modelling approach as “N input”. Details of the time shift connected with total transport time between “N surplus” and related “N input” are outlined at the end of Chapter 4.1.2.6.

Within the study of 1992 P balance values had also been calculated for the German part, though on a more general basis, but they were of minor concern for the present project.

Poland

For calculations of nutrient balances in Poland the following equation has been applied:

$$NU_{sur} = NU_{in} - NU_{up} \tag{4.9}$$

with NU_{sur} = annual nutrient (N or P) surplus at the soil surface [kg/ha],
NU_{in} = annual nutrient input [kg/ha] and
NU_{up} = annual nutrient uptake of the crops [kg/ha].

Nutrient input is the sum of mineral fertilizer (NU_{min}) and organic manure (NU_{org})according to formula:

$$NU_{in} = NU_{\min} + NU_{org} \tag{4.10}$$

NU_{min} were taken directly from statistical yearbooks, whereas NU_{org} was calculated on the base of the number of major animal breed expressed in the terms of Animal Units (AU), conversion factors for calculating the AU, adapted from HELCOM RECOMMENDATION 13/7 are given in Table 4.6.

Table 4.6: Conversion factors for calculating Animal Units (AU).

Type of animal	AU per animal
Cattle	0,80
Pigs	0,15
Sheep	0,08
Horses	1,00

For calculation of NU_{org} it was assumed, that 1 Animal Unit supplies 85 kg N and 42.5 kg P_2O_5 annually (HELCOM RECOMMENDATION 13/9, DZIEZYC 1983).

Nutrient uptake NU_{up} was calculated from the nutrient content of harvested material, taking into account cropping area of particular crops and its yield. Phosphorus and nitrogen content in yields of main crops were adapted from BACH (1997), BACH & FREDE (1998), BRAUN et al. (1994) and SCHLEFF & KLEINHANSS (1994), (Table 4.7).

Table 4.7: Nutrient uptake by selected crops [% of yield].

Type of crop	Nitrogen uptake	Phosphorus uptake
Cereals (wheat, barley, oat and rye)	1,80	0,80
Potato	0,35	0,11
Sugar beet	0,18	0,19
Rape	3,50	0,34

Within the Phase II of the Project very detailed calculations of nitrogen surpluses in the year 1989/1990 were done for each individual gmina (the smallest administrative unit) in the Odra basin. During the current phase of the project detailed calculation of phosphorus surpluses 1989/1990 (in kg P_2O_5/ha year) were done. All calculations of nitrogen and phosphorus surpluses were based on data of GUS (Central Statistical Office of Poland) at gmina level.

An additional assessment of nitrogen and phosphorus surpluses for each gmina was done for the period 1949-1996, with the time increment of 5 years. The base for the calculations of nutrient surpluses in an individual gmina in a given year were exact data for the gminas in the year 1989/1990 (as reference year) and the average surplus of nitrogen and phosphorus in the given year for the voivodship in which the gmina is located according to formula:

$$NU_{Sxg} = NU_{S90g} \cdot \frac{NU_{Sxw}}{NU_{S90w}} \qquad (4.11)$$

with NU_{Sxg} = nutrient surplus in the certain gmina in the year **x** [kg/ha],
NU_{S90g} = nutrient surplus in the same gmina in 1989/1990 [kg/ha],
NU_{Sxw} = average surplus in the voivodship in the year **x** [kg/ha] and
NU_{S90w} = average surplus in the same voivodship in the year 1989/1990 [kg/ha].

Calculations of nitrogen and phosphorus surpluses for voivodships were done using equations (4.9) and (4.10).

Average NU_{in} for each voivodship have been using the following data published in yearbooks by GUS:

- mean values of mineral fertilizers used in voivodships in the period 1949-1996,
- average number of domestic animals (taking into account cattle, pigs, sheep and horses) in the same period at voivodship level.

Nitrogen uptake with the yield of crops was calculated using cropping area of main crops (cereals, rape and oil-yielding rape, potatoes and sugar beets) in the period 1949-1996 and average yields of particular crops in the same period at voivodship level.

It is necessary to point at problems with the accuracy of the data for assessment of nitrogen surpluses in voivodships. The first problem is connected with particularity of certain data in statistical yearbooks, for example in some years only the total consumption (N+P+K) or total sown area of all crops is published. The second major problem concerns changes of numbers and borders of voivodships in post-war history of Poland. Until 1950 there were 14 voivodships, during the period 1950-1975 there were 17 ones and after the reform of state administration in 1975 the number of voivodship arose to 49. In 1999, as a result of another reform the number of voivodship was 16.

Czech Republic

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

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

- *inorganic or chemical nitrogen and phosphorus fertiliser*: quantity consumed by agriculture;
- *livestock manure nutrient production*: total numbers of live animals (cattle, pigs, sheep, goats, poultry, horses, and other livestock) in terms of different categories according to species (e.g. chickens, turkeys), sex, age and purpose (e.g. milk cow, beef cattle), multiplied by respective coefficients of the quantity of nitrogen and phosphorus contained in manure per animal and year (see Table 4.8);

- *atmospheric deposition of nutrients:* total agricultural land area multiplied by a single coefficient of nutrient deposited per hectare. It was a constant deposition rate of 22 kgN/ha·a and 1 kgP/ha·a assumed;
- *biological nitrogen fixation:* area of harvested legume crops (e.g. field beans, soybeans, clover, alfalfa) multiplied by respective coefficients of nitrogen fixation/ha, plus the nitrogen fixation by free living soil organisms computed from the total agricultural land area multiplied by a single coefficient of nitrogen fixation/ha (see Table 4.9);
- *nutrients from recycled organic matter:* quantity of sewage sludge applied to agricultural land multiplied by a single coefficient of nutrient content of sewage sludge. For the sludge a nutrient content of 1.5 kgN/t and 0.5 kgP/t was assumed;
- *nutrients contained in seeds and planting materials:* quantity of seeds and planting materials (e.g. cereals, potato tubers) multiplied by respective coefficients of nutrient content of seeds/planting materials.

Table 4.8: Specific nutrient emissions for anaimals used in Czech Republic ([kgP/head];[kgN/head]).

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

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

- *harvested crops:* quantity of harvested crop production (e.g. cereals, root crops, pulses, fruit, vegetables and industrial crops) multiplied by respective coefficients of nutrient uptake to produce a tonne of harvested crop (see Table 4.10);
- *forage crops:* quantity of forage crop production (e.g. fodder beets, hay, silage, and grass from temporary and permanent pasture) multiplied by respective coefficients of nutrient uptake to produce a tonne of forage.

Table 4.9: Rates of nitrogen fixation by different plants.

Description	**N [kgN/ha]**
Pulses	80
Clover	240
Alfalfa	240
Other Legume Crops	25
Free living organisms	
Permanent Crops	5
Permanent pasture	5

Based on these parameters and the given coefficients in Table 4.9 to 4.10 the nutrient surplus in the agricultural areas was estimated by the following equations.

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

Nutrient Output = Total Harvested Crops + Total Forage

Nutrient Surplus = Nutrient Outputs – Nutrient Inputs

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

The nutrient balances were calculated on the one hand for the long term period 1950 to 1999 for the whole country and for the districts within the Czech part of the Odra basin for the year 1988 and 1996.

The nutrient surplus for the districts is combined with the calculated values for the German and Polish part of the Odra basin using the map of the administrative areas.

Table 4.10: Specific N and P uptake by main crops used in Czech Republic.

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

4.1.2.2 Nutrient Emissions via Atmospheric Deposition

The basis for estimating direct inputs into freshwaters by atmospheric deposition is the knowledge of the area of all surface waters within a basin, which is connected to the river system. The land use map according to CORINE-landcover was used for the estimation of the area of larger lakes and rivers. Additionally, the area of the river system itself has to be taken into account. According to BEHRENDT & OPITZ (1999), the area of a river system is dependent on the size of the catchment. Newer investigations of data available for the Germany showed, that the slope of the catchment has to be taken into account additionally. Figure 4.x shows the relation between the water area from municipality statistics and the calculated water area according to the following formula:

$$A_W = A_{WCLC} + 0{,}0052 \cdot A_{CA}^{1{,}078} \cdot SL_{CA}^{-0{,}278} \tag{4.12}$$

with A_W = total water surface area [km²],
A_{WCLC} = water surface area from CORINE-Landcover [km²],
A_{CA} = catchment area [km²] and
SL_{CA} = mean slope of the catchment [%].

For phosphorus the concentration in wet deposition was interpolated for the whole investigation area from measurements for 14 Polish stations (Map 4.1). Because other data where not available, it was decided to use this small dataset for an interpolation instead of using one

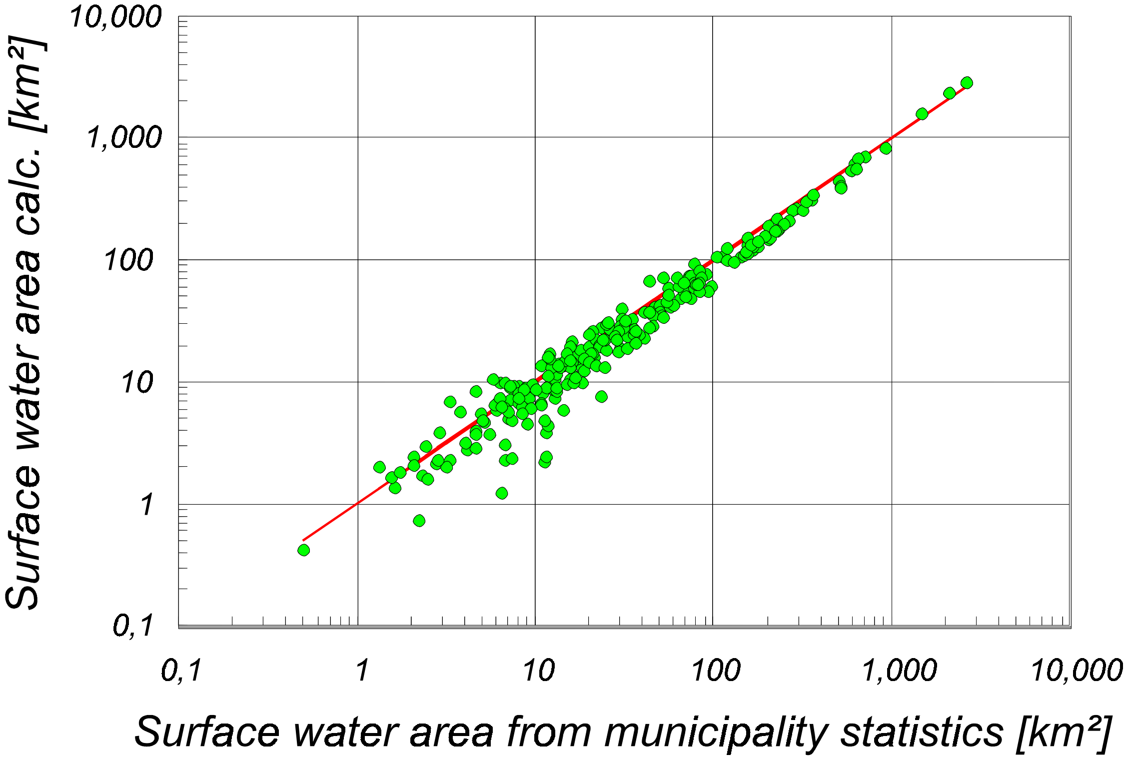
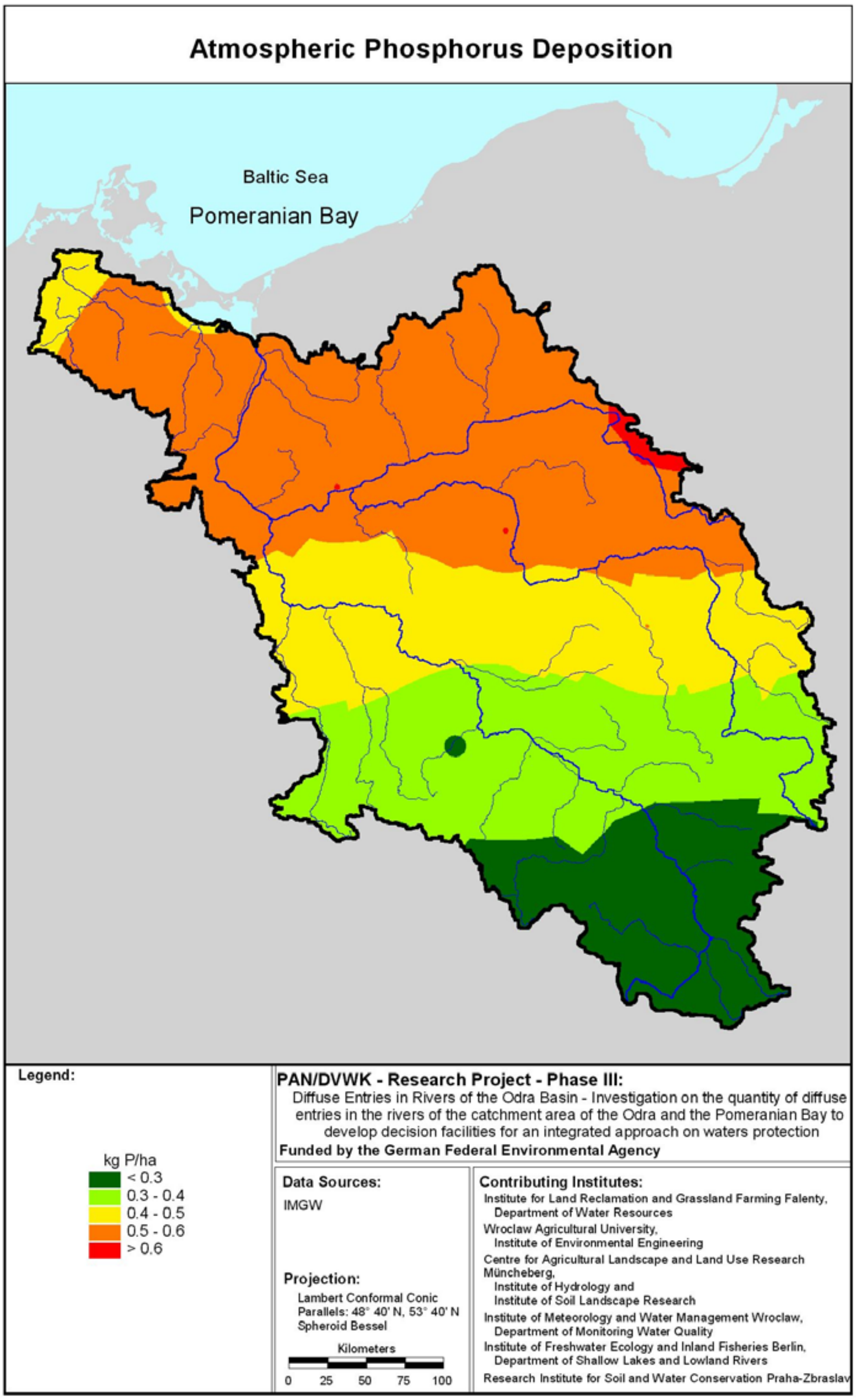


Figure 4.2: Relation between the surface water area from municipality statistics and the calculated surface water area according to equation 4.12 for German catchments.

value for the whole investigation as in BEHRENDT et al. (2000). The values of the P deposition range from 0,22 to 0,65 kg/(ha·a). For the interpolation the inverse distance model with a radius of 200km and a power of 1 was used.

For nitrogen the results of the EMEP-program were considered for 1996 (TSYRO, 1998a, b; BARTNICKI et al. 1998). The EMEP-data are available as grid maps with a cell size of 50 km for the year 1996 as NOx-N- and NH4-N-deposition in kg N/(ha·a). The EMEP-grid maps were overlaid with the boundaries of the river basins for the estimation of the mean NOx-N- and NH4-N-deposition within the catchments (Map 3.6).



Map 4.1: Phosphorus deposition.

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

$$EAD_{N,P} = A_W \cdot DEP_{N,P} \tag{4.13}$$

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

4.1.2.3 Nutrient Emissions via Surface Runoff

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The inputs of dissolved nutrients by surface runoff were determined according to the scheme presented in Figure 4.3.

The annual (Map 4.2) and winter precipitation for the period 1993-1997 in the Odra catchment was interpolated from the available 148 stations. For this the inverse distance interpolation with a power of 1 and a radius of 200 km was used.

The surface runoff is calculated using a function (see Equation 4.15), from the US SOIL CONSERVATION SERVICE (1972):

$$q_{RO} = q_G \cdot 2 \cdot 10^{-6} \cdot (P_Y - 500)^{1,65} \tag{4.14}$$

with q_{RO} = specific surface runoff [mm/(m²·a)].
q_G = average yearly specific runoff [mm/(m²·a)],
P_Y = average annual precipitation [mm/(m²·a)],

The average yearly specific runoff q_G was calculated for each catchment as the quotient between the measured runoff (Q) and the area of the catchment. For sub catchments without data on runoff, the runoff was calculated from the difference of the runoff of the downstream and upstream station.

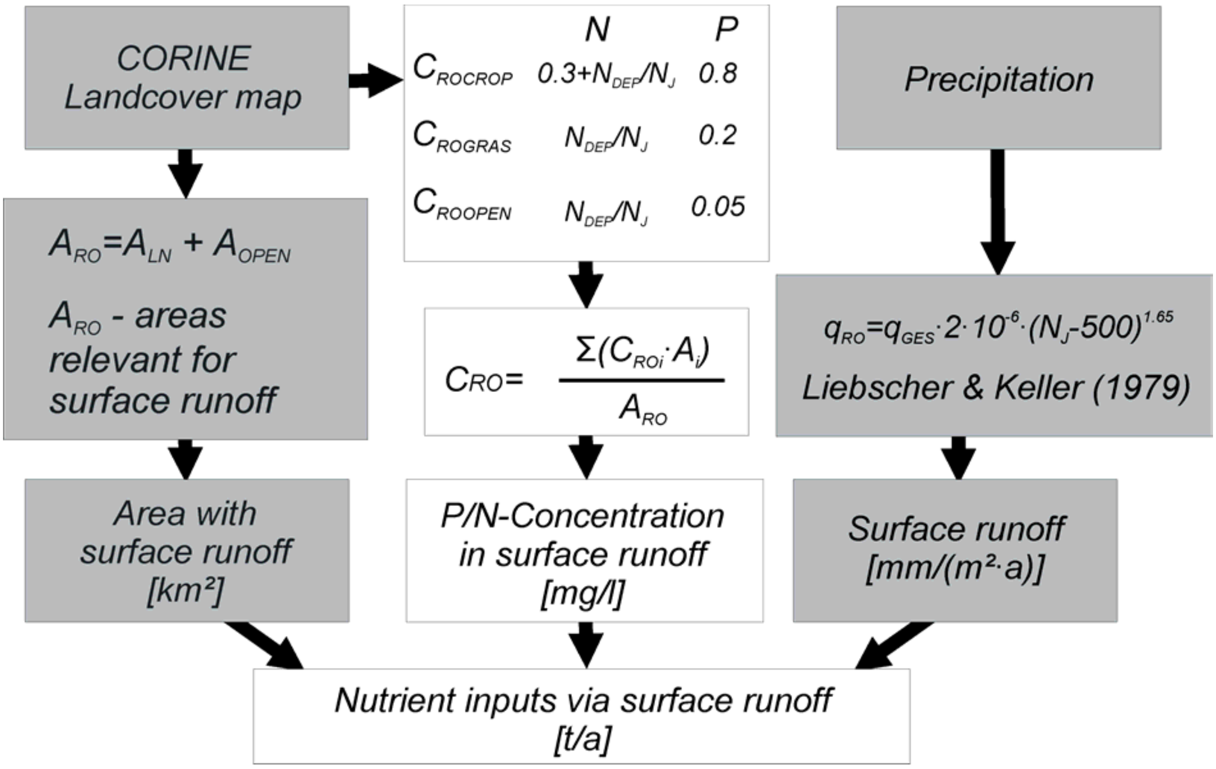
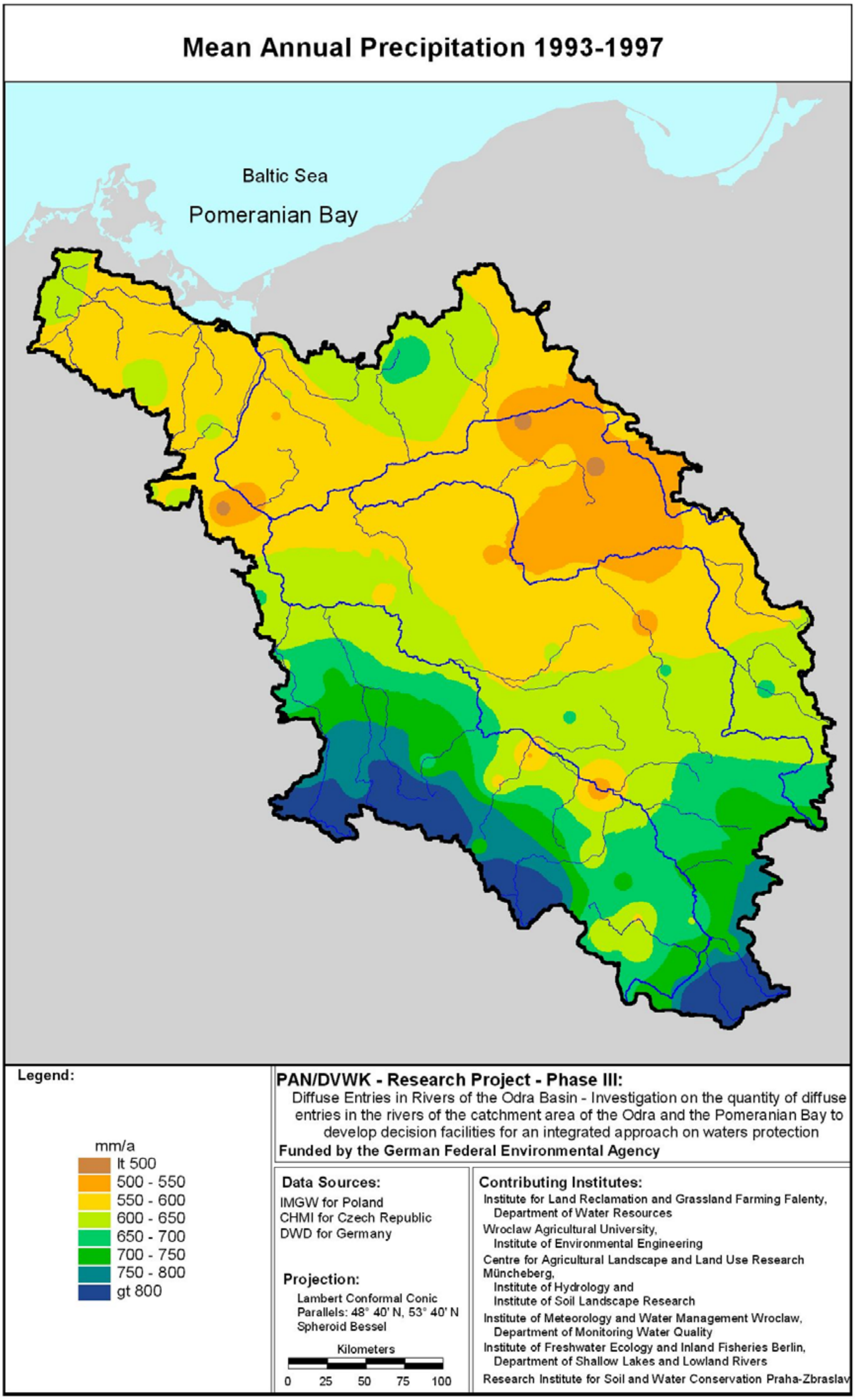


Figure 4.3: Nutrient emissions via surface runoff.



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IMGW for Poland
CHMI for Czech Republic
DWD for Germany

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 4.2: Mean annual precipitation in the period 1993-1997.

Sometimes this procedure results in impossible high or negative values of the specific runoff of the sub catchment. For these cases the total specific runoff of the sub catchment is calculated according to the approach of LIEBSCHER & KELLER (1979). In this method the annual, the mean summer and winter precipitation are the main variables controlling the volume of the total runoff.

$$q_G = 0{,}86 \cdot P_Y - 111{,}6 \cdot \frac{P_{SU}}{P_{WI}} - 241{,}4 \tag{4.15}$$

with P_{SU} = average precipitation in the summer half year [mm/(m²·a)] and
P_{WI} = average precipitation in the winter half year [mm/(m²·a)].

Further, it was assumed that surface runoff does not occur in forest, on wetlands and mining areas, so only the surface runoff from agricultural and open land is calculated:

$$Q_{RO} = a \cdot q_{RO} \cdot (A_{AG} + A_{OP}) \tag{4.16}$$

with Q_{RO} = surface runoff from non-paved areas [m³/a],
a = unit conversion factor,
A_{AG} = agricultural area [km²] and
A_{OP} = open area [km²].

For the further calculations, it is assumed that all of the surface runoff reaches the river system. The estimation of nutrient inputs via surface runoff considers only the dissolved nutrient components transported with the surface runoff into river systems. The nutrient concentration in surface runoff of every basin can be estimated as area-weighted mean of the concentrations in the surface runoff of the different land use categories. For that it is necessary to divide the agricultural areas into arable land and grassland. For the area-weighted concentrations of nitrogen and phosphorus in surface runoff, the following is valid:

$$C_{RO_{N,P}} = \frac{C_{ROAR_{N,P}} \cdot A_{AR} + C_{ROGRAS_{N,P}} \cdot A_{GRAS} + C_{ROOP_{N,P}} \cdot A_{OP}}{A_{AR} + A_{GRAS} + A_{OP}} \tag{4.17}$$

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

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

$$ERO_{N,P} = C_{RO_{N,P}} \cdot Q_{RO} \cdot a \tag{4.18}$$

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

For the calculation of the surface runoff loadings the nutrient concentrations given in Table 4.11 are used for all catchment areas (BEHRENDT et al. 2000).

Table 4.11: Nutrient concentrations in surface runoff for arable land, grassland and open areas.

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

4.1.2.4. Nutrient Emissions via Water Erosion

The data base for water erosion calculations in the three countries is different. For the Czech and German parts of the Odra catchment, a similar GIS-based methodology was applied. A detailed database was used to calculate the soil loss by means of the Universal Soil Loss Equation (USLE) for each municipality. The Medium-scale Agricultural Site Mapping (MMK, LIEBEROTH et al. 1983; work scale 1:25.000 up to the aggregated scale 1:100.000) served as soil data basis for the German part. The MMK follows a concept of characteristic combined site properties in a limited area (contours), the so-called ”mapping units”. Each mapping unit combines different properties like slope steepness, substratum, hydromorphy, and other properties representing an area between 15 and nearly 130 ha. In the Czech Republic the work scale is 1:5,000. The BPEJ unit is the five-digit code of the Valuated Soil Ecological Unit (VSEU, in Czech: BPEJ) for a polygon, of which the first digit denotes a climatic region, the second and the third ones the corresponding main soil unit (HPJ) and the fourth stands for the slope and its orientation (JANECEK 1995). The aggregation level then can be related to administrative (represented by districts or municipalities) or natural units (catchments). Also a direct integration of the mapping units using GIS in further calculations is possible. The “cadastr” is the smallest administrative scale representing soil information in aggregated manner in the Czech Republic.

For the following erosion-related calculations, all soil interpretation data were aggregated on municipalities for the Czech, Polish, and German parts.

Potential Soil Loss Estimation Based on the Universal Soil Loss Equation by Use of Regionalised Data

USLE is a simple multiplicative model to calculate potential soil loss, derived from over 10,000 plot-years of data (WISCHMEIER & SMITH 1978). The values of the factors were updated following the analysis of thousands of new measurements (RENARD et al. 1991). The USLE as well as the Revised Universal Soil Loss Equation (RUSLE) can be written as:

$$SOL = R * K * LS * C * P \qquad (4.19)$$

with

SOL – computed spatial *average soil loss and temporal average soil loss per unit of area*, expressed in the units selected for *K* and for the period selected for *R*. In practice, these are usually chosen to express *A* in t/ha/a.

R – *rainfall-runoff erosivity factor* – the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K – *soil erodibility factor* – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 22.1 m length of uniform 9 % slope in continuous clean-tilled fallow.

L – *slope length factor* – the ratio of soil loss from the field slope length to soil loss from a 22.1 m length under identical conditions.

S – *slope steepness factor* – the ratio of soil loss from the field slope gradient to soil loss from a 9 % slope under otherwise identical conditions.

C – *cover-management factor* – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P – *support practice factor* – the ratio of soil loss with a support practice like contouring, stripcropping, or terracing, to soil loss with straight-row farming up and down the slope.

Data preparation in general

In the German part the soil erodibility factor (*K*) was parameterised and weighted on the basis of soil types of agricultural areas or arable land within the MMK polygons. *LS* was calculated in a similar way. These conditions were weighted and regionally differentiated, because slope length is not integrated into the MMK. The slope length was determined from topographic maps for hundreds of slopes in different regions to derive *LS* factors for regional slope steepness association groups.

For the Polish side, the *LS* factor was estimated from topographic maps at a scale of 1:50,000. *L* and *S* values were measured for all regions and the average *LS* for the "gmina" (municipality) was calculated. The *K*-factor was determined for the dominating texture class of the top layer using soil maps. Statistical data to compute the *C* factor as well as long-term data of single precipitation events to calculate the *R* factor were also used. The estimated soil loss served as input data for the subsequent calculations of nutrient loads and sediment yield.

For the Czech part, for all cadastral units, the VSEU characteristics and the information about the spatial extent of VSEUs stored in the database were used. A weighted average value was calculated multiplying the factors of soil erodibility and slope steepness ($k = K * S$). This value multiplied by about 10 gives the potential soil loss in t/ha (JANECEK 1995). The *C*-factor is based on statistical data for districts.

In all the three countries, land use and management are represented by $C * P$ and can be estimated from field observations or farm records. $C * P$ may also, with some difficulty, be inferred from aerial photography or satellite imagery and ground-truth data (Prietzsch et al. 1997).

Data preparation in detail

Rain erosivity (*R*) can be computed directly from maximum 30 minute rainfall intensities and the amount of rainfall for each single event. The long-term average of the total *R* value over a year is then integrated into the equation. Often these values are documented in Isoerodent Maps. The Rain erosivity (*R* in N/hour) is calculated here by (Deumlich 1993)

$$R = -6.88 + 0.152\, P_S \qquad r^2 = 70\ \% \tag{4.20}$$

with P_S = precipitation during summer period, in mm

The *Soil erodibility* (*K*) values can be measured in long-term studies or estimated for mapped soil series using a nomograph. Soil series are mapped at scales of 1:5,000 to 1:500,000 in Czech, Germany and Poland. *K* was obtained from the soil database (see example for Germany in Table 4.11).

Table 4.12: K factors based on Medium Scale Agricultural Site Mapping (Germany).

Natural site unit	**Dominating soil texture in the top layer**	**Substrate description**	***K* factor**
D1	S	> 80 % sand	0.1
D2	l'S, S	> 60 % loamy sand or sand, < 40 % covered[1] loam	0.2
D3	l'S...lS	40 - 60 % covered loam, loam-sand or cover-loam or cover-loam-sand, 40 - 60 % sand or loamy sand	0.3
D4	lS, sL	> 60 % covered loam or covered clay (partially cover loam), cover-sand-loess or cover-sand-loam	0.35
D5	lS...L	40 - 60 % loam, 40-60 % covered loam; > 60 % loam and covered loam; > 60 % sand loess	0.25
D6	sL...T	> 60 % loam or heavy loam, partially loam or clay	0.2

[1] covered = substrate below 60 cm soil depth

The spatial percentage of different *soil erodibility* (*K* factors) were weighted for municipalities and GIS-coupled by the identification number (Mun-ID).

LS factor: The effects of topography and hydrology on soil loss are characterised by the combined *LS* factor. Soil loss predictions are more sensitive to slope steepness than to slope length. Estimation of the *LS* factor poses more problems than any of the other factors combined in the USLE and appears to be a particular problem in applying this model as a part of a GIS realisation to landscapes (Wilson 1986, Renard et al. 1991, Auerswald 1989). The slope length depends on field length and other factors of influence such as ditches or roads.

In Phase II, the methodology was presented to get the regionalised and weighted *LS* value for each mapping unit (polygon) in detail.

Cover and management (*C*): For the main crops and crop rotations, the *C* factor was estimated for combined regional weather (rain erosivity) and management data (Table 4.13).

Table 4.13: C factors of crops (related to continuous fallow in %, example for Brandenburg).

Crop	C factor	Average
Winter wheat	7.7...14.4	9.2
Winter barley	5.7...10.4	8.0
Winter rye	3.2...5.9	4.2
Summer barley	2.9...6.6	4.7
Oats	2.9...6.6	4.7
Winter rape	8.9...12.7	11.4
Potatoes	15.0...24.2	20.5
Sugar beet	17.7...28.5	21.8
Corn (silage)	25.6...37.8	33.8

C for different municipalities was determined from statistical data for the year 1989.

For the Polish and Czech parts of the Odra catchment the average values of *C* from Table 4.11 have been chosen. *C* was calculated for “gmina” or “cadastr”. The plant cover differentiation has been taken from voivodships (PL) or “okres” (CZ – district) statistics for different gminas/cadastral units.

Support practice factor *P* was assumed to be 1.

Nutrient Content in Arable Soils

For Czech soils, the N and P content is given in Table 4.14 using the Czech profile database (VOPLAKAL & DAMAŠKA 1971).

Table 4.14: Total nutrient content in topsoil, mg P or N/100 g dry soil (Czech Republic).

Hydrological soil group	P content	Retention group	N content
A	48	1	80
A-B	53	2	100
B	65	3	120
B-C	80	4	150
C	70	5	160
C-D	70	6	70
D	70		

At the end of all GIS preparations, a database was created containing the factors of the USLE, the nutrient contents, statistical data for arable land, the identification number of each municipality. Then the catchment polygons were combined with the municipalities. Data for the erosion calculations were appended.

A soil database called PRODAT (LIEBEROTH 1982) was investigated to determine the texture-dependent total N and P content in the upper soil layer for eastern Germany soils. For different fertilisation groups (dependent on variously textured soils and their hydromorphologic conditions) the average of the N and P contents were calculated (Table 4.15). For northern Polish regions, KOCMIT (pers. Comm.) found similar values between 30 mg/100 g soil for poor sandy and >100 mg/100 g soil for organic soils.

Table 4.15: Nitrogen and phosphorus contents in eastern German soils.

Soil groups of the Fertilisation advisory system DS87	**Soil (particle size) class**	**Average nitrogen content (mg/100 g soil)**	**Average phosphorus content (mg/100 g soil)**
1.1	S	69	42
1.2		137	49
1.3		100	46
2.1	Sl, lS	76	51
2.2		89	47
2.3		90	49
3.1	SL, sL, lU	105	59
3.2		115	58
3.3		120	59
4.1	L, UL	128	73
4.2		153	70
4.3		140	71
4.4		148	75
5.1	T, lT, uT	170	101
5.2		242	97
5.3		210	99
6.1	M	737	165
6.2		2193	286
6.3		2000	286

Calculation of Nutrient Input into the Rivers – The NIIRS Approach

The calculation of **p**articulate **N**utrient **I**nput **i**nto the **R**iver **S**ystem (pNIIRS) is based on the procedure reported in HAMM (1991).

Estimating the Enrichment Ratio (*ER*) for nutrients (N and P) in sediments is based on the findings by AUERSWALD (1989).

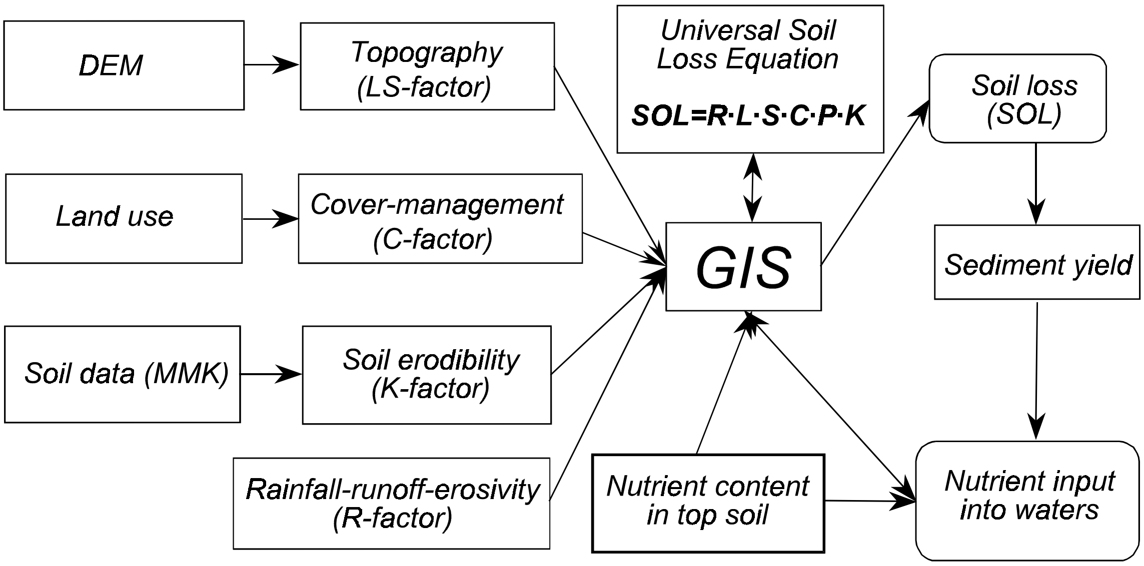


Figure 4.4: Calculation procedure for the nutrient inputs by erosion according to the pNIIRS methodology.

$$ER = 2.53 * SOL^{-0.21} \tag{4.21}$$

with SOL – average soil loss on arable land calculated with USLE, in t/ha

Sediment yield from the catchment (soil loss – deposit) has been calculated using

$$SED = 700 + 8.5 * A * SOL_c^{0.5} \tag{4.22}$$

with SED – sediment transport by rivers, in t/year

A – catchment area, in km²

SOL_c – mean soil loss of the whole catchment area, in t

and finally the particular *nutrient input* is calculated from

EER of 1,000 km² * *CA* * *ER* * *N/P content* of arable lands (4.23)

In order to quantify dissolved N and P forms transported to the river system, calculations of runoff were done for the 46 catchments, assuming concentrations in the runoff water of 0.32 mg/l for N and 0.6 mg/l for P. The quantity of runoff from the agricultural area was assumed to be 10 mm/a in all the calculated catchments.

Calculation of nutrient inputs by erosion – The MONERIS approach

For the calculation of the nutrient inputs into the river system of the Odra a second approach used in MONERIS (BEHRENDT et al., 2000) was applied in relation to the sediment delivery ratio (SDR) and the enrichment ratio (ER). The reason was to show the variation of the results depending on the used approach.

Figure 4.5 shows the procedure for estimating nutrient inputs by erosion, based on the soil loss rate, the sediment delivery ratio and the enrichment ratio of nutrients. To calculate soil loss (SOL) in the river basins maps on the potential soil loss in Germany, Poland and the Czech Republic were used (see above). The mean soil loss in each subcatchment is calculated with the help of the GIS.

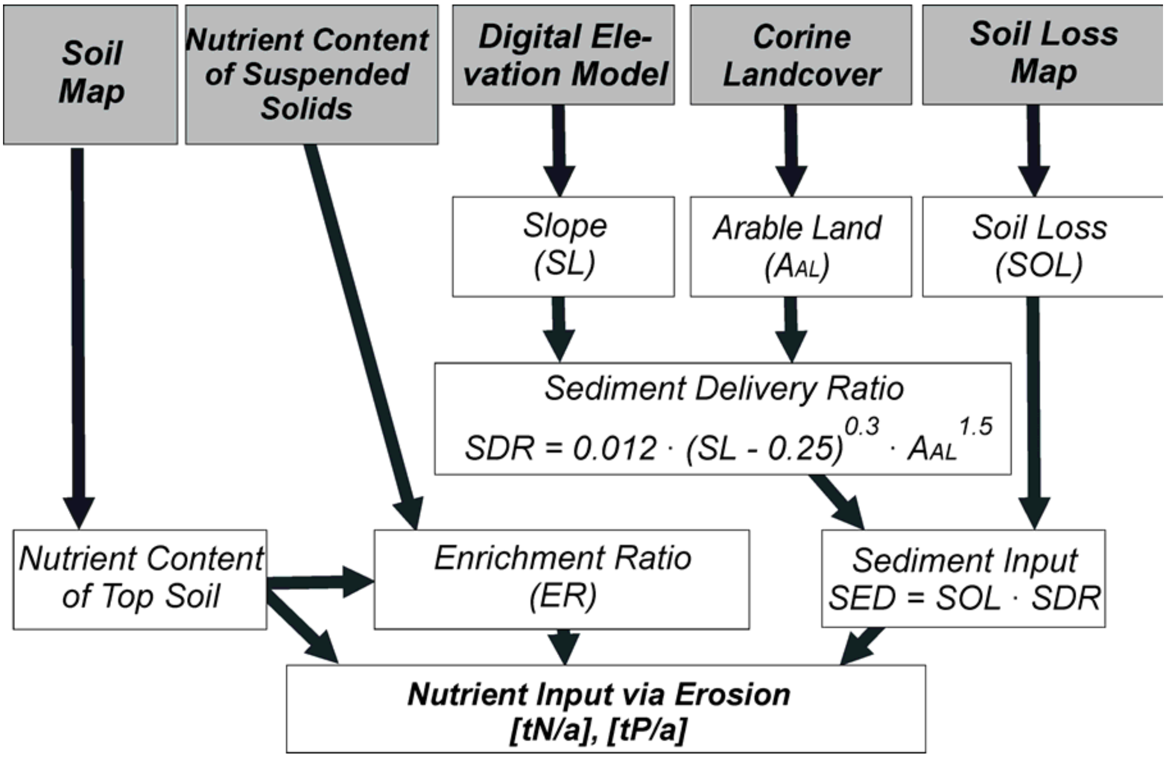


Figure 4.5: Nutrient emissions via erosion

The difference in relation to the pNIIRS approach is mainly focused on the calculation of the sediment delivery ratio (SDR) and the enrichment ratio (ER).

The sediment delivery ratios for the sub catchments are determined according to Equation 4.24 (BEHRENDT et al. 2000):

$$SDR = 0.012 \cdot (SL_{CA} - 0.25)^{0.3} \cdot A_{AR}{}^{1.5} \tag{4.24}$$

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

The sediment input due to erosion for the river basins is then calculated according to Equation 4.25:

$$SED = SOL \cdot SDR \tag{4.25}$$

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

For the TP- and TN- content of the topsoil the values derived in the pNIIRS approach is used (see above).

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

$$ER_P = 18 \cdot \left(\frac{SOL}{A} \right)^{-0.47} \tag{4.26}$$

with ER_P = enrichment ratio for phosphorus

$$ER_N = 7.7 \cdot \left(\frac{SOL}{A} \right)^{-0.47} \tag{4.27}$$

with ER_N = enrichment ratio for nitrogen.

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

$$EER_P = a \cdot P_{SOIL} \cdot ER_P \cdot SED \tag{4.28}$$

$$EER_N = a \cdot N_{SOIL} \cdot ER_N \cdot SED \tag{4.29}$$

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

4.1.2.5 Nutrient Emissions via Tile Drainage

For the quantification of nitrogen and phosphorus inputs by tile drainage only the MONERIS approach was applied. This approach is based on the size of the drained area, the amount of drainage water and the average nutrient concentrations in the drainage water (Figure 4.6).

For the estimation of the size of drained areas within a basin the data from Polish and Czech statistics and for Germany from BEHRENDT et al. (2000) were used.

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

$$q_{DR} = 0.5 \cdot P_{WI} + 0.1 \cdot P_{SU} \tag{4.25}$$

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

This approach takes into account the regional different distribution of rainfall and the volume of drainage water. On the basis of measurements, average P-concentrations in the drainage water for various soil types were determined. The results are shown in Table 4.16. The P-

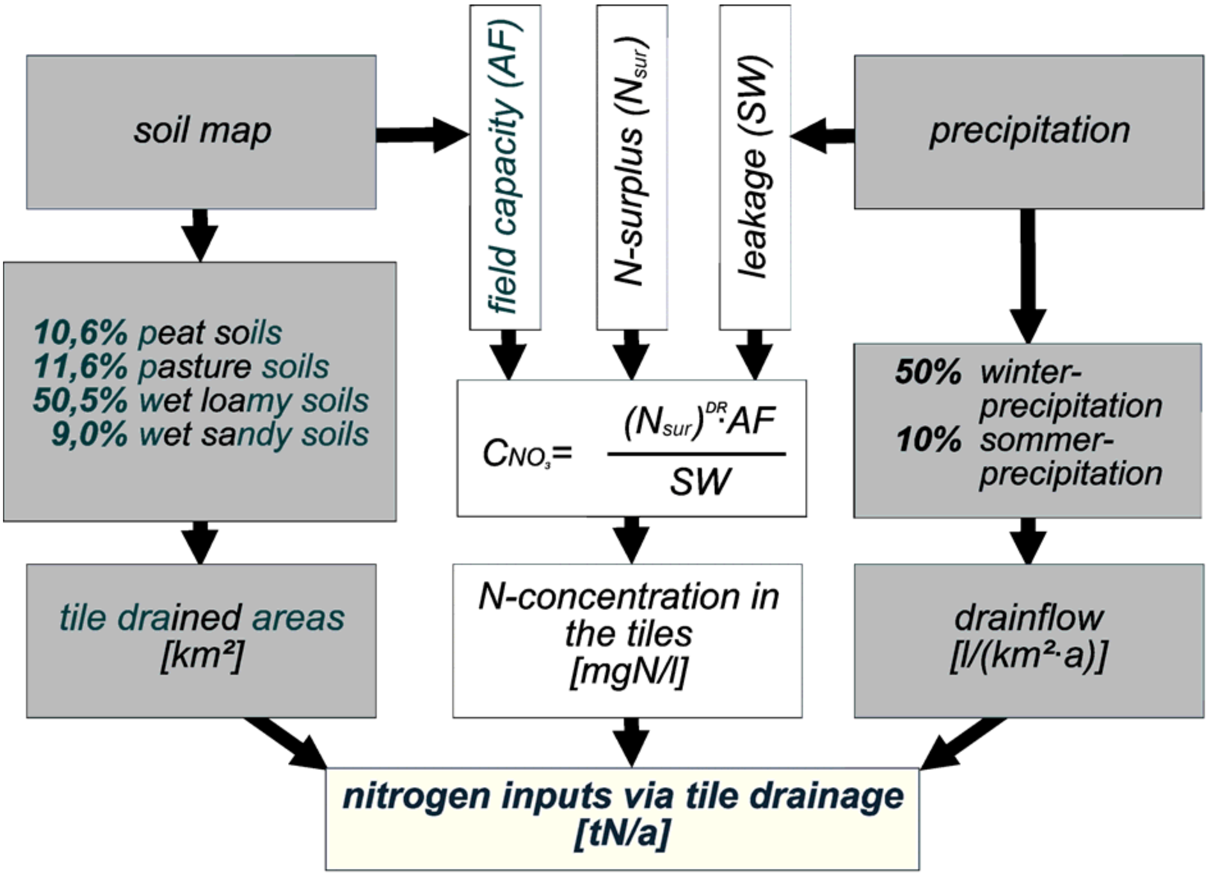


Figure 4.6: Nitrogen emissions via tile drainage

concentration in the catchments was calculated as an area-weighted mean on the basis of the values in Table 4.14 and the areas of sandy soils, loams, fen and bog soils according to the soil map:

$$C_{DR_P} = \frac{C_{DRS_P} \cdot A_{DRS} + C_{DRL_P} \cdot A_{DRL} + C_{DRF_P} \cdot A_{DRF} + C_{DRB_P} \cdot A_{DRB}}{A_{DRS} + A_{DRL} + A_{DRF} + A_{DRB}} \tag{4.26}$$

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

The calculation of nitrogen concentrations follows the methods described in BEHRENDT et al. (2000) and is based on the regionally differentiated N-surpluses. From the N-surpluses, the leakage water quantity and the exchange factor, which is calculated from the field capacity, the potential nitrate concentration in the infiltrating water is calculated according to FREDE & DABBERT (1998). This potential nitrate concentration in the upper soil layer is reduced by a denitrification factor (DR) which was estimated to 0.85 (BEHRENDT et al. 2000). The following equation is used for the calculation of the nitrate concentration in drainage water:

Table 4.16: P-concentrations used for drainage water for different soil types.

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

$$C_{DR_{NO3-N}} = a \cdot \frac{(N_{SUR})^{DR} \cdot 100}{LW} \tag{4.27}$$

with $C_{DR_{NO3-N}}$ = nitrate concentration in drainage water [g N/l],
a = unit conversion factor
N_{SUR} = nitrogen surplus of agricultural areas [kg N/(ha·a)],
DR = exponent for denitrification (0.85) and
LW = leakage water quantity [l/(m^2·a)].

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

$$EDR_{N,P} = a \cdot A_{DR} \cdot q_{DR} \cdot C_{DR_{N,P}} \tag{4.28}$$

with $EDR_{N,P}$ = nutrient emissions via tile drainage [t/a],

a = unit conversion factor and
A_{DR} = drained area [km²].

4.1.2.6 Nutrient Emissions via Groundwater

The MONERIS approach

The nutrient inputs by groundwater are calculated from the product of the groundwater outflow and the groundwater nutrient concentration and include the natural interflow and the base flow. This is caused by the absence of methods to calculate the natural interflow separately. Figure 4.7 shows a scheme for the calculation of nitrogen emissions via groundwater.

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

$$Q_{GW} = Q - Q_{DR} - Q_{RO} - Q_{URB} - Q_{AD} \tag{4.29}$$

with Q_{GW} = base flow and natural interflow [m³/s],
Q = average runoff [m³/s],
Q_{DR} = tile drainage flow [m³/s],

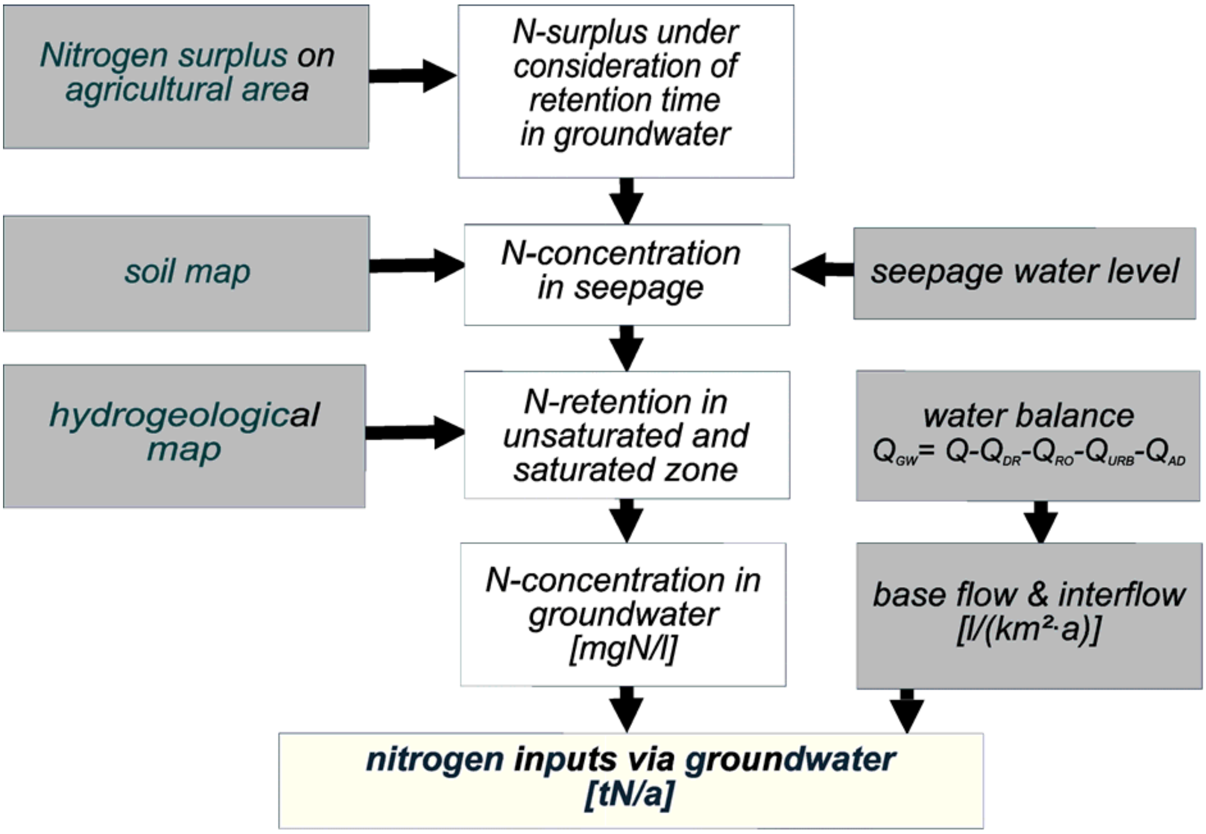


Figure 4.7: Nitrogen emissions via groundwater.

Q_{RO} = surface runoff from non-paved areas [m³/s],
Q_{URB} = surface runoff from urban areas [m³/s] and
Q_{AD} = atmospheric input flow [m³/s].

Groundwater concentrations of soluble reactive phosphorus (SRP) for the different soil types are taken from Behrendt et al. (2000) (Table 4.11).

Using these values the P-concentration in the catchment areas is calculated on the basis of the concentrations and the areas of sandy soils, loamy soils, fen and bog soils as area weighted average for the agricultural land according to Equation 4.30:

$$C_{GWAG_{SRP}} = \frac{C_{GWS_{SRP}} \cdot A_S + C_{GWL_{SRP}} \cdot A_L + C_{GWF_{SRP}} \cdot A_F + C_{GWB_{SRP}} \cdot A_B}{A_S + A_L + A_F + A_B} \tag{4.30}$$

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

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

$$C_{GW_{SRP}} = \frac{C_{GWAG_{SRP}} \cdot A_{AG} + C_{GWWOOP_{SRP}} \cdot A_{WOOP}}{A_{AG} + A_{WOOP}} \tag{4.31}$$

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

Further it is to take into account that there are clear differences between the concentrations of dissolved inorganic phosphorus (SRP) and total phosphorus in anaerobic groundwater (DRIESCHER & GELBRECHT 1993). According to BEHRENDT (1996a) and DRIESCHER & GELBRECHT (1993) can be concluded that the total phosphorus concentrations are 2 to 5 times higher than SRP concentrations determined in the normal standard monitoring programmes. Because information on areas of anaerobic groundwater is not available areas with a higher probability of anaerobic conditions are determined through a comparison of nitrate concentrations in groundwater and those in leakage water (see below). For the calculation of total phosphorus concentrations in groundwater it was therefore determined that in accordance with Equations 4.32 and 4.33, nitrogen concentrations in groundwater are less than 5% of those in leakage water and the TP-concentrations in groundwater are 2.5 times greater than the SRP-concentrations:

$$C_{GW_{TP}} = 2.5 \cdot C_{GW_{SRP}} \quad \text{if } C_{GW_N} \leq 0.15 \cdot C_{LW_N} \tag{4.32}$$

$$C_{GW_{TP}} = C_{GW_{SRP}} \qquad \text{if } C_{GW_N} > 0.15 \cdot C_{LW_N} \tag{4.33}$$

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

The N-concentrations in the groundwater are also derived from the potential nitrate concentration in the to soil. Because the residence time of water and substances on their way from the root-zone to the groundwater and in the groundwater itself is much larger as for tile drainage, this residence time have to be taken into account for the groundwater pathway. The reasons are on the one side that the amount of the losses (denitrifikation) can be dependent on time. On the other hand the level of the nitrogen surplus of the agricultural area is changing over time and therefore the nitrogen in groundwater flowing recently into the surface waters is in correspondence to the N-surpluses in the past.

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

BEHRENDT et al. 2000 found in a comparison of long-term changes of the nitrogen surplus averaged over different periods of previous years with the long-term behaviour of the observed nitrate concentrations in the river Elbe mean residence times of about 30 years. For the Odra river the longest available time series for nitrate concentration was only 19 years, which is to short for such an analysis. But this time series of nitrate (see Figure 4.8) already shows that the nearly constant nitrate concentrations are not related to the big changes of the N-surplus in the agricultural land in the last 10 years. That is an indication that the residence time is at least larger as ten years.

Based on application of the Model WEKU KUNKEL & WENDLAND (1999) found a median of 29 years for the residence time for groundwater in the unconsolidated rock region of the Elbe basin, which corresponds with the result of BEHRENDT et al. (2000). The application of the WEKU model for the unconsolidated rock region of the Odra done in the second phase of this project have shown

Table 4.17: Residence time according to the mean annual precipitation.

Mean Annual Precipitation	**Residence Time**
[mm]	**[years]**
< 600	40
600 - 650	30
650 - 700	25
700 - 800	15
> 800	5

that the mean residence time in the unsaturated zone and in the groundwater aquifers of the this region of the Odra river basin varies between 20 and more than 40 years (DVWK 1999).

From this result it can be concluded that because of the comparable hydrological and geological conditions the residence times in the Odra river are comparable to the Elbe river. Therefore a value of 30 years is taken for the residence time. A comparison between the regionalized residence times estimated for the Elbe catchment and its tributaries with the WEKU model KUNKEL & WENDLAND (1999) and the long term level of precipitation in this regions indicates that the residence time in the groundwater is dependent on the precipitation. Therefore it was assumed that the residence time of groundwater varies in a range between 5 and 40 years and the mean residence time of each sub catchment was estimated from the relation shown in Table 4.15. Based on these results the nitrogen surpluses for the different basins were corrected according to the following formula:

$$N_{TSUR} = \frac{N_{SUR} \cdot A_{AG} \cdot CLS + N_{DEP} \cdot (A_{EZG} - A_{LN} - A_W - A_{IMP} - A_M)}{A_{CA} - A_W - A_{IMP} - A_M} \tag{4.34}$$

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

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

$$C_{LWPOT_{NO3-N}} = \frac{N_{TSUR} \cdot 100}{LW} \tag{4.35}$$

with $C_{LWPOT_{NO3-N}}$ = potential nitrate concentration in leakage water for the total area with base flow [g N/m^3],
LW = leakage water quantity [l/(m^2·a)].

The leakage water quantity (LW) is calculated from the water balance (see Equation 4.29) for each sub catchment. But the calculation of the mean water balances along the river shows that very high or negative specific runoff can occur at least for small catchments between two discharge stations. That is the consequence of the errors for the discharge estimations. In such cases the leakage rate cannot be calculated from the water balance. The total specific runoff

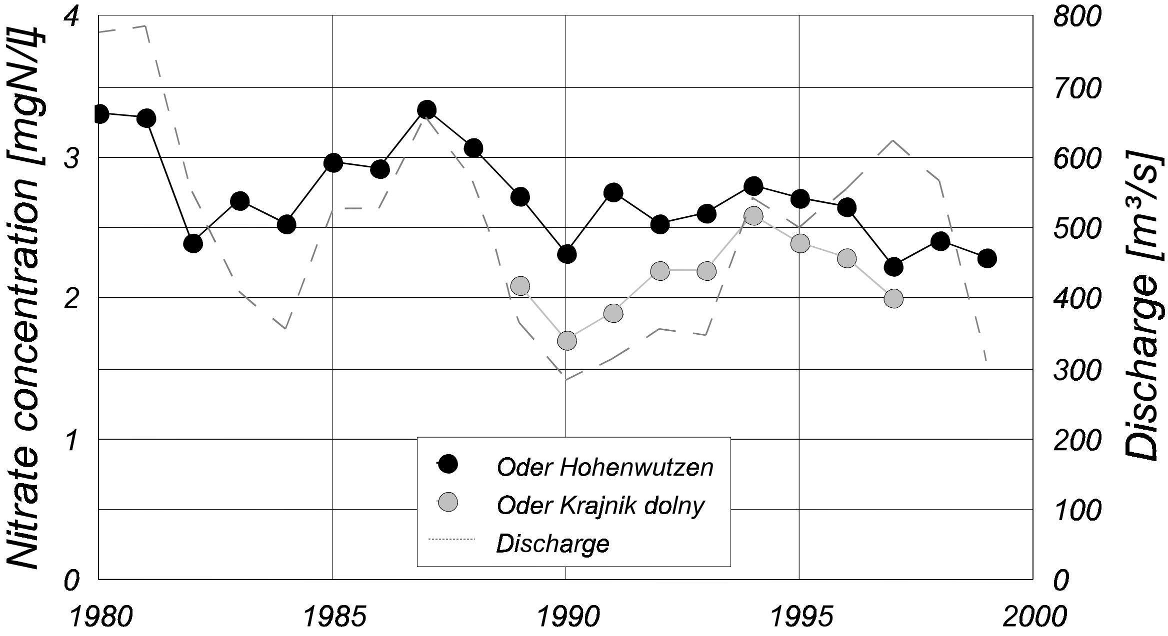


Figure 4.8: Long term changes of the mean annual nitrate concentration in the Odra at the stations Hohenwutzen and Krajnik Dolny for the period 1980 to 1999.

was then calculated for this basins according to the approach of LIEBSCHER & KELLER (1979) (see chapter 4.1.2.3). The leakage rate for this areas can be the following

$$ETR = P_Y - q_G \tag{4.36}$$

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

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

$$ETR_{MAX} < 0.95 \cdot P_Y \tag{4.37}$$

$$ETR_{MAX} < 600 \tag{4.38}$$

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

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

$$q_G = P_Y - ETR_{MAX} \tag{4.39}$$

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

$$LW = P_Y - ETR - q_{RO} \tag{4.40}$$

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

The nitrogen retention (mainly denitrification) in the soil, unsaturated zone and in the groundwater is calculated from the comparison of the regionalized groundwater concentrations of nitrate and the potential nitrate concentration in leakage water. This comparison was done for the area of whole Germany. It could be found that the nitrogen retention is dependent on the level of infiltration water and the hydrogeological conditions according to map 3.8.

The nitrate concentrations in groundwater can than be calculated from the nitrate concentrations in leakage water under consideration of the retention within the soil, which depends on the hydrogeologically rock types, according to Equation 4.41 from Behrendt et al. (2000). The model coefficients are given in Table 4.16.

Table 4.18: Model coefficients for the determination of N-retention in areas with different hydrological conditions (Behrendt et al.2000).

Hydrological rock type	**K$_1$**	**K$_2$**	**B**
Unconsolidated rock areas near groundwater	2.752	-1.54	0.627
Unconsolidated rock areas far groundwater	68.560	-1.96	0.627
Consolidated rock areas with good porosity	6.02	-0.90	0.627
Consolidated rock areas with poor porosity	0.0127	0.66	0.627

$$C_{GW_{NO3-N}} = \left(\sum_{i=1}^{4} \frac{1}{1 + k_{1i} \cdot LW^{k2i}} \cdot \frac{A_{HRT\,i}}{A_{CA}} \right) \cdot C^{b}_{LWPOT_{NO3-N}} \tag{4.41}$$

with $C_{GW_{NO3-N}}$ = nitrate concentration in groundwater [g N/m³],

b = model coefficient for denitrifikation (0.627)

k_1 and k_2 = model coefficients and

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

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

$$EGW_{N,P} = a \cdot Q_{GW} \cdot C_{GW_{N,P}} \tag{4.42}$$

with $EGW_{N,P}$ = nutrient emissions via groundwater [t/a] and

a = unit conversion factor.

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

The MODEST approach

Subsurface non-point N emissions transported via groundwater are the very sustaining component of the river N load and marked by relatively growing importance as compared with other components. Based on modelling the path/time behaviour of the analysed subsurface flow system, scenario calculations are the instrument of choice for evaluating future alternatives in land use policy and agricultural management with respect to their long-term, spatially differentiated impact on river water quality.

For sufficiently detailed studies on the subsurface nitrogen transport, in contrast and enhancement of the MONERIS methodology, an emission-oriented distributed approach has been developed and applied by the groups from ZALF, IMUZ, and ARW (Figure 4.7). This approach called **MODEST** (**Mo**delling **D**iffuse Nitrogen **E**ntries via **S**ubsurface **T**rails) is providing the required spatially distributed cause-effect analysis within the boundaries of coupled small river catchments of arbitrary size. It makes detailed local differentiation possible for analysing the impact of nitrogen on the quality of river water in consideration of the varying intensity of agricultural land use, as well as climatic, topographic, geohydrological, and soil conditions at catchment scale.

The task of quantifying the subsurface N load received by ground and finally surface waters had been integrated into the GIS environment during the previous project phases (DVWK 1999). On the one hand, this prototype resulted in an effective comprehensive model-based methodology for analysing the dominating processes under maximum utilisation of large sets of spatially distributed data as required for complex river basins. On the other hand is the opportunity to upgrade the approach towards a GIS-based Decision Support System that can be applied by authorities responsible for land use policies or basin-wide water management in such complex river basins.

The MODEST modelling procedure was established to perform calculations on the long-term mean risk and path/time behaviour of vertical N transports from diffuse sources towards groundwater, and to calculate the path/time behaviour of the lateral N transport via groundwater into the river network. Nitrate leaching is the initiatory process for any subsurface N transport. The steady-state ‘piston flow’ concept describes the travelling time required for N (as dissolved nitrate) to reach the groundwater table by percolating from the ground surface vertically downwards. Residence time, as determined by the groundwater flow conditions, characterises the lateral, groundwater-borne nitrate transport to the river network. Mainly based on the calculated temporal flow characteristics of the lateral solute transport subprocess, nitrate decomposition is taken into account. In this way, a realistic process-oriented estimation of the spatially highly variable subsurface water-induced N migration within river catchments is achieved. From reasons of the basic modelling conception, application of the methodology is preferably restricted to unconsolidated rock conditions.

GIS-based modelling is being performed under direct and integrated using the ArcView Extension SPATIAL ANALYST.

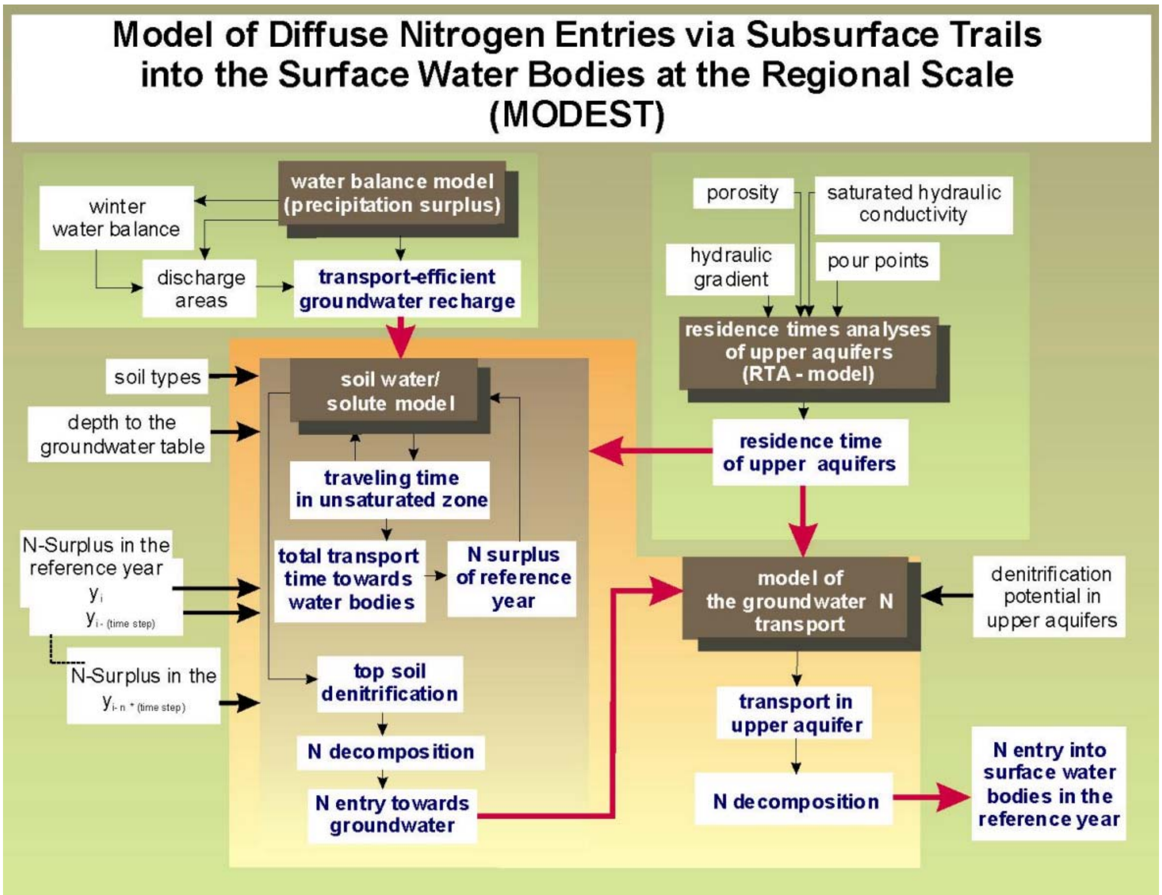


Figure 4.9: Schematic of the MODEST modelling procedure

Thus, the GIS is not simply linked with the modelling procedure as a pre- or postprocessor for preparing input data or illustrating the results (such as applied in the MONERIS approach), but provides the basic environment for all the modelling calculations. The programming code is written in AVENUE (the ArcView programming language) and AML (Arc Macro Language – ARC/INFO and GRID procedures). MODEST itself is working within the ArcView Extension, whereas the N input grids and the residence time distribution are created by means of AMLs. The grid size is variable, but has been chosen to 250 m for the present study, as a compromise between the available medium-scale input information (Chapter 3), the required process-adequate spatial resolution, and the purposive reduction of computational expenditure.

The following modelling components are used to characterise the processes of vertical and lateral subsurface water flow and dissolved N transport to the water courses and have been combined into the GIS-based MODEST methodology (Figure 4.9):

1. Flow Calculation

- The modelling tool ABIMO (Glugla & Fürtig 1997; cf. Bonta & Müller 1999) to calculate the long-term mean annual excess precipitation (considered as steady-state subsurface flux resp. groundwater recharge). It fits very well into the chosen class of process-oriented modelling with high spatial resolution and has been proven to be valid for the water balance of unconsolidated rock regions of eastern Germany and western Poland. For linking the stand-alone computer model ABIMO with the grid-oriented project database, a bi-directional data interface has been developed at ZALF.

- A piston-flow soil water model (Equation 4.43) based on GÄTH & WOHLRAB (1992) to describe the mean percolating velocity of the nitrate front $v_T(i,j)$ in dm/a in a certain grid cell (i,j) resulting from groundwater recharge and exchange of the stored soil water volume throughout the unsaturated zone:

$$v_T(i,j) = \frac{R(i,j)}{FC_{sub}(i,j)} \tag{4.43}$$

with $v_T(i,j)$ – Long-term mean vertical percolating velocity in grid cell (i,j), in dm/a
$R(i,j)$ – Mean groundwater recharge from ABIMO (cell i,j), in mm/a
$FC_{sub}(i,j)$ – Field capacity of the subsoil (cell i,j), in mm/dm

Dividing the groundwater depth $DGT(i,j)$ by $v_T(i,j)$ results in the following relationship for calculation of the travelling time of dissolved nitrate $t_T(i,j)$ in years, vertically downwards from the soil surface to the groundwater, in grid cell (i,j):

$$t_T(i,j) = 10 \cdot DGT(i,j) \frac{FC_{sub}(i,j)}{R(i,j)} \tag{4.44}$$

with $t_T(i,j)$ – Long-term mean vertical travelling time in grid cell (i,j), in a
$DGT(i,j)$ – Depth to the groundwater table (cell i,j), in m

- Modelling the groundwater-borne lateral nitrate flow at the medium scale, based on a calculation of the long-term mean groundwater residence time according to the WEKU model (KUNKEL & WENDLAND 1997). Renouncing their stochastic treatment of hydrogeological information, a deterministic steady-state approach to calculate the subsurface pathways and residence times has been integrated into the own grid-oriented GIS procedure. Following Darcy's law, the groundwater velocity $v_a(i,j)$ in grid cell (i,j) in m/d is calculated:

$$v_a(i,j) = \frac{k_f(i,j)}{n_f(i,j)} I(i,j) \tag{4.45}$$

with $v_a(i,j)$ – Mean groundwater flow velocity in grid cell (i,j), in m/d
$k_f(i,j)$ – Saturated hydraulic conductivity (cell i,j), in m/d
$n_f(i,j)$ – Effective yield of pore space (cell i,j), derived from $k_f(i,j)$, in m³/m³
$I(i,j)$ – Hydraulic gradient (cell i,j), in m/m

Analysis of the interpolated groundwater surface provides the flow direction and the hydraulic gradient for each grid cell (i,j). The flow path from any cell (i,j) towards the pour point (m,n) at the receiving water is detected using GRID's neighbourhood analysis functions.

Exercising the following Equation 4.46 will result in the long-term mean residence time $t_{tot}(i,j)$. It describes the time required for dissolved nitrate to be laterally (regionally) transported through the aquifer between the initial grid cell (i,j) $(k = 1)$ and the final grid cell (m,n) at the pour point $(k = p)$, as calculated by the sum of the elementary residence times within each of the consecutive grid cells $t_a(k)$, along with the groundwater flow path $k = 1 \ldots p$:

$$t_{tot}(i,j) = \frac{1}{365}\sum_{k=1}^{p} t_a(k) = \frac{1}{365}\sum_{k=1}^{p} \frac{l_a(k)}{v_a(k)} \tag{4.46}$$

with $t_{tot}(i,j)$ – Total long-term mean groundwater residence time between any grid cell (i,j) and the receiving water, in a
k – Number of a grid cell along with the groundwater flow path
$t_a(k)$ – Elementary residence time within cell k, in d
$l_a(k)$ – Flow length within cell k, in m
$v_a(k)$ – Long-term mean groundwater flow velocity within cell k, in m/d

The validity of this approach is restricted to groundwater drained by those receiving waters which are taken into consideration in creating the underlying groundwater table map.

2. Calculation of N Load/N Concentration

Between specific N load and dissolved N concentration, the following general relationship exists:

$$N(i,j) = c_N(i,j) \cdot R(i,j)/100 \tag{4.47}$$

with $N(i,j)$ – Specific N load entering resp. leaving a certain compartment of the subsurface pathway related to cell (i,j), in kg/ha/a
$c_N(i,j)$ – Concentration of dissolved N entering resp. leaving a certain compartment of the subsurface pathway related to cell (i,j), in mg/l
$R(i,j)$ – Subsurface discharge/specific flow (cell i,j), in mm/a

According to the piston-flow concept, the steady-state flux along the subsurface path is equal to groundwater recharge, $R(i,j)$. Dispersion is not taken into consideration. Within the MODEST model, calculation of N depletion is performed on the basis of c_N. The respective specific N loads are used for evaluation, interpretation and presentation, but also to quantify the primary N input at the soil surface, topsoil denitrification, as well as the total N load received by a water from its catchment. In detail, the following N-related modelling components have been included into MODEST:

- A denitrification model (KÖHNE & WENDLAND 1992) to calculate the microbial reduction of the annually and spatially variable specific "N input" $N_0(i,j)$ within the topsoil layer (0.5 m). $N_0(i,j)$ is equal to the N input related to the year of pouring out into the surface water body, shifted by the total transport time (cf. Table 4.17). The specific N load $N_1(i,j)$

in kg/ha/a ("N leaching") released from the root zone in cell (*i,j*) and moving towards groundwater is calculated by:

$$N_1(i,j) = N_0(i,j) \cdot \left(1 - \frac{D_{\max}(i,j)}{7.5 \cdot K(i,j) + N_0(i,j)}\right) \tag{4.48}$$

with $N_1(i,j)$ – Specific N load released from the root zone in grid cell (*i,j*) ("N leaching"), in kg/ha/a
$N_0(i,j)$ – Specific N input at the soil surface (cell *i,j*), in kg/ha/a
$D_{max}(i,j)$ – Denitrification potential (cell *i,j*), in kg/ha/a
$K(i,j)$ – MICHAELIS-MENTEN reaction constant (cell *i,j*), in mg N per kg soil per year

$N_0(i,j)$ is obtained from summarising the specific agricultural N surplus NU_{sur} (Chapter 4.1.2.1) and the specific N load from atmospheric deposition for a certain year. Topsoil denitrification is considered as completed within one year without noticeable time lag. From $N_1(i,j)$ the N leaching concentration $c_{N1}(i,j)$ is derived after Equation (4.49).

- An optional N reduction (Equation 4.49) in the percolating water before entering the groundwater body in grid cell (*i,j*). N concentration resp. N load ("N entry") remaining at the groundwater surface, $c_{N2}(i,j)$ or $N_2(i,j)$, is important e. g. to quantify the risk and amount of N pollution to groundwater:

$$c_{N2}(i,j) = c_{N1}(i,j) \cdot k_v \tag{4.49}$$

with $c_{N2}(i,j)$ – N concentration entering groundwater in grid cell (*i,j*) ("N entry"), in mg/l
$c_{N1}(i,j)$ – N concentration at the top soil bottom (cell *i,j*), in mg/l
k_v – Reduction constant, in mg/mg

In general, denitrification in the unsaturated zone is limited due to the presence of oxygen, and nitrate decomposition will hardly occur before reaching the capillary fringe and the uppermost groundwater zone. Processes are not really well-understood, and geological as well as hydrochemical parameters of this zone are not available for regional modelling. As a consequence, no kinetic approach has been applied for the vertical compartment. The reduction constant k_v may be chosen between 0.5 and 1.0. However, as test runs by MODEST have indicated, vertical denitrification is of minor concern for the N load calculated to enter the waters, compared with the lateral compartment.

- Loss of nitrogen along the lateral groundwater path using a first-order model of the concentration-triggered decomposition of dissolved nitrate. The basics of such an approach are outlined e. g. in BÖTTCHER et al. (1989). N concentration $c_{N3}(i,j)$ in mg/l ("N charge") entering the receiving water from a certain grid cell (*i,j*) is calculated based on the total groundwater residence time $t_{tot}(i,j)$ (following Equation 4.46, in years now) for this grid cell:

$$c_{N3}(i,j) = c_{N2}(i,j) \cdot e^{\frac{-0.693 \cdot t_{tot}(i,j)}{t_{1/2}}} \qquad (4.50)$$

with $c_{N3}(i,j)$ – N concentration entering the receiving water from grid cell (i,j) ("N charge"), in mg/l

$c_{N2}(i,j)$ – N concentration entering groundwater (cell i,j), in mg/l

$t_{tot}(i,j)$ – Total residence time between cell (i,j) and the receiving water, in years (Equation 4.46)

$t_{½}$ – Half life of denitrification along the lateral path, in a

Compared with the unsaturated zone, denitrification in the groundwater zone of the unconsolidated rock region is presumably more effective. This is due to predominantly reduced aquifer conditions as characterised by a lack of oxygen and the often concomitant presence of oxidable material (organic carbon, pyrite) prevailing in wide areas of that region (WENDLAND & KUNKEL 1999).

Half life (in years) characterising the denitrification potential is calibrated for selected catchments in preliminary model runs and finally to be regionalised. In general, $t_{½}$ will be between 2 and 5 years.

- A procedure for summarising partial N loads $a \cdot N_3(i,j)$ – related to a certain reference year, but considering the spatially variable residence time – of all the grid cells contributing to the water w to provide the N load $n_{tot}(\mathbf{W})$ in tons per year entering the water w via groundwater from its catchment area **W** in a reference year:

$$n_{tot}(\mathbf{W}) = \frac{a}{10^7} \sum_i \sum_j N_3(i,j) \qquad i,j \in \mathbf{W} \qquad (4.51)$$

with $n_{tot}(\mathbf{W})$ – Total N load entering the water w in a certain reference year, in t/a

$N_3(i,j)$ – Specific partial N load as derived from N charge from grid cell (i,j), in kg/ha/a

a – Grid cell area (a = 62,500 m²)

W – Set of the grid cells defining the catchment area of water w

Despite the steady-state solution of the flow problem, even scenarios of the temporal change of emitted N load reflecting any change of N input can be handled by MODEST. This is possible by stepwise superimposing annual total N loads resulting from the period before and, for future-oriented scenarios, after the current modelling time period. As mentioned above, spatial distributions of N input are required as input grids for the duration (history, present, and future) of the scenario to be analysed. The required convolution procedure has been implemented into the MODEST Extension (Figure 4.5).

A measure for the overall N retention potential $RET(i,j)$ at catchment scale is derived from the following equation:

$$RET(i,j)=\frac{N_0(i,j)-N_3(i,j)}{N_0(i,j)}, \qquad RET(i,j) \in (0,1) \tag{4.52}$$

RET(*i,j*) covers all the discussed sub-processes of the subsurface dissolved nitrate transport and decomposition and varies between 0 and 1.

In Equation 4.52, the specific N input at soil surface $N_0(i,j)$ has to be taken into account as shifted by the time lag $t_T(i,j) + t_{tot}(i,j)$ – the sum from travelling and residence times – related to the reference year (t_0) for calculating $N_3(i,j)$. This should also be the rule for evaluating all the other interim specific N loads according to the Table 4.19.

In principle, the time axis is to be understood as paralleled with the subsurface flow path, starting in the reference year from the pour point at the water body and traced backwards up to the soil surface in grid cell (*i,j*). In Chapter 5 this conception will be applied in presenting and discussing the results.

Table 4.19: Relation between interim specific N load, time shift due to transport, and related year

Interim specific N load portion	**Time shift**	**Related year**
$N_3(i,j)$ … N charge/load	0	$t_0(i,j)$ … Reference year
$N_2(i,j)$ … N entry	$t_{tot}(i,j)$	$t_0(i,j) - t_{tot}(i,j)$
$N_1(i,j)$ … N leaching	$t_{tot}(i,j) + t_T(i,j)$	$t_0(i,j) - t_{tot}(i,j) - t_T(i,j)$
$N_0(i,j)$ … N input	$t_{tot}(i,j) + t_T(i,j)$	$t_0(i,j) - t_{tot}(i,j) - t_T(i,j)$

4.1.2.7 Nutrient Emissions via Urban Areas

Within this pathway nutrient inputs stem from four different routes:

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

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

$$A_{IMP} = 9.6 \cdot \left(0.4047 \cdot POP_{DEN}\right)^{0.573-0.0391 \cdot \log\left(0.4047 \cdot POP_{DEN}\right)} \cdot A_{URB} \tag{4.53}$$

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

The total paved urban area is split into the different sewer systems according to the percentage of the different sewer systems in the river basins. For Germany, the statistics of the German states is used for the length of combined, waste water and separate sewers. The information was available for larger river basins.

For the Czech Republic it is assumed according to the available data for some towns (see Table 3.8) that only combined sewer systems are used.

For Poland the proportion of the sewer systems for the towns is calculated. The sewage system ratio (ratio of the sum of the length of the combined sewers and the sanitary sewers to the combined sewers) of the known Polish and Czech towns is related to the elevation of the towns (Figure 4.10). In towns situated more than 200m a.sl. normally the combined sewer system is used. The sewage system ratio for the Polish towns for which no data are available is calculated with the following formula:

$$SER = \frac{l_{CSO} + l_{SAS}}{l_{CSO}} = \frac{0.01534 - 0.97541}{1 + e^{(h_M - 196.66)/9}} + 0.97541 \tag{4.54}$$

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

The mean elevation of the subcatchments is derived from the Digital Elevation Model (Map 3.x).

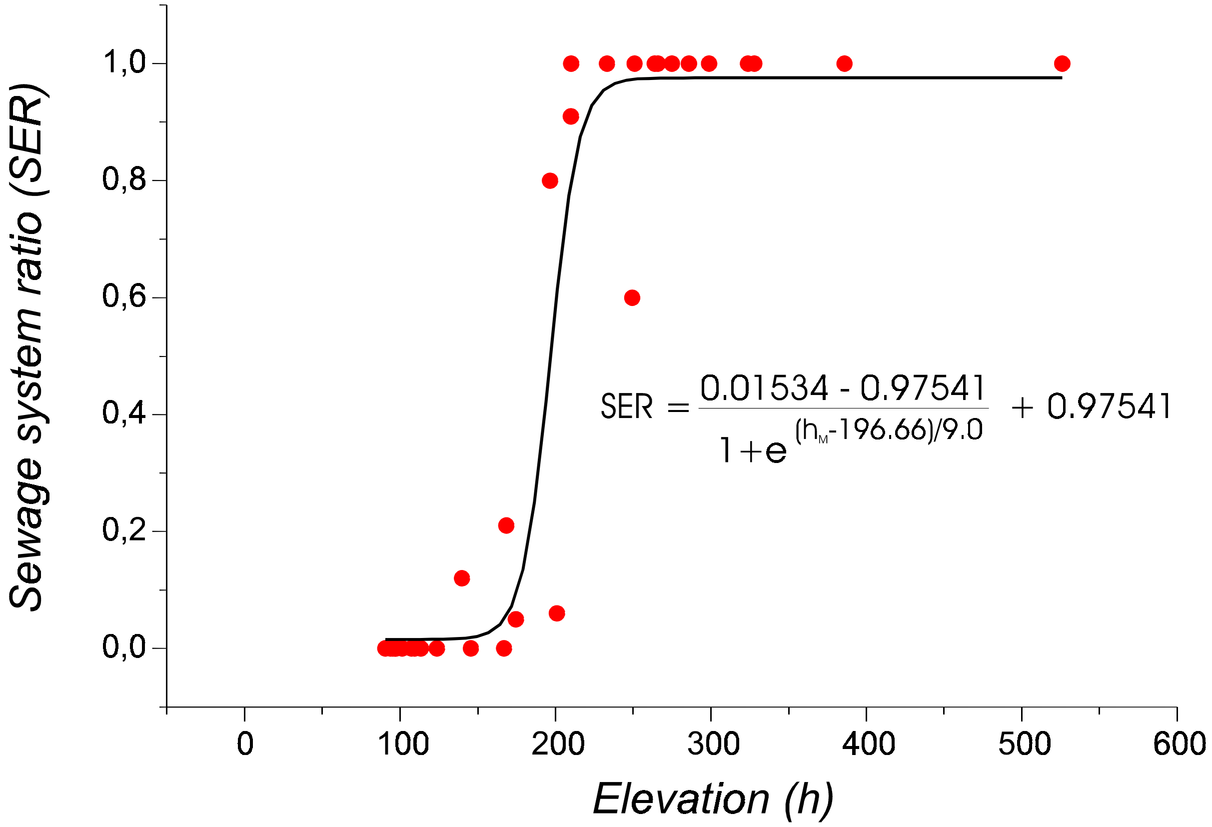


Figure 4.10: Comparison between the calculated sewage system ratio and the known values for Polish and Czech towns within the Odra basin.

To calculate the total discharge from the different sewer systems the calculation of surface runoff from impervious areas as the proportion of precipitation is necessary. These values can be calculated according to HEANEY et al. (1976) for every catchment area from the level of impervious areas with Equation 4.55:

$$a_{IMP} = 0.15 + 0.75 \cdot \frac{A_{IMP}}{A_{URB}} \tag{4.55}$$

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

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

$$q_{IMP} = a_{IMP} \cdot P_Y \tag{4.56}$$

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

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

A schematic overview of the applied method is given Figure 4.11.

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

$$EUS_{N,P} = ES_{IMP_{N,P}} \cdot A_{IMPS} \tag{4.57}$$

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

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

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

$$Q_{IMPC} = q_{URBV} \cdot A_{IMPC} + Z_{NST} \cdot (IN_C \cdot q_{IN} + a_{COM} \cdot q_{COM} \cdot 100 \cdot 86.4 \cdot A_{URB}) \tag{4.58}$$

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

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

$$Z_{NST} = 0.0000013 \cdot P_Y^{2.55}) \tag{4.59}$$

Consequently the number of effective storm water days vary in the Odra catchment between lower than 10 for the flatland areas and about 50 in the cities of the mountain region.

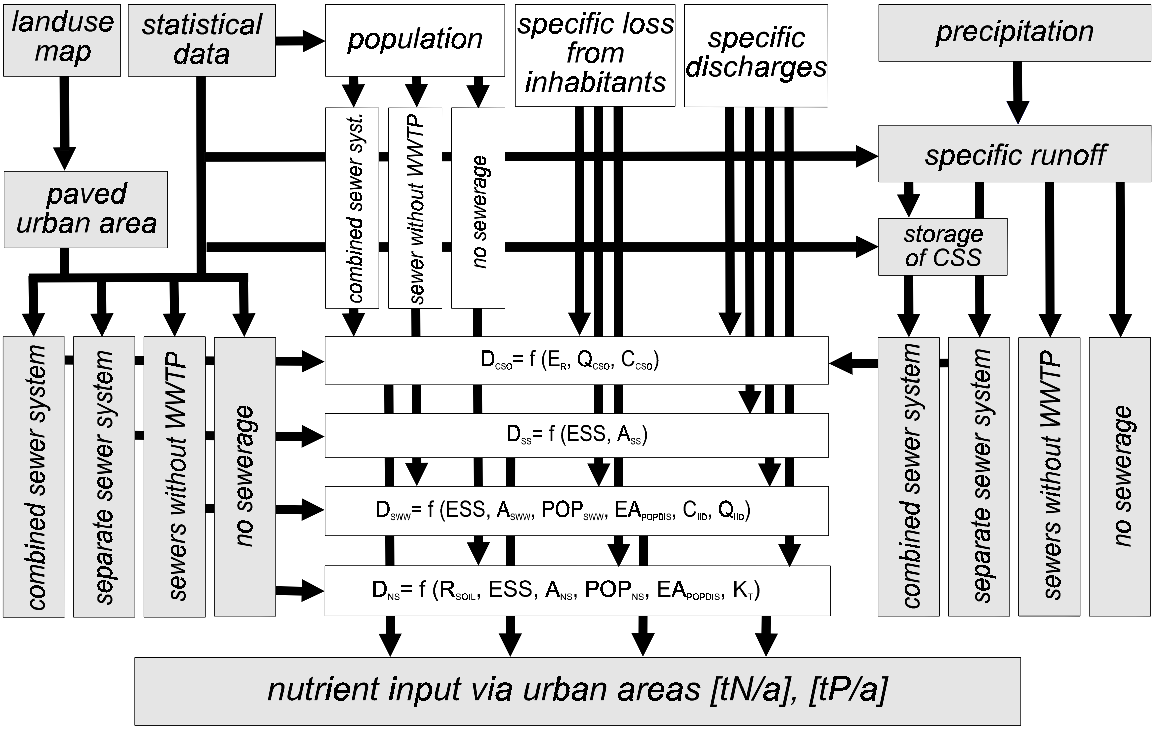


Figure 4.11: Nutrient emissions via urban areas.

The discharge rate of a combined sewer system was estimated according to a method developed by MEISSNER (1991) and is dependent on the annual precipitation as well as the storage volume of the combined sewer. The storage volume holds back a fraction of the waste water during the storm water event and retards the flow to the treatment plant. Data on the storage volume of the combined sewers in the German countries was taken from the sewage water statistics. For Poland and the Czech Republic the storage volume was assumed to be 5,0 m³/ha. The discharge rate was estimated according to Equation 4.60:

$$RE = \frac{\dfrac{4000 + 25 \cdot q_R}{0.551 + q_R}}{V_S + \dfrac{36.8 + 13.5 \cdot q_R}{0.5 + q_R}} - 6 + \frac{P_Y - 800}{40} \tag{4.60}$$

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

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

$$C_{C_{N,P}} = \frac{\left((EIN_{N,P} \cdot IN_C + C_{COM_{N,P}} \cdot Q_{COMC}) \cdot Z_{NT} + ES_{IMP_{N,P}} \cdot A_{IMPC} \cdot 100 \right) \cdot \dfrac{RE}{100}}{Q_{COMC}} \tag{4.61}$$

with $C_{C_{N,P}}$ = nutrient concentration in combined sewers during overflow [g/m³],

$EIN_{N,P}$ = inhabitant specific nutrient output [g/(E·d)],

IN_C = number of inhabitants connected to combined sewer system,

$C_{COM_{N,P}}$ = nutrient concentration in commercial wastewater [g/m³] and

Q_{COMC} = runoff from commercial areas connected to combined sewers [m³/d].

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

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

$$EUC_{N,P} = C_{C_{N,P}} \cdot RE \cdot Q_{IMPC} \tag{4.62}$$

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

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

It is supposed that the particulate fraction of the human nutrient output from inhabitants only connected to sewers is transported to waste water treatment plants. For the dissolved fraction it is assumed that this proportion is fully supplied to the sewer system. The total nutrient input along this pathway will then be calculated according to Equation 4.63:

$$EUSO_{N,P} = ES_{N,P} \cdot A_{IMPSO} \cdot 100 + IN_{SO} \cdot EIN_{D_{N,P}} \cdot 0.365 + C_{COM_{N,P}} \cdot Q_{COMSO} \tag{4.63}$$

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

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

IN_{SO} = inhabitants connected only to sewers,

Q_{COMSO} = annual runoff from commercial areas only connected to sewers [m³/s]

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

The specific human dissolved nitrogen outputs was assumed to 9 g N/(inh·d) for all inhabitants in the Odra basin. For Phosphorus it have to be assumed that the dissolved emissions are different for Germany, Poland and Czech Republic because use of phosphorus in detergents varies between the countries. The analysis of the inhabitant specific P-emissions in Germany (Schmoll, 1998) has that about 0.75 gP/(inh.·d) will be emitted as particulate phosphorus. If this assumption is transferred to Poland and Czech Republic a dissolved emission of 2.5 gP/(inh.·d) and 1.75 gP/(inh.·d), respectively.

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

$$EUN_{N,P} = (100 - R_{S_{N,P}}) \cdot (ES_{IMP_{N,P}} \cdot A_{IMPN} \cdot 100 + IN_N \cdot EIN_{D_{N,P}} \cdot 0.365 \cdot (100 - W_{TR})) \qquad (4.64)$$

with $EUN_{N,P}$ = nutrient input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants [t/a],

$R_{S_{N,P}}$ = nutrient retention in soil (80% for nitrogen and 90% for phosphorus),

A_{IMPN} = impervious urban area connected neither to a sewer nor to a wastewater treatment plant [km²],

IN_N = inhabitants connected neither to sewers nor to wastewater treatment plants and

W_{TR} = proportion of dissolved human nutrient output transported to wastewater treatment plants [%].

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

4.2 *Method for the estimation of Heavy Metal Emissions*

As shown by Vink & Behrendt (2001) and Fuchs et al. (2001) heavy metal emissions into medium and large German river basins can be estimated, if an adapted MONERIS approach will be used for the diffuse heavy metal inputs. Within this study we tried to apply this adapted MONERIS version for the Odra basin, in order to access on the same geographic and statistic input data, used for the calculation of nutrient emissions into German river systems (e.g. total amount of paved areas, status of waste water treatment, area of river catchment etc.). The model is based on a Geographic Information System (GIS) which includes extensive statistical information (see chapter 3). Within the scope of this project specific concentration and load data as well as the main transport and retention processes were integrated in the provided framework of the model.

4.2.1 Point sources

To quantify the emissions from point sources two pathways (input from municipal waste water treatment plants (MWWTP), direct input from industrial sites) were taken into account. Fuchs et al. (2001) proposed the need for a third pathway (discharges caused by historic mining activities). This pathway could not be considered caused by the lack of data. For the point source pathways the preferred method of Fuchs et al. (2001) was to estimate the total annual load discharged into the river systems by multiplication of average effluent concentrations and annual waste water flow.

4.2.1.1 Input via municipal wastewater treatment plants

The calculation of heavy metal emissions via municipal wastewater treatment plants (WWTP) for the time periods of 1993-1997 was based on a nation-wide survey of MWWTP effluent concentrations in Germany. According to Fuchs et al. (2001) the quantity and quality of data received from different authorities varied distinctly. Especially the wide range of the notified quantification limits required a method to improve the data-basis. In a multistage process implausible data sets were removed (see Böhm et al., 2001).

Table 4.20: Average effluent concentrations of MWWTPs within Odra Basin for the time periods of 1993-1997 (Data for Germany according to Fuchs et al., 2002).

Watershed	Year	Cd [µg/l]	Cu [µg/l]	Pb [µg/l]	Zn [µg/l]
German part	1995	0.74	14.2	5.71	71.1
Czech part	1997	2.2	11.4	10.3	146.7

For the German part of the Odra basins Fuchs et al. (2001) reported the effluent concentrations of heavy metals shown in Table 4.20 in the period 1993-1997. Data for the effluent concentrations of heavy metals was available for WWTP`s in the Czech part of the Odra basins (Kovarova, pers. comm.). If these data from different individual WWTP`s are summarized the effluent concentrations given in Table 4.20 can be assumed. For Poland effluent concentrations of heavy metals were not available. Therefore it was assumed that the heavy metal concentration of the outflow od Polish WWTP`s is the same as for the Czech WWTP`s.

The point discharges of heavy metals by WWTP`s are calculated by multiplication of the annual average concentrations with the effluent discharge of treated waste water into the recipient waters of each individual sub catchment of the Odra basin.

4.2.1.2 Input via direct industrial discharges

For the inventories of direct industrial point sources, different individual and aggregated data were used such as Federal state monitoring data, international reports, environmental reports of companies, reports from industrial associations and the results of different research projects. The quality of the available data was very different, and therefore they had to be checked for plausibility and compatibility. Usually, several iteration steps were necessary for this process which often led to corrections of formerly used emission figures. There were some deviations from previously published figures, e.g. in international reports.

For the Odra only on detailed study in relation to the heavy metal discharges from direct industrial sources was available. That is the analysis done by BCEOM (1992). The given figure for this pathway in this study were representative for the period before the changes in the three countries or for the begin of the 1990`s. Therefore it is questionable to use this data for an analysis of heavy metal inputs in the period 1993-1997. On the other hand the study is use full, because it includes a detailed inventory of the location of possible sources of heavy metal discharges.

Some of these can be also found within the preliminary inventory on the direct industrial discharges published by the ICPO (ICPO, 1999). But heavy metal emissions of the different plants are given in the ICPO report very seldom.

To have at least a raw estimation on the heavy metal inputs from direct industrial sources, we assumed the following:

- The possible locations for heavy metal inputs into the river catchments were in the mid of 1990`s the same as given by BCEOM (1992).
- The discharges of heavy metals by these locations were reduced substantially to the mid of 1990`s, by reduction of the production or implementation of newer technologies for production or waste water treatment.

Based on these basic assumption we have taken into account that the direct industrial discharges of cadmium, lead and zinc were reduced to 10% in comparison to the results of BCEOM (1992). For copper it was assumed a lower reduction to 50% only because copper is a main industrial product in the area of upper Odra.

4.2.2 Diffuse sources of heavy metal inputs

In order to access on the same geographic and statistic input data, used for the calculation of nutrient emissions into the Odra system (e.g. total amount of paved areas, status of waste water treatment, area of river catchment etc.), the diffuse emissions of heavy metals were calculated applying an adapted version of MONERIS (MOdelling Nutrient Emissions in RIver Systems, see Chapter 4.1). The model is based on a Geographic Information System (GIS) which includes extensive statistic information.

The diffuse entries of heavy metals into surface waters represent the sum of various pathways, which have been realized over the different components of the runoff. There are six pathways considered by MONERIS:

- Direct input on the water surface area by atmospheric deposition
- Input via groundwater
- Input via tile drainage
- Input via erosion
- Input via surface runoff (only dissolved components)
- Input from paved urban areas

The input via the pathways farmyard seepage and spraydrift, fertilizer and manure washoff and shipping (given by Fuchs et al., 2001) were not quantified because the database was to pure.

4.2.2.1 Direct heavy metal input to the surface waters via atmospheric deposition

The direct input of heavy metals on the water surface by atmospheric deposition was estimated by multiplication of the deposition rate of heavy metals and the total area of surface waters in the individual sub basin of the Odra:

$$E_D = A_W \cdot D \cdot 1000 \qquad (4.65)$$

E_D = input of heavy metals via atmospheric deposition [kg/a]
A_W = total water surface area [ha]
D = atmospheric deposition rate of heavy metals [g/(ha·a)]

Atmospheric deposition (wet and dry) of the metals Cd and Pb was modeled for Europe since 1996 by EMEP/MSC-East on the basis of a 50x50 km grid. The deposition rates of Cd and Pb within the Odra basins are shown in Map 3.14 and 3.15. Based on these data, the direct input into surface waters via atmospheric deposition was calculated for the large river basins. For the other metals (Zn and Cu), the same distribution as for Cd within the basins was assumed and the total amount of Zn and Cu deposition was estimated by the ratio between the average deposition rates (Zn/Cd and Cu/Cd) was used which was estimated for Germany by Fuchs et al. (2002). The ratio can be calculated by means of Table 4.21.

Table 4.21: Total deposition rates of heavy metals [g/(ha·a)].

	Year	Cd	Cu	Pb	Zn
Germany	1995	0.81[6)]	23.4[7)]	24.8[6)]	253[6)]

[6)] 1996, 1999 (EMEP, 2001); [7)] 1994-1996, 1999 (UBA, 2001)

4.2.2.2 Heavy metal input via surface runoff

Emissions from surface runoff are defined as the dissolved share of heavy metals within surface runoff from unpaved areas such as arable land, grassland and other open areas caused by high rainfall events. Emissions of particle bound heavy metals within surface runoff are considered in the erosion pathway.

The calculation of specific surface runoff within the MONERIS model is based on the approach according to Liebscher & Keller (1979) and shown in detail in Chapter 4.1.2.3.

Data on dissolved heavy metal concentrations in surface runoff from unpaved areas does not exist in the literature. Therefore metal concentrations in rainfall have been used as emission factors (Table 4.22).

Table 4.22: Heavy metal concentrations in rainfall [µg/l].

	Year	Cd	Cu	Pb	Zn
Germany (UBA, 2001)	1995	0.12	3.3	2.06	13.6

4.3.2.3 Heavy metal input via erosion

Emissions of heavy metals via erosion were determined using the sediment input into surface waters, the concentration of heavy metals in topsoil and an enrichment factor of metals in eroded sediments due to the preferential transport of fine particles:

$$E_{ER} = C_B \cdot SED \cdot ER \cdot 1000 \qquad (4.66)$$

E_{ER} = input of heavy metals via erosion [kg/a]
C_B = concentration of heavy metals in topsoil [mg/kg]
SED = sediment input [t/a]
ER = enrichment ratio [-]

In the framework of the MONERIS system the sediment input into the German river basins was determined by Behrendt et al. (2000).

Heavy metal concentrations in the topsoil of agricultural land were provided for each Federal state of Germany by LABO (1998) (Table 4.23). As the measurements have been made between 1995-1997 it was assumed that these data are representative for the year 1995.

Table 4.23: **Concentrations of heavy metals in the topsoil of agricultural land [mg/kgDM] (LABO, 1998).**

Federal state	Cd	Cr	Pb	Zn
Brandenburg	0.1	4	11.5	15.5
Mecklenburg West Pommerania	0.133	22.7	16.7	45.33
Saxony	0.418	37	52.5	71

Caused by selective erosion and deposition processes, sediments entering the receiving waters show a higher metal concentration than the upper soil. According to the method suggested by Behrendt et al. (2000) and Vink (2000) enrichment ratios were calculated for several river basins using heavy metal contents in suspended solids within the rivers (UBA, 1999) and the upper soil of agricultural land (LABO, 1998). The enrichment ratios received were plotted versus the specific sediment yield of each catchment taken into account.

The relation of enrichment ratios and specific sediment yields can be explained by non linear regressions. Based on these regressions the enrichment of heavy metals was calculated from the specific sediment yield of each German river basin. Average enrichement ratios for German river basins are listed in Table 4.24.

4.3.2.4 Heavy metal input via tile drainage

The input from tile drainage was calculated as the product of the drained area, drainage water volume and average heavy metal concentrations.

$$E_{DR} = \frac{Q_{DR} \cdot A_{DR} \cdot C_{DR}}{1000000} \qquad (4.67)$$

E_{DR} = input of heavy metals via tile drainage [kg/a]

Table 4.24: Average enrichment ratios (ER) for heavy metals.

	Cd	Cu	Pb	Zn
Mean Enrichment Ratios	3.0	3.0	1.5	3.4

Q_{DR} = specific drainage flux [$m^3/m^2 \cdot a$]

A_{DR} = drained area [m^2]

C_{DR} = heavy metal concentration in drainage water [µg/l]

Table 4.25: Mean metal concentrations in seepage water [µg/l] (Bielert et al., 1999).

	Cd	Cu	Pb	Zn
Metal concentrations in seepage water [µg/l]	0.14	4	0.28	19

The drainage area and the specific drainage flux were given within the MONERIS model. The metal concentrations within drainage water are uncertain as only a few literature data are available. Alternatively mean metal concentrations in seepage water were used given by Bielert et al. (1999). For the whole period of 1985-2000 constant heavy metal concentrations in drainage water were assumed, because it is likely that the concentrations in seepage water within a soil depth of 0.8–1 m show only slight changes within this time period. Heavy metal concentrations in seepage water are listed in Table 4.25.

4.2.2.5 Heavy metal input via groundwater

Heavy metal input through groundwater was calculated from the product of groundwater outflow and heavy metal concentrations in springs:

$$E_{GW} = \frac{Q_{GW} \cdot C_{GW}}{1000000} \tag{4.68}$$

E_{GW} = input of heavy metals via groundwater [kg/a]
Q_{Gw} = groundwater flux [m³/a]
C_{GW} = heavy metal concentration in springs [µg/l]

The groundwater flux within MONERIS is calculated from the difference between total average runoff and the sum of surface runoff, drainage flow, atmospheric input flow and wastewater flow. It was assumed that the remaining water quantity is mainly attributed to groundwater inflow.

Taking into account that chemical reactions of heavy metals, especially for groundwater that is poor in oxygen, may occur during the transfer of groundwater into surface waters, groundwater concentrations are unsuitable to determine the heavy metal input via groundwater. In place of groundwater concentrations measured heavy metal concentrations within springs of small streams provided by the geochemical survey of German surface waters (Federal Institute for Geosciences and Natural Resources, Birke et al., 2003) were used (Table 2.26). The load discharged into river systems via groundwater flux is predominantly caused by geogenous sources.

Table 4.26: Median of heavy metal concentrations in springs [µg/l] (Birke et al., 2003).

	Cd	Cu	Pb	Zn
Heavy metal concentration in springs [µg/l]	0.02	1.03	0.11	3.0

4.2.2.6 Heavy metal input via urban areas

In this pathway the diffusive emissions of heavy metals from urban areas are traced to the following sources:

- input from paved urban areas via separate sewer systems,

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

The area of the urban catchments connected to the sewer systems was adopted from MONERIS.

4.2.2.6.1 Heavy metal input via separate sewers

The emissions of heavy metals via separate sewer systems were calculated using specific metal input from the surface of impervious urban areas:

$$E_{UT} = AS_{URB} \cdot A_{URBVT} \cdot 100 \tag{4.69}$$

E_{UT} = heavy metal input via separate sewers [kg/a]
AS_{URB} = specific heavy metal input from impervious urban areas [g/(ha·a)]
A_{URBVT} = impervious urban area connected to separate sewer systems [km^2]

Specific heavy metal inputs from paved urban areas were derived from concentrations within separate sewers given by a literature study (Brombach et al., 2001). The different atmospheric deposition rates were used to carry out this readjustment (see Chapter 4.2.2.1).

The average specific heavy metal input used to calculate the load from paved urban areas are given in Table 4.27 according to Fuchs et al. (2001).

Table 4.27: Specific heavy metal input from paved urban areas [g/(ha·a)].

Specific metal input [g/(ha·a)]	Cd	Cu	Pb	Zn
Germany 1995	6.4	300	222	1972

For the spatial distribution the maps of atmospheric deposition of heavy metals (Map 3.14 and 3.15) were used. The total amount of specific heavy metal input were calculated by the ratio of the data given in Table 4.25 and 4.19 for the average specific heavy metal inputs from paved urban areas and the specific atmospheric deposition.

4.2.2.6.2 Heavy metal input via combined sewer overflows

Combined sewer systems collect the input from households, indirect industrial input and rain water runoff from paved urban areas. During storm water events, the quantity of water which exceeds the realized storage volume is discharged to surface water. The total input of heavy metals caused by combined sewer overflows was calculated using the following equation:

$$E_{UM} = (AG_E \cdot E_{KA} + C_{GEW} \cdot Q_{GEWM}) \cdot TE + (AS \cdot A_{URBVM} \cdot 100) \cdot \frac{RE}{100} \tag{4.70}$$

E_{UM} = input of heavy metals via combined sewer overflows [kg/a]
AG_E = inhabitant specific metal load [mg/(l·h)]
E_{KA} = inhabitants connected to waste water treatment plants
C_{GEW} = metal concentration in industrial-commercial wastewater [µg/l]
Q_{GEWM} = specific runoff from commercial areas [l/h]
TE = mean time of discharge via combined sewer overflow [h/a]
AS = specific metal input from impervious urban areas [g/(ha·a)]
A_{URBVM} = impervious urban area connected to combined sewer systems [km^2]
RE = discharge rate

Inhabitant specific metal loads are given in Table 4.28. For the former GDR, the inhabitant specific load of Cu was decreased, because Cu was not a common raw material for water pipes. The share of Cu originating from corrosion of water pipes within wastewater from households was estimated by Zessner (1999) as 39 %.

Table 4.28: Inhabitant specific heavy metal load [g/(I·a)].

Inhabitant specific load	Year	Cd	Cu	Pb	Zn
Total load [g/(I·a)]	1995	0.05$^{1)}$	4$^{1)}$	1.6$^{1)}$	23$^{1)}$
Dissolved load [g/(I·a)]$^{2)}$		0.04	2.9	1.5	15.4

$^{1)}$ Zessner (1999); $^{2)}$ Dissolved inhabitant specific input was calculated from total inhabitant input based on information given by Zessner (1999).

For the calculation of the load from industrial-commercial wastewater, Mohaupt et al. (1998) give a figure of 0.5 l/(ha·s) for the specific runoff from commercial urban areas for 10 hours a day based on a total urban area in commercial use of 0.8 %. Metal concentrations in industrial-commercial wastewater are highly variable, from there only a rough estimation is stated in Table 4.29. The discharge rate of a combined sewer system varies in relation to the retention volume of the combined sewer. The discharge rate was estimated according to Meissner (1991). The specific metal input from impervious urban areas correspond to the parameters used for separate sewer systems (see Chapter 4.2.2.6.1).

Table 4.29: Estimation of heavy metal concentrations in industrial-commercial wastewater [µg/l].

	Cd	Cu	Pb	Zn
1995 (Schäfer, 1999)	4.7	149.2	152.3	523.1

4.2.2.6.3 *Heavy metal input via sewers not connected to wastewater treatment plants*

Heavy metal input from households and paved urban areas connected to a sewer system but not to a waste water treatment plant were estimated using the following equation:

$$E_{UK} = E_{UAK} + E_{EWK} \cdot AG_{EG} \cdot 365 + E_{GEWK} \tag{4.71}$$

E_{UK} = heavy metal input via sewers not connected to WWTP`s [kg/a]
E_{UAK} = input from urban areas connected only to sewers [kg/a]
E_{EWK} = inhabitants connected only to sewers
AG_{EG} = inhabitant specific load of dissolved heavy metals [kg/(I·d)]
E_{GEWK} = input from industrial-commercial wastewater [kg/a]

The input of heavy metals from paved urban areas only connected to sewers can be considered in the same way as the areas with separate sewer system (see Chapter 4.2.2.6.1). In addition, the input from inhabitants only connected to sewers must be taken into account. It was assumed that the particulate portion of human heavy metal load is mainly transported to waste water treatment plants. For the dissolved fraction it is assumed that this portion is fully supplied to the sewer system. The specific dissolved heavy metal loads are given in Table 4.26. The proportion of heavy metal input from commercial wastewater is estimated in the same way as explained for the combined sewer overflows (see Chapter 4.2.2.6.2).

4.2.2.6.4 Heavy metal Input via households connected neither to wastewater treatment plants nor sewers

For the households neither connected to wastewater treatment plants nor sewers it was assumed that only the dissolved portion of heavy metals of human load reaches water bodies after percolating through the soil. The fraction of heavy metals retained during the passage in the soil was estimated as 95 %.

$$E_{UN} = (E_{AUN} + E_{EWN} \cdot AG_{EG} \cdot 365) \cdot 0.05 \tag{4.72}$$

E_{UN} = heavy metal input via inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants [kg/a]
E_{AUN} = heavy metal input from paved urban areas connected neither to sewers nor to wastewater treatment plants [kg/a]
AG_{EG} = inhabitant specific load of dissolved heavy metals [kg/(I·d)]
E_{EWN} = inhabitants connected neither to sewers nor to wastewater treatment plants.

4.3 River Loads

For the calculation of nutrient loads the data sets for 42 monitoring cross-sections of the subbasins are used. Heavy metal loads (zinc, cadmium, copper and lead) were calculated using values obtained from 15 cross-sections only.

For each of the investigated subbasins the overall volume of nutrients and heavy metals is calculated according to the Equation 4.73 for each year. This method for calculation of load is also the favored 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.

$$L_y = a \cdot \frac{Q_y}{\sum_{i=1}^{n} q_i} \sum_{i=1}^{n} q_i c_i \tag{4.73}$$

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

From the annual values, the mean load for the studied time period 1993-1997 is estimated according to Equation 4.74:

$$L_P = \frac{1}{p} \cdot \sum_{i=1}^{p} L_Y \tag{4.74}$$

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

4.4 *Retention in the Rivers*

With a comparison between the estimated nutrient emissions and the load in the catchment areas, considerable variation will be determined (BEHRENDT, 1996b; BEHRENDT & OPITZ, 1999) which cannot be explained by an underestimate of the load or an overestimate of the inputs (BEHRENDT & BACHOR, 1998). The differences are due to retention and loss processes within the river systems e.g. sedimentation, denitrification and plant uptake.

Figure 4.12 shows the relationship between the observed nutrient loads and nutrient emissions for various European catchment areas.

On the basis of data for nutrient emissions and loads in 100 catchment areas with a size of 100 to 200,000 km², an empirical model is derived (BEHRENDT & OPITZ, 1999) for the retention of nitrogen and phosphorus in relation to the specific runoff or the hydraulic load in the catchment area. The base for the model is the mass balance of a catchment area, after which the observed nutrient load for a time period of one or more years is the result of the balance of the sum of all inputs from point and diffuse sources and the sum of all retention and loss processes:

$$L_{N,P} = ET_{N,P} - R_{N,P} = \sum EP_{N,P} + \sum ED_{N,P} - \sum R_{N,P} \tag{4.75}$$

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

After adjustments of Equation 4.75 is derived:

$$\frac{L_{N,P}}{ET_{N,P}} = \frac{1}{1+R_{L_{N,P}}} \tag{4.76}$$

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

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

$$R_{L_{N,P}} = a \cdot x^b \tag{4.77}$$

with a, b = model coefficients.

Figures 4.12 to 4.13 show that on the basis of the available data, there are relationships between retention and specific runoff and also the hydraulic load in the catchment areas. Additionally, to the retention derived only for the load of inorganic dissolved nitrogen (DIN) (Figure 4.12 to 4.13) a corresponding relationship was found for total nitrogen (TN) (Figure 4.14). The following models are used for the calculation of retention of TN, DIN and TP:

$$\text{TN}: \quad R_{L_N} = 1.9 \cdot HL^{-0.49} \qquad n = 56,\ r^2 = 0.52 \tag{4.78}$$

with HL = hydraulic load [m/a].

$$\text{DIN}: \quad R_{L_N} = 5.9 \cdot HL^{-0.75} \qquad n = 100,\ r^2 = 0.654 \tag{4.79}$$

$$\text{TP}: \quad R_{L_P} = 26.6 \cdot q^{-1.71} \qquad n = 89,\ r^2 = 0.81 \tag{4.80}$$

with q = specific runoff [l/(s·km²)].

If these approaches are applied, the nutrient load can be calculated from the nutrient inputs for all studied catchment areas (Equation 4.81) and the results can be compared with measured loads.

$$L_{N,P} = \frac{1}{1+R_{L_{N,P}}} \cdot ET_{N,P} \tag{4.81}$$

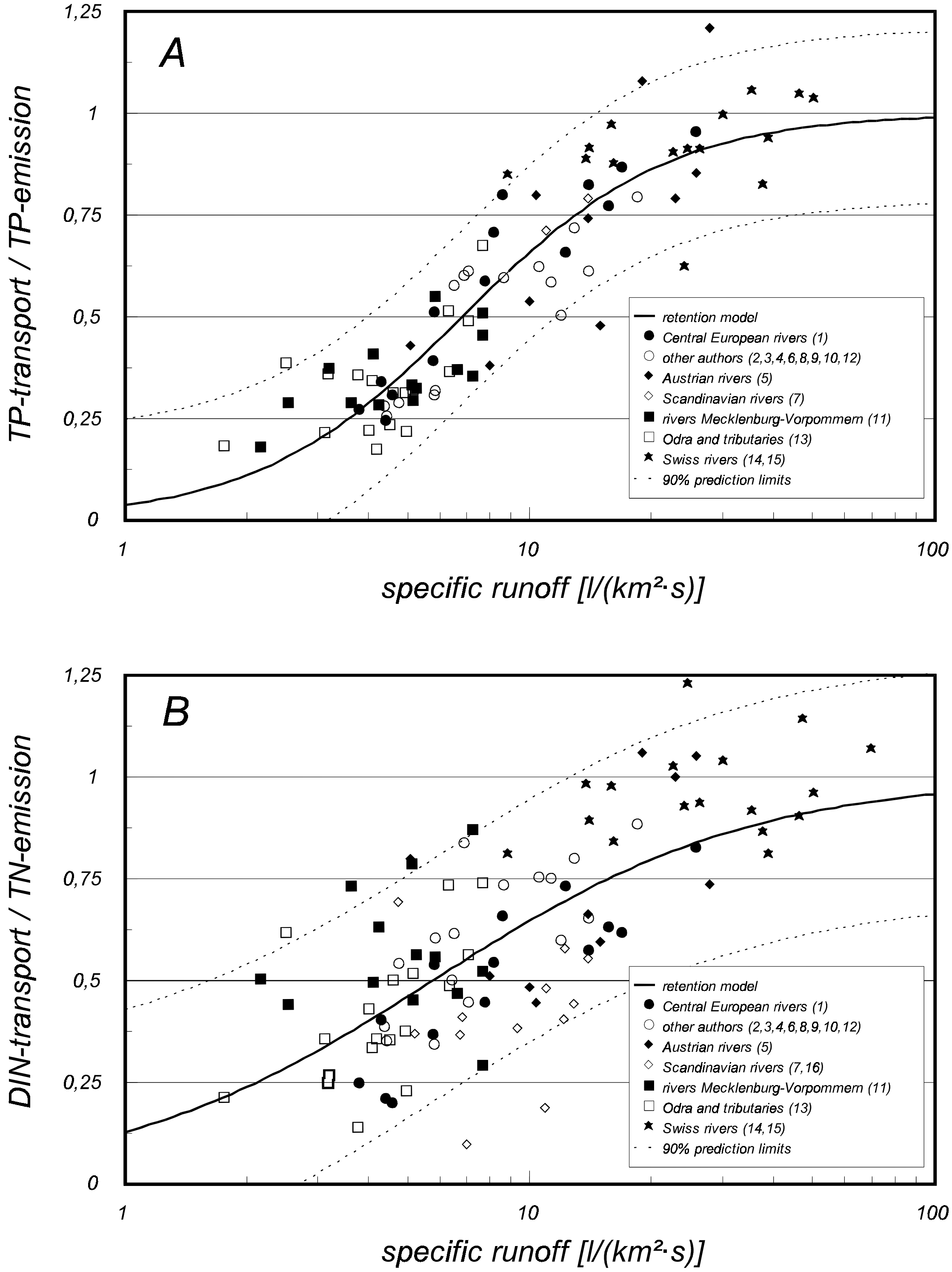


Figure 4.12: Dependence of the fractions of nutrient loadings to nutrient emissions from the specific runoff in the studied catchment areas.

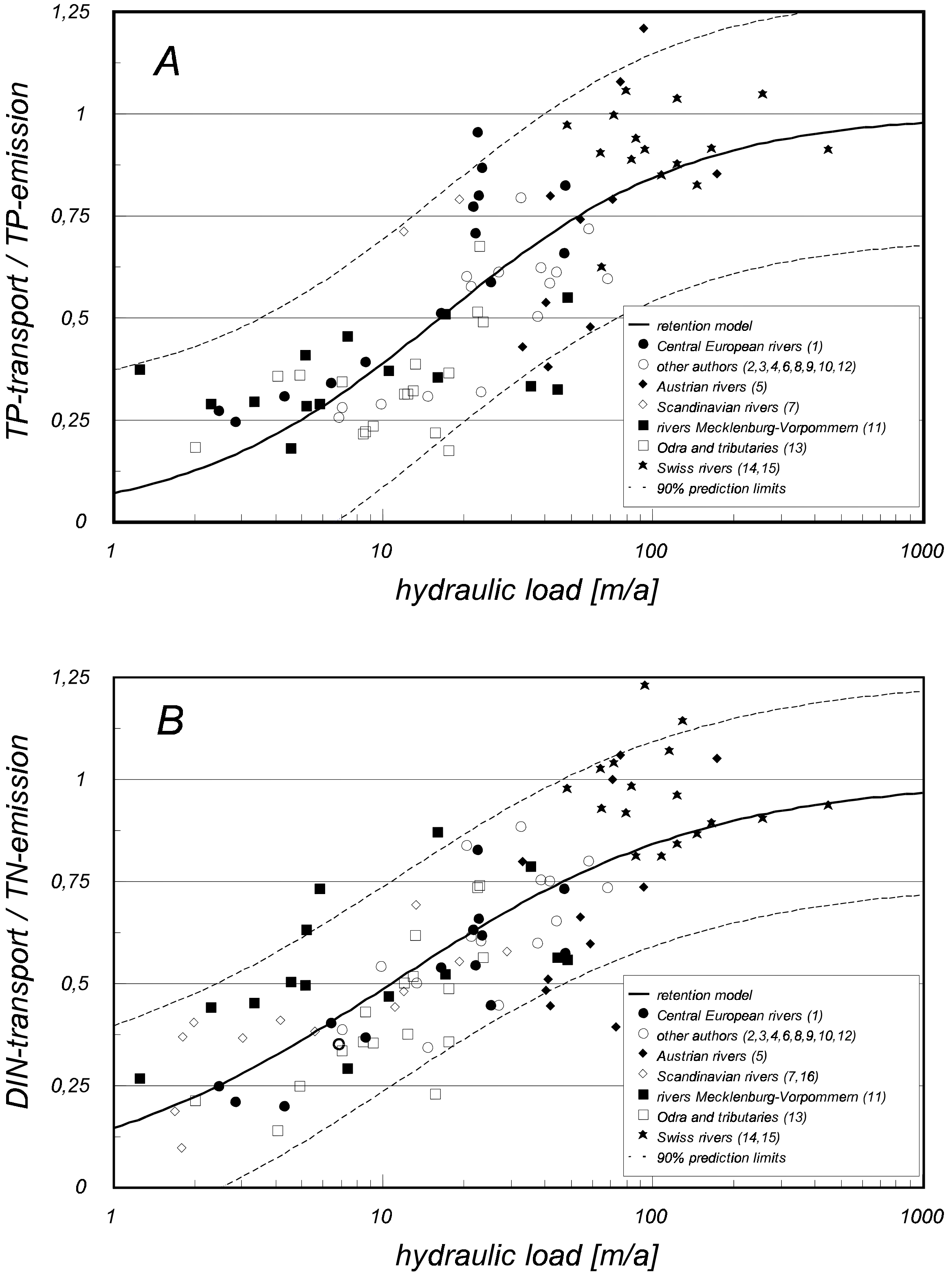


Figure 4.13: *Dependence of the fractions of nutrient loadings to nutrient emissions from the hydraulic load in the studied catchment areas.*

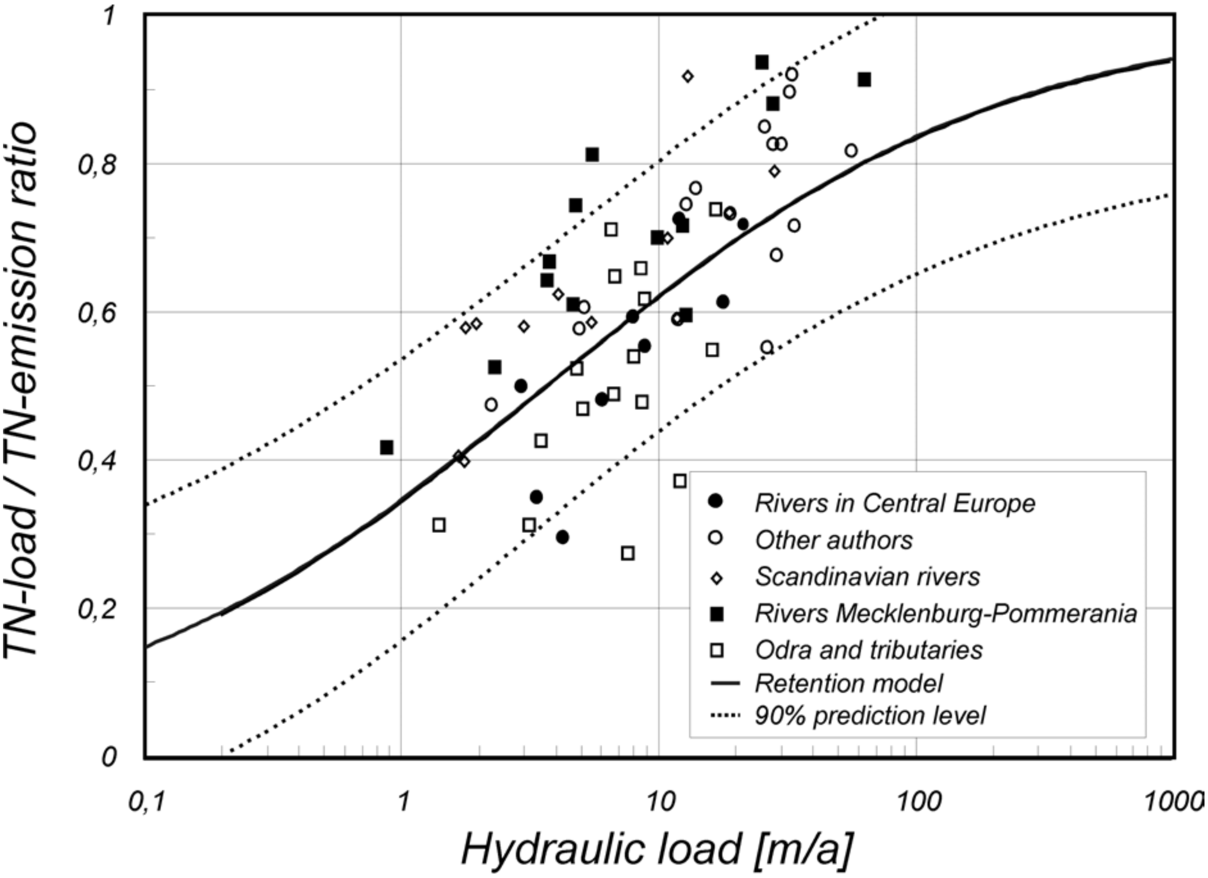


Figure 4.14: Dependence of the fractions of TN load to TN emissions from the hydraulic load in the studied catchment areas.

4.6 Immission Method

The immission method for the calculation of the proportion of the point and diffuse emissions on the load of a river is based on the models of BEHRENDT (1993) and applied for the Rhine and the Elbe and their tributaries, for rivers in Mecklenburg-Western Pomerania and for German rivers (WERNER & WODSAK 1994, BEHRENDT 1996a,b, BEHRENDT et al. 2000).

The monitored load is the sum of the point (LP) and the diffuse load (LD). From the different types of the ratio between the concentrations of the load components the possible relations between the load or concentrations and the discharge are derived (Figure 4.15).

The immission method tries to find out a value for the proportion of the point load from dependencies of the concentration or load from the discharge. For the part A shown in Figure 4.15 (dilution of a constant load – point load) the following applies:

$$LP_{N,P} = L_{0_{N,P}} + C_{D_{N,P}} \cdot Q_P \tag{4.82}$$

with $LP_{N,P}$ = Nutrient load from point sources [t/a],
$L_{0_{N,P}}$ = hypothetic load [t/a] at a discharge 0,
$C_{D_{N,P}}$ = mean concentration of the diffuse emissions [mg/l] and
Q_P = discharge from point sources [m³/s].

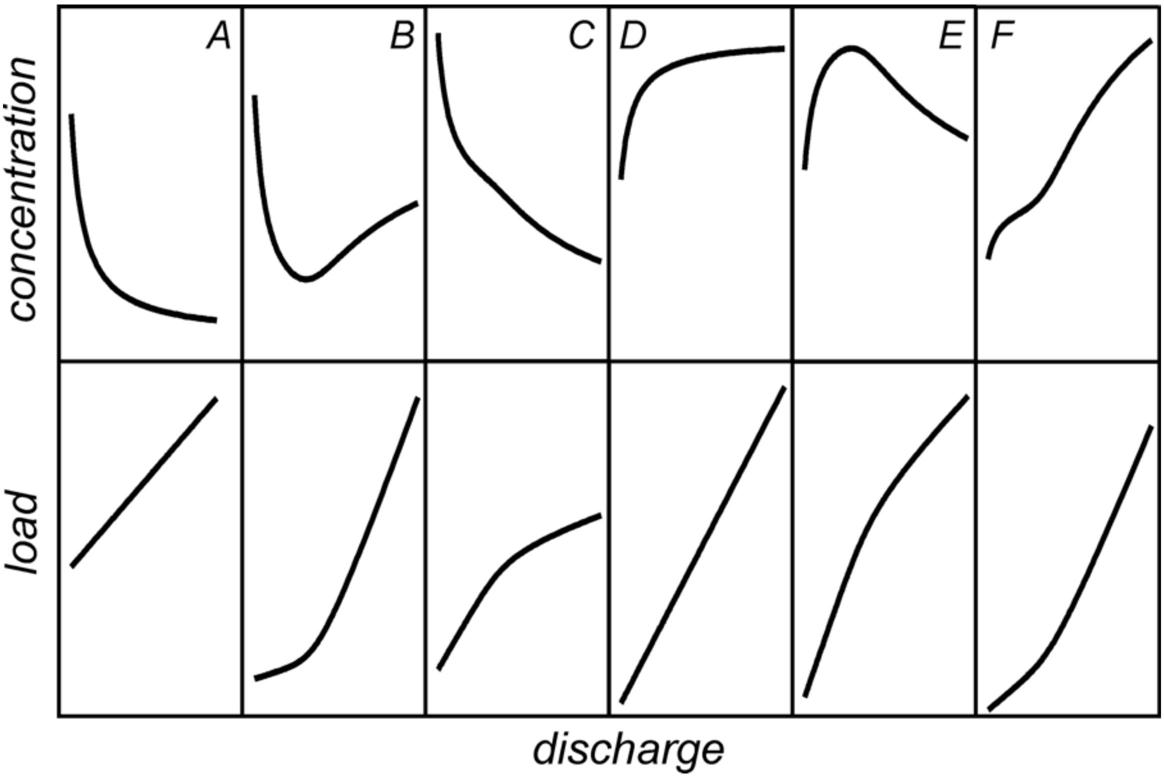


Figure 4.15: Possible relations between concentration or load and discharge within a river.

The parameters L_0 and C_D were calculated from the linear regression between load and discharge or the non-linear regression between concentration and discharge. For the cases B and C the parameters can despite non-linear load dependencies be solved with Equation 4.82, if the regression analyses focuses only on the values of low discharge, where the relation is linear. For the cases D to F Equation 4.82 normally gives no results, because the regressions between load or concentration and discharge result in negative values for L_0. So also LP would be negative, which is not realistic. This is caused by the transfer of the regression result to the value of Q_P which normally is much lower then the river discharge used for the derivation of the regression. Because the load can't be negative, the linear regression is not valid down to a discharge of zero. This is caused by the dilution of the very low point discharges, which after dilution have only a small influence on the on the dependencies of the concentration and load on the discharge. Figure 4.16 shows the derivation of the discharge which is caused by point sources only. If L_0 is above zero, the intersection of the point load L_P with the regression line is situated at Q_P. If L_0 is below zero L_P is the sum of the Q_P and Q_{MIN}:

$$LP_{N,P} = L_{0_{N,P}} + C_{D_{N,P}} \cdot (Q_P + Q_{MIN}) \tag{4.83}$$

with Q_{MIN} = minimum discharge [m³/s].

Q_{MIN} is the discharge, at which the load would be zero, if the regression is used.

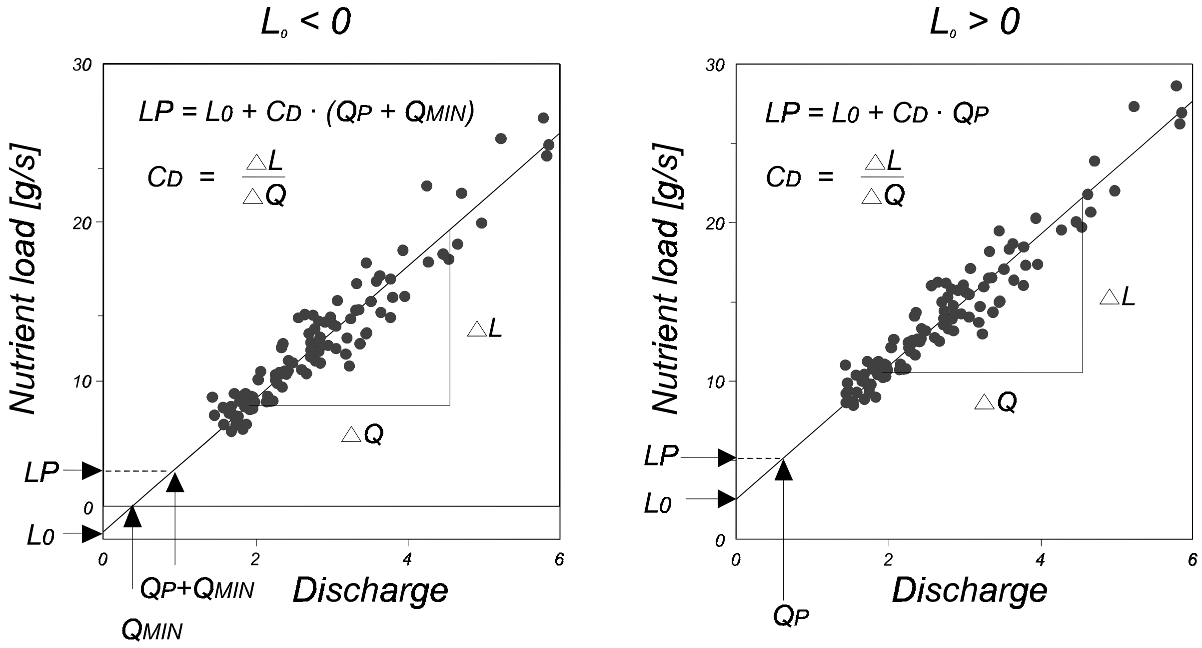


Figure 4.16: Scheme for the estimation of the point load.

The summarised load from diffuse sources is calculated as the difference of the mean load and the point load:

$$LD_{N,P} = L_{N,P} - LP_{N,P} \tag{4.84}$$

with $LD_{N,P}$ = nutrient load from diffuse sources [t/a].

For the calculation in the case of nitrogen a temperature correction of the measured concentrations according to BEHRENDT et al. (1999) is used.

5 Results and Discussion - present state

5.1 Nutrient Emissions from Point Sources

The Tables 5.1 and 5.2 present an overview on the point source inputs into the river system of the Odra and its main tributaries.

According to these Tables the total amount of point source inputs into the Odra river system is about 7970 tP/a and 45300 tN/a for the investigation period 1993 to 1997. As shown in figure 5.1 the major part of the point source emissions into the river system of Odra is caused by Poland (91% and 89% for P and N, respectively). This portions are 7% (P) and 5% (N) higher than the percentage of polish population on the total population living in the Odra basin (84%). This is not only an indication for the present state regarding nutrient elimination in the WWTP`s in the countries but also for the different phosphorus emissions per inhabitant (Poland 3.26 gP/(Inh.·d); Germany 1.8 gP/(Inh.·d); Czech Republic 2.5 gP/(Inh.·d) or different levels of direct industrial inputs especially for nitrogen.

A comparison with other estimations is possible for the Odra basin upstream Krajnik Dolny. According to TONDERSKI (1997) the point source emissions were 14460 tP/a and 60147 tN/a for the period 1992 to 1994. Based on different approaches BEHRENDT et al. (1999) found that point sources discharges were in a range of 10200 to 10800 tP/a and 47800 and 54500 tN/a for the period 1991 to 1994. Whereas the point source discharges of TONDERSKI (1997) estimated by an immission approach seem to be to high, the comparison with the estimations of BEHRENDT et al. (1999)(2000?)would indicate a reduction of point source discharges.

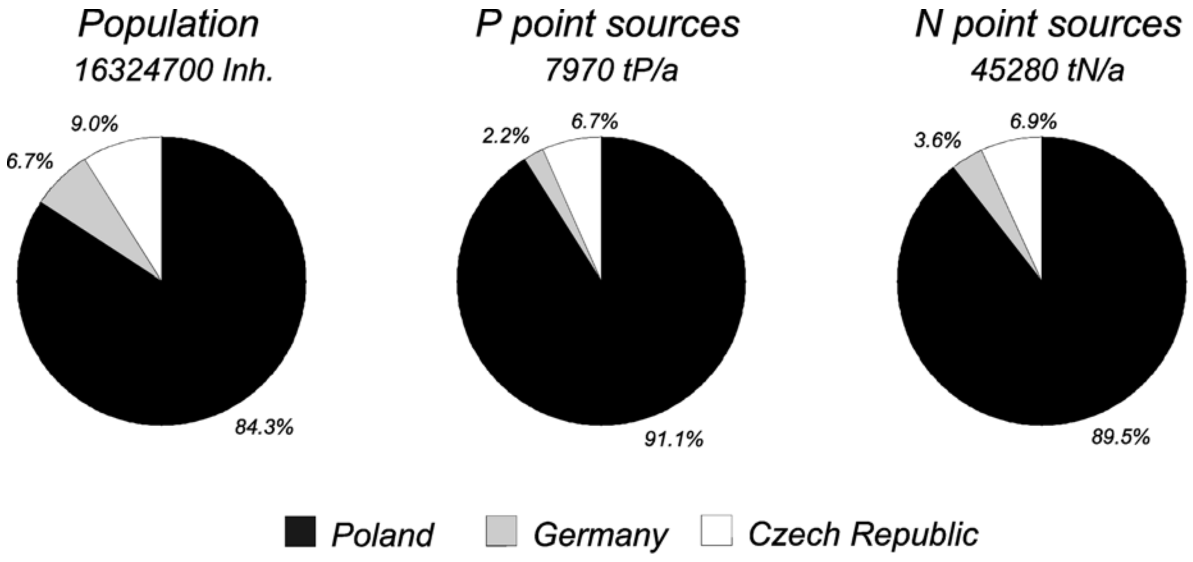


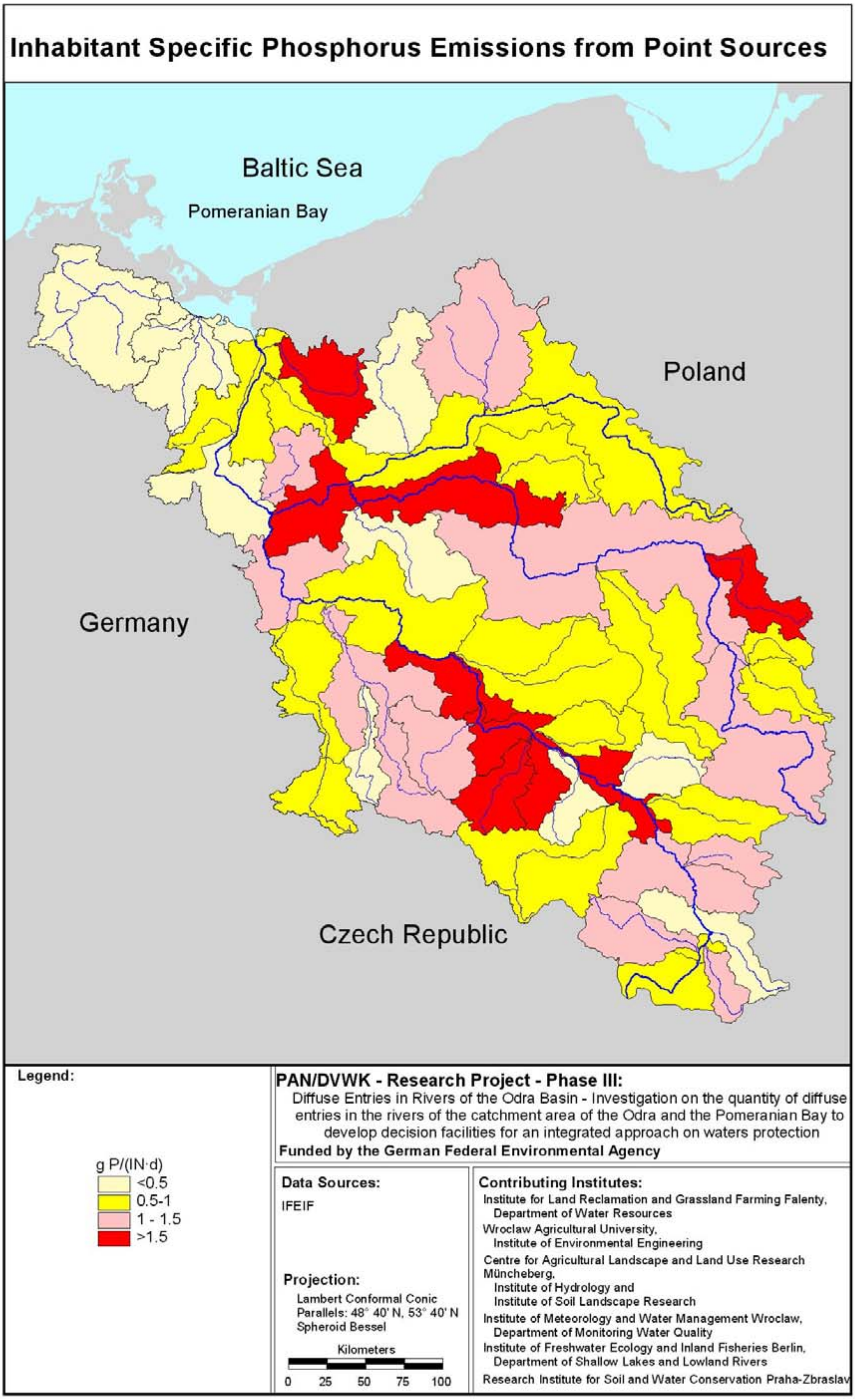
Figure 5.1: Portion of the countries to the total population and the total phosphorus and nitrogen discharges by point sources.

Table 5.1: Phosphorus emissions from point sources (EP_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Population	EP_P	EP_P-PL	EP_P-GE	EP_P-CZ	EP_P-PL	EP_P-GE	EP_P-CZ
	[1000 Inh.]	[t P/a]				[%]		
Odra-Pola	129	46.1	0.0	0.0	46.1	0.0	0.0	100.0
Opava	172	66.4	0.0	0.0	66.4	0.0	0.0	100.0
Ostravice	268	128.4	0.0	0.0	128.4	0.0	0.0	100.0
Odra-Chal	995	396.5	0.0	0.0	396.5	0.0	0.0	100.0
Odra-Raci	1,627	505.1	43.3	0.0	461.8	8.6	0.0	91.4
Klodnica	963	544.6	544.6	0.0	0.0	100.0	0.0	0.0
Odra-Gros	3,242	1,368.3	904.1	0.0	464.2	66.1	0.0	33.9
Mala Panew	310	97.5	97.5	0.0	0.0	100.0	0.0	0.0
Nysa Klod	450	124.0	113.3	0.0	10.7	91.4	0.0	8.6
Stobrawa	108	17.9	17.9	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	4,333	1,857.8	1,382.9	0.0	474.9	74.4	0.0	25.6
Olawa	181	16.6	16.6	0.0	0.0	100.0	0.0	0.0
Bystrzyca	507	340.9	340.9	0.0	0.0	100.0	0.0	0.0
Widawa	178	51.7	51.7	0.0	0.0	100.0	0.0	0.0
Kaczawa	280	139.8	139.8	0.0	0.0	100.0	0.0	0.0
Odra-Scin	6,128	3,202.8	2,727.9	0.0	474.9	85.2	0.0	14.8
Barycz	478	144.1	144.1	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	6,869	3,549.0	3,074.1	0.0	474.9	86.6	0.0	13.4
Kwisa	97	18.4	18.4	0.0	0.0	100.0	0.0	0.0
Bobr	628	242.3	242.3	0.0	0.0	100.0	0.0	0.0
Odra-Pole	7,908	3,936.3	3,461.4	0.0	474.9	87.9	0.0	12.1
Ny Lu-Zgor	442	97.4	31.7	7.9	57.8	32.5	8.1	59.4
Ny Lu-Gubi	623	156.1	49.5	48.8	57.8	31.7	31.2	37.0
Odra-Kost	8,744	4,197.3	3,522.4	142.2	532.7	83.9	3.4	12.7
Grabia	86	28.0	28.0	0.0	0.0	100.0	0.0	0.0
Widawka	244	70.8	70.8	0.0	0.0	100.0	0.0	0.0
Warta-Sier	1,061	412.9	412.9	0.0	0.0	100.0	0.0	0.0
Ner	781	827.1	827.1	0.0	0.0	100.0	0.0	0.0
Prosna	531	162.5	162.5	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	3,813	2,114.3	2,114.3	0.0	0.0	100.0	0.0	0.0
Welna	216	65.0	65.0	0.0	0.0	100.0	0.0	0.0
Obra	183	22.2	22.2	0.0	0.0	100.0	0.0	0.0
Notec-Osie	464	110.8	110.8	0.0	0.0	100.0	0.0	0.0
Gwda	291	121.3	121.3	0.0	0.0	100.0	0.0	0.0
Drawa	97	11.9	11.9	0.0	0.0	100.0	0.0	0.0
Notec-Sant	1,056	304.5	304.5	0.0	0.0	100.0	0.0	0.0
Warta-Kost	5,984	3,312.7	3,312.7	0.0	0.0	100.0	0.0	0.0
Mysla	68	27.8	27.8	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	14,977	7,573.8	6,872.4	168.7	532.7	90.7	2.2	7.0
Plonia	99	37.6	37.6	0.0	0.0	100.0	0.0	0.0
Ina	163	233.8	233.8	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	15,836	7,970.5	7,261.0	176.8	532.7	91.1	2.2	6.7
Peene	299	27.6	0.0	27.6	0.0	0.0	100.0	0.0
Zarow	32	2.2	0.0	2.2	0.0	0.0	100.0	0.0
Uecker	125	15.2	0.0	15.2	0.0	0.0	100.0	0.0
Odra Haff	489	46.7	0.3	46.4	0.0	0.7	99.3	0.0

Table 5.2: Nitrogen emissions from point sources (EP_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Population	EP_N	EP_N-PL	EP_N-GE	EP_N-CZ	EP_N-PL	EP_N-GE	EP_N-CZ
	[1000]	[t N/a]				[%]		
Odra-Pola	129	239			239			100.0
Opava	172	327			327			100.0
Ostravice	268	672			672			100.0
Odra-Chal	995	2,144			2,144			100.0
Odra-Raci	1,627	2,811	229		2,582	8.1		91.9
Klodnica	963	2,820	2,820			100.0		
Odra-Gros	3,242	7,125	4,531		2,594	63.6		36.4
Mala Panew	310	504	504			100.0		
Nysa Klod	450	740	686		54	92.7		7.3
Stobrawa	108	108	108			100.0		
Odra-Wroc	4,333	9,773	7,125		2,648	72.9		27.1
Olawa	181	74	74			100.0		
Bystrzyca	507	1,619	1,619			100.0		
Widawa	178	233	233			100.0		
Kaczawa	280	551	551			100.0		
Odra-Scin	6,128	16,742	14,094		2,648	84.2		15.8
Barycz	478	670	670			100.0		
Odra-Nowa	6,869	18,103	15,455		2,648	85.4		14.6
Kwisa	97	120	120			100.0		
Bobr	628	1,267	1,267			100.0		
Odra-Pole	7,908	20,262	17,614		2,648	86.9		13.1
Ny Lu-Zgor	442	787	169	144	474	21.4	18.3	60.3
Ny Lu-Gubi	623	1,240	245	521	474	19.8	42.0	38.3
Odra-Kost	8,744	22,345	17,912	1,311	3,122	80.2	5.9	14.0
Grabia	86	137	137			100.0		
Widawka	244	594	594			100.0		
Warta-Sier	1,061	3,096	3,096			100.0		
Ner	781	3,991	3,991			100.0		
Prosna	531	1,352	1,352			100.0		
Warta-Pozn	3,813	12,045	12,045			100.0		
Welna	216	291	291			100.0		
Obra	183	115	115			100.0		
Notec-Osie	464	492	492			100.0		
Gwda	291	771	771			100.0		
Drawa	97	53	53			100.0		
Notec-Sant	1,056	1,641	1,641			100.0		
Warta-Kost	5,984	20,291	20,291			100.0		
Mysla	68	124	124			100.0		
Odra-Kraj	14,977	43,044	38,370	1,552	3,122	89.1	3.6	7.3
Plonia	99	170	170			100.0		
Ina	163	1,104	1,104			100.0		
Odra-Mouth	15,836	45,282	40,520	1,639	3,122	89.5	3.6	6.9
Peene	299	586		586			100.0	
Zarow	32	16		16			100.0	
Uecker	125	154		154			100.0	
Odra Haff	489	805	1	803		0.2	99.8	



PAN/DVWK - Research Project - Phase III:

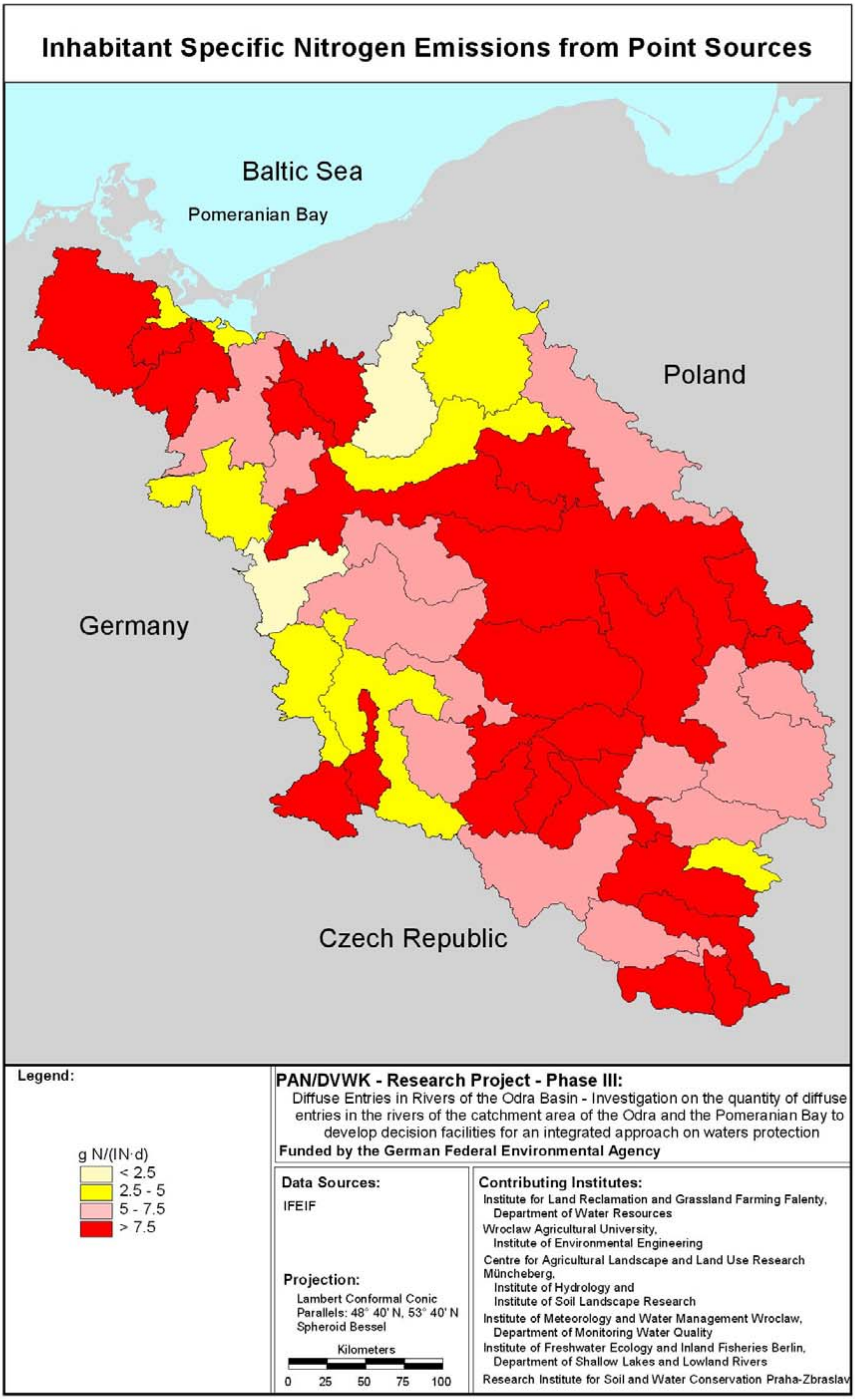
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.1: Inhabitant specific phosphorus emissions from point sources in the period 1993-1997.



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.2: *Inhabitant specific nitrogen emissions from point sources in the period 1993-1997.*

The Maps 5.1 and 5.2 show the regional distribution of the inhabitant specific point source emissions within the investigated sub catchments of the Odra. For both nutrients these specific discharges vary in a large range. It have to be taken into account that these specific discharges are calculated based on the total population living within the catchments and reflect two effects: the level of nutrient elimination in the municipal and industrial WWTP`s and the level of population connected to WWTP`s.

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

Table 5.3 shows the average inhabitant specific nutrient emissions into the Odra basins and other river basins in Central Europe. For phosphorus it is obvious that the inhabitant specific discharges are in the Odra in the period 1993 to 1997 lower as for the other rivers in the period 1993-1997 but substantially higher as in the period 1993-1997. SCHMOLL (1998) estimated that in Germany the reduction of the point discharges of phosphorus is caused to 50% by the introduction of P-free detergent and to 50% by the increase of the P-elimination in municipal WWTP`s. If this is translated to the Odra, a large potential exists for the reduction of phosphorus point source emissions in the Odra basin in the next years.

For nitrogen the Odra shows the lowest inhabitant specific value compared to the other river basins. This is mainly caused by the lower rate of population connected to WWTP`s. From this it can be concluded that the expected increase of the population connected to WWTP`s and the increase of N-elimination in municipal and industrial WWTP`s will not lead to a substantially decrease of the inhabitant specific nitrogen discharges in the Odra basin.

Table 5.3: Inhabitant specific point source discharges of phosphorus and nitrogen for different rivers in Central Europe.

River basin	Specific P discharges [gP/(inh.·d)]	Specific N discharges [gN/(inh.·d)]	Reference
Odra	1.4	7.8	this study
Odra up. Krajnik Dolny 92-94	2.6	10.6	TONDERSKI (1997)
Vistula up. Kiezmark 92-94	2.1	10.5	TONDERSKI (1997)
Rhine up. Lobith 83-87	2.3	12.5	BEHRENDT et al. (2000)
Rhine up. Lobith 93-97	0.4	8.0	BEHRENDT et al. (2000)
Elbe up. Zollenspieker 83-87	2.7	19.8	BEHRENDT et al. (2000)
Elbe up. Zollenspieker 93-97	0.6	10.2	BEHRENDT et al. (2000)
Danube up. Jochenstein 83-87	2.5	13.3	BEHRENDT et al. (2000)
Danube up. Jochenstein 93-97	0.5	8.3	BEHRENDT et al. (2000)
Seine		9.0	BILLEN & GARNIER (1999)

5.2 Nutrient Emissions from Diffuse Sources

5.2.1 Nutrient Balances

Most diffuse nutrient input is caused through agriculture. Therefore, the models for the quantification of nutrient inputs in the river systems must consider these agricultural activities in an appropriate way. One of the main factors, which determines the size of the nutrient loadings from diffuse sources, is the yearly surplus of nutrients on agricultural areas. Since an essential task of this study is the regional differentiation of nutrient surpluses in individual river basins, it is also necessary to regionalize the nutrient surpluses. A summarized overview of the nitrogen and phosphorus surpluses from agricultural areas for the year 1995 is shown in Maps 5.3 and 5.4. The regional differences in nutrient surpluses in agricultural areas shown in these maps were overlaid with the boundaries of the catchment areas to determine the average surpluses in the individual river basins for this reference year.

Besides the regional differences in the nutrient surpluses, an investigation of the time related changes of the nutrient surpluses in the agricultural areas is also essential for the quantification of the changes of the nutrient inputs in the river basins. However, a spatial differentiation could not be done below the level of the three countries. Therefore the changes in nutrient surpluses were calculated for the German states located in the Odra basin (Mecklenburg-Vorpommern, Brandenburg und Sachsen), Poland and Czech Republic for the period 1950 to 1995 or 1999, respectively. The results for long-term changes in nitrogen surpluses since 1950 are shown in Tables 5.4. The Figures 5.2 and 5.3 shows the long term changes of the nitrogen and phosphorus surplus in the agricultural area.

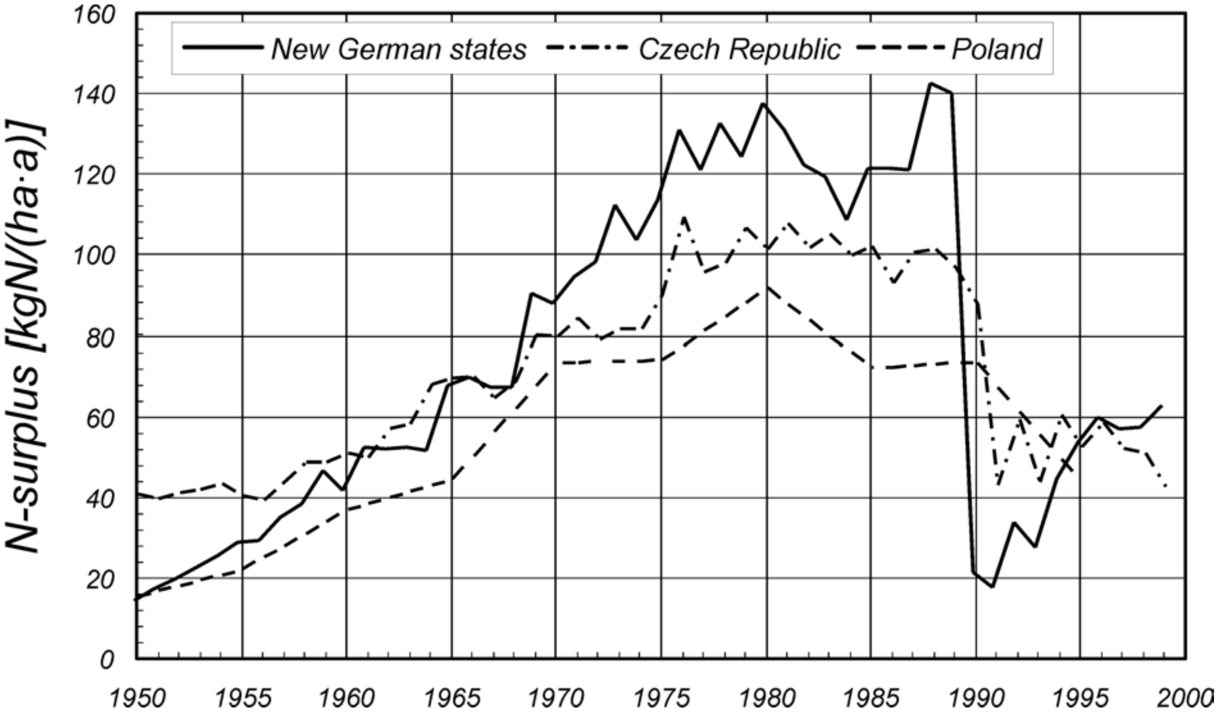
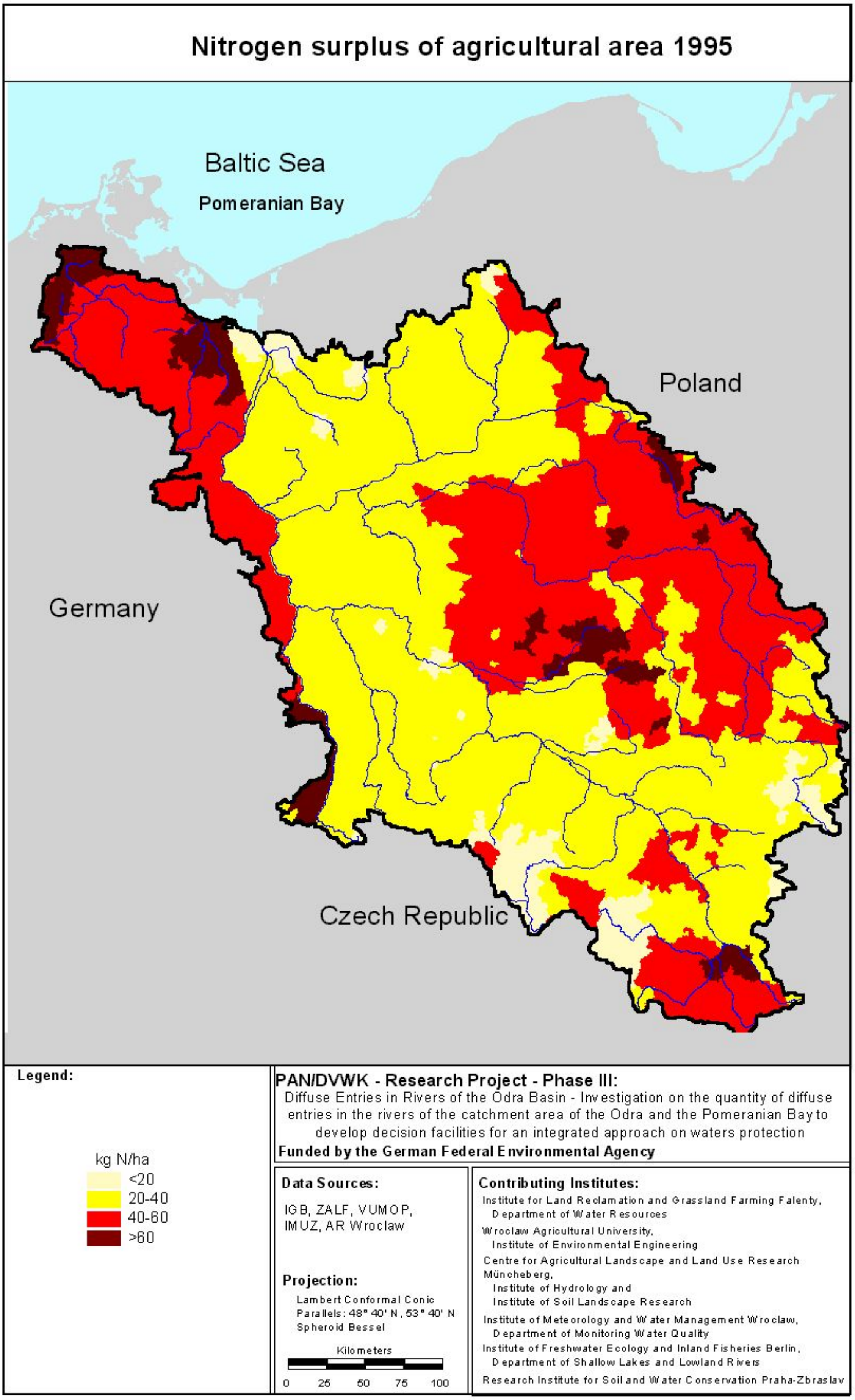
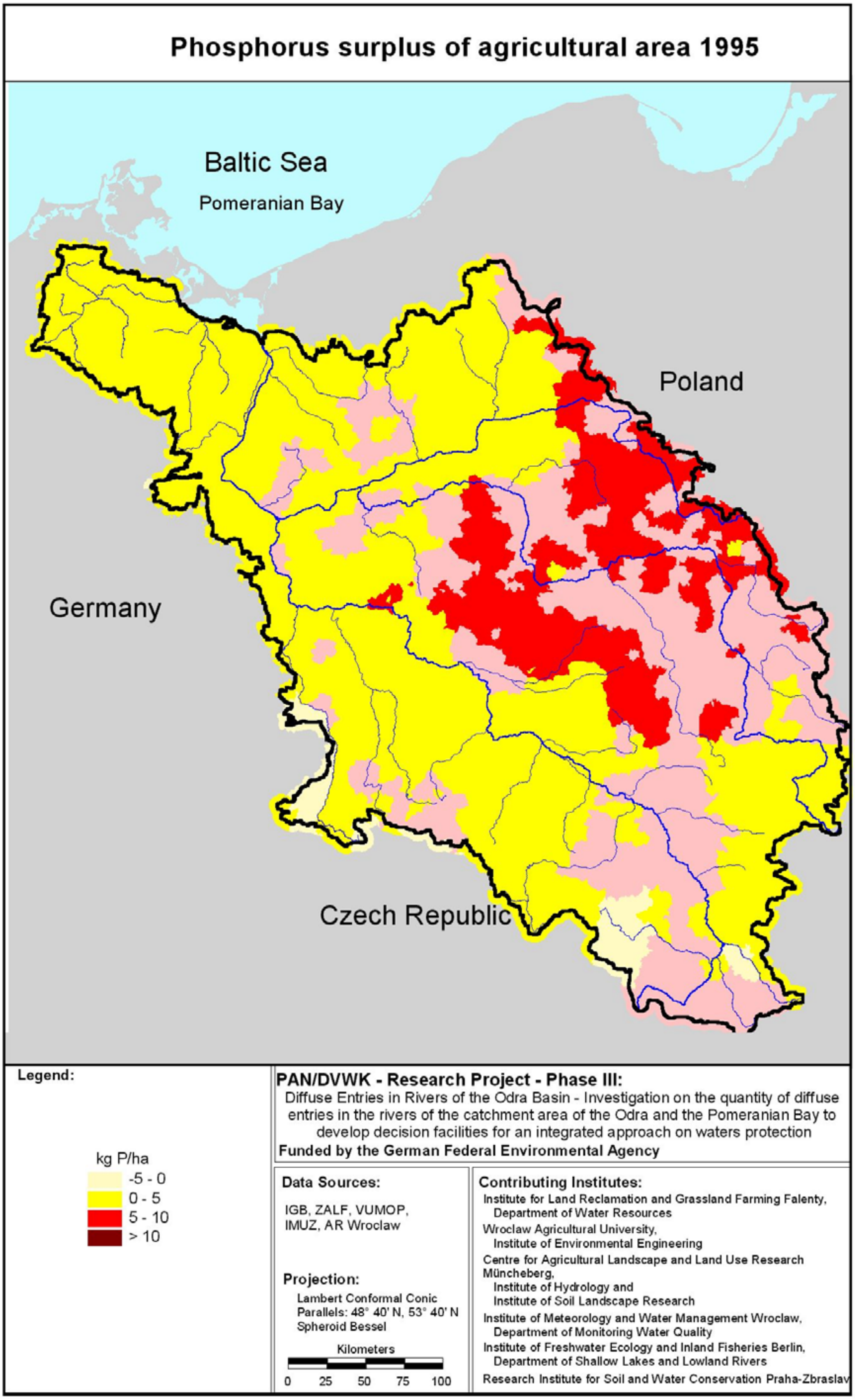


Figure 5.2: Long-term changes in the nitrogen surpluses of agricultural areas of the new German states, Poland and Czech Republic from 1950 to 1995.



Map5.3: *Distribution of nitrogen surplus within the Odra basins in the year 1995.*



Map5.4: Distribution of nitrogen surplus within the Odra basins in the year 1995.

From the Figure 5.2 it can be concluded that the development of the nitrogen surplus in agricultural areas shows the same trend for all three countries. Three periods can be distinguished. The period of continual increase of the nitrogen surplus reaches from 1950 to about 1970 or 1975. The second period of stability of nitrogen surpluses ends with the political changes in the three countries in the year 1989. During this period the level of the nitrogen surpluses in the countries differ within a certain range. The highest surpluses were realized in East Germany with about 120 kgN/(ha·a) followed by Czech Republic with a level of about 100 kgN/(ha·a) and Poland of about 80 kgN/(ha·a). The begin of the nineties is characterized with a very large decrease of the nitrogen surplus. Especially in East Germany and Czech Republic the nitrogen surplus decreases within on year to 20 and 40 kgN/(ha·a), respectively. This is due to the very dramatic changes in agriculture of these countries leading back to the changes in 1989. Both the use of mineral fertilizer and livestock numbers were very greatly reduced at this time. It can be assumed that the decrease was realized in Poland also within one or two years, but this is not to see in Figure 5.2, because data of nitrogen surplus in Poland was only available for 5 years. The largest reduction of nitrogen surplus could be observed in the new German countries, but these level is increasing since 1992. A nearly constant level will be reached since 1996. Contrary to this the decrease of nitrogen surplus was lower in Czech Republic but constant within the following years.

As shown in Figure 5.3 the same long term trend can be observed for phosphorus surplus in agricultural area. But for phosphorus, which is accumulated in the upper soil layers until a saturation level is reached, the P surpluses from 1948 onwards have to be calculated. P-accumulations in topsoil are shown in Table 5.4. It can be concluded from this table that the P-accumulation in the agricultural topsoil is about 800 kgP/ha since 1950.

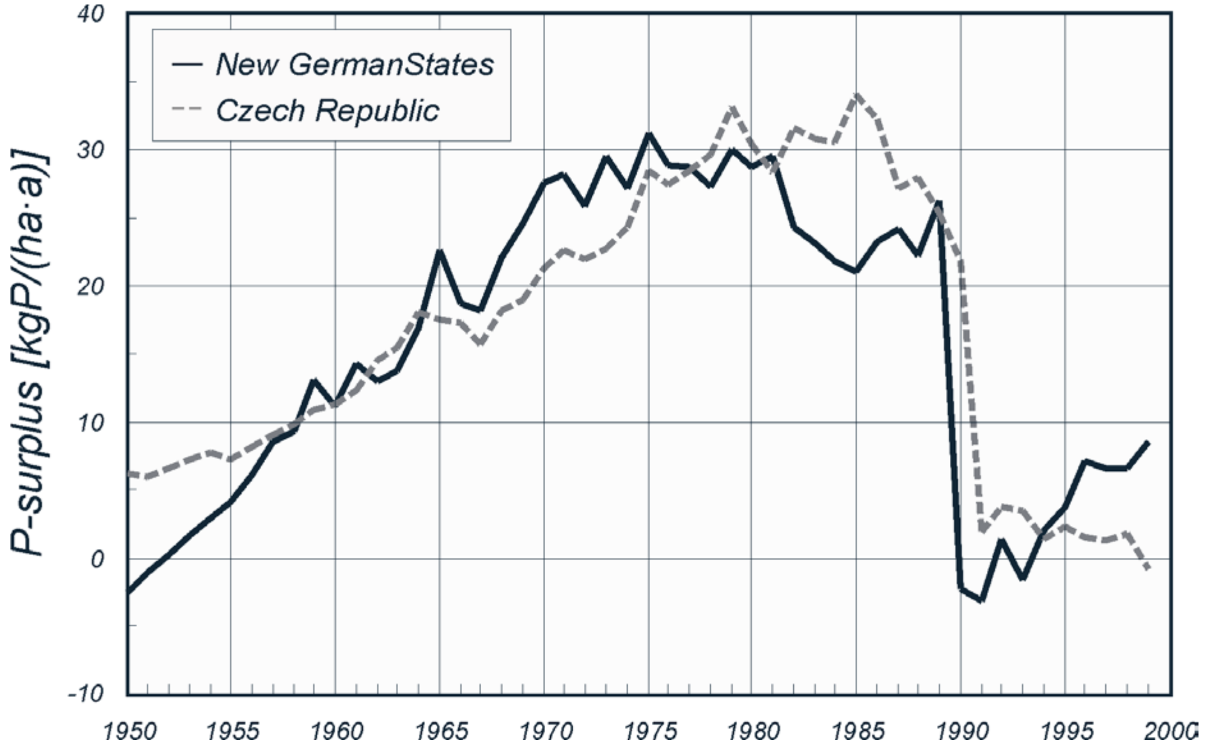


Figure 5.3: Long-term changes in the phosphorus surpluses of the agricultural areas of the new German states, Poland and Czech Republic from 1950 to 1999.

Table 5.4: Long term changes of nitrogen and phosphorus surplus in agricultural areas in the new German states, Poland and Czech Republic since 1950.

	New Germany states	Czech Republic	Poland	New Germany states		Czech Republic	
		[kg N/(ha·a)]		[kg P/(ha·a)]	[kg P/(ha)]	[kg P/(ha·a)]	[kg P/(ha)]
1950	13.6	40.9	15.4	-2.5	-3	6.2	6
1951	16.4	39.9		-1.1	-4	6	12
1952	19.1	41.2		0.2	-3	6.6	19
1953	22.0	42.0		1.6	-2	7.2	26
1954	24.9	43.6		3	1	7.8	34
1955	28.0	40.5	22.1	4.1	5	7.3	41
1956	28.7	39.3		6.1	11	8.2	49
1957	34.3	43.8		8.6	20	9.1	58
1958	37.6	48.7		9.3	29	9.9	68
1959	46.0	48.8		13.1	42	10.9	79
1960	41.1	51.2	37.0	11.2	54	11.3	91
1961	51.7	50.1		14.3	68	12.3	103
1962	51.4	57.4		13	81	14.5	117
1963	51.9	58.5		13.7	95	15.5	133
1964	50.9	68.2		16.9	112	18	151
1965	67.3	69.6	44.8	22.6	134	17.6	168
1966	69.4	70.0		18.7	153	17.3	186
1967	66.7	64.8		18.2	171	15.7	201
1968	66.9	68.9		22.1	193	18.2	220
1969	90.3	80.4		24.6	218	19	239
1970	87.5	79.9	73.5	27.6	245	21.3	260
1971	94.2	84.6		28.2	274	22.6	283
1972	98.0	79.2		25.9	299	22	305
1973	112.3	81.9		29.5	329	22.7	327
1974	103.6	82.0		27.2	356	24.3	352
1975	113.7	90.3	74.2	31.2	387	28.5	380
1976	131.1	109.8		28.9	416	27.4	407
1977	121.1	96.1		28.7	445	28.5	436
1978	132.6	98.2		27.3	472	29.7	466
1979	124.5	107.0		30	502	33.1	499
1980	137.8	101.7	92.1	28.7	531	30.4	529
1981	131.1	107.9		29.5	560	28.4	558
1982	122.4	101.9		24.3	585	31.6	589
1983	119.3	105.5		23.2	608	30.8	620
1984	108.6	100.1		21.8	630	30.5	650
1985	121.5	102.5	72.2	21	651	34.1	685
1986	121.3	93.3		23.3	674	32.3	717
1987	121.1	101.1		24.2	698	27.2	744
1988	142.9	101.5		22.2	720	27.9	772
1989	140.1	97.3		26.3	747	25.3	797
1990	20.6	87.9	73.6	-2.3	744	21.9	819
1991	16.7	43.0		-3.2	741	1.9	821
1992	33.0	59.4		1.4	743	3.8	825
1993	26.9	44.0		-1.6	741	3.5	828
1994	44.1	60.7		2.1	743	1.4	830
1995	53.1	52.5	43.4	3.7	747	2.3	832
1996	59.3	58.8		7.1	754	1.5	834
1997	56.4	52.1		6.6	761	1.3	835
1998	57.0	51.0		6.6	767	1.8	837
1999	62.3	42.6		8.6	776	-0.8	836

5.2.2 Nutrient Emissions via Atmospheric Deposition (MONERIS)

The analysis of the atmospheric deposition of nutrients within the Odra basin shows that about 130 tP/a and 3460 tN/a were directly emitted into the surface waters of the Odra catchment (see Figure 5.4 and Table 5.5 to 5.6). The portion of the countries to the total inputs by atmospheric deposition corresponds for Poland with the portion on the area of surface waters. For Czech Republic the inputs by nitrogen deposition are about 4.4% and higher as the portion of surface waters. This is caused by the higher atmospheric deposition rates in the south of the Odra catchment.

Because this pathway take into account the nutrient inputs by atmospheric deposition directly to the surface waters, the highest specific inputs for this pathway were found for the sub catchments of the Odra with a large area of surface waters especially lakes. This is shown in Maps 5.5 and 5.6. Especially the catchments characterized by the moraine landscape of the Weichselian period located in the Notec basin and northern from the Wartha have the highest specific nutrient inputs related to the total area of the sub catchments.

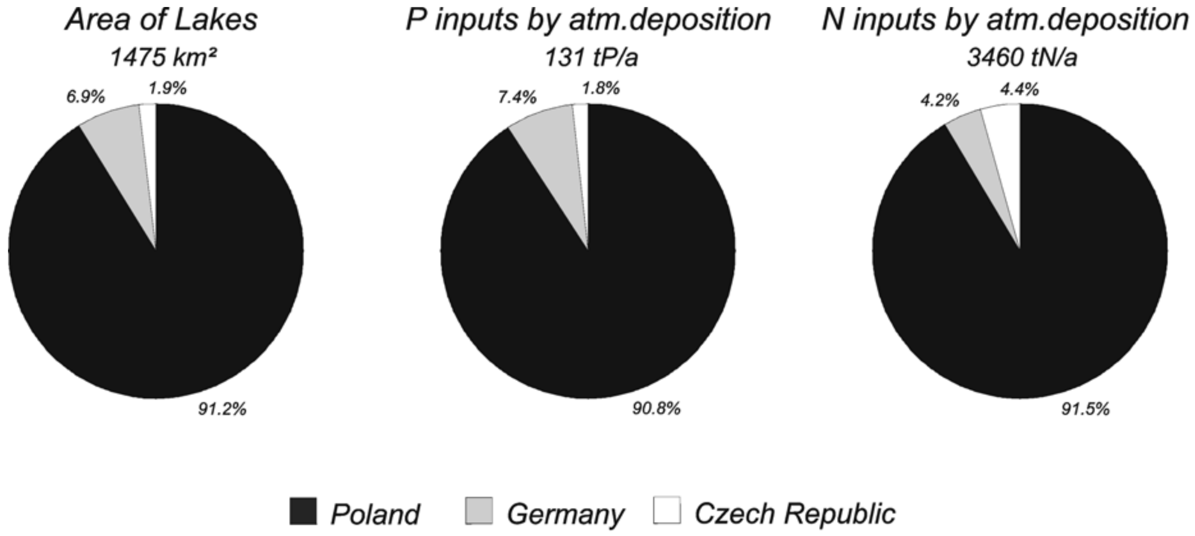


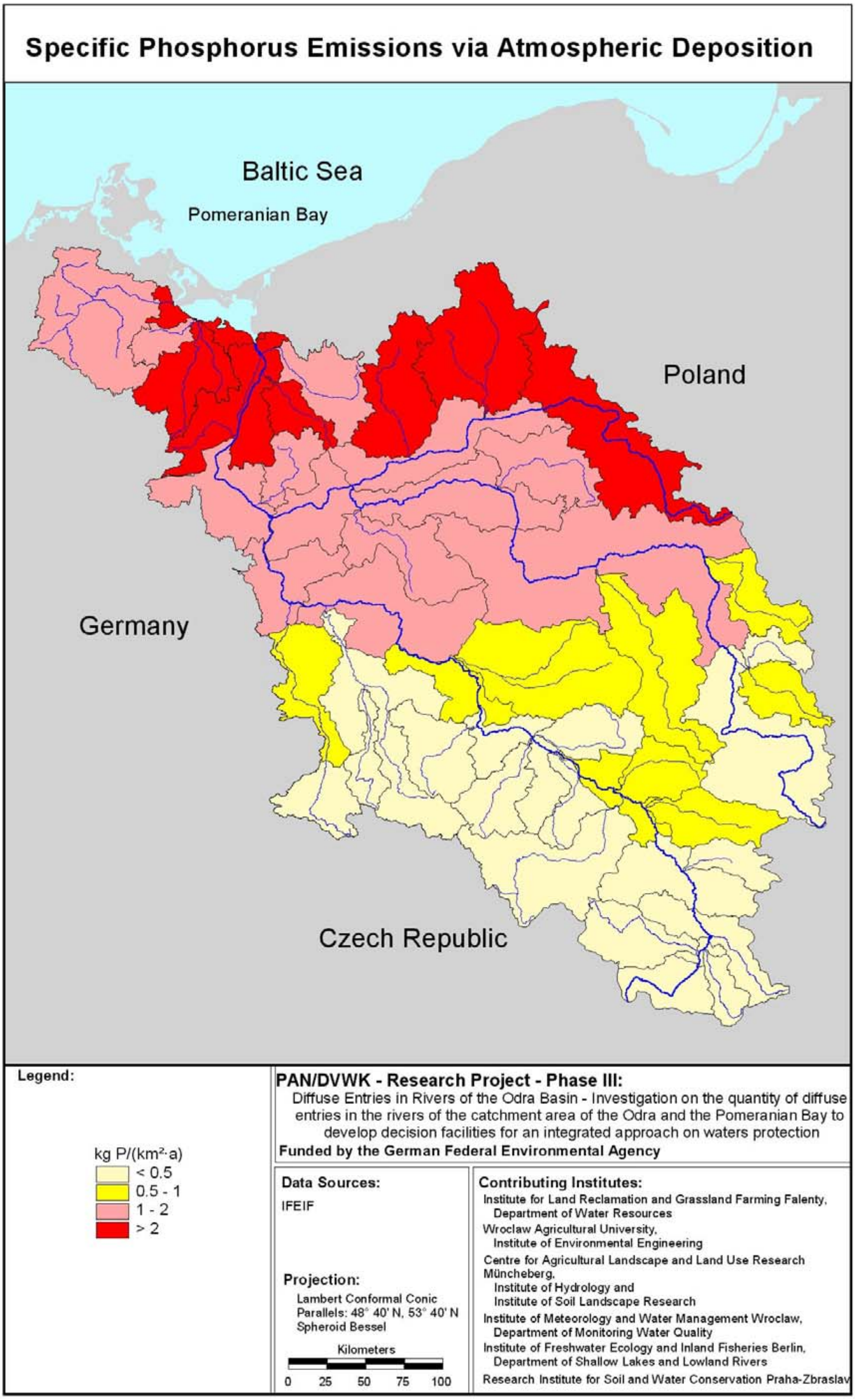
Figure 5.4: Portion of the countries to the total area of lakes and the total phosphorus and nitrogen discharges by atmospheric deposition.

Table 5.5: Phosphorus emissions via atmospheric deposition ($\mathrm{EAD_P}$) in the period 1993-1997 for the whole catchment and for the countries.

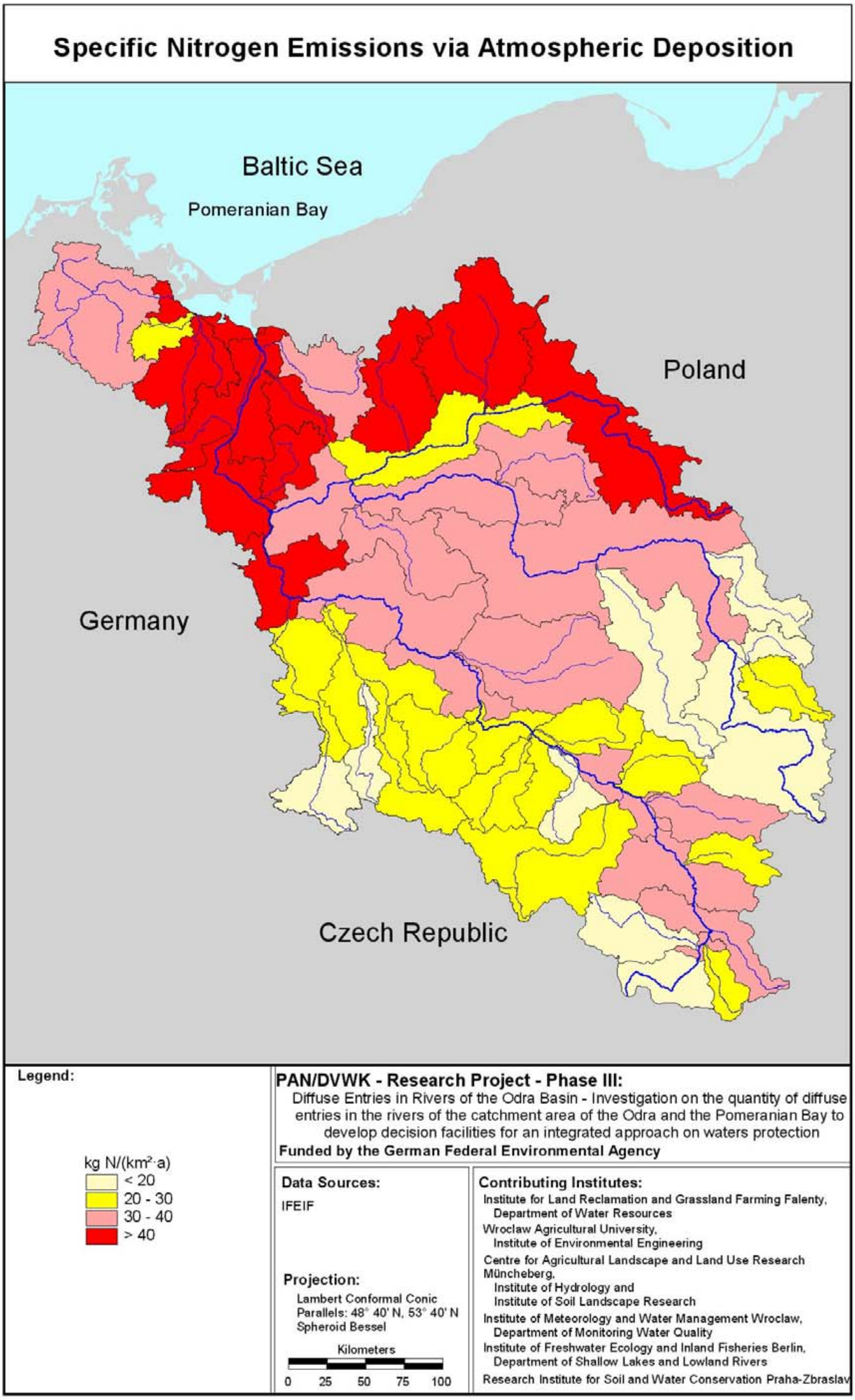
Short name	Area	$\mathrm{EAD_P}$	$\mathrm{EAD_P}$-PL	$\mathrm{EAD_P}$-GE	$\mathrm{EAD_P}$-CZ	$\mathrm{EAD_P}$-PL	$\mathrm{EAD_P}$-GE	$\mathrm{EAD_P}$-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	0.5	0.0	0.0	0.5	0.0	0.0	100.0
Opava	2,091	0.5	0.0	0.0	0.5	7.0	0.0	93.0
Ostravice	824	0.3	0.0	0.0	0.28	0.0	0.0	100.0
Odra-Chal	4,666	1.3	0.0	0.0	1.3	2.7	0.0	97.3
Odra-Raci	6,684	2.1	0.5	0.0	1.6	25.6	0.0	74.4
Klodnica	1,085	0.6	0.6	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	4.1	2.4	0.0	1.7	58.9	0.0	41.1
Mala Panew	2,123	1.3	1.3	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	1.9	1.6	0.0	0.4	80.6	0.0	19.4
Stobrawa	1,601	0.9	0.9	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	9.2	7.1	0.0	2.1	77.4	0.0	22.5
Olawa	1,167	0.4	0.4	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	0.6	0.6	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	0.8	0.8	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	1.2	1.2	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	13.5	11.4	0.0	2.1	84.6	0.0	15.4
Barycz	5,535	5.6	5.6	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	20.4	18.3	0.0	2.1	89.8	0.0	10.2
Kwisa	1,026	0.4	0.3	0.0	0.0	97.3	0.0	2.7
Bobr	5,869	2.9	2.9	0.0	0.0	99.4	0.0	0.6
Odra-Pole	47,152	28.7	26.6	0.0	2.1	92.7	0.0	7.3
Ny Lu-Zgor	1,609	0.5	0.1	0.1	0.2	21.1	31.1	47.8
Ny Lu-Gubi	3,974	1.9	1.2	0.5	0.2	63.7	24.8	11.5
Odra-Kost	53,532	33.8	29.7	1.9	2.3	87.7	5.5	6.8
Grabia	813	0.4	0.4	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	1.3	1.3	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	3.9	3.9	0.0	0.0	100.0	0.0	0.0
Ner	1,867	1.2	1.2	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	2.7	2.7	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	20.8	20.8	0.0	0.0	100.0	0.0	0.0
Welna	2,621	4.2	4.2	0.0	0.0	100.0	0.0	0.0
Obra	2,758	3.8	3.8	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	11.4	11.4	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	10.7	10.7	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	9.2	9.2	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	35.3	35.3	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	73.1	73.1	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	2.5	2.5	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	114.2	106.5	5.4	2.3	93.3	4.7	2.0
Peonia	1,101	3.6	3.6	0.0	0.0	100.0	0.0	0.0
Ina	2,163	3.0	3.0	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	118,861	131.3	119.2	9.7	2.3	90.8	7.4	1.8
Peene	5,110	8.1	0.0	8.1	0.0	0.0	100.0	0.0
Zarow	748	0.8	0.0	0.8	0.0	0.0	100.0	0.0
Uecker	2,401	5.4	0.0	5.4	0.0	0.6	99.4	0.0
Odra Haff	8,885	16.2	0.6	15.6	0.0	3.4	96.6	0.0

Table 5.6: Nitrogen emissions via atmospheric deposition (EAD$_N$) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EAD$_N$	EAD$_N$-PL	EAD$_N$-GE	EAD$_N$-CZ	EAD$_N$-PL	EAD$_N$-GE	EAD$_N$-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	28	0	0	28	0.0	0.0	100.0
Opava	2,091	29	2	0	27	7.0	0.0	93.0
Ostravice	824	22	0	0	22	0.0	0.0	100.0
Odra-Chal	4,666	88	2	0	86	2.5	0.0	97.5
Odra-Raci	6,684	152	43	0	109	28.2	0.0	71.8
Klodnica	1,085	32	32	0	0	100.0	0.0	0.0
Odra-Gros	10,989	284	167	0	118	58.7	0.0	41.3
Mala Panew	2,123	67	67	0	0	100.0	0.0	0.0
Nysa Klod	4,515	111	90	0	22	80.6	0.0	19.4
Stobrawa	1,601	37	37	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	554	415	0	139	74.9	0.0	25.1
Olawa	1,167	22	22	0	0	100.0	0.0	0.0
Bystrzyca	1,760	37	37	0	0	100.0	0.0	0.0
Widawa	1,716	34	34	0	0	100.0	0.0	0.0
Kaczawa	2,261	60	60	0	0	100.0	0.0	0.0
Odra-Scin	29,584	779	640	0	139	82.1	0.0	17.9
Barycz	5,535	195	195	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	1,031	892	0	139	86.5	0.0	13.5
Kwisa	1,026	16	15	0	0	97.3	0.0	2.7
Bobr	5,869	126	125	0	1	99.4	0.0	0.6
Odra-Pole	47,152	1,319	1,179	0	140	89.4	0.0	10.6
Ny Lu-Zgor	1,609	22	5	7	11	21.1	31.1	47.8
Ny Lu-Gubi	3,974	76	46	19	11	60.8	25.2	13.9
Odra-Kost	53,532	1,487	1,278	59	151	85.9	4.0	10.1
Grabia	813	13	13	0	0	100.0	0.0	0.0
Widawka	2,355	50	50	0	0	100.0	0.0	0.0
Warta-Sier	8,140	154	154	0	0	100.0	0.0	0.0
Ner	1,867	34	34	0	0	100.0	0.0	0.0
Prosna	4,825	86	86	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	620	620	0	0	100.0	0.0	0.0
Welna	2,621	100	100	0	0	100.0	0.0	0.0
Obra	2,758	104	104	0	0	100.0	0.0	0.0
Notec-Osie	5,508	261	261	0	0	100.0	0.0	0.0
Gwda	4,943	219	219	0	0	100.0	0.0	0.0
Drawa	3,296	192	192	0	0	100.0	0.0	0.0
Notec-Sant	17,330	759	759	0	0	100.0	0.0	0.0
Warta-Kost	54,518	1,799	1,799	0	0	100.0	0.0	0.0
Mysla	1,334	56	56	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	3,456	3,161	145	151	91.5	4.2	4.4
Plonia	1,101	86	86	0	0	100.0	0.0	0.0
Ina	2,163	66	66	0	0	100.0	0.0	0.0
Odra-Mouth	118,861	3,865	3,464	251	151	89.6	6.5	3.9
Peene	5,110	198	0	198	0	0.0	100.0	0.0
Zarow	748	20	0	20	0	0.0	100.0	0.0
Uecker	2,401	142	1	141	0	0.6	99.4	0.0
Odra Haff	8,885	401	13	388	0	3.2	96.8	0.0



Map 5.5: *Specific phosphorus emissions via atmospheric deposition in the period 1993-1997.*



Map 5.6: *Specific nitrogen emissions via atmospheric deposition in the period 1993-1997.*

5.2.3 Nutrient Emissions via Surface Runoff

5.2.3.1 Results of the NIIRS approach

The transported dissolved nutrient loads are difficult to be estimated. The highest P concentration is often connected with high discharge resulting from rainstorm events. For that reason the calculated values are related to 10 mm surface runoff from the agricultural area. Concentrations of 0.65 mg/l P and 0.32 mg/l N are underlying. Once higher or lower runoff occurs, these values need to be multiplied by a certain factor. Aggregated for the basin as a whole, the results correspond to those of Phase II: 382 t P and 188 t N per year. The dissolved specific loads related to the entire basin are 0.03 kg/ha/a P and 0.015 kg/ha/a N. The presented long-term average calculation can provide but an initial, very rough estimation.

5.2.3.2 Results of the MONERIS approach

As shown in Figure 5.5 and the Tables 5.8 and 5.9 the P- and N-inputs by surface runoff calculated with the MONERIS are for Phosphorus lower and for nitrogen higher as estimated by NIIRS. For phosphorus the calculated mean concentrations of this pathway are in a range of 0.5 to 0.73 mgP/l and comparable with the assumed NIIRS-concentrations.

Within the catchments of the Odra the rates of surface runoff are much lower. Only in the sub catchments of the Ostravice, the Odra between Chalupki and Raciborz and the Nysa Luzycka above Zgorzelec/Görlitz a surface runoff of about 10mm/a or more was estimated based on the approach of LIEBSCHER & KELLER (1979). In the flatlands the estimated rates of surface runoff were in general lower as 1 mm/a. Because the surface runoff was very high in the Czech part of the Odra, the nutrient inputs by surface runoff are nearly 30% of the total inputs by this pathway.

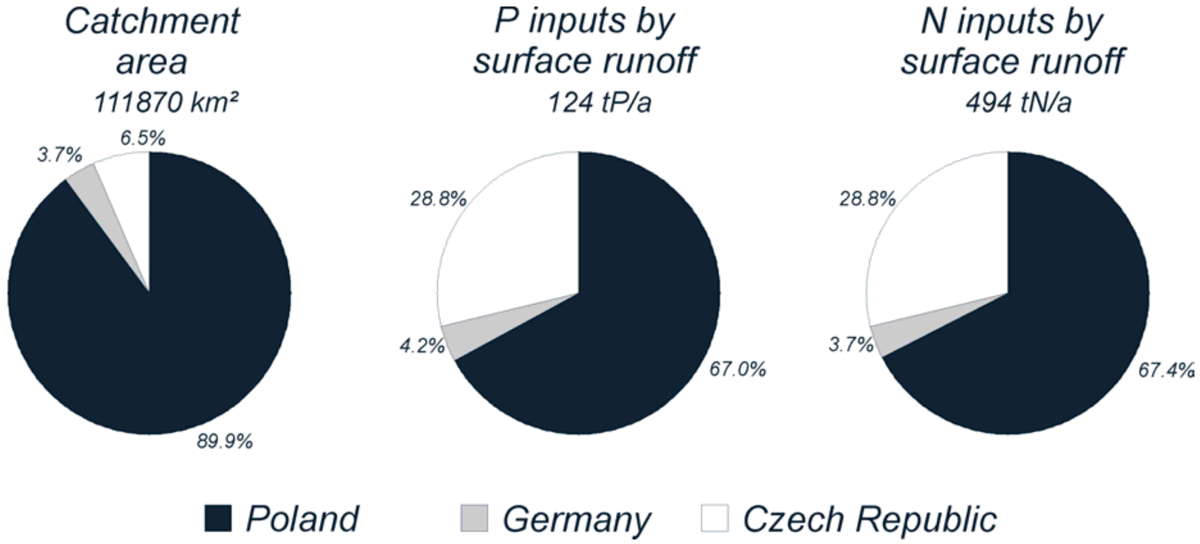


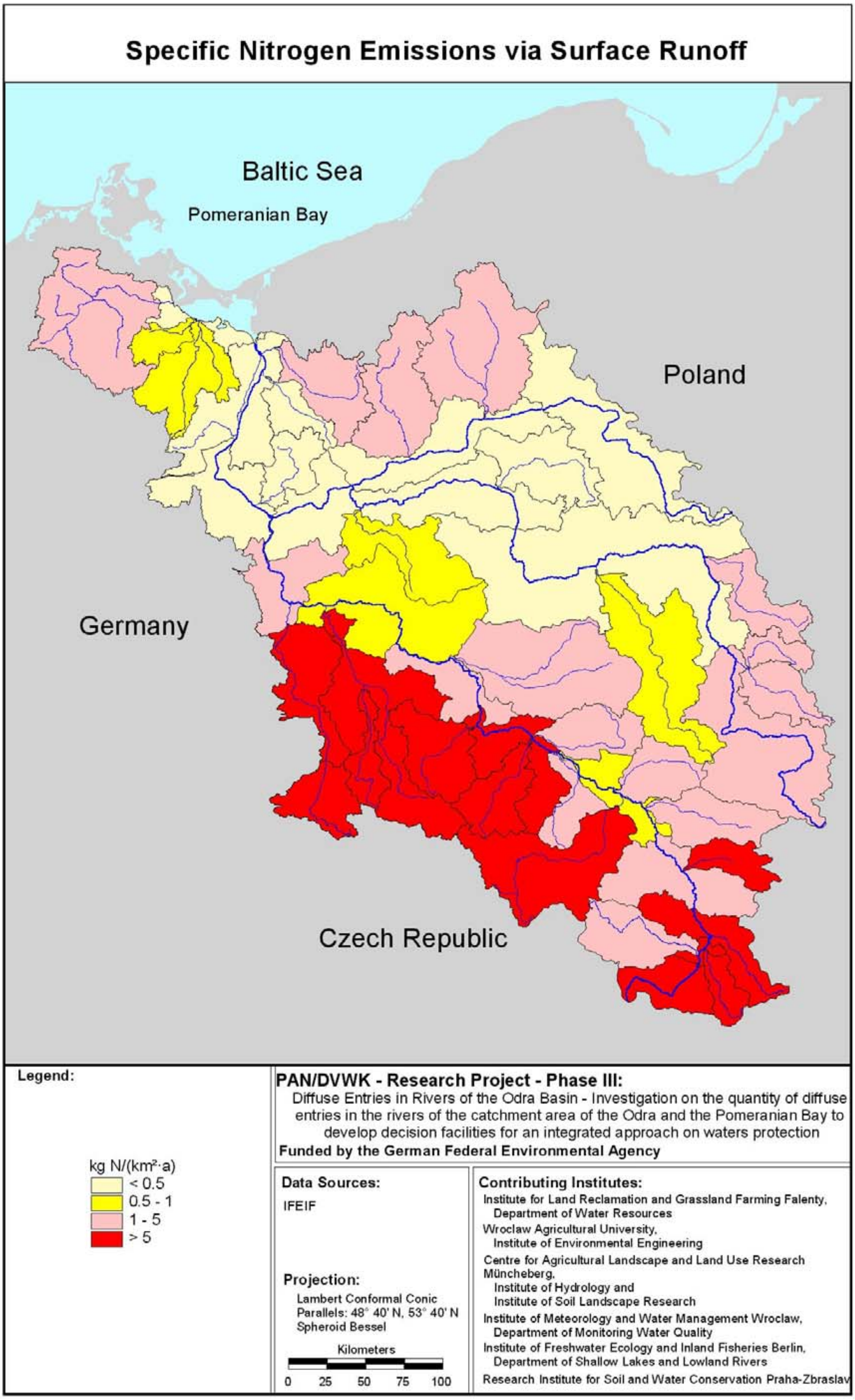
Figure 5.5: Portion of the countries to the total catchment area of the Odra and the total phosphorus and nitrogen discharges by surface runoff.

Table 5.7: Phosphorus emissions via surface runoff (ERO_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ERO_P	ERO_P-PL	ERO_P-GE	ERO_P-CZ	ERO_P-PL	ERO_P-GE	ERO_P-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	5.5	0.0	0.0	5.5	0.0	0.0	100.0
Opava	2,091	2.4	0.2	0.0	2.2	7.0	0.0	93.0
Ostravice	824	13.8	0.0	0.0	13.8	0.0	0.0	100.0
Odra-Chal	4,666	23.7	0.2	0.0	23.5	0.8	0.0	99.2
Odra-Raci	6,684	34.8	7.3	0.0	27.5	20.9	0.0	79.1
Klodnica	1,085	1.8	1.8	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	39.7	11.9	0.0	27.8	29.9	0.0	70.1
Mala Panew	2,123	2.3	2.3	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	13.8	11.1	0.0	2.7	80.6	0.0	19.4
Stobrawa	1,601	0.5	0.5	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	56.5	26.1	0.0	30.5	46.1	0.0	53.9
Olawa	1,167	0.7	0.7	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	2.4	2.4	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	0.7	0.7	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	4.9	4.9	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	68.2	37.8	0.0	30.5	55.3	0.0	44.7
Barycz	5,535	1.8	1.8	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	71.2	40.7	0.0	30.5	57.2	0.0	42.8
Kwisa	1,026	4.6	4.5	0.0	0.1	97.3	0.0	2.7
Bobr	5,869	20.5	20.3	0.0	0.2	99.2	0.0	0.8
Odra-Pole	47,152	92.7	62.1	0.0	30.7	66.9	0.0	33.1
Ny Lu-Zgor	1,609	10.7	2.3	3.3	5.1	21.1	31.1	47.8
Ny Lu-Gubi	3,974	14.2	4.9	4.1	5.1	34.7	29.1	36.2
Odra-Kost	53,532	108.9	68.1	5.0	35.8	62.5	4.6	32.9
Grabia	813	0.4	0.4	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	1.2	1.2	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	5.5	5.5	0.0	0.0	100.0	0.0	0.0
Ner	1,867	0.6	0.6	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	1.3	1.3	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	8.4	8.4	0.0	0.0	100.0	0.0	0.0
Welna	2,621	0.2	0.2	0.0	0.0	100.0	0.0	0.0
Obra	2,758	0.6	0.6	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	0.5	0.5	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	2.2	2.2	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	2.5	2.5	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	5.3	5.3	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	15.0	15.0	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	0.1	0.1	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	124.4	83.4	5.2	35.8	67.0	4.2	28.8
Plonia	1,101	0.1	0.1	0.0	0.0	100.0	0.0	0.0
Ina	2,163	1.2	1.2	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	118,861	126.1	85.0	5.4	35.8	67.4	4.3	28.4
Peene	5,110	1.5	0.0	1.5	0.0	0.0	100.0	0.0
Zarow	748	0.1	0.0	0.1	0.0	0.0	100.0	0.0
Uecker	2,401	0.5	0.0	0.5	0.0	0.6	99.4	0.0
Odra Haff	8,885	2.2	0.0	2.2	0.0	1.2	98.8	0.0

Table 5.8: Nitrogen emissions via surface runoff (ERO$_N$) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ERO$_N$	ERO$_N$-PL	ERO$_N$-GE	ERO$_N$-CZ	ERO$_N$-PL	ERO$_N$-GE	ERO$_N$-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	19.8	0	0	20	0.0	0.0	100.0
Opava	2,091	10.3	1	0	10	7.0	0.0	93.0
Ostravice	824	53.1	0	0	53	0.0	0.0	100.0
Odra-Chal	4,666	95.4	1	0	94	0.9	0.0	99.1
Odra-Raci	6,684	145.9	33	0	113	22.6	0.0	77.4
Klodnica	1,085	6.5	6	0	0	100.0	0.0	0.0
Odra-Gros	10,989	166.5	52	0	114	31.4	0.0	68.6
Mala Panew	2,123	10.0	10	0	0	100.0	0.0	0.0
Nysa Klod	4,515	53.6	43	0	10	80.6	0.0	19.4
Stobrawa	1,601	2.0	2	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	233.3	109	0	125	46.6	0.0	53.4
Olawa	1,167	3.0	3	0	0	100.0	0.0	0.0
Bystrzyca	1,760	9.8	10	0	0	100.0	0.0	0.0
Widawa	1,716	2.7	3	0	0	100.0	0.0	0.0
Kaczawa	2,261	18.7	19	0	0	100.0	0.0	0.0
Odra-Scin	29,584	280.0	156	0	125	55.5	0.0	44.5
Barycz	5,535	7.0	7	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	291.6	167	0	125	57.3	0.0	42.7
Kwisa	1,026	19.1	19	0	1	97.3	0.0	2.7
Bobr	5,869	82.3	82	0	1	99.1	0.0	0.9
Odra-Pole	47,152	377.7	253	0	125	66.8	0.0	33.2
Ny Lu-Zgor	1,609	36.0	8	11	17	21.1	31.1	47.8
Ny Lu-Gubi	3,974	50.1	18	14	17	36.9	28.8	34.4
Odra-Kost	53,532	435.5	275	18	142	63.2	4.1	32.7
Grabia	813	1.6	2	0	0	100.0	0.0	0.0
Widawka	2,355	5.8	6	0	0	100.0	0.0	0.0
Warta-Sier	8,140	22.8	23	0	0	100.0	0.0	0.0
Ner	1,867	2.3	2	0	0	100.0	0.0	0.0
Prosna	4,825	4.8	5	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	33.8	34	0	0	100.0	0.0	0.0
Welna	2,621	0.8	1	0	0	100.0	0.0	0.0
Obra	2,758	2.3	2	0	0	100.0	0.0	0.0
Notec-Osie	5,508	1.9	2	0	0	100.0	0.0	0.0
Gwda	4,943	7.0	7	0	0	100.0	0.0	0.0
Drawa	3,296	8.4	8	0	0	100.0	0.0	0.0
Notec-Sant	17,330	17.9	18	0	0	100.0	0.0	0.0
Warta-Kost	54,518	57.1	57	0	0	100.0	0.0	0.0
Mysla	1,334	0.5	0	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	494.0	333	18	142	67.4	3.7	28.8
Plonia	1,101	0.4	0	0	0	100.0	0.0	0.0
Ina	2,163	4.1	4	0	0	100.0	0.0	0.0
Odra-Mouth	118,861	500.3	339	19	142	67.7	3.8	28.5
Peene	5,110	5.3	0	5	0	0.0	100.0	0.0
Zarow	748	0.6	0	1	0	0.0	100.0	0.0
Uecker	2,401	1.9	0	2	0	0.6	99.4	0.0
Odra Haff	8,885	8.1	0	8	0	1.4	98.6	0.0



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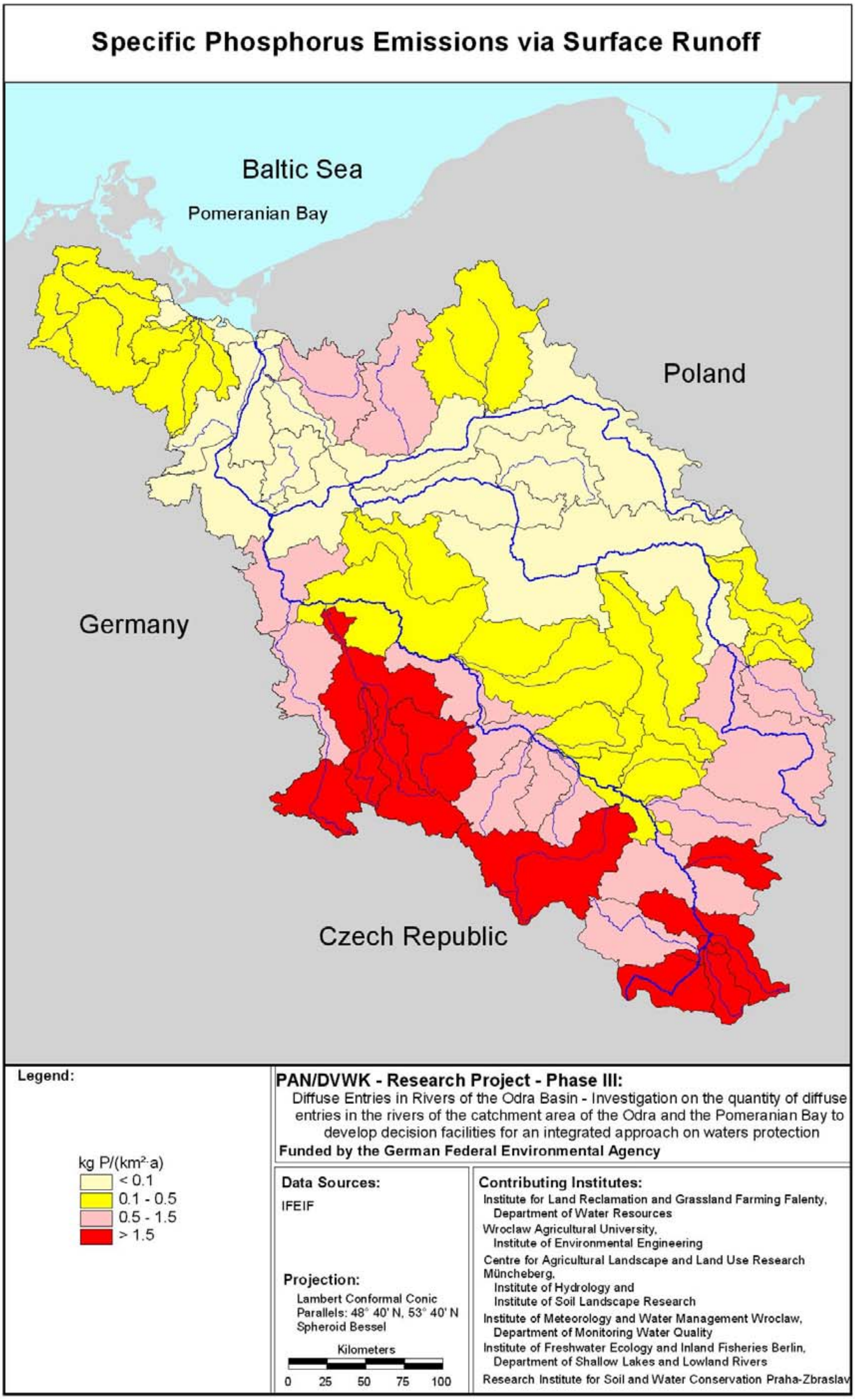
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.7: Specific nitrogen emissions via surface runoff in the period 1993-1997.



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Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.8: Specific phosphorus emissions via surface runoff in the period 1993-1997.

5.2.4 Nutrient Emissions via Erosion

5.2.4.1 Results of the NIIRS approach

The following results give a rough estimation on sediment yield and the particle-bound nutrient (P and N) loads from the Odra Basin into the Pomeranian Bay. The results are regionally differentiated based on varying information concerning soil, topography, rain erosivity, crop rotation (statistical data), and management practices. Comparing calculated data and data measured in monitoring stations to obtain more information about materials transported in the rivers appears necessary.

Soil loss, sediment yield and nutrient load by water erosion were estimated for the present state as shown in Table 5.9.

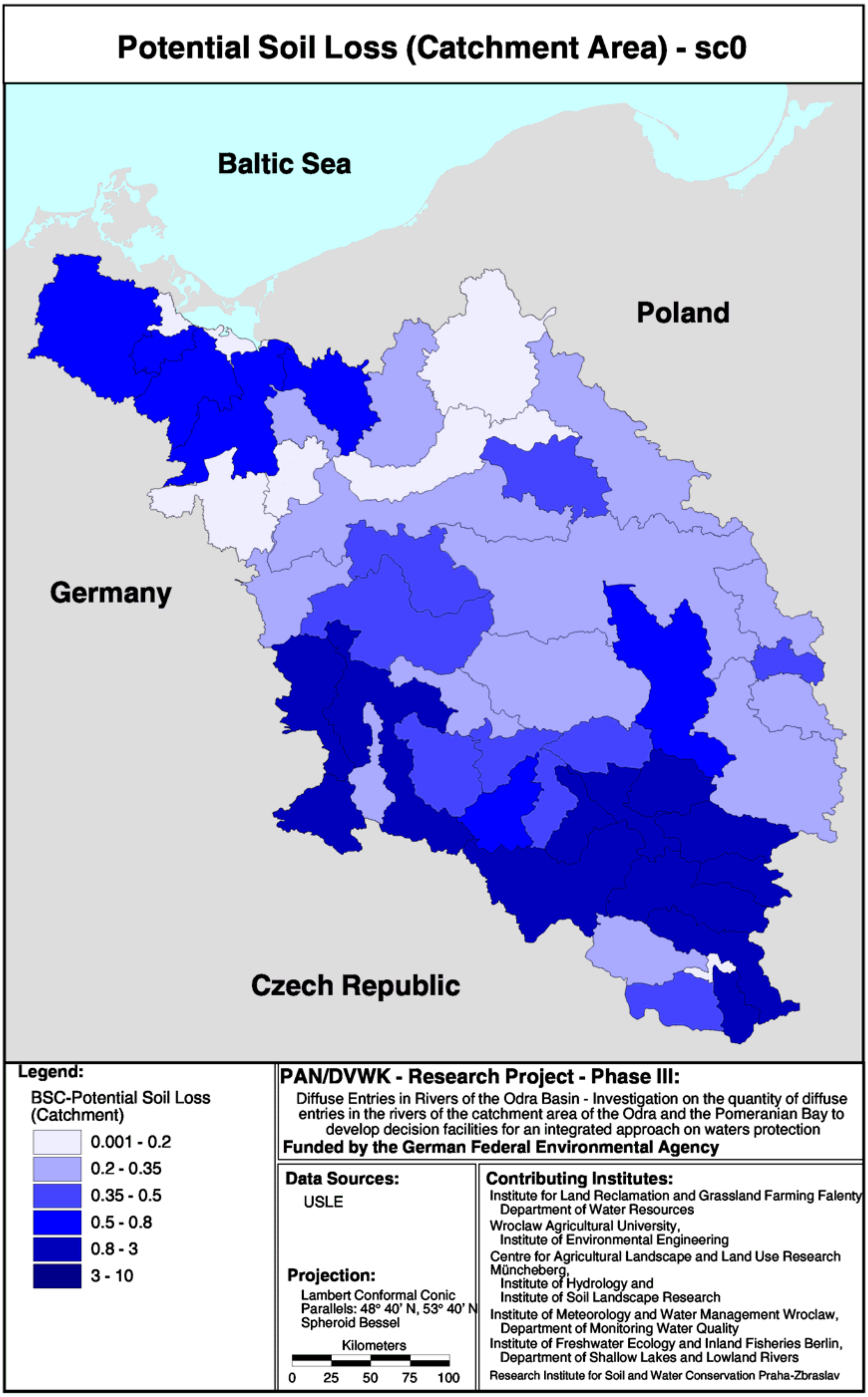
Table 5.9: Soil loss, sediment yield, and nutrient load as a result of water erosion (basic scenario).

	Total Soil loss		Sediment yield	Total Nutrient loads		Specific sediment yield	Specific nutrient loads rel. to the catchment area	
	Arable land	Catchment area		N	P		N	P
	t/ha		kt	t		t/ha	kg/ha	
present state	1.131	0.522	783	1897	1153	0.061	0.149	0.090

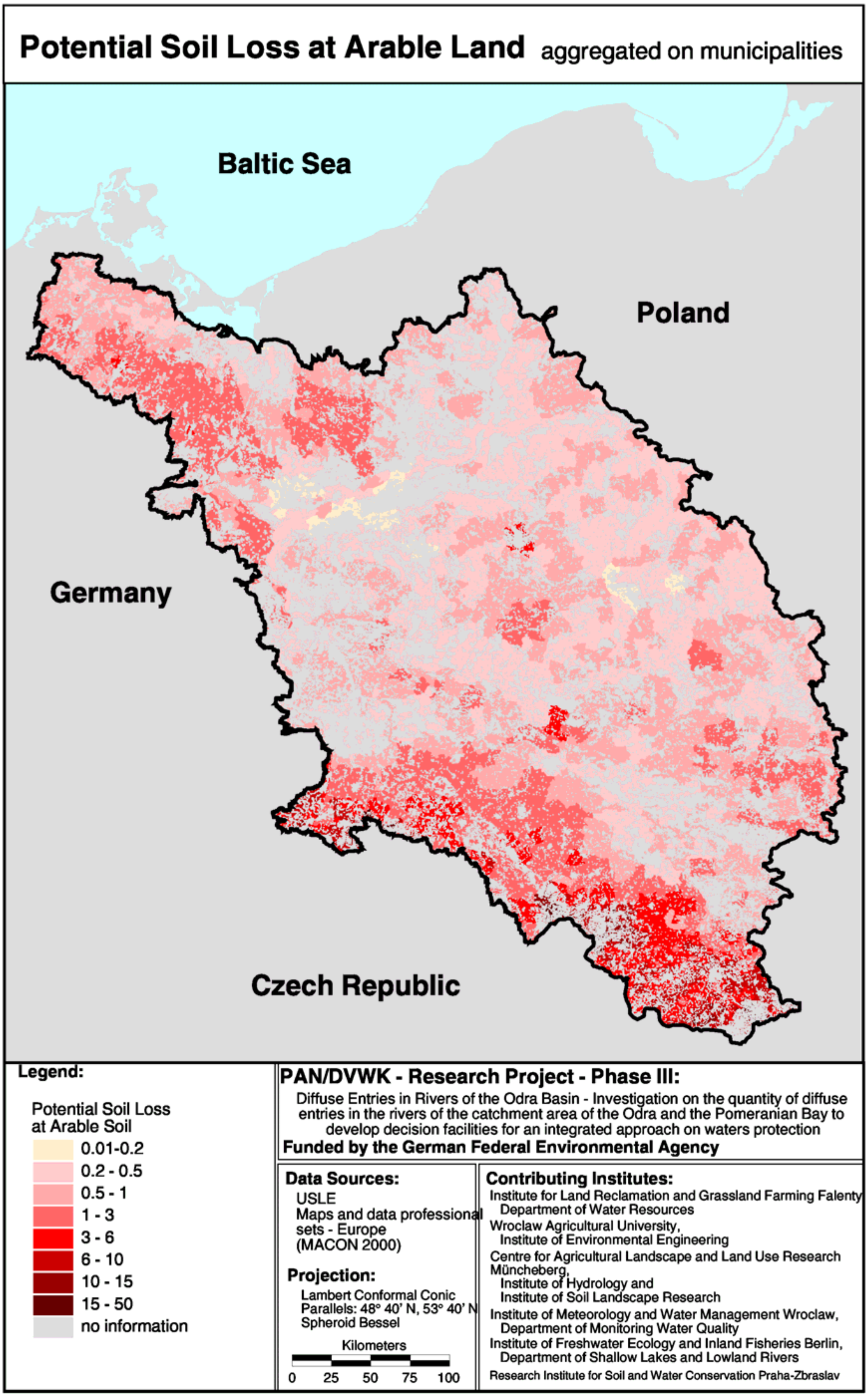
For the present state or the comparable scenario 1, the computed mass of sediment yields is about 783 for the entire basin. About 1.9 kt/a of particulate N and 1.2 kt/a of particulate P can be transported with sediments.

In Map 5.9, the potential soil loss is presented as related to the catchment area in total. Map 5.10 shows the potential soil loss aggregated for municipalities. The highest soil losses are related to steeper slopes in the southern mountainous region (in the Opawa catchment up to about 24 t/ha arable land) and in regions with higher relief energy in the northern lowlands, particularly in the end-moraine of the Pomeranian Stage (up to 3.5 t/ha arable land).

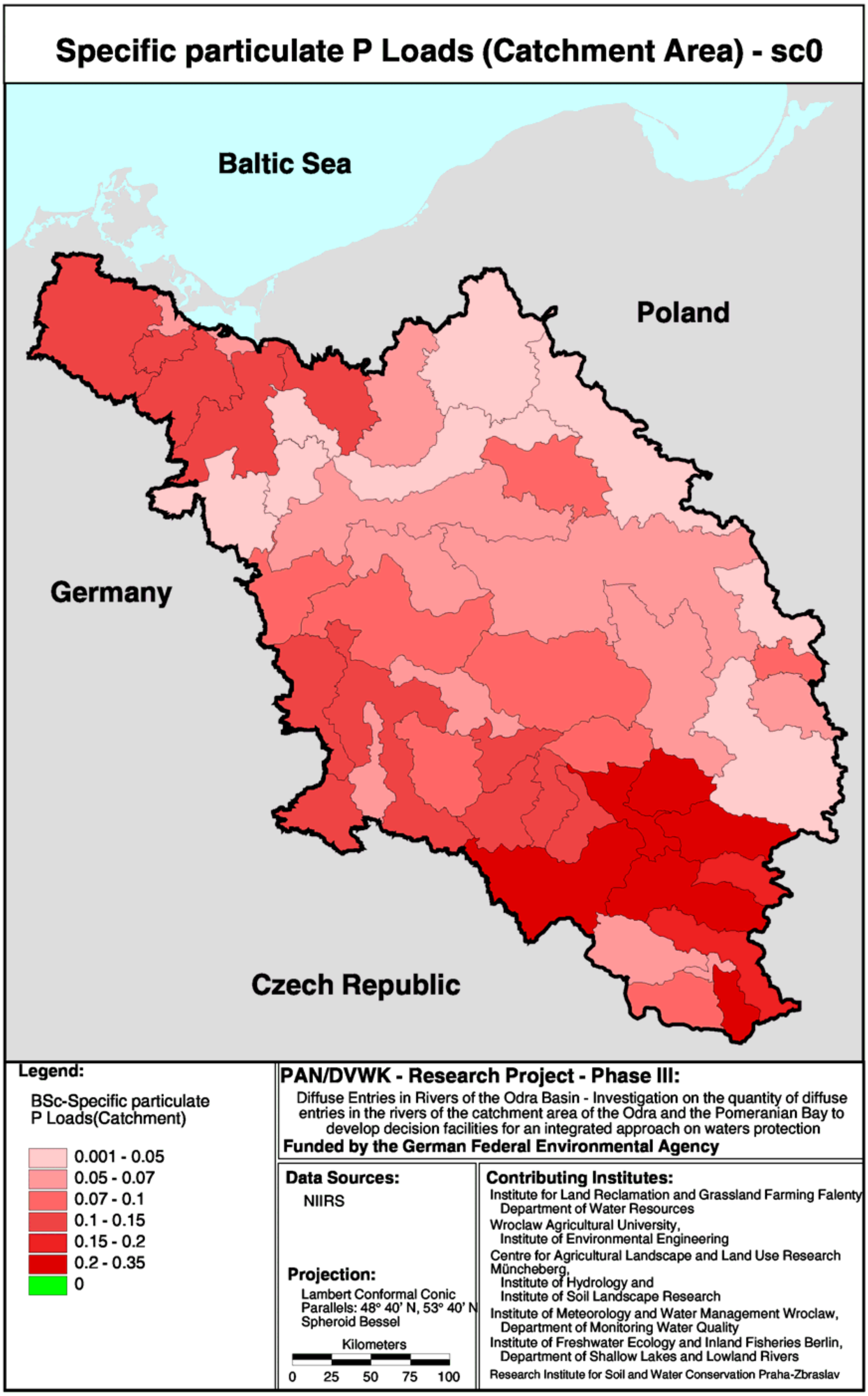
It should be stressed that the presented results are related to long-term mean climatic conditions and mean soil, topographical, and soil cover and management conditions. These values can be exceeded by far in single rainstorm events. Summarising the results for subcatchments is also not possible. In the calculation method, the process of deposition is considered. During natural disasters such as the 1997 summer flood, a much higher material transport than calculated can occur in a single event (measured values of particulate loads of this event are not available). In Phase II of the project, comparing observed and calculated values, the validity of the calculation was described by “the order of magnitude may be affirmed” (DVWK-Materialien 9/1999, page 85). Maps 5.11 and 5.12 present a geographic overview of the specific N and P loads from diffuse (non-point) agricultural sources in the basin as aggregated for catchments. Differing databases must be taken into account.



Map 5.9: Potential soil loss as related to the catchment area.



Map 5.10: Potential soil loss aggregated for arable land.



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Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Data Sources:

NIIRS

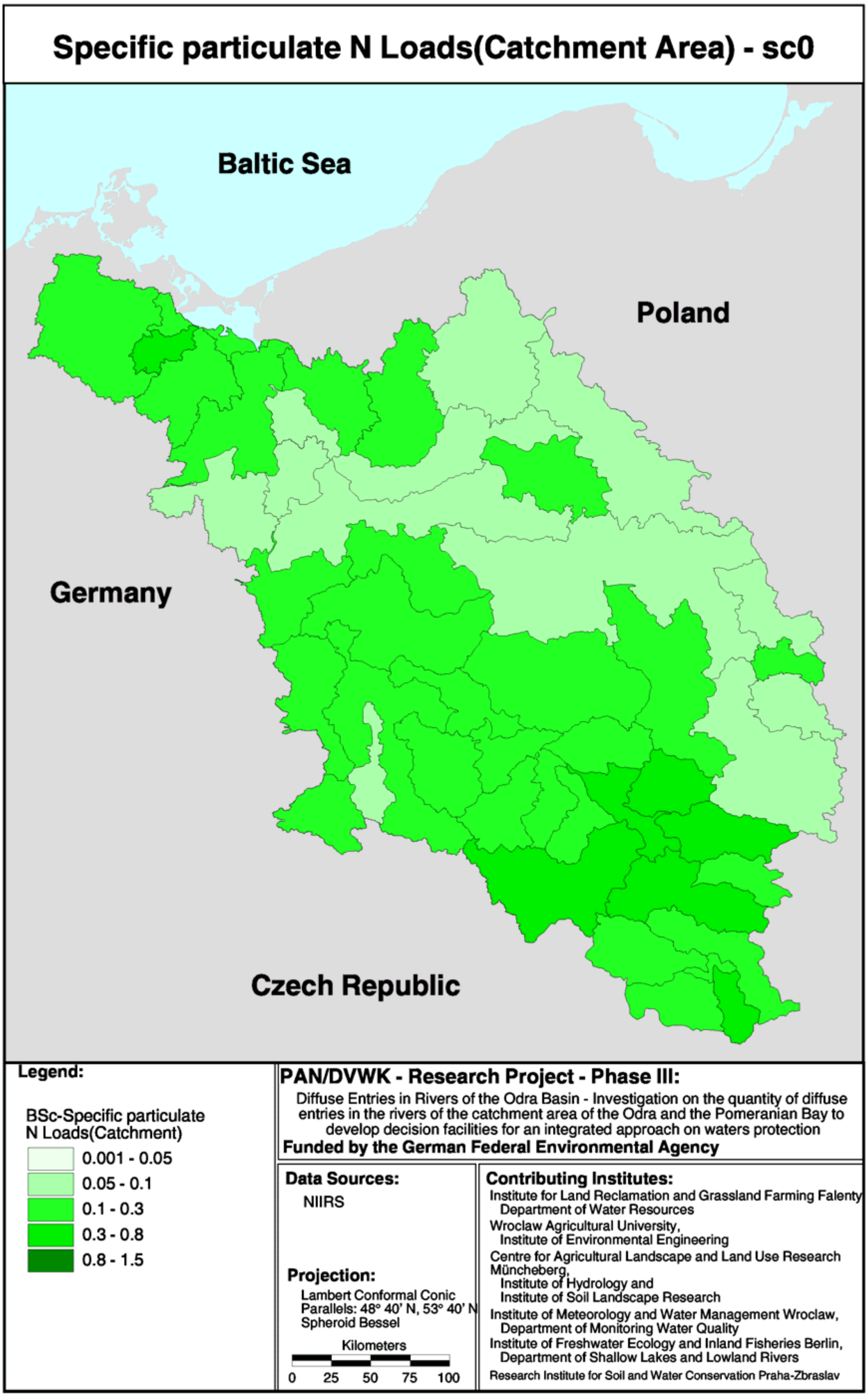
Projection:

Lambert Conformal Conic
Parallels: 48° 40′ N, 53° 40′ N
Spheroid Bessel

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.11: Specific particulate P loads (NIIRS) from diffuse agricultural sources.



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NIIRS

Projection:

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Spheroid Bessel

Contributing Institutes:

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Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.12: Specific particulate N loads (NIIRS-model) from diffuse agricultural sources.

In Czech Republic and in Germany, the higher resolved maps were used at a scale of 1:5,000 down to scales not lesser than 1:100,000. For the Polish regions, the soil map of 1:500,000 was the basis. In addition, the aggregation level of statistical data pools was in the range of municipalities to voivodships.

5.2.4.2 Results of the MONERIS approach

MONERIS uses the same soil losses and specific nutrient content of arable topsoil as the NIIRS model. Therefore the estimated specific soil losses shown in Map 5.7 corresponds with the specific soil losses used for the MONERIS approach regarding the nutrient inputs by erosion. Differences between NIIRS and MONERIS exist for the sediment delivery ratio (SDR) and the enrichment ratio (ER) of phosphorus and nitrogen (see Chapter 4.1.2.4). The consequence is that the estimated nutrient inputs by erosion are different. The nutrient inputs calculated with MONERIS are about 1522 tP/a and 1022 tN/a, respectively. The portion of the Czech part of the Odra basin to the total inputs by erosion (about 16%) is above the portion at the total catchment area (see Figure 5.6). This is caused by the higher soil losses within the mainly mountainous areas of the Czech part of the Odra.

The Map 5.13 and 5.14 gives an overview on the spatial distribution of the nutrient inputs by erosion within the Odra catchment. The highest specific inputs can be observed in the sub catchments with high slope and high portion of arable land. Consequently the nutrient inputs by erosion are the highest within the sub catchments of the upper Odra and moderate to low within the catchment of the Wartha and the lower Odra. Exceptions are the catchment of the Plonia for phosphorus and of the Uecker for nitrogen. This is caused by the high P- or N-contents of topsoil within these catchments and the high portion of arable land at the total catchment area.

These estimations differ significantly from these given in Table 5.9 according to the NIIRS. In the following a comparison of both model results will be done to identify possible sources of deviation.

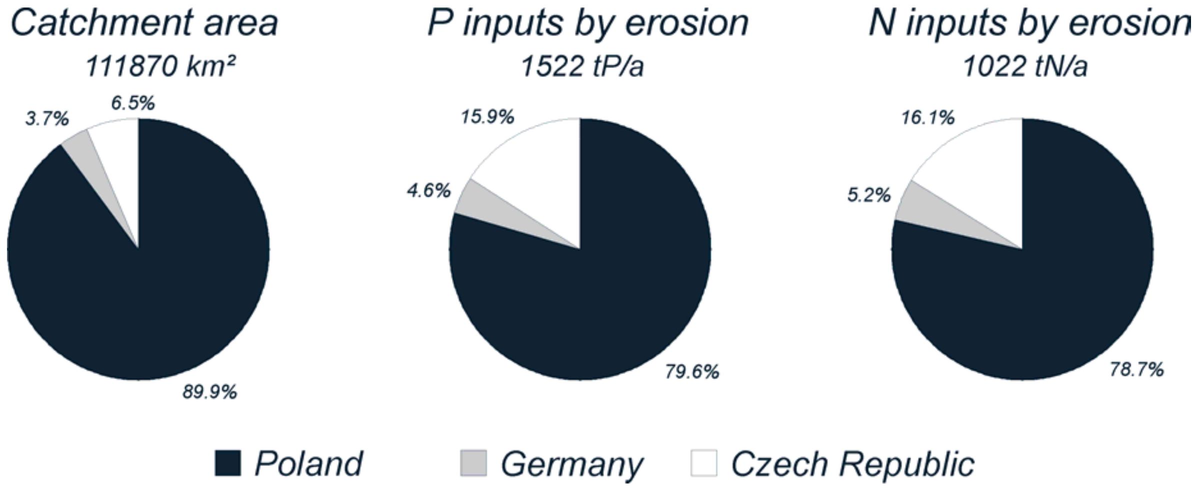


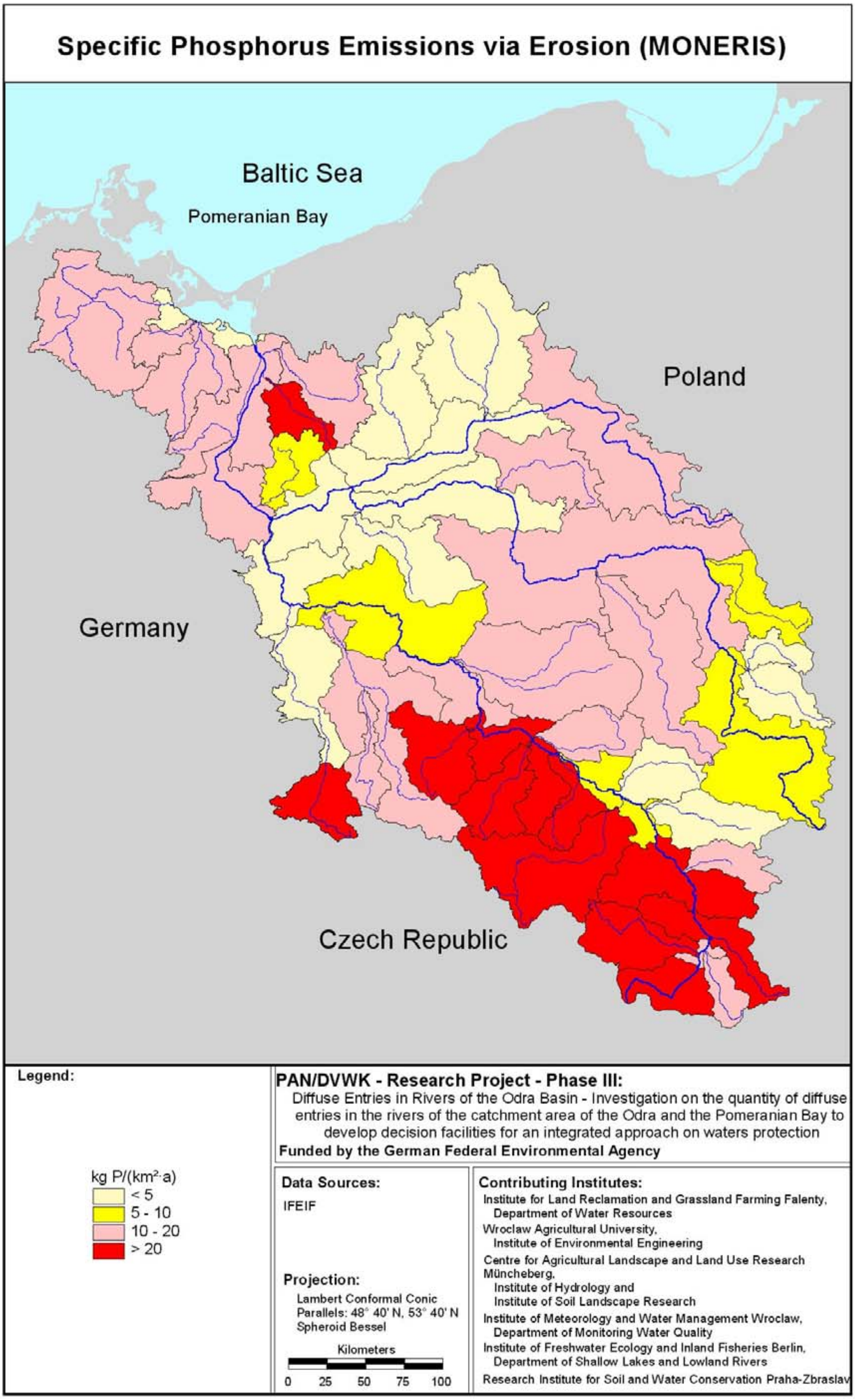
Figure 5.6: Portion of the countries to the total catchment area of the Odra and the total phosphorus and nitrogen discharges by erosion .

Table 5.10: Phosphorus emissions via erosion (EER_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EER_P	EER_P-PL	EER_P-GE	EER_P-CZ	EER_P-PL	EER_P-GE	EER_P-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	74	0.0	0.0	73.9	0.0	0.0	100.0
Opava	2,091	71	5.0	0.0	66.0	7.0	0.0	93.0
Ostravice	824	12	0.0	0.0	11.8	0.0	0.0	100.0
Odra-Chal	4,666	161	5.1	0.0	156.0	3.1	0.0	96.9
Odra-Raci	6,684	236	52.6	0.0	183.4	22.3	0.0	77.7
Klodnica	1,085	12	11.6	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	323	133.4	0.0	189.6	41.3	0.0	58.7
Mala Panew	2,123	5	5.3	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	122	98.0	0.0	23.6	80.6	0.0	19.4
Stobrawa	1,601	7	6.7	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	466	252.8	0.0	213.3	54.2	0.0	45.8
Olawa	1,167	33	33.3	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	45	45.3	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	22	21.6	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	58	58.5	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	677	464.0	0.0	213.3	68.5	0.0	31.5
Barycz	5,535	80	80.2	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	785	571.5	0.0	213.3	72.8	0.0	27.2
Kwisa	1,026	18	17.8	0.0	0.5	97.3	0.0	2.7
Bobr	5,869	80	79.6	0.0	0.7	99.1	0.0	0.9
Odra-Pole	47,152	895	681.3	0.0	213.9	76.1	0.0	23.9
Ny Lu-Zgor	1,609	57	12.1	17.9	27.5	21.1	31.1	47.8
Ny Lu-Gubi	3,974	66	18.5	19.8	27.5	28.2	30.0	41.8
Odra-Kost	53,532	968	703.8	22.8	241.4	72.7	2.4	24.9
Grabia	813	3	3.2	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	8	7.7	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	48	47.9	0.0	0.0	100.0	0.0	0.0
Ner	1,867	12	12.3	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	60	60.2	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	245	245.3	0.0	0.0	100.0	0.0	0.0
Welna	2,621	27	26.7	0.0	0.0	100.0	0.0	0.0
Obra	2,758	10	9.7	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	64	64.4	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	15	15.4	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	9	8.9	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	96	96.1	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	406	405.6	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	7	6.7	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	1,420	1,126.3	52.7	241.4	79.3	3.7	17.0
Plonia	1,101	24	23.6	0.0	0.0	100.0	0.0	0.0
Ina	2,163	37	37.1	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	118,861	1,522	1,210.9	69.6	241.4	79.6	4.6	15.9
Peene	5,110	73	0.0	73.0	0.0	0.0	100.0	0.0
Zarow	748	10	0.0	9.5	0.0	0.0	100.0	0.0
Uecker	2,401	47	0.3	46.4	0.0	0.6	99.4	0.0
Odra Haff	8,885	130	0.4	129.2	0.0	0.3	99.7	0.0

Table 5.11: Nitrogen emissions via erosion (EER_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EER_N	EER_N-PL	EER_N-GE	EER_N-CZ	EER_N-PL	EER_N-GE	EER_N-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	49	0	0	49	0.0	0.0	100.0
Opava	2,091	50	4	0	46	7.0	0.0	93.0
Ostravice	824	8	0	0	8	0.0	0.0	100.0
Odra-Chal	4,666	109	4	0	106	3.2	0.0	96.8
Odra-Raci	6,684	159	35	0	124	22.1	0.0	77.9
Klodnica	1,085	8	8	0	0	100.0	0.0	0.0
Odra-Gros	10,989	219	91	0	128	41.4	0.0	58.6
Mala Panew	2,123	4	4	0	0	100.0	0.0	0.0
Nysa Klod	4,515	81	65	0	16	80.6	0.0	19.4
Stobrawa	1,601	4	4	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	314	170	0	144	54.1	0.0	45.9
Olawa	1,167	20	20	0	0	100.0	0.0	0.0
Bystrzyca	1,760	28	28	0	0	100.0	0.0	0.0
Widawa	1,716	13	13	0	0	100.0	0.0	0.0
Kaczawa	2,261	33	33	0	0	100.0	0.0	0.0
Odra-Scin	29,584	437	293	0	144	67.0	0.0	33.0
Barycz	5,535	58	58	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	511	367	0	144	71.8	0.0	28.2
Kwisa	1,026	10	10	0	0	97.3	0.0	2.7
Bobr	5,869	46	46	0	0	99.2	0.0	0.8
Odra-Pole	47,152	577	432	0	145	74.9	0.0	25.1
Ny Lu-Zgor	1,609	42	9	13	20	21.1	31.1	47.8
Ny Lu-Gubi	3,974	49	14	15	20	28.4	30.0	41.6
Odra-Kost	53,532	631	449	17	165	71.2	2.7	26.1
Grabia	813	2	2	0	0	100.0	0.0	0.0
Widawka	2,355	6	6	0	0	100.0	0.0	0.0
Warta-Sier	8,140	34	34	0	0	100.0	0.0	0.0
Ner	1,867	9	9	0	0	100.0	0.0	0.0
Prosna	4,825	38	38	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	180	180	0	0	100.0	0.0	0.0
Welna	2,621	19	19	0	0	100.0	0.0	0.0
Obra	2,758	7	7	0	0	100.0	0.0	0.0
Notec-Osie	5,508	45	45	0	0	100.0	0.0	0.0
Gwda	4,943	9	9	0	0	100.0	0.0	0.0
Drawa	3,296	5	5	0	0	100.0	0.0	0.0
Notec-Sant	17,330	65	65	0	0	100.0	0.0	0.0
Warta-Kost	54,518	291	291	0	0	100.0	0.0	0.0
Mysla	1,334	5	5	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	959	753	41	165	78.5	4.3	17.2
Plonia	1,101	13	13	0	0	100.0	0.0	0.0
Ina	2,163	22	22	0	0	100.0	0.0	0.0
Odra-Mouth	118,861	1022	805	53	165	78.7	5.2	16.1
Peene	5,110	65	0	65	0	0.0	100.0	0.0
Zarow	748	9	0	9	0	0.0	100.0	0.0
Uecker	2,401	51	0	51	0	0.6	99.4	0.0
Odra Haff	8,885	125	0	125	0	0.4	99.6	0.0



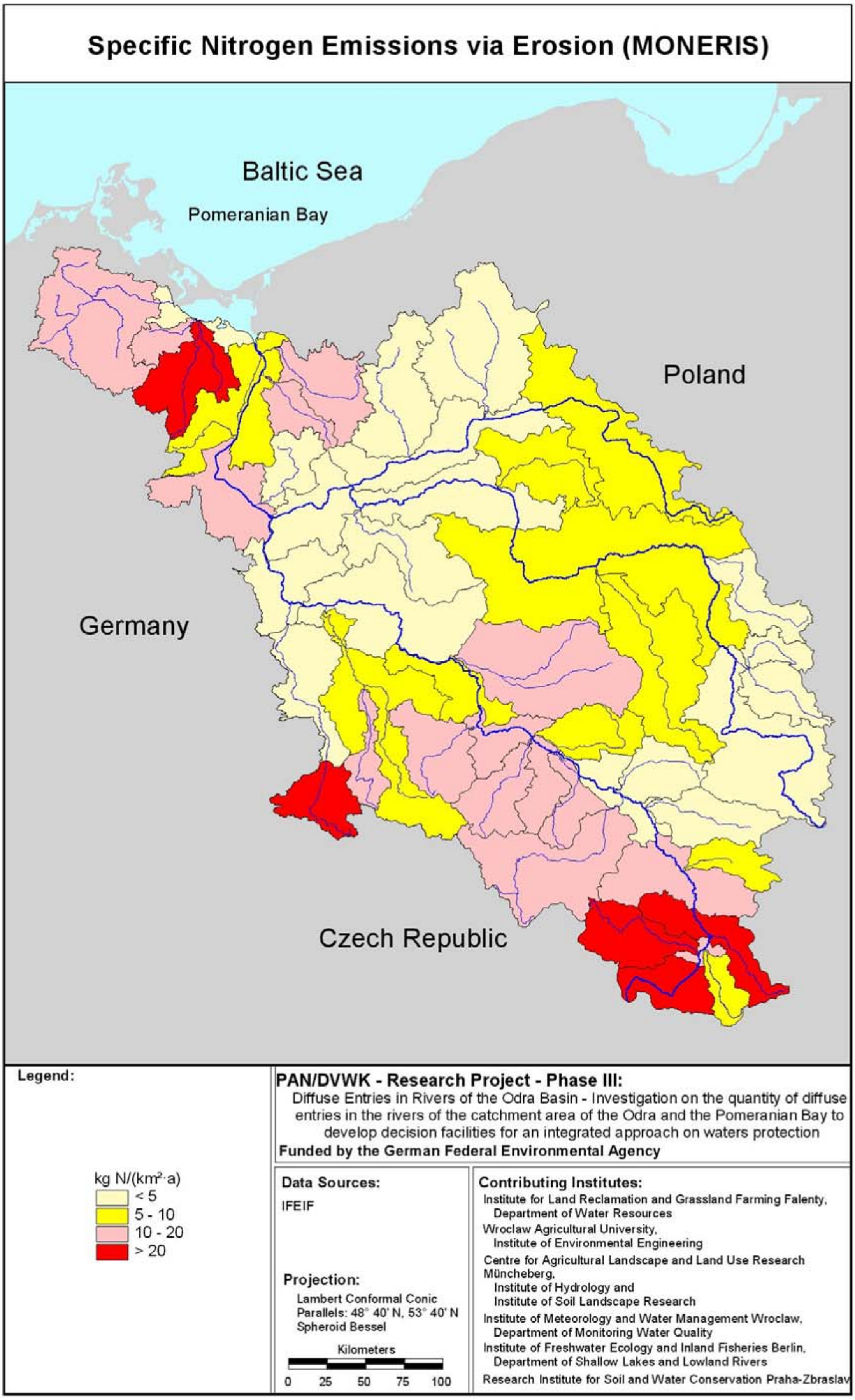
PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.13: Specific phosphorus emissions via erosion (MONERIS) in the period 1993-1997.



Specific Nitrogen Emissions via Erosion (MONERIS)

PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
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Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.14: Specific nitrogen emissions via erosion (MONERIS) in the period 1993-1997.

5.2.4.3 Comparison of the results of the NIIRS and the MONERIS approach

Figure 5.7 shows the estimated model results of P- and N-inputs by erosion for the different sub catchments of the Odra basin. For the sub catchments with low P-inputs by erosion the results of both models are approximately comparable. But for the catchments with large P-inputs significant differences exist. The P- input calculated with the NIIRS model is about 50% lower compared with the estimations based on MONERIS. On the other hand the nitrogen inputs of the NIIRS approach are higher for all sub catchments as the estimated results of MONERIS. The reason for the higher N-inputs of the NIIRS model is mainly that this model uses the same enrichment ratio as for phosphorus, whereas in MONERIS the ER of nitrogen is only the half of the phosphorus ER.

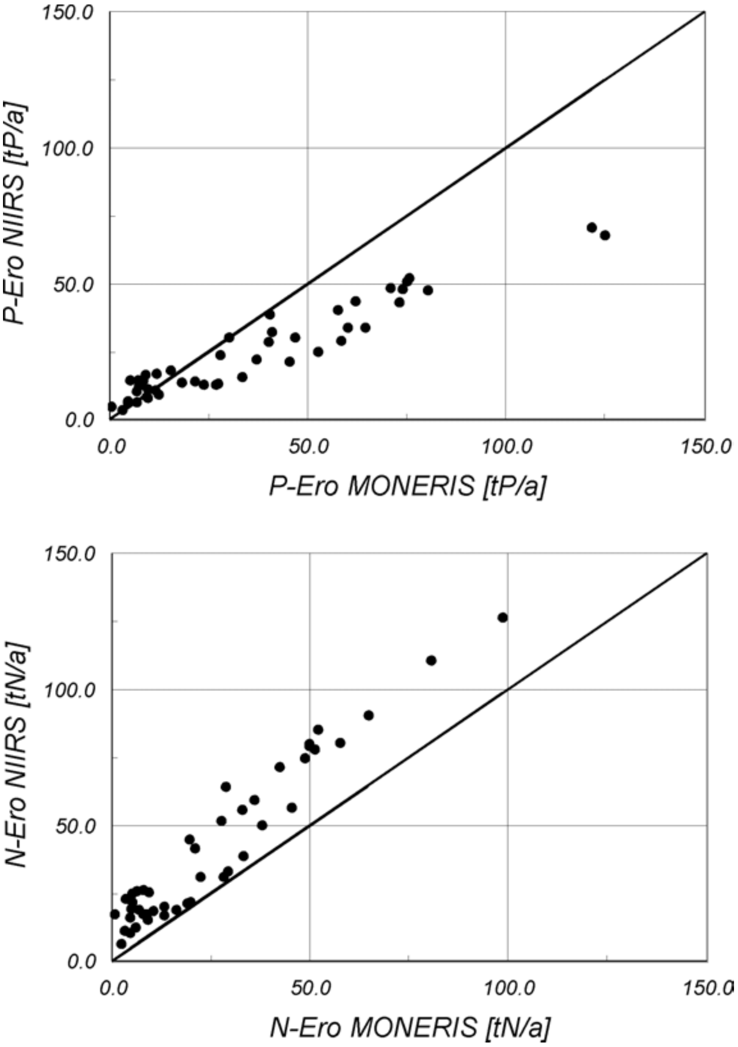


Figure 5.7: Comparison of the estimated nutrient inputs via erosion by the NIIRS and MONERIS approach for the different sub catchment of the Odra.

The source of the deviation of the P-inputs can be the different approaches for the sediment delivery ratio as well as for the enrichment ratio.

Unfortunately a direct comparison of the calculated P-inputs by both models with the observed P-loads at the monitoring stations must be failed caused by the very high portion of point sources at the total P-emissions and P- loads within the sub catcments.

One possibility to evaluate the results of both models is to compare the calculated sediment transports into the different river systems with the calculated transports of suspended solids at the monitoring station of the individual catchments. But it have to be taken into account that the sources of the observed sediment transport are not only the inputs by erosion. Point sources, inputs by urban areas and especially the autochthon production of particles (growth of phytoplankton) within the river system itself can be important sources for suspended solids

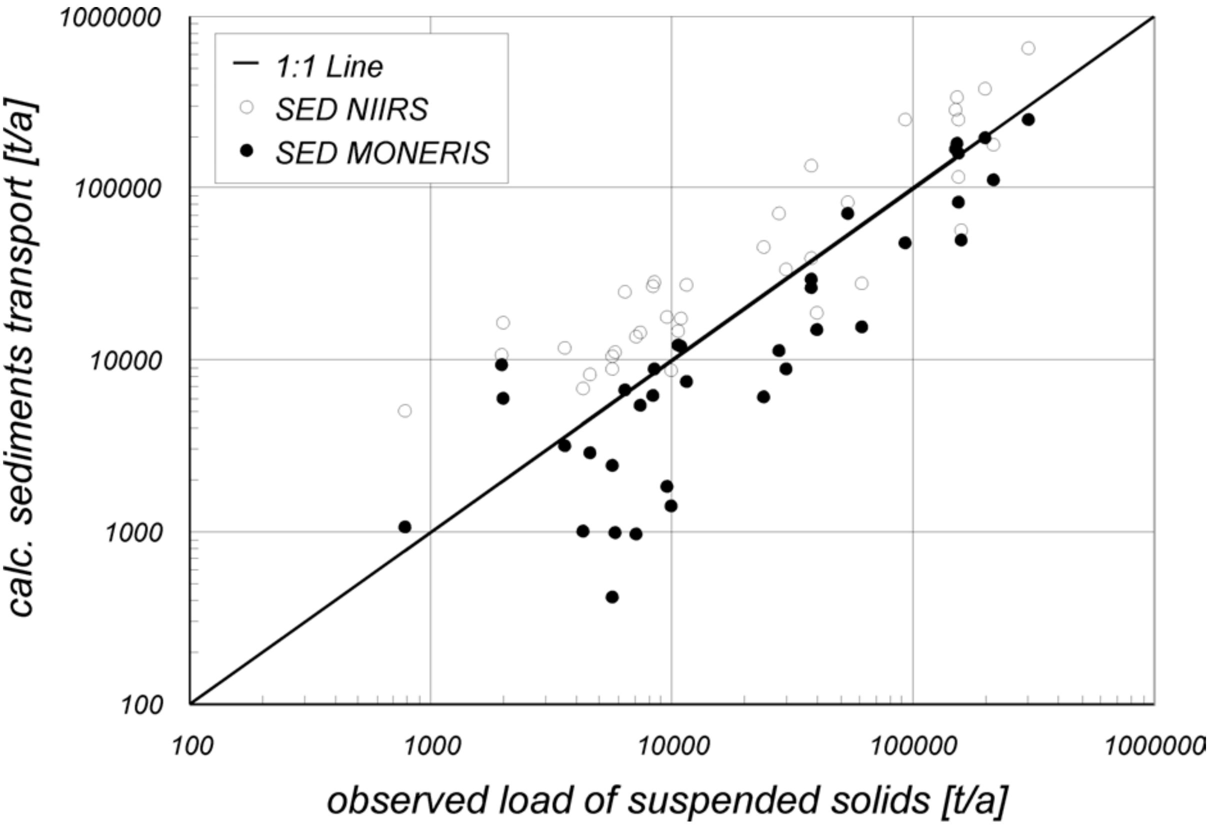


Figure 5.8: Comparison of the observed transports of suspended solids within the catchments of the Odra and the calculated sediment transports by NIIRS and MONERIS.

especially in the larger basins. On the other hand retention of suspended solids can be an important loss process. From this it can be concluded that the calculated sediment transports into the river systems can show large deviations to the observed loads of suspended solids, but in general the calculated sediment transports should be lower or in the same order of magnitude as the observed loads.

Figure 5.8 shows this comparison of the calculated sediment transports by NIIRS and MONERIS with the observed loads of suspended solids. One can see that the NIIRS results are mainly above the observed loads of suspended solids. In contrast to this the MONERIS results are mainly lower as the observed loads. This is also illustrated by Table 5.12 where the comparison is summarized. On the average the sediment transports of the NIIRS model are 124 % higher as the observed loads and the sediment transports calculated with the MONERIS model are about 26 % lower. On the other hand the average absolute deviation of the MONERIS results is with 48% much lower as of the NIIRS results.

If the calculated SDR and ER of both models are directly compared very large differences exist (see Figure 5.8). In the sub catchments of the flatlands where MONERIS estimates a sediment delivery ratio (SDR) lower as 4% the NIIRS results are in a range of 10% to more than 30%. On the other hand in the range where MONERIS SDR is larger than 5% the NIIRS SDR is nearly the same.

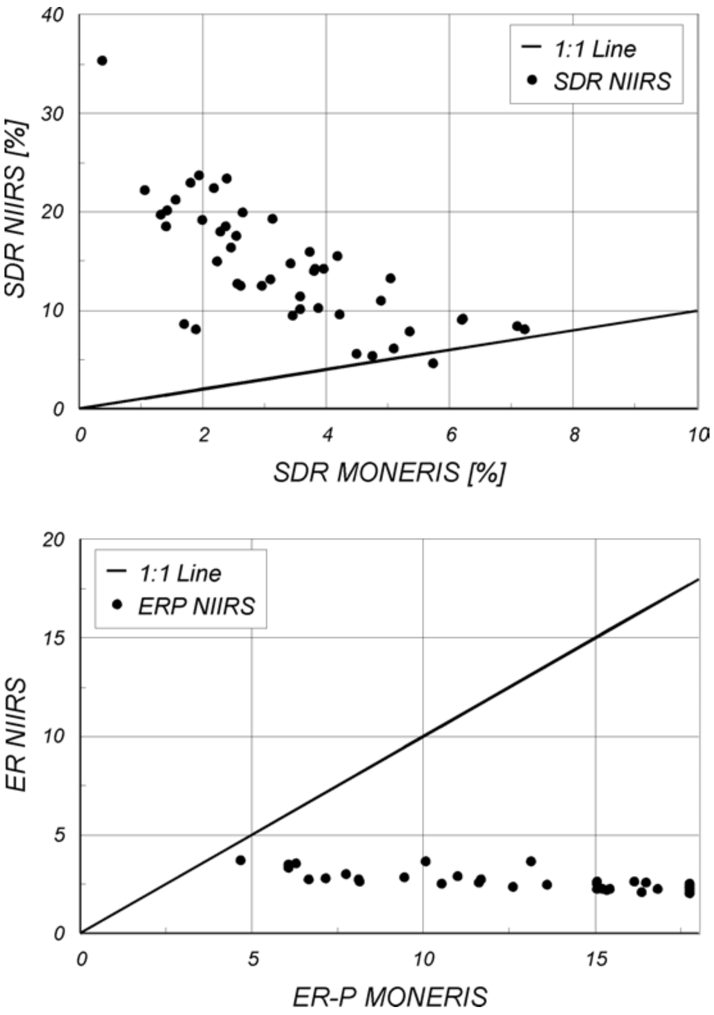


Figure 5.9: *Comparison of the estimated SDR and ER of the NIIRS model with those of the MONERIS model.*

From this it can be concluded that NIIRS approach for the SDR seems to be questionable, because this approach estimates higher sediment delivery ratios for the catchments in the flatlands, where the connectivity between land and the river system and the slope of the area near the river system is in general lower as for the mountainous regions.

For the enrichment ratio similar large deviation between the model results can be observed from Figure 5.9. But there the enrichment ratios of the NIIRS model are low and nearly constant, whereas the ER of MONERIS varies in a range between 5 and 18.

If the large differences of the SDR and the ER approaches of both models are considered, the result is surprisingly that the deviation in the calculated nutrient inputs by erosion is relatively small and only due to the fact that an over- or underestimation of the SDR on the one hand is compensated by an under- or overestimation of the ER on the other hand.

Based on the comparison of the results of both models a conclusion on the better approach can not given. Further detailed studies on the both important ratios are necessary for the further development to describe these processes.

Table 5.12: Relative deviation between the calculated sediment transports of the models NIIRS and MONERIS and the observed load of suspended solids (averages for all monitoring stations)

Rel. Deviation NIIRS Average of all deviations	Rel. Deviation NIIRS Average of absolute deviations	Rel. Deviation MONERIS Average of all deviations	Rel. Deviation MONERIS Average of absolute deviations
[%]	[%]	[%]	[%]
123.6	135.9	-26.4	47.5

5.2.5 Nutrient Emissions via Tile Drainage (Moneris)

Based on the state of the nitrogen surplus in the different sub catchments of the Odra (see Map 5.3) the inputs by tile drainage were calculated according to the method given in Chapter 4.1.2.5. The tile drained area within the Odra basin is about 15950 km². This corresponds to 13 % of the total area or 23 % of the agricultural area. It was found that the phosphorus inputs by tile drainage are about 425 tP/a. For nitrogen the emissions by this pathway were calculated as 32260 tN/a (see Table 5.13 and 5.14). The Maps 5.15 and 5.16 present a overview on the spatial distribution of the specific nutrient inputs by drains.

For Czech Republic investigations exist for the drainage runoff. From this it can be concluded that in winter 59% and in summer 23% of the precipitation are realized as drainage runoff (Soukup, pers. comm.). Compared to the assumption within MONERIS this drainage runoff is in both periods of the year about 10% higher.

The calculated nitrogen concentrations within the sub catchments vary in a range between 8.7 mgN/l (Welna) and 21.3 mgN/l (Ner). Behrendt et al. (2000) could show that the calculated mean nitrogen concentrations within the tile drainage are within the range of measurements for drained areas in the flatlands of Northeastern Germany. For the sub catchments within the Czech part of the Odra the nitrogen concentration of tile drained areas is in a range between 9.1 mgN/l (Ostravice) and 15.6 mgN/l (Odra upstream Polanka). Measurements of nitrate concentrations in different drained areas of Czech Republic show that the concentrations vary in a range between 4 and 40 mgN/l (Svobodová & Klímová, 1981 Kvítek 1996; Ivanek, Soukup & Královcová 1998; Soukup et al.,1997). The averages are in a range of 8 and 14 mgN/l, which corresponds well with the calculated drainage concentrations for the Czech part of the Odra. In general one can conclude from this comparison with measured data that the present approach for the calculation of nutrient inputs leads probably to a small underestimation. But more data especially on the drainage runoff are necessary to implement a better approach into the model.

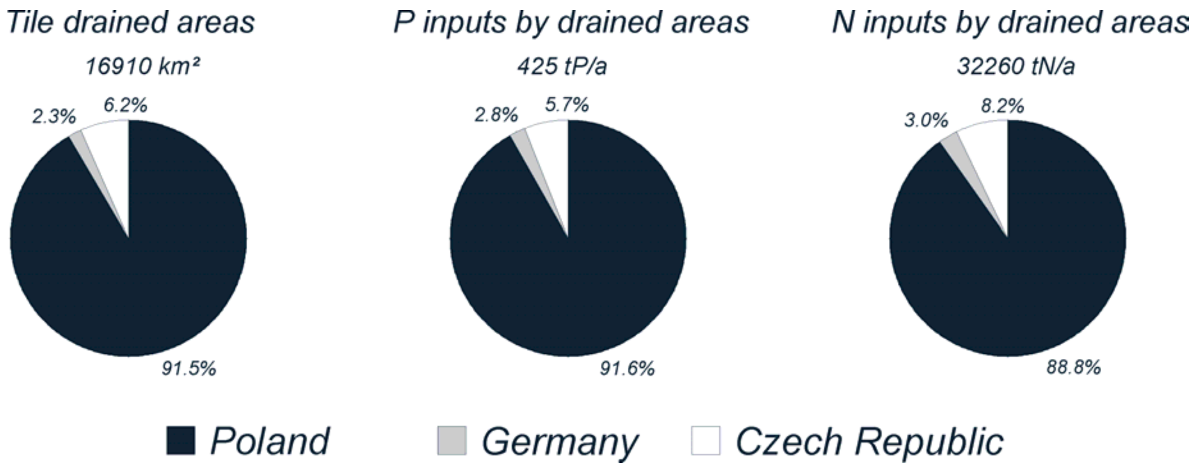


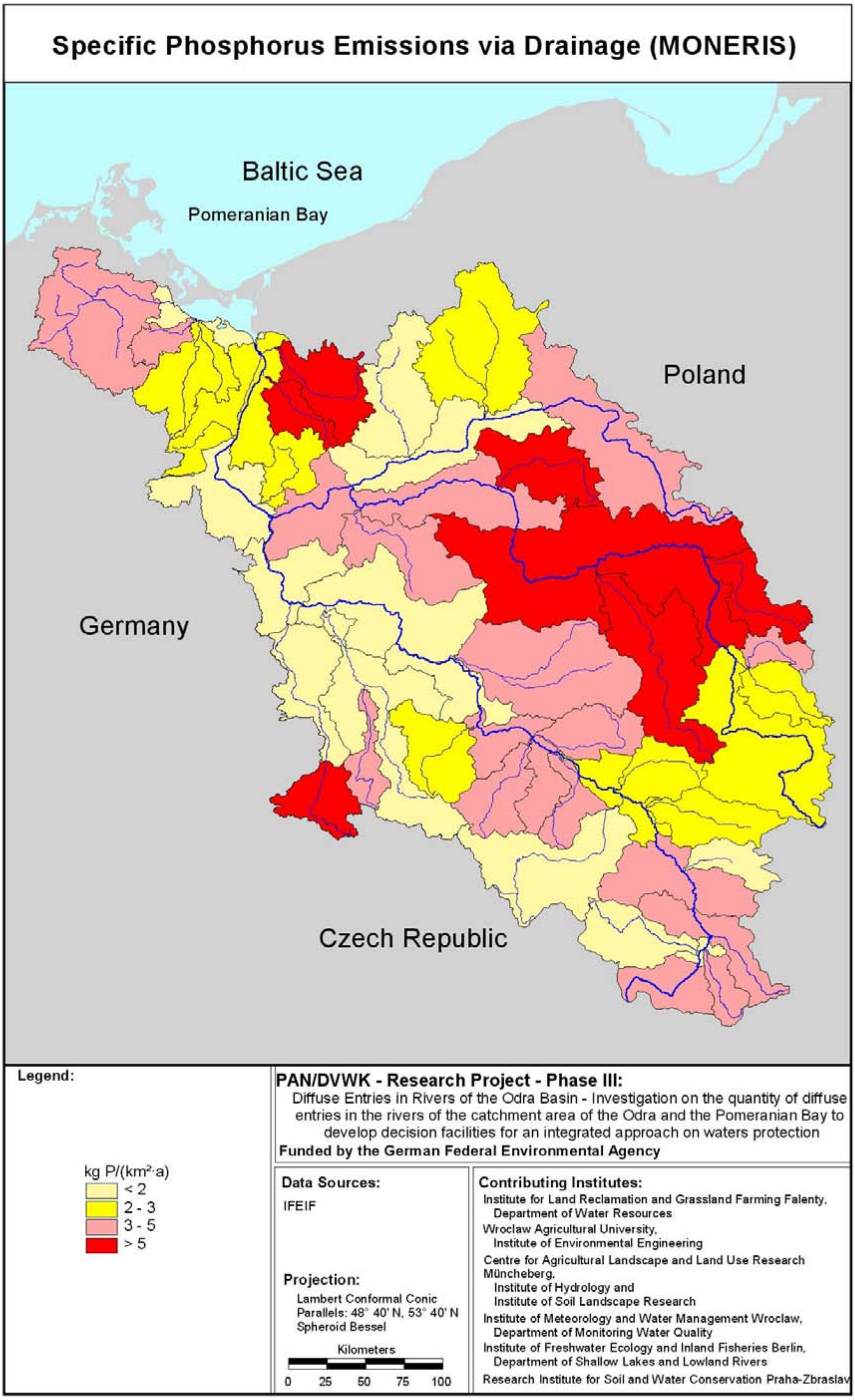
Figure 5.10: Portion of the countries to the total tile drained area of the Odra and the total phosphorus and nitrogen discharges by tile drainage .

Table 5.13: Phosphorus emissions via tile drainage (EDR$_P$) in the period 1993-1997 for the whole catchment and for the countries.

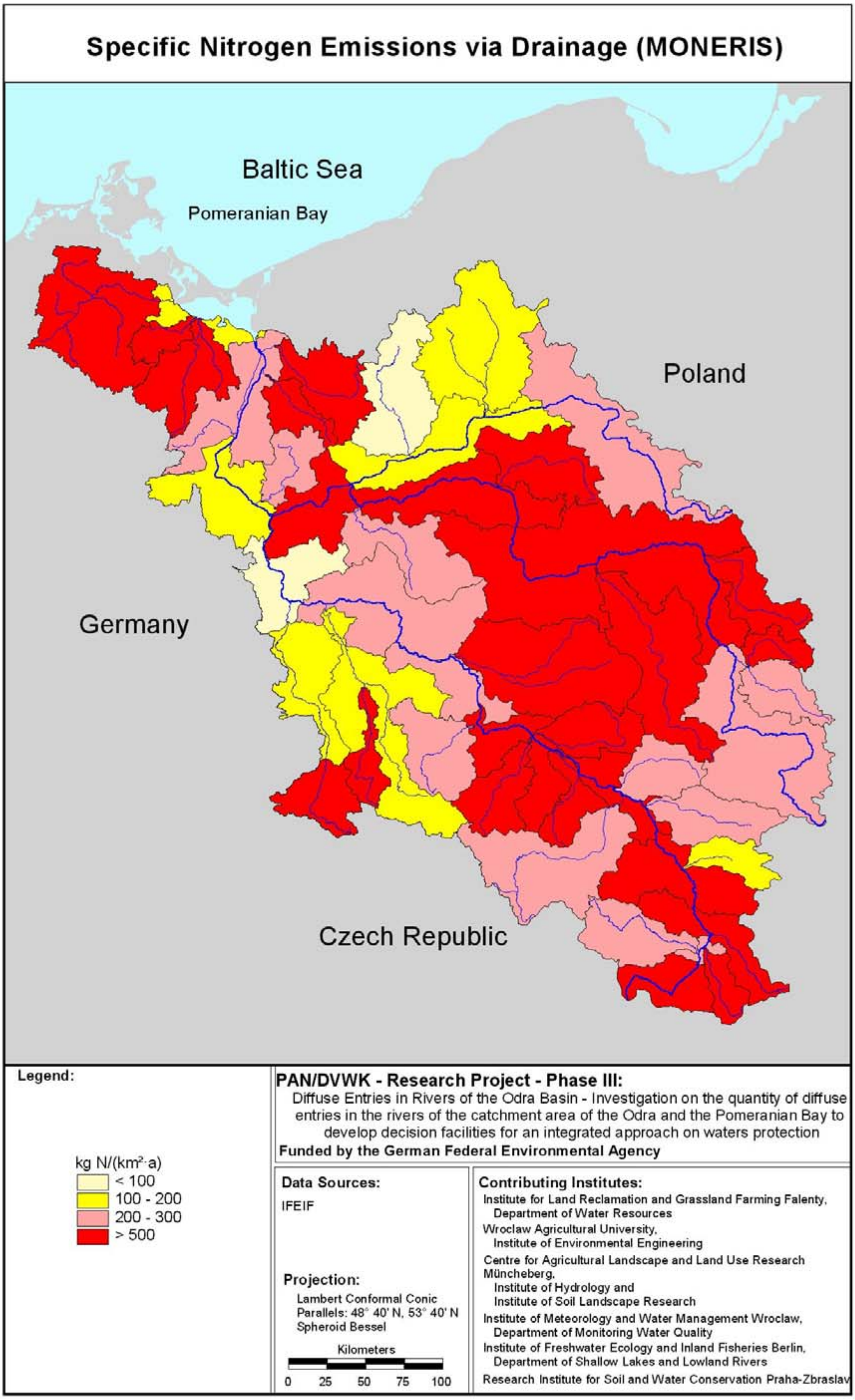
Short name	Area	EDR$_P$	EDR$_P$-PL	EDR$_P$-GE	EDR$_P$-CZ	EDR$_P$-PL	EDR$_P$-GE	EDR$_P$-CZ
	[km^2]	[t P/a]				[%]		
Odra-Pola	1,570	5.9	0.0	0.0	5.9	0.0	0.0	100.0
Opava	2,091	3.8	0.3	0.0	3.5	7.0	0.0	93.0
Ostravice	824	3.1	0.0	0.0	3.1	0.0	0.0	100.0
Odra-Chal	4,666	13.0	0.3	0.0	12.8	2.1	0.0	97.9
Odra-Raci	6,684	22.4	6.2	0.0	16.2	27.8	0.0	72.2
Klodnica	1,085	1.8	1.8	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	33.5	16.6	0.0	17.0	49.4	0.0	50.6
Mala Panew	2,123	5.8	5.8	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	8.5	6.9	0.0	1.7	80.6	0.0	19.4
Stobrawa	1,601	4.1	4.1	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	55.5	36.9	0.0	18.6	66.4	0.0	33.6
Olawa	1,167	5.7	5.8	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	6.1	6.1	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	7.7	7.7	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	6.7	6.7	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	92.6	73.9	0.0	18.6	79.9	0.0	20.1
Barycz	5,535	26.9	26.9	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	122.8	104.2	0.0	18.6	84.8	0.0	15.2
Kwisa	1,026	5.0	4.9	0.0	0.1	97.3	0.0	2.7
Bobr	5,869	13.5	13.3	0.0	0.2	98.8	0.0	1.2
Odra-Pole	47,152	145.0	126.2	0.0	18.8	87.0	0.0	13.0
Ny Lu-Zgor	1,609	11.1	2.3	3.4	5.3	21.1	31.1	47.8
Ny Lu-Gubi	3,974	13.7	4.4	4.1	5.3	31.9	29.5	38.6
Odra-Kost	53,532	160.1	131.4	4.6	24.1	82.1	2.9	15.0
Grabia	813	2.7	2.7	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	7.0	7.0	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	19.2	19.2	0.0	0.0	100.0	0.0	0.0
Ner	1,867	9.6	9.6	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	28.1	28.1	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	135.2	135.2	0.0	0.0	100.0	0.0	0.0
Welna	2,621	18.8	18.8	0.0	0.0	100.0	0.0	0.0
Obra	2,758	8.4	8.4	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	24.7	24.7	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	12.6	12.6	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	4.2	4.2	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	46.6	46.6	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	229.9	229.9	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	3.2	3.2	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	398.5	365.9	8.6	24.1	91.8	2.1	6.0
Plonia	1,101	6.5	6.5	0.0	0.0	100.0	0.0	0.0
Ina	2,163	12.5	12.5	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	118,861	425.3	389.4	11.8	24.1	91.6	2.8	5.7
Peene	5,110	19.5	0.0	19.5	0.0	0.0	100.0	0.0
Zarow	748	2.3	0.0	2.3	0.0	0.0	100.0	0.0
Uecker	2,401	6.7	0.0	6.6	0.0	0.6	99.4	0.0
Odra Haff	8,885	29.9	0.5	29.4	0.0	1.5	98.5	0.0

Table 5.14: Nitrogen emissions via tile drainage (EDR_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EDR_N	EDR_N-PL	EDR_N-GE	EDR_N-CZ	EDR_N-PL	EDR_N-GE	EDR_N-CZ
	[km²]	[t Na]			[%]			
Odra-Pola	1,570	976	0	0	976	0.0	0.0	100.0
Opava	2,091	526	37	0	489	7.0	0.0	93.0
Ostravice	824	254	0	0	254	0.0	0.0	100.0
Odra-Chal	4,666	1819	38	0	1,781	2.1	0.0	97.9
Odra-Raci	6,684	2647	564	0	2,084	21.3	0.0	78.7
Klodnica	1,085	114	114	0	0	100.0	0.0	0.0
Odra-Gros	10,989	3520	1,374	0	2,147	39.0	0.0	61.0
Mala Panew	2,123	348	348	0	0	100.0	0.0	0.0
Nysa Klod	4,515	835	672	0	162	80.6	0.0	19.4
Stobrawa	1,601	307	307	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	5324	3,015	0	2,309	56.6	0.0	43.4
Olawa	1,167	370	370	0	0	100.0	0.0	0.0
Bystrzyca	1,760	423	423	0	0	100.0	0.0	0.0
Widawa	1,716	535	535	0	0	100.0	0.0	0.0
Kaczawa	2,261	340	340	0	0	100.0	0.0	0.0
Odra-Scin	29,584	7649	5,340	0	2,309	69.8	0.0	30.2
Barycz	5,535	3009	3,009	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	10925	8,616	0	2,309	78.9	0.0	21.1
Kwisa	1,026	258	251	0	7	97.3	0.0	2.7
Bobr	5,869	730	721	0	8	98.9	0.0	1.1
Odra-Pole	47,152	12480	10,162	0	2,317	81.4	0.0	18.6
Ny Lu-Zgor	1,609	677	143	210	324	21.1	31.1	47.8
Ny Lu-Gubi	3,974	920	330	266	324	35.9	28.9	35.2
Odra-Kost	53,532	13545	10,575	329	2,641	78.1	2.4	19.5
Grabia	813	271	271	0	0	100.0	0.0	0.0
Widawka	2,355	596	596	0	0	100.0	0.0	0.0
Warta-Sier	8,140	1752	1,752	0	0	100.0	0.0	0.0
Ner	1,867	899	899	0	0	100.0	0.0	0.0
Prosna	4,825	2556	2,556	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	10896	10,896	0	0	100.0	0.0	0.0
Welna	2,621	686	686	0	0	100.0	0.0	0.0
Obra	2,758	552	552	0	0	100.0	0.0	0.0
Notec-Osie	5,508	1227	1,227	0	0	100.0	0.0	0.0
Gwda	4,943	700	700	0	0	100.0	0.0	0.0
Drawa	3,296	237	237	0	0	100.0	0.0	0.0
Notec-Sant	17,330	2651	2,651	0	0	100.0	0.0	0.0
Warta-Kost	54,518	16380	16,380	0	0	100.0	0.0	0.0
Mysla	1,334	252	252	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	30662	27,329	691	2,641	89.1	2.3	8.6
Plonia	1,101	362	362	0	0	100.0	0.0	0.0
Ina	2,163	584	584	0	0	100.0	0.0	0.0
Odra-Mout	118,861	32263	28,659	963	2,641	88.8	3.0	8.2
Peene	5,110	2940	0	2,940	0	0.0	100.0	0.0
Zarow	748	268	0	268	0	0.0	100.0	0.0
Uecker	2,401	978	6	972	0	0.6	99.4	0.0
Odra Haff	8,885	4312	43	4,270	0	1.0	99.0	0.0



Map 5.15: Specific phosphorus emissions via tile-drainage in the period 1993-1997.



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.16: Specific phosphorus emissions via tile-drainage in the period 1993-1997.

5.2.6 Nutrient Emissions via Groundwater

5.2.6.1 Results of the MODEST approach

The MODEST approach (Chapter 4.1.2.6) has been applied as an important alternative to calculate the spatial and temporal development of groundwater-induced N emissions into the surface waters. Applying this approach, a spatially differentiated identification of problematic agricultural areas and the scenario-based analysis of future developments are possible. This distributed analysis has been restricted to that part of the unconsolidated rock region with complete information of the groundwater conditions. The area (106,781 km²) is the same as analysed in Phase II. Excluded from evaluation are the lakes, thus leading to a net evaluated area of 105,397 km². In Table 5.15 an overview on the evaluated sub catchment areas is given. Areas characterised by shallow groundwater (such as river lowlands), though fully integrated into water budget calculations, were excluded from N load calculations as far as their water balance was negative.

<u>MODEST validation/calibration</u>

Performing preliminary calculations, the MODEST approach had to be validated. Further, the variables k_v (Equation 4.49) and $t_{½}$ (Equation 4.50) needed to be defined respectively calibrated.

To validate the water balance/discharge values calculated by ABIMO, those 17 sub catchments were chosen for which long-term streamflow records were available (Table 5.16). These observed data were used to determine mean discharge values to be compared to ABIMO results. In Figure 5.11 the comparison is shown. With the exception of three basins: Warta-Sieradz, Prosna, and Plonia, the calculated discharge ranges between –25 % and +25 % from the observed discharge. For Plonia and Ina it is to consider that the a part of the discharge within the Plonia catchment is transferred to the Ina river.

As an interim result, Map 5.15 illustrates the spatial distribution of the long-term mean annual discharge as calculated by means of ABIMO. This is the steady-state flux required for all the further subsurface nitrate transport analyses.

With the set of subcatchments which are headwaters, the parameters k_v and $t_{½}$ were calibrated by means of measured values of the groundwater N concentration, and the calculated N concentration was compared to values observed in the period 1993 to 1997. This was done on the basis of N concentration values measured under conditions of groundwater-dominated streamflow with neglectible riverine N retention – situations characterised by low discharge ($Q < 2/3\ MQ$) and water temperature < 10 °C and additionally low portion of point sources as proposed by Behrendt et al. (2001) (see also below). After defining $k_v = 0.5$ as an estimate for denitrification in the unsaturated zone, model runs were performed to find the best fitting $t_{½}$ value. It was determined to $t_{½} = 2$ a. The resulting overall matching is not really good (Table 5.17, Figure 5.12), as the calculated N concentration shows almost no trend.

Table 5.15: Overview of the evaluated subcatchment areas (MODEST analyses).

Catchment name	Area						
	total	inside		agricultural		Evaluated	
	km^2	km^2	%	km^2	%	km^2	%
Odra - Polanka	1569.8	0.0	0	0.0	0.0	0.0	0.0
Opawa	2066.2	0.0	0	0.0	0.0	0.0	0.0
Ostravice	824.3	0.0	0	0.0	0.0	0.0	0.0
Odra - Chalupki	237.5	0.0	0	0.0	0.0	0.0	0.0
Odra - Raciborz	2092.6	442.3	21	350.7	16.8	420.3	21.0
Klodnica	1104.1	912.7	83	514.0	46.6	875.6	81.7
Odra - Groszowice	2984.1	2478.4	83	1551.9	52.0	2456.3	82.7
Mala Panew	2084.8	2008.7	96	870.3	41.8	1973.3	95.3
Nysa Klodzka	4500.3	1774.4	39	1366.8	30.4	1725.5	38.5
Stobrawa	1593.1	1593.1	100	845.3	53.1	1593.0	99.9
Odra - Wroclaw	1357.8	1357.1	100	848.4	62.5	1353.4	99.9
Olawa	1166.4	958.3	82	843.4	72.3	924.1	82.2
Bystrzyca	1750.0	0.0	0	0.0	0.0	0.0	0.0
Widawa	1707.2	1529.7	90	1143.9	67.0	1523.1	89.6
Kaczawa	2247.5	574.1	26	293.0	13.0	529.3	25.5
Odra - Scinawa	2352.3	641.4	27	479.7	20.4	521.6	27.3
Barycz	5490.4	5336.9	97	3611.5	65.8	4899.0	96.6
Odra - Nowa Sol	1642.2	1641.5	100	1121.6	68.3	1408.0	99.9
Kwisa	1028.2	190.5	19	69.9	6.8	190.5	18.5
Bobr	4843.8	2762.1	57	1255.6	25.9	2702.3	56.9
Odra - Polecko	4717.0	4717.0	100	2413.6	51.2	4264.3	99.1
Nysa Luzycka Z	1627.5	0.0	0	0.0	0.0	0.0	0.0
Nysa Luzycka G	2428.0	2198.4	91	842.9	34.7	2110.5	90.1
Odra - Kostrzyn	2229.3	2229.3	100	745.3	33.4	1969.1	98.9
Grabia	788.6	787.4	100	589.1	74.7	701.9	99.4
Widawka	1517.9	1517.9	100	1038.6	68.4	1412.7	99.6
Warta - Sieradz	5705.7	5305.0	93	3594.9	63.0	5178.3	92.8
Ner	1825.4	1825.4	100	1422.1	77.9	1662.6	99.2
Prosna	4808.1	4808.1	100	3707.4	77.1	4570.5	100.0
Warta - Poznan	11064.7	11064.7	100	8641.6	78.1	9913.1	99.4
Welna	2623.1	2623.1	100	1970.1	75.1	2387.7	98.4
Obra	2730.3	2730.3	100	1524.3	55.8	2350.4	98.5
Notec - Osiek	5491.8	5491.2	100	4286.3	78.1	4984.3	97.5
Gwda	4908.4	4908.4	100	2406.6	49.0	4631.3	97.2
Drawa	3277.1	3276.8	100	1310.3	40.0	3026.2	95.9
Notec - mouth	3517.8	3517.8	100	1916.5	54.5	2996.9	99.3
Warta - Kostrzyn	5879.1	5879.1	100	3261.1	55.5	5182.8	98.9
Mysla	1330.9	1330.9	100	793.5	59.6	1187.2	97.6
Odra - Krajnik	2772.1	2772.1	100	1534.3	55.4	2355.8	98.7
Plonia	1065.3	1065.3	100	833.9	78.3	948.9	94.5
Ina	2200.8	2200.8	100	1598.4	72.6	2038.8	98.4
Odra - mouth	3447.8	3447.8	100	1983.0	57.5	2960.8	96.7
Peene	4990.9	4990.2	100	4017.0	80.5	4694.0	97.6
Zarow	739.5	739.3	100	564.6	76.3	600.4	98.4
Uecker	2436.9	2436.9	100	1822.8	74.8	2081.3	96.8
Odra Haff	718.2	717.4	100	426.3	59.4	558.5	98.8

Table 5.16: ABIMO validation results.

Catchment ame	Gauging stations			ABIMO calculation					
	Catchment area	R_0	R_1	Catchment area (GIS)		R_2	$R_2 – R_0$	$(R_2 – R_0)/R_0$	$(R_2 – R_1)/R_1$
	km²	mm/a	mm/a	Km²	%	mm/a	mm/a	%	%
Odra – Polecko	47,370	172	180	47,360	100	215	43	25	19
Nysa Luzycka G	3,974	236	259	4,055	102	237	1	1	-8
Grabia	811	154	158	789	97	154	0	0	-3
Warta - Sieradz	8,140	161	166	8,012	98	230	69	43	39
Ner	1,712	158	169	1,825	107	150	-8	-5	-11
Prosna	4,304	107	103	4,808	112	180	73	69	75
Warta – Poznan	25,126	112	120	25,710	102	114	2	2	-5
Welna	1,130	88	93	2,623	232	106	18	20	14
Obra	2,618	106	102	2,730	104	113	7	7	11
Notec – Osiek	11,288	129	134	10,400	92	149	20	15	11
Gwda	4,698	172	165	4,908	104	179	7	4	8
Drawa	3,298	205	205	3,277	99	165	-40	-20	-20
Notec – mouth	15,970	137	134	17,195	108	125	-12	-9	-7
Mysla	765	113	80	1,331	174	105	-8	-7	31
Plonia	999	141	52	1,065	107	66	-75	-53	26
Ina	2,163	164	195	2,201	102	125	-39	-24	-36
Uecker	1,435	109	195	1,435	100	100	-9	-9	-49

R_0 – observed discharge (long-term mean); R_1 – observed discharge (1993/97); R_2 – calculated discharge

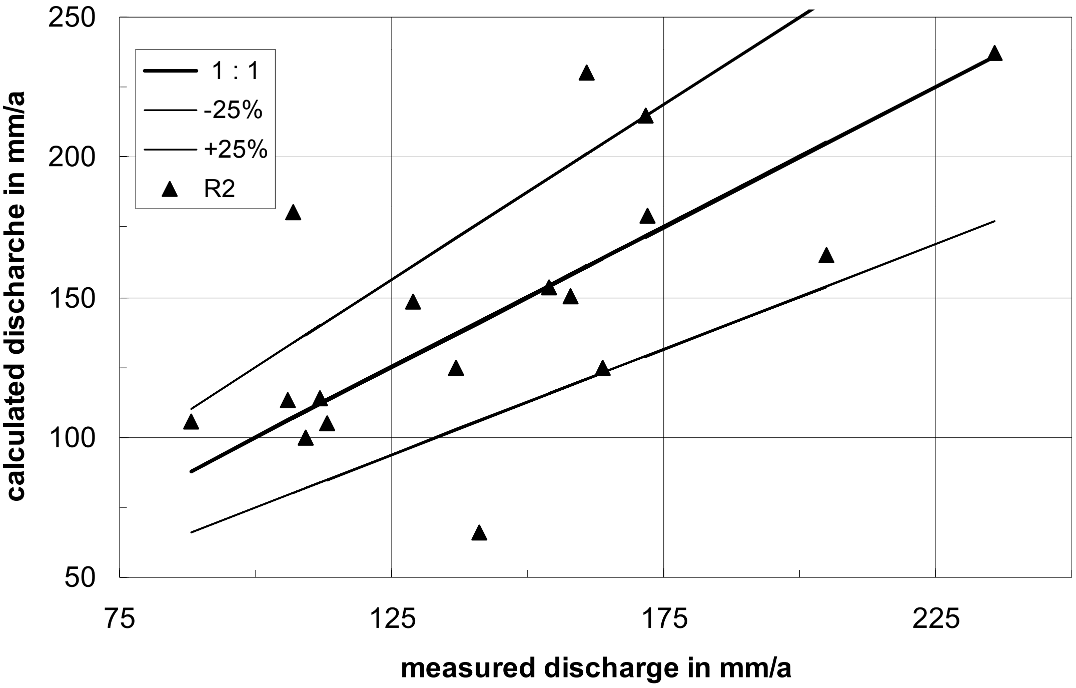


Figure 5.11: Comparison of long-term mean discharge values for gauged basins (calculated: ABIMO model).

Table 5.17: Comparison of measured and calculated N concentration in groundwater.

Catchment name	Concentration measured	Concentration calculated (MODEST)	$(c_{meas}-c_{calc})/c_{meas}$
	mg/l	mg/l	%
Ina	1.8	1.64	-0.68
Plonia	0.4	3.69	604
Mysla	0.73	1.29	77.1
Gwda	0.90	0.89	-0.56
Obra	0.67	2.11	216
Welna	1.99	2.74	38.0
Prosna	2.41	1.60	-33.7
Grabia	1.28	1.81	41.8
Kaczawa	3.19	1.39	-56.4
Uecker	1.68	1.47	-12.4
Zarow	2.36	1.78	-24.6
Peene	1.72	1.62	-6.0

For five of the catchments (Plonia, Obra, Grabia, Welna, Mysla) the N concentration is distinctly overestimated, whereas N concentration for the Kaczawa and Prosna catchment is notedly underestimated by MODEST.

For another five of the evaluated headwater basins, however, the deviation between

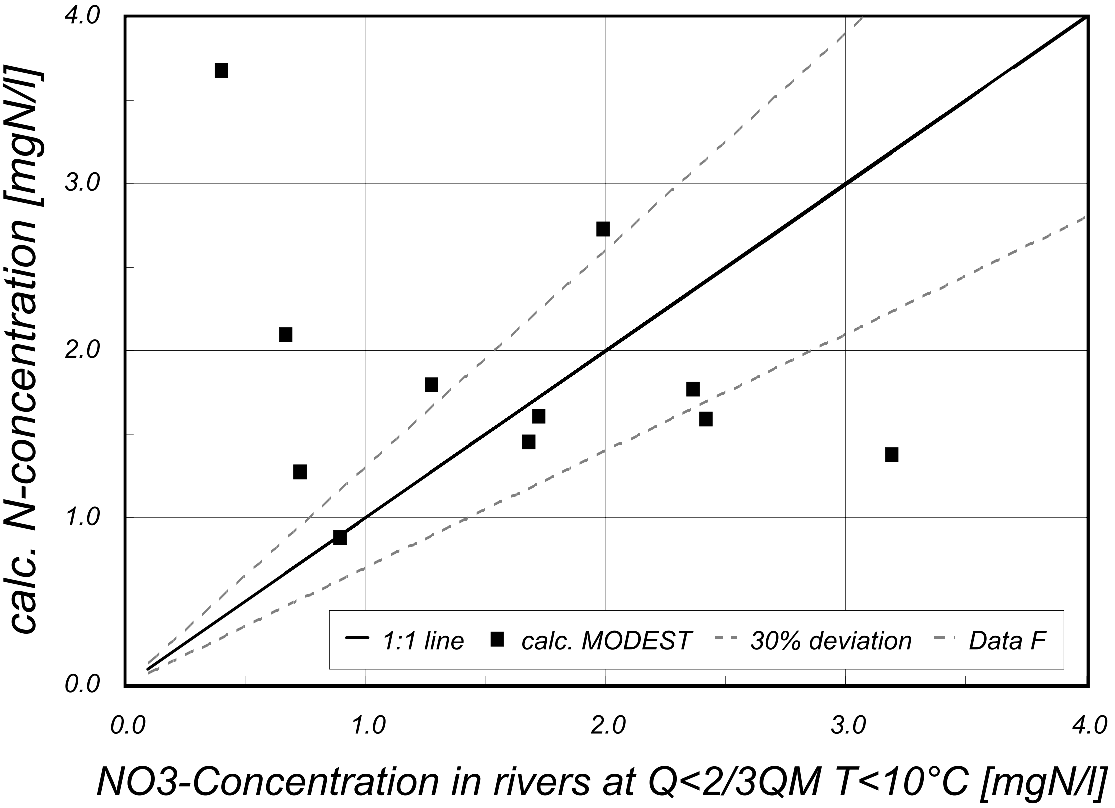


Figure 5.12: Comparison of groundwater N concentration values for headwater basins (calculated: MODEST model).

calculated and observed groundwater N concentrations ranges from –30 % to +30 %, which is satisfactory.

Even though the spatial database resolution underlying the MODEST calculation seems to play a significant role – the deviation is comparably small for catchments in the German part – the reason for the detected divergence could not be identified. Trials to specify $t_{½}$ in dependence on regionalised catchment characteristics (e. g. portion of lowland areas, distribution of the depth to groundwater) failed. Any further attempts were defeated by the lack of hydrogeologic information.

MODEST results

Based on the calibrated denitrification parameter and embracing the spatial and temporal database as a whole, MODEST was finally used to calculate the fate of nitrogen in form of dissolved nitrates along the subsurface path, including the historical development as well as scenarios 0, 1, 2 (Chapters 4.2.2 and 5.2.2) for N surplus.

Based on the calculated precipitation surplus (Map 5.15), the soil water storage capacity, and the depth to the groundwater, in Map 5.16 the calculated spatial distribution of the vertical travelling time (Equation 4.44) is shown. Map 5.17 presents the distribution of the residence time (Equation 4.46) as calculated from subsurface flux and the regional hydrogeologic characteristics.

In Tables 5.18 the nitrogen surplus is listed for the evaluated area of each single sub catchment, as resulting from the historical development. Table 5.19 shows the total nitrogen surplus summarised over whole catchments. That means that e. g. the value at the catchment Warta-Kostrzyn was summarised over all sub catchments of the Warta river system. In the same manner the tables 5.20 and 5.21 present the calculated N loads received by waters and discharge areas from groundwater. The Table 5.22 finally shows the calculated *RET* values (Equation 4.52).

For the evaluated part of the Odra Basin as a whole, hardly ever more than 3.5 kg/ha/a of nitrogen may have been transported into the rivers via groundwater. According to the MODEST results, this maximum occurred in 1985. At present, as a result of the additional drop in N surplus following the year 1990, the specific groundwater N load has decreased to 1.8 kg/ha/a. In Figure 5.13 this is illustrated on the basis of calculated time courses of the mean interim specific N portions (N_x, $x = 0…3$) entering the consecutive compartments: top soil, unsaturated zone, aquifer, water course – of N transported at the subsurface path in the analysed region as a whole. The differences between specific N surplus ($NU_{sur} + N_{depos}$) and the 'related' specific N input (N_0) shown in Figure 5.13 are due to the orientation of the time axis along with the subsurface flow path backwards from the pour point, such as established in Chapter 4.1.2.6. The same conception, though not so clearly visible, underlies the other interim specific N loads shown in Figure 5.13. Besides a time shift of the maxima, a much more flattened and smoothed run of the calculated curves is evident. This is most distinctive in the specific N load entering the waters, N_3, but similarly applies also for other interim

Table 5.18: Specific N surplus at the evaluated subcatchment area.

Catchment			Specific N surplus (kg/ha/a)										
Name	Area		History										
	Total	Evaluated											
	km²	%	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Odra - Polanka	1569.8	0.0											
Opawa	2066.2	0.0											
Ostravice	824.3	0.0											
Odra - Chalupki	237.5	0.0											
Odra - Raciborz	2092.6	21.0	17.8	24.2	33.9	41.1	58.5	63.9	58.2	61.3	60.5	27.6	28.0
Klodnica	1104.1	81.7	15.2	23.7	27.3	31.1	44.6	47.6	39.5	45.0	44.4	20.1	20.4
Odra-Groszowice	2984.1	82.7	18.1	23.3	32.9	39.8	55.3	59.2	66.4	59.9	59.4	31.7	32.1
Mala Panew	2084.8	95.3	15.3	20.5	25.9	30.1	41.3	46.6	51.3	45.3	43.8	24.5	24.8
Nysa Klodzka	4500.3	38.5	15.7	19.1	29.5	37.0	52.8	55.2	68.7	56.8	55.4	29.7	30.0
Stobrawa	1593.1	99.9	13.9	16.9	25.2	30.9	42.7	45.8	56.5	47.2	46.6	25.9	26.2
Odra - Wroclaw	1357.8	99.9	15.9	19.2	28.1	34.5	47.8	51.0	63.3	52.3	52.2	29.5	29.8
Olawa	1166.4	82.2	15.7	17.5	28.2	36.8	56.0	58.4	74.7	56.3	56.7	26.6	26.9
Bystrzyca	1750	0.0											
Widawa	1707.2	89.6	14.4	15.9	25.6	33.2	52.4	55.0	69.0	53.4	54.0	28.2	28.5
Kaczawa	2247.5	25.5	14.9	15.8	23.5	29.9	44.8	46.6	57.5	43.7	41.5	21.7	22.1
Odra - Scinawa	2352.3	27.3	15.1	15.7	25.3	33.3	52.2	55.0	71.6	50.7	52.3	22.7	23.1
Barycz	5490.4	96.6	16.1	17.8	29.0	37.4	65.8	61.9	78.1	62.8	65.0	37.9	38.2
Odra - Nowa Sol	1642.2	99.9	14.2	15.7	25.0	32.3	54.7	56.2	72.7	52.8	51.2	23.0	23.3
Kwisa	1028.2	18.5	13.8	15.2	19.9	23.7	33.1	34.9	37.9	30.3	32.6	22.8	23.1
Bobr	4843.8	56.9	13.9	15.8	21.8	26.1	41.8	43.6	53.3	40.8	40.0	23.2	23.5
Odra - Polecko	4717	99.1	13.0	15.3	22.0	26.5	46.3	44.3	56.2	43.6	43.9	25.9	26.1
Nysa Luzycka Z	1627.5	0.0											
Nysa Luzycka G	2428	90.1	14.5	16.8	22.1	26.4	39.7	42.2	51.2	41.1	35.5	25.7	26.0
Odra - Kostrzyn	2229.3	98.9	13.3	16.0	19.9	23.7	33.0	37.2	44.3	37.1	27.8	23.9	24.2
Grabia	788.6	99.4	15.5	21.7	25.1	28.7	48.1	57.6	58.9	48.1	54.9	33.8	34.1
Widawka	1517.9	99.6	16.0	21.6	25.1	28.4	45.9	55.6	54.9	44.9	51.0	31.5	31.9
Warta - Sieradz	5705.7	92.8	14.2	21.1	23.9	27.1	42.4	52.3	54.8	46.0	45.4	25.1	25.4
Ner	1825.4	99.2	15.8	22.4	26.4	30.6	53.4	60.0	64.5	52.9	57.0	40.1	40.4
Prosna	4808.1	100.0	13.7	16.8	23.6	28.5	48.7	55.2	62.5	54.1	52.8	34.5	34.8
Warta - Poznan	11065	99.4	14.4	17.2	25.1	30.6	54.3	58.7	71.5	58.9	61.3	41.4	41.6
Welna	2623.1	98.4	13.0	15.4	22.2	26.6	46.4	55.7	77.4	55.4	58.9	32.4	32.7
Obra	2730.3	98.5	13.4	15.4	21.7	26.0	43.7	47.0	62.1	46.4	46.9	27.3	27.6
Notec - Osiek	5491.8	97.5	12.1	15.5	22.8	26.1	48.5	54.3	69.1	51.3	54.7	40.6	40.8
Gwda	4908.4	97.2	9.7	11.5	16.6	19.4	36.3	37.3	51.0	36.7	39.0	21.3	21.5
Drawa	3277.1	95.9	10.2	10.5	16.4	18.1	32.5	34.2	45.9	34.4	34.5	19.8	20.0
Notec - mouth	3517.8	99.3	11.5	13.3	18.0	20.9	34.1	40.4	53.9	39.1	40.3	21.7	21.9
Warta - Kostrzyn	5879.1	98.9	12.3	14.3	19.9	23.6	39.3	43.6	58.7	43.8	44.9	27.3	27.6
Mysla	1330.9	97.6	9.8	5.3	19.6	19.9	46.2	43.4	59.6	43.2	41.8	22.6	22.9
Odra - Krajnik	2772.1	98.7	14.0	17.6	24.9	31.6	45.0	53.9	66.5	56.9	26.5	31.6	31.9
Plonia	1065.3	94.5	9.4	1.4	22.5	21.9	60.3	51.9	78.8	56.1	52.6	21.7	22.0
Ina	2200.8	98.4	8.9	1.7	20.3	19.8	52.6	46.3	67.9	48.5	46.0	21.2	21.5
Odra - mouth	**3447.8**	**96.7**	**12.0**	**11.7**	**22.2**	**25.7**	**44.2**	**46.7**	**61.3**	**49.6**	**32.2**	**25.9**	**26.2**
Peene	4990.9	97.6	11.1	19.8	25.8	38.1	47.3	58.7	64.4	58.9	22.7	35.0	35.2
Zarow	739.5	98.4	12.5	24.3	32.3	49.3	61.8	77.0	85.0	77.4	26.5	44.2	44.4
Uecker	2436.9	96.8	13.1	20.2	25.8	35.6	44.9	56.5	64.4	58.0	22.9	34.3	34.6
Odra Haff	**718.2**	**98.8**	**10.7**	**15.0**	**22.0**	**29.8**	**40.7**	**47.0**	**54.3**	**47.7**	**24.6**	**28.0**	**28.3**

Table 5.19: Total N surplus at the evaluated catchment area.

Gauge Catchment			Total N surplus (t/a)										
Name	Area		History										
	Total	Eval.											
	(km²)	%	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Odra - Polanka	1569.8	0.0											
Opawa	2066.2	0.0											
Ostravice	824.3	0.0											
Odra - Chalupki	4697.9	0.0											
Odra - Raciborz	6790.5	6.2	785	1069	1497	1815	2585	2822	2571	2708	2675	1218	1236
Klodnica	1104.1	79.3	1383	2156	2490	2832	4059	4340	3595	4096	4046	1827	1855
Odra - Groszowice	10878.7	34.5	6643	8992	12129	14492	20336	21806	22601	21628	21405	10892	11037
Mala Panew	2084.8	94.7	3070	4105	5196	6039	8282	9339	10289	9093	8780	4903	4964
Nysa Klodzka	4500.3	38.3	2777	3394	5232	6565	9364	9788	12183	10071	9835	5263	5326
Stobrawa	1593.1	100.0	2216	2697	4011	4917	6800	7293	8998	7516	7417	4127	4172
Odra - Wroclaw	20414.6	50.9	16863	21789	30375	36698	51272	55145	62669	55409	54522	29182	29547
Olawa	1166.4	79.2	1508	1675	2702	3522	5368	5596	7154	5397	5434	2545	2580
Bystrzyca	1750.0	0.0											
Widawa	1707.2	89.2	2202	2437	3913	5083	8014	8410	10558	8176	8266	4308	4356
Kaczawa	2247.5	23.5	856	910	1351	1718	2573	2673	3303	2506	2380	1248	1267
Odra - Scinawa	29638.1	46.9	22398	27820	39961	49156	70577	75354	88278	74741	73959	38741	39231
Barycz	5490.4	89.2	8576	9477	15480	19949	35116	33011	41703	33501	34679	20224	20376
Odra - Nowa Sol	36770.7	54.9	33300	39879	59539	74399	114676	117597	141913	116913	117049	62743	63437
Kwisa	1028.2	18.5	262	290	379	452	630	665	721	577	621	435	441
Bobr	5872.0	49.3	4099	4656	6401	7661	12186	12714	15433	11856	11666	6832	6926
Odra - Polecko	47359.7	57.8	43540	51741	76300	94571	148714	151200	183844	149352	149429	81770	82688
Nysa Luzycka Z	1627.5	0.0											
Nysa Luzycka G	4055.5	52.0	3160	3674	4815	5765	8648	9205	11154	8966	7729	5609	5676
Odra - Kostrzyn	53644.5	58.6	49653	58959	85533	105599	164683	168667	204835	166555	163332	92692	93737
Grabia	788.6	89.0	1211	1695	1963	2246	3766	4508	4604	3766	4295	2643	2665
Widawka	2306.4	91.7	3631	4962	5744	6531	10696	12898	12896	10540	11998	7404	7473
Warta - Sieradz	8012.2	91.0	11151	16118	18396	20864	33128	40598	41920	34900	36054	20689	20897
Ner	1825.4	91.1	2857	4056	4775	5537	9662	10841	11657	9566	10301	7249	7298
Prosna	4808.1	95.1	6586	8082	11360	13701	23408	26521	30037	25995	25387	16597	16724
Warta - Poznan	25710.4	91.2	36487	47312	62295	73921	126210	142882	162654	135667	139526	90293	90974
Welna	2623.1	91.0	3407	4037	5815	6971	12162	14616	20298	14519	15462	8496	8565
Obra	2730.3	86.1	3648	4191	5933	7107	11933	12831	16966	12660	12795	7458	7532
Notec - Osiek	5491.8	90.8	6612	8425	12422	14251	26447	29606	37650	27973	29813	22104	22248
Gwda	4908.4	94.4	4761	5642	8146	9480	17745	18273	24963	17961	19100	10408	10522
Drawa	3277.1	92.3	3331	3448	5348	5921	10636	11189	15004	11252	11276	6459	6537
Notec - mouth	17195.1	90.9	18749	22181	32251	37001	66826	73264	96562	70923	74352	46600	47021
Warta - Kostrzyn	54137.9	90.5	69518	86104	117976	138862	240243	269220	330991	259498	268525	168913	170309
Mysla	1330.9	89.2	1302	711	2607	2649	6143	5777	7938	5744	5558	3011	3045
Odra - Krajnik	111885.4	75.1	124314	150614	212972	255786	423438	458488	562057	447447	444689	273307	275853
Plonia	1065.3	89.1	998	149	2394	2336	6424	5529	8396	5971	5599	2315	2343
Ina	2200.8	92.6	1955	382	4439	4344	11513	10139	14868	10626	10068	4648	4701
Odra - mouth	**118599.2**	**75.8**	**131393**	**155149**	**227423**	**271301**	**456556**	**490219**	**606386**	**481086**	**471435**	**289172**	**291891**
Peene	4990.9	94.1	5522	9813	12807	18877	23440	29096	31934	29184	11259	17349	17472
Zarow	739.5	81.2	924	1794	2389	3640	4567	5690	6278	5720	1959	3263	3282
Uecker	2436.9	85.4	3184	4893	6253	8642	10891	13704	15640	14072	5553	8329	8394
Odra Haff	**8885.5**	**89.3**	**10382**	**17553**	**22998**	**33248**	**41760**	**51794**	**57665**	**52327**	**20500**	**30911**	**31133**

Table 5.20: Calculated specific N load (N_3), at the evaluated subcatchment area

Subcatchment			Specific N Load (kg/ha/a)									
Name	Area		History									
	Total	Evaluated										
	km²	%	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Odra - Polanka	1570	0.0										
Opawa	2066	0.0										
Ostravice	824.3	0.0										
Odra - Chalupki	237.5	0.0										
Odra - Raciborz	2093	21.0	0.58	0.83	1.13	1.67	2.24	2.27	2.34	2.49	1.84	1.23
Klodnica	1104	81.7	0.82	1.16	1.44	2.06	2.68	2.59	2.57	2.71	1.92	1.17
Odra - Groszowice	2984	82.7	0.65	0.96	1.38	2.02	2.60	2.97	3.07	2.92	2.13	1.41
Mala Panew	2085	95.3	0.74	1.05	1.33	1.90	2.40	2.81	2.69	2.46	1.58	1.06
Nysa Klodzka	4500	38.5	0.66	1.06	1.67	2.63	3.42	4.22	4.40	4.03	2.99	2.06
Stobrawa	1593	99.9	0.56	0.89	1.34	2.01	2.52	3.09	3.12	2.80	1.91	1.22
Odra - Wroclaw	1358	99.9	0.56	0.89	1.40	2.14	2.80	3.44	3.59	3.17	2.28	1.39
Olawa	1166	82.2	0.47	0.69	1.19	1.96	2.84	3.43	3.77	3.12	2.46	1.36
Bystrzyca	1750	0.0										
Widawa	1707	89.6	0.45	0.70	1.18	2.03	2.85	3.43	3.57	2.98	2.23	1.27
Kaczawa	2248	25.5	0.56	0.69	1.16	1.86	2.89	3.32	3.85	2.98	2.29	1.08
Odra - Scinawa	2352	27.3	0.48	0.59	1.02	1.67	2.65	3.13	3.68	2.79	2.31	1.03
Barycz	5490	96.6	0.82	1.14	1.92	3.23	4.97	5.53	6.05	5.28	4.47	2.86
Odra - Nowa Sol	1642	99.9	0.62	0.81	1.31	2.34	3.72	4.77	5.36	4.74	3.72	2.29
Kwisa	1028	18.5	0.67	0.92	1.29	2.04	2.53	2.82	2.54	2.31	1.76	1.31
Bobr	4844	56.9	0.63	0.87	1.22	2.09	2.75	3.36	3.21	2.78	1.92	1.28
Odra - Polecko	4717	99.1	0.55	0.77	1.12	1.98	2.75	3.28	3.36	3.00	2.29	1.59
Nysa Luzycka Z	1628	0.0										
Nysa Luzycka G	2428	90.1	0.89	1.14	1.52	2.39	3.15	3.86	3.89	3.36	2.50	1.93
Odra - Kostrzyn	2229	98.9	0.49	0.59	0.73	1.05	1.34	1.67	1.71	1.45	1.11	1.02
Grabia	788.6	99.4	0.71	0.97	1.18	1.71	2.68	3.25	3.23	2.97	2.78	1.96
Widawka	1518	99.6	0.85	1.09	1.30	1.93	2.83	3.24	3.04	2.91	2.49	1.87
Warta - Sieradz	5706	92.8	0.57	0.77	0.92	1.41	2.12	2.50	2.36	2.11	1.55	1.05
Ner	1825	99.2	0.64	0.90	1.14	1.75	2.77	3.30	3.32	3.03	2.75	2.14
Prosna	4808	100.0	0.61	0.85	1.20	2.00	2.96	3.61	3.75	3.51	2.88	2.21
Warta - Poznan	11065	99.4	0.50	0.69	1.04	1.68	2.77	3.39	3.91	3.66	3.34	2.56
Welna	2623	98.4	0.39	0.53	0.81	1.31	2.25	3.24	3.93	3.44	2.90	1.91
Obra	2730	98.5	0.51	0.70	1.00	1.73	2.46	3.30	3.42	3.10	2.39	1.74
Notec - Osiek	5492	97.5	0.38	0.53	0.77	1.24	2.03	2.65	2.95	2.62	2.41	2.00
Gwda	4908	97.2	0.33	0.44	0.61	1.08	1.60	2.08	2.22	1.97	1.59	1.08
Drawa	3277	95.9	0.28	0.35	0.48	0.81	1.25	1.63	1.77	1.55	1.20	0.81
Notec - mouth	3518	99.3	0.52	0.68	0.90	1.51	2.28	3.38	3.38	3.20	2.32	1.69
Warta - Kostrzyn	5879	98.9	0.42	0.56	0.78	1.33	1.95	2.67	2.91	2.63	2.14	1.59
Mysla	1331	97.6	0.20	0.27	0.47	0.88	1.43	1.81	1.96	1.73	1.35	0.94
Odra - Krajnik	2772	98.7	0.45	0.57	0.76	1.06	1.51	1.99	2.46	2.27	1.39	1.26
Plonia	1065	94.5	0.18	0.15	0.27	0.51	1.24	1.76	2.48	2.56	2.42	1.73
Ina	2201	98.4	0.19	0.24	0.53	1.03	2.00	2.39	2.94	2.49	2.04	1.29
Odra - mouth	**3448**	**96.7**	**0.32**	**0.43**	**0.60**	**1.02**	**1.43**	**1.89**	**2.13**	**1.93**	**1.36**	**1.13**
Peene	4991	97.6	0.57	0.91	1.38	2.11	2.85	3.62	3.95	3.11	1.95	2.34
Zarow	739.5	98.4	0.47	0.85	1.31	2.07	2.80	3.57	3.90	3.11	1.62	2.09
Uecker	2437	96.8	0.46	0.63	0.84	1.19	1.59	2.08	2.43	2.17	1.30	1.48
Odra Haff	**718.2**	**98.8**	**0.39**	**0.62**	**0.95**	**1.46**	**1.93**	**2.39**	**2.49**	**1.80**	**1.25**	**1.22**

Table 5.21: Calculated total N load (N_3) at the evaluated catchment area

Catchment			Total N load (t/a)									
Name	Area		History									
	Total	Eval.										
	(km²)	%	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Odra - Polanka	1569.8	0.0										
Opawa	2066.2	0.0										
Ostravice	824.3	0.0										
Odra - Chalupki	4697.9	0.0										
Odra - Raciborz	6790.5	6.2	25.6	36.3	49.6	73.5	98.9	100.1	103.1	109.7	81.1	54.3
Klodnica	1104.1	79.3	74.1	104.9	130.0	185.8	241.2	233.5	232.1	244.5	172.9	105.9
Odra - Groszowice	10878.7	34.5	259.6	378.6	519.2	757.8	981.7	1065.9	1094.0	1074.3	780.2	507.8
Mala Panew	2084.8	94.7	147.8	207.7	264.5	377.2	477.2	557.8	535.2	489.4	313.5	210.5
Nysa Klodzka	4500.3	38.3	114.5	182.8	288.5	455.1	591.6	730.2	762.3	697.2	517.0	356.0
Stobrawa	1593.1	100.0	89.8	142.1	213.6	319.8	400.4	491.9	497.0	446.1	303.9	194.6
Odra - Wroclaw	20414.6	50.9	687.9	1032.0	1475.5	2199.7	2830.2	3312.4	3375.9	3136.8	2224.1	1458.0
Olawa	1166.4	79.2	45.4	65.9	114.3	187.9	272.1	329.0	361.1	298.7	235.4	129.9
Bystrzyca	1750.0	0.0										
Widawa	1707.2	89.2	69.6	106.5	181.2	310.2	435.5	524.4	546.3	456.4	340.8	194.9
Kaczawa	2247.5	23.5	32.1	39.5	66.3	106.4	165.6	190.2	220.9	170.5	131.5	61.8
Odra - Scinawa	29638.1	46.9	865.9	1281.7	1902.9	2911.0	3873.3	4556.9	4739.9	4241.1	3079.7	1910.3
Barycz	5490.4	89.2	435.9	605.4	1016.0	1711.5	2633.9	2931.2	3210.1	2798.7	2369.5	1516.4
Odra - Nowa Sol	36770.7	54.9	1403.4	2019.2	3133.6	5006.7	7117.5	8270.9	8828.8	7818.1	6058.7	3801.8
Kwisa	1028.2	18.5	12.7	17.5	24.6	38.9	48.2	53.7	48.4	44.0	33.4	25.0
Bobr	5872.0	49.3	186.1	257.5	361.8	615.4	804.5	978.0	932.4	809.7	561.3	378.0
Odra - Polecko	47359.7	57.8	1847.1	2637.0	4019.2	6545.9	9205.8	10781.7	11331.0	10030.3	7691.4	4921.3
Nysa Luzycka Z	1627.5	0.0										
Nysa Luzycka G	4055.5	52.0	194.0	249.6	331.9	522.2	688.6	844.1	851.6	734.2	548.1	422.5
Odra - Kostrzyn	53644.5	58.6	2148.6	3016.4	4512.2	7299.2	10189.1	11993.2	12560.1	11084.8	8484.4	5568.2
Grabia	788.6	89.0	55.8	75.6	92.3	133.7	210.2	255.0	253.3	232.8	217.8	153.6
Widawka	2306.4	91.7	184.2	240.1	288.8	426.1	637.9	745.6	712.3	673.5	595.0	436.4
Warta - Sieradz	8012.2	91.0	484.1	646.0	773.9	1174.6	1761.5	2067.2	1960.8	1792.8	1413.2	990.3
Ner	1825.4	91.1	116.2	163.4	206.2	317.7	500.9	598.6	601.4	548.9	498.4	386.9
Prosna	4808.1	95.1	295.5	409.7	575.6	960.1	1422.9	1733.8	1802.4	1689.3	1384.9	1061.6
Warta - Poznan	25710.4	91.2	1450.9	1973.7	2699.6	4297.4	6727.3	8125.2	8666.7	8050.3	6971.0	5248.4
Welna	2623.1	91.0	101.1	137.0	209.6	337.6	580.0	835.9	1013.4	888.3	747.9	493.0
Obra	2730.3	86.1	136.5	188.2	268.1	464.7	661.9	887.9	918.9	832.6	643.7	466.7
Notec - Osiek	5491.8	90.8	201.8	283.4	411.7	661.6	1086.0	1416.8	1576.6	1403.7	1287.6	1068.5
Gwda	4908.4	94.4	157.0	211.5	290.2	516.5	764.6	991.6	1061.8	940.4	758.3	514.4
Drawa	3277.1	92.3	86.8	110.3	151.4	255.1	391.8	511.6	556.2	485.9	377.9	254.6
Notec - mouth	17195.1	90.9	626.0	841.6	1167.4	1962.7	3038.5	4100.3	4374.6	3949.4	3233.3	2429.0
Warta - Kostrzyn	54137.9	90.5	2555.9	3464.2	4801.2	7833.9	12139.7	15501.3	16664.1	15252.3	12840.8	9562.7
Mysla	1330.9	89.2	26.0	34.9	61.2	113.7	186.4	234.6	254.6	224.5	175.3	121.9
Odra - Krajnik	111885.4	75.1	4854.5	6671.1	9583.0	15536.8	22928.4	28273.8	30150.9	27183.8	21879.9	15596.1
Plonia	1065.3	89.1	18.2	15.4	27.5	51.3	124.5	177.5	249.6	257.5	244.0	173.9
Ina	2200.8	92.6	41.6	52.1	115.7	222.1	434.2	517.4	637.4	538.4	442.4	278.4
Odra - mouth	**118599.2**	**75.8**	**5020.4**	**6880.6**	**9925.2**	**16149.3**	**23965.4**	**29599.5**	**31747.1**	**28624.7**	**23020.4**	**16426.0**
Peene	4990.9	94.1	276.5	444.2	672.8	1026.5	1389.6	1764.0	1923.4	1516.5	948.5	1138.9
Zarow	739.5	81.2	34.1	61.6	95.2	150.9	203.8	259.5	283.9	226.2	118.0	152.2
Uecker	2436.9	85.4	108.3	148.0	197.7	280.7	375.4	490.6	572.4	510.9	306.5	348.7
Odra Haff	**8885.5**	**89.3**	**446.6**	**697.5**	**1033.2**	**1561.5**	**2105.9**	**2683.9**	**2956.3**	**2381.1**	**1461.6**	**1726.7**

Table 22: Calculated N retention potential (Equation 4-16).

Subcatchment			$RET(i,j)=\frac{N_0(i,j)-N_3(i,j)}{N_0(i,j)}$									
Name	Area											
	Total	Evaluated	History									
	km²	%	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000
Odra - Polanka	1569.8	0.0										
Opawa	2066.2	0.0										
Ostravice	824.3	0.0										
Odra - Chalupki	237.5	0.0										
Odra - Raciborz	2092.6	21.0	0.968	0.958	0.947	0.930	0.917	0.920	0.923	0.923	0.942	0.959
Klodnica	1104.1	81.7	0.949	0.935	0.926	0.908	0.896	0.905	0.910	0.911	0.933	0.956
Odra - Groszowice	2984.1	82.7	0.965	0.952	0.938	0.920	0.908	0.905	0.907	0.915	0.936	0.956
Mala Panew	2084.8	95.3	0.954	0.940	0.930	0.912	0.902	0.896	0.905	0.915	0.941	0.958
Nysa Klodzka	4500.3	38.5	0.959	0.942	0.921	0.896	0.885	0.877	0.882	0.895	0.919	0.941
Stobrawa	1593.1	99.9	0.961	0.944	0.925	0.904	0.895	0.888	0.894	0.908	0.934	0.955
Odra - Wroclaw	1357.8	99.9	0.965	0.950	0.931	0.910	0.898	0.890	0.894	0.908	0.931	0.954
Olawa	1166.4	82.2	0.970	0.959	0.938	0.913	0.894	0.887	0.888	0.907	0.926	0.955
Bystrzyca	1750	0.0										
Widawa	1707.2	89.6	0.969	0.956	0.934	0.905	0.888	0.882	0.886	0.906	0.927	0.955
Kaczawa	2247.5	25.5	0.963	0.956	0.935	0.911	0.886	0.883	0.879	0.904	0.924	0.959
Odra - Scinawa	2352.3	27.3	0.968	0.963	0.942	0.919	0.894	0.888	0.882	0.907	0.923	0.960
Barycz	5490.4	96.6	0.949	0.935	0.907	0.874	0.847	0.848	0.850	0.868	0.886	0.918
Odra - Nowa Sol	1642.2	99.9	0.957	0.947	0.926	0.895	0.868	0.860	0.861	0.879	0.901	0.932
Kwisa	1028.2	18.5	0.952	0.938	0.922	0.897	0.890	0.890	0.904	0.913	0.930	0.944
Bobr	4843.8	56.9	0.955	0.942	0.927	0.896	0.882	0.874	0.885	0.901	0.928	0.948
Odra - Polecko	4717	99.1	0.958	0.946	0.929	0.898	0.881	0.876	0.883	0.897	0.918	0.939
Nysa Luzycka Z	1627.5	0.0										
Nysa Luzycka G	2428	90.1	0.940	0.928	0.913	0.885	0.871	0.863	0.871	0.888	0.911	0.928
Odra - Kostrzyn	2229.3	98.9	0.964	0.959	0.952	0.938	0.928	0.920	0.921	0.932	0.945	0.950
Grabia	788.6	99.4	0.955	0.943	0.934	0.914	0.887	0.879	0.887	0.899	0.908	0.932
Widawka	1517.9	99.6	0.948	0.938	0.930	0.909	0.888	0.886	0.899	0.907	0.921	0.938
Warta - Sieradz	5705.7	92.8	0.962	0.951	0.945	0.925	0.903	0.897	0.907	0.918	0.938	0.956
Ner	1825.4	99.2	0.960	0.948	0.939	0.918	0.891	0.883	0.889	0.901	0.911	0.929
Prosna	4808.1	100.0	0.956	0.943	0.928	0.899	0.877	0.871	0.877	0.890	0.909	0.928
Warta - Poznan	11064.7	99.4	0.965	0.956	0.940	0.917	0.889	0.881	0.875	0.887	0.898	0.919
Welna	2623.1	98.4	0.970	0.962	0.947	0.926	0.897	0.877	0.867	0.884	0.900	0.929
Obra	2730.3	98.5	0.963	0.952	0.937	0.908	0.888	0.872	0.876	0.889	0.911	0.932
Notec - Osiek	5491.8	97.5	0.969	0.960	0.947	0.928	0.902	0.890	0.886	0.900	0.910	0.925
Gwda	4908.4	97.2	0.967	0.957	0.946	0.918	0.897	0.885	0.888	0.904	0.922	0.945
Drawa	3277.1	95.9	0.973	0.967	0.957	0.936	0.916	0.904	0.905	0.919	0.937	0.956
Notec - mouth	3517.8	99.3	0.956	0.947	0.936	0.911	0.890	0.870	0.876	0.886	0.910	0.929
Warta - Kostrzyn	5879.1	98.9	0.967	0.958	0.946	0.923	0.904	0.889	0.888	0.900	0.916	0.935
Mysla	1330.9	97.6	0.979	0.973	0.957	0.931	0.905	0.896	0.896	0.911	0.930	0.949
Odra - Krajnik	2772.1	98.7	0.968	0.963	0.955	0.945	0.933	0.923	0.914	0.918	0.945	0.949
Plonia	1065.3	94.5	0.980	0.984	0.974	0.962	0.926	0.914	0.895	0.897	0.900	0.924
Ina	2200.8	98.4	0.977	0.973	0.950	0.923	0.884	0.880	0.872	0.892	0.910	0.939
Odra - mouth	**3447.8**	**96.7**	**0.973**	**0.968**	**0.959**	**0.943**	**0.930**	**0.920**	**0.914**	**0.917**	**0.935**	**0.944**
Peene	4990.9	97.6	0.952	0.934	0.915	0.893	0.877	0.865	0.864	0.883	0.916	0.908
Zarow	739.5	98.4	0.968	0.953	0.943	0.929	0.921	0.915	0.913	0.917	0.949	0.939
Uecker	2436.9	96.8	0.966	0.958	0.950	0.937	0.926	0.914	0.907	0.910	0.939	0.934
Odra Haff	**718.2**	**98.8**	**0.965**	**0.953**	**0.938**	**0.922**	**0.911**	**0.904**	**0.905**	**0.923**	**0.943**	**0.944**

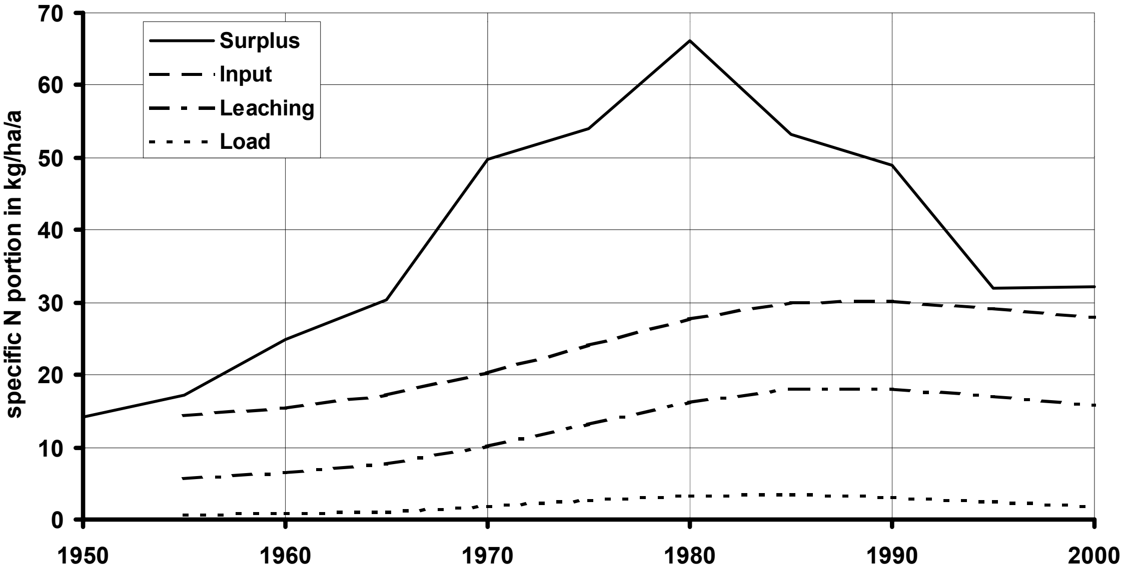


Figure 5.13 Calculated progression of mean specific interim N portions (evaluated part of the Odra Basin as a whole).

N portions. Taking the more or less fluctuating N surplus into consideration, the temporal characteristics of the subsurface N transport is comparable with the damping behaviour of an extreme low-pass filter. In the run of the calculated curves, the summarised effects of the piston flow assumption (time lag caused by both travelling and residence times) and the nitrate decomposition are expressed.

In Figures 5.14-a to 5.14-d, by the example of four selected catchments, the time courses of the specific N surplus, as well as the calculated specific N input and specific N load are visualised more in detail, based on the values from Tables 5.17 and 5.20. All of these catchments are dominated by agriculture, about ¾ of the catchment area is under agricultural use for Grabia, Uecker and Zarow, about 2/3 for Barycz. Specific N surplus is between 60 and 85 kg/ha/a. In the Polish catchments (Figure 5.14-a, b), the maximum N surplus occurs before 1980, the drop in 1990 is not as distinctive as in German catchments (Figure 5.14-c, d), and specific N input is reaching its maximum not before 1985 and more sustained. Though maximum specific N surplus is comparably high in the Barycz and Zarow catchments, the Barycz river, due to different path-time and denitrification behaviour of the subsurface transport, will receive about twice as much N via groundwater as related to the catchment area. Taking the retention potential *RET* (Table 5.22) into account, this difference is expressed by different *RET* levels (e. g. RET_{1995} = 0.89 for Barycz, RET_{1995} = 0.95 for Zarow catchment). Uecker catchment may serve as an example for medium specific N surplus and high denitrification potential (RET_{1995} = 0.94), whereas the Zarow catchment shows raised denitrification potential at a raised level of specific N surplus. The Grabia catchment, in turn, has medium denitrification potential (RET_{1995} = 0.91) at medium level of specific N surplus. – In the demonstrated manner also any more of the evaluated catchments could be discussed.

Map 5.18 shows the specific N load N_3 in its detailed spatial distribution as related to the reference year 1995, based on the MODEST grid calculation. In Map 5.19 an overview is given of the spatial distributions of the interim specific N portions, also related to the year 1995 of pouring N_3 into the surface waters. The difference between specific N input and the specific N load is relatively expressed in the retention term $RET(i,j)$ (for subcatchments see Table 5.22). Map 5.20 visualises this retention potential in its spatial distribution as related to the year 1995.

In Map 5.21 the specific N load N_3 is presented aggregated for the evaluated catchments. There again the relatively high level of groundwater-borne N entries in the Barycz region is visible remaining from the increased N surplus among the evaluated Polish catchments. Maps 5.22 and 5.23 illustrate the N_2 concentration that following the MODEST calculation should have been entering the groundwater after passing the unsaturated zone in 1995. Due to topsoil denitrification and vertical N depletion, most of the evaluated area (85.7 %) full fill the requirements of drinking water protection ($c_{N2} \leq 11.3$ mg/l N). Especially the river lowlands, however, show increased N_2 concentrations. According to Equation 4.47., this is an artifact resulting from the very small mean annual water budget calculated for areas with shallow groundwater table and should be carefully discussed. To illustrate this, as an extreme, c_{N2} would be negative for areas with negative water balance, which is physically absolutely meaningless. The same effect is also the main reason why the N_2 concentration is displayed notedly increased in the Zarow catchment in northeastern Germany. A higher portion of fen areas with shallow groundwater table is boosting the average calculated N_2 concentration in this relatively small catchment. In a more lessened form this can be observed also in the eastern Polish part of the Odra Basin.

In Maps 5.18 to 5.20, the meaning of areas close to the water courses and river lowlands becomes evident for the actual N load to be received by the waters. Vice versa, because of the total transport delay $t_T + t_{tot}$, only part of the evaluated area comes into question as the source of the N load entering the Odra river system via groundwater in a reference year (e. g. 1995). This is listed in the following Table 5.23.

Table 5.23: Portion of catchment sub-areas related to classes of total transport time.

Total transport time (a)	Part of the evaluated catchment area (%)
≤ 5	17.5
> 5…10	7
> 10…20	10
> 20…40	14.5
> 40…80	16.5
> 80	34.5

Regardless the relatively high N surplus, which is of concern also in the Polish part of the Odra Basin, most of the initially leached N load is depleted along the long-distant and -lasting subsurface transport path dominating most of the catchment area. For the reference year 1995, the overall N retention potential RET is 0.918 for the evaluated area of the Odra Basin. This means only the ninth part ($N_3 \leq 3.5$ kg/ha/a) of the related N input

($N_0 \leq 30$ kg/ha/a) is entering the river system via groundwater flow. This is the result of all the denitrification subprocesses taking place and being included into the MODEST approach, as there are: the difference between N surplus and N input due to the time shift; about 8…12 kg/ha/a (related to the evaluated catchment area as a whole) of topsoil denitrification; up to 50 % of N depletion in the unsaturated zone; and finally the nitrate decomposition in groundwater characterised by the small half life of $t_{½} = 2$ a.

After ten years of groundwater-borne transport, merely about 3 % of the N load initially entering the groundwater (N_2) will remain contributing into the river N load as N_3. Correspondingly the share in N_3 from areas with 5 a < t_{tot} < 15 a is progressively vanishing. Sub-areas with more than 15 years of total transport time do practically not contribute into the groundwater-borne N load to the river system. They are excluded from subsurface N entry into surface waters due to denitrification. This is of concern for about 70 % of the evaluated area.

The time shift between the maximum N input (about 1980) and the maximum N_3 load entering the river system (about 1985) is about 5 years for the evaluated part of the Odra Basin as a whole (Figure 5.13), varying between 5 and 15 years for selected catchments (cf. Figure 5.14-a to d). Thus, the maximum specific N input resulting from the early 1980s should have passed the subsurface transport path at the latest until the early 1990s. For the time being there seems no fear of further increasing N_3 received by the river system from groundwater, unless a new rise of the N surplus will occur. This last situation will be briefly discussed with the scenario results in Chapter 5.2.2.

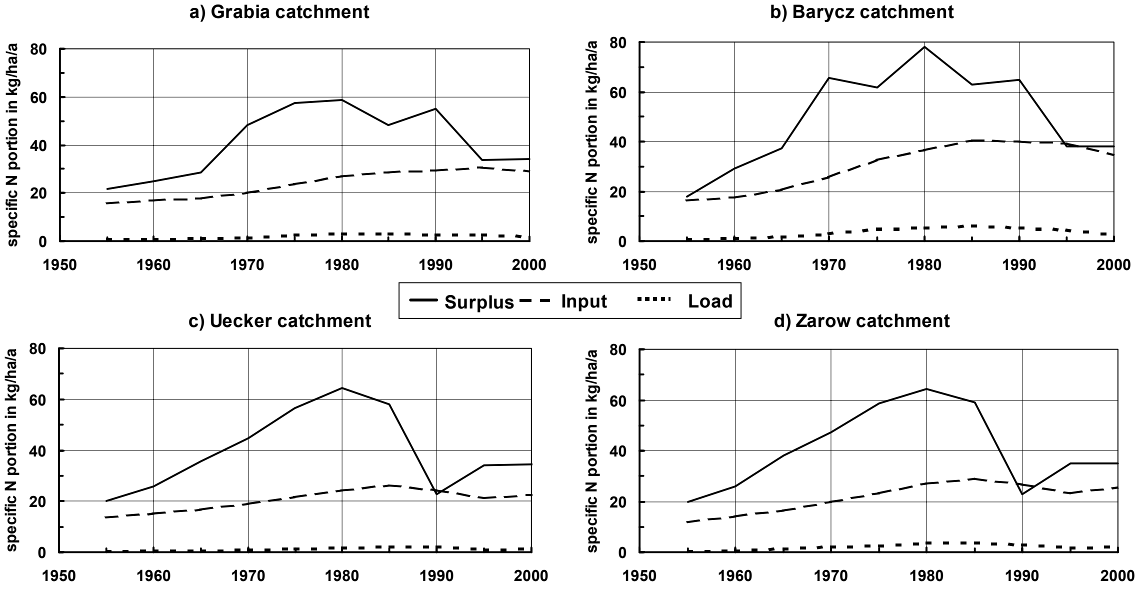
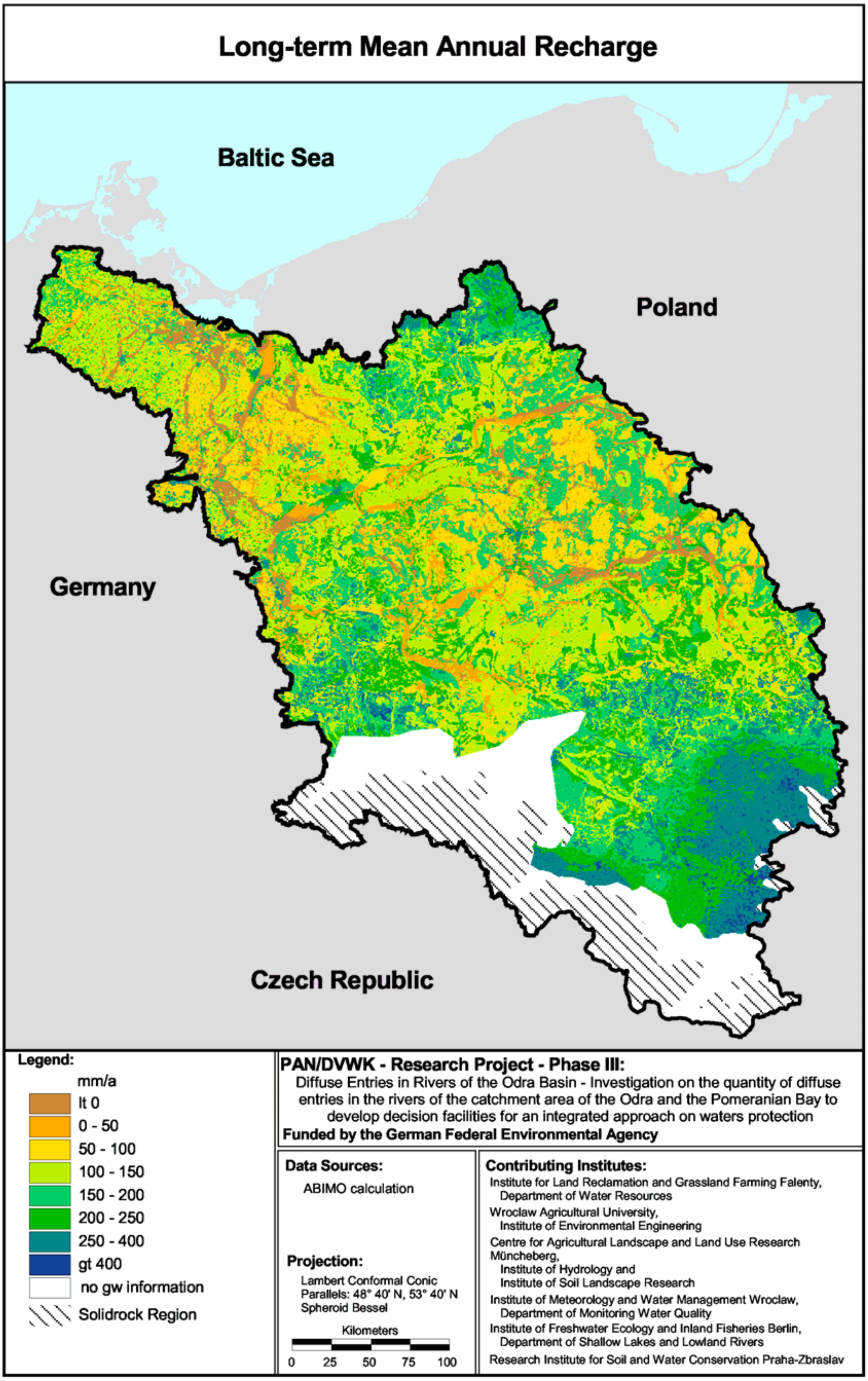
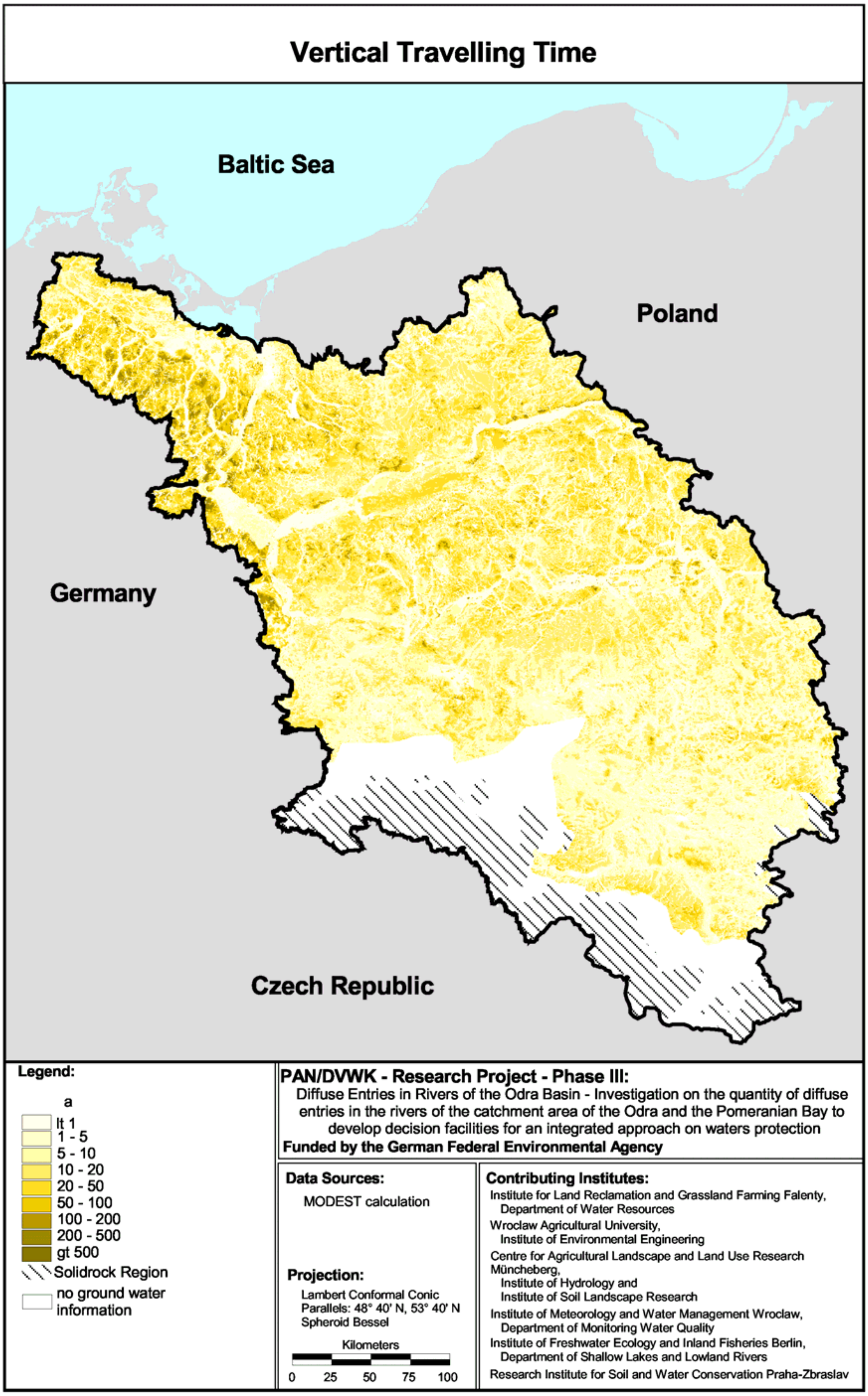


Figure 5.14: Comparison of N surplus and calculated specific N input and N load for selected catchments.



Map 5.17: Long-term mean water budget/groundwater recharge calculated by ABIMO.



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Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
MODEST calculation

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
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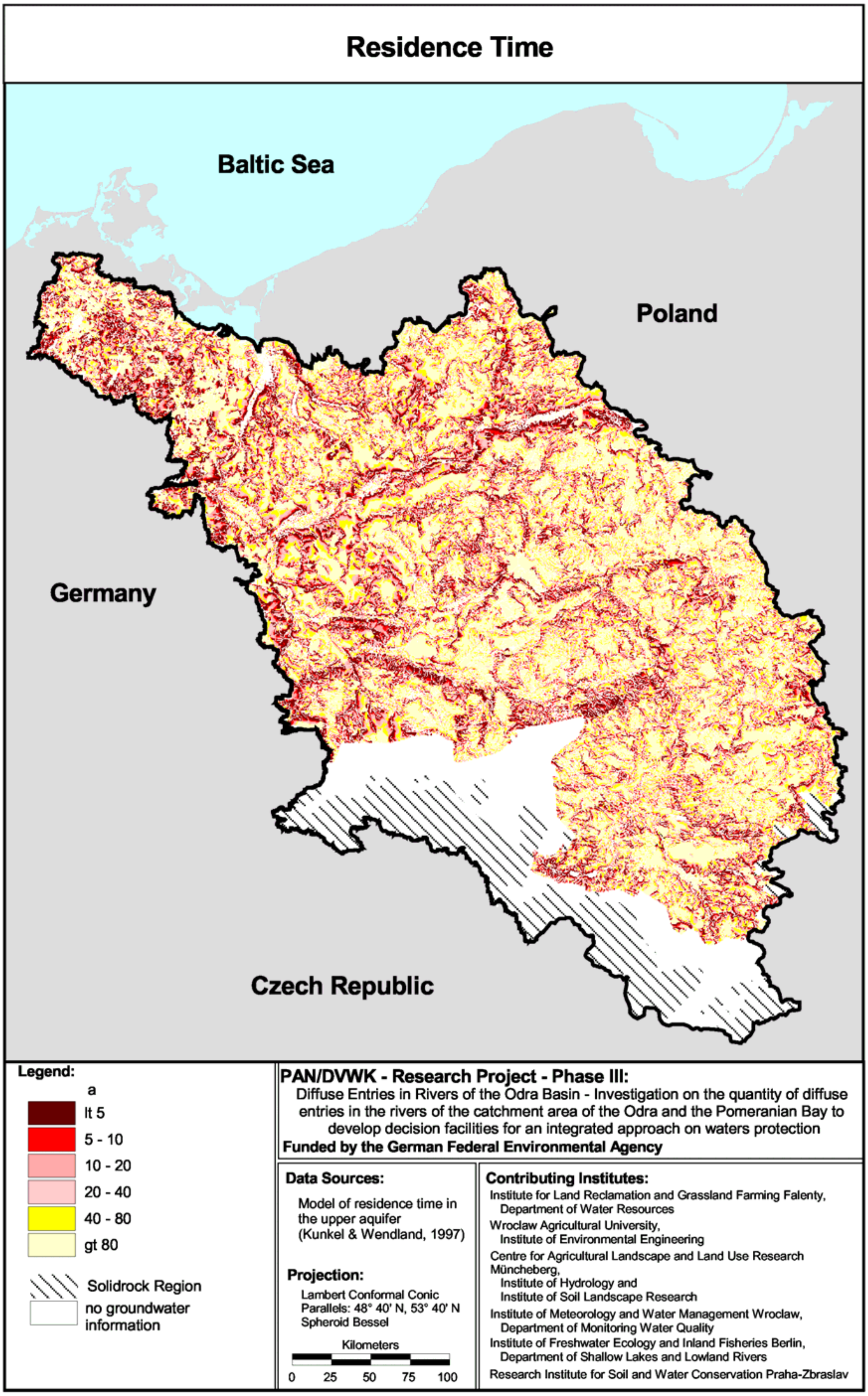
Map 5.18: Travelling time t_T calculated by MODEST.



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Data Sources:
Model of residence time in the upper aquifer (Kunkel & Wendland, 1997)

Projection:
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Spheroid Bessel

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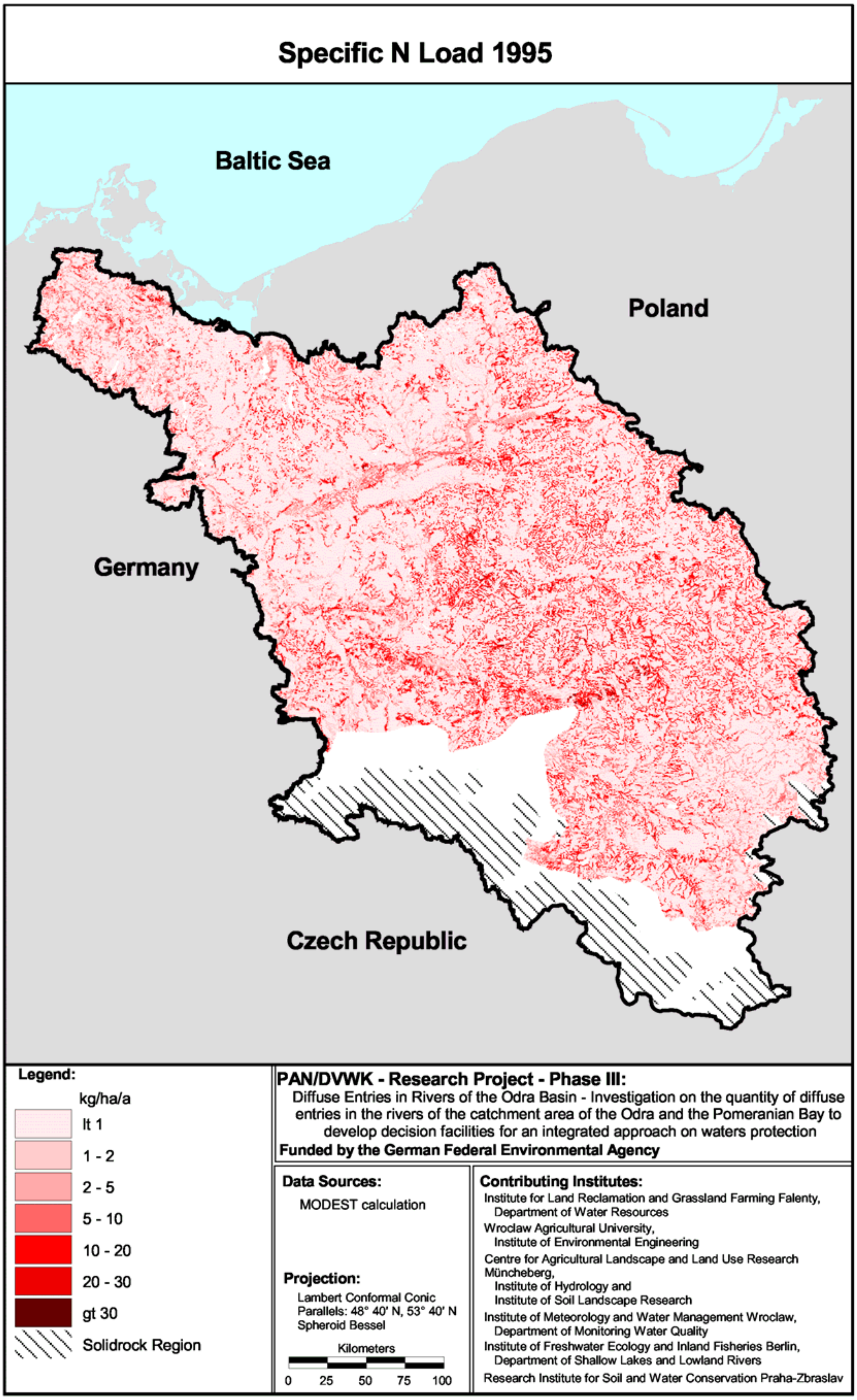
Map 5.19: Groundwater residence time t_{tot} calculated by MODEST.



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Data Sources:
MODEST calculation

Projection:
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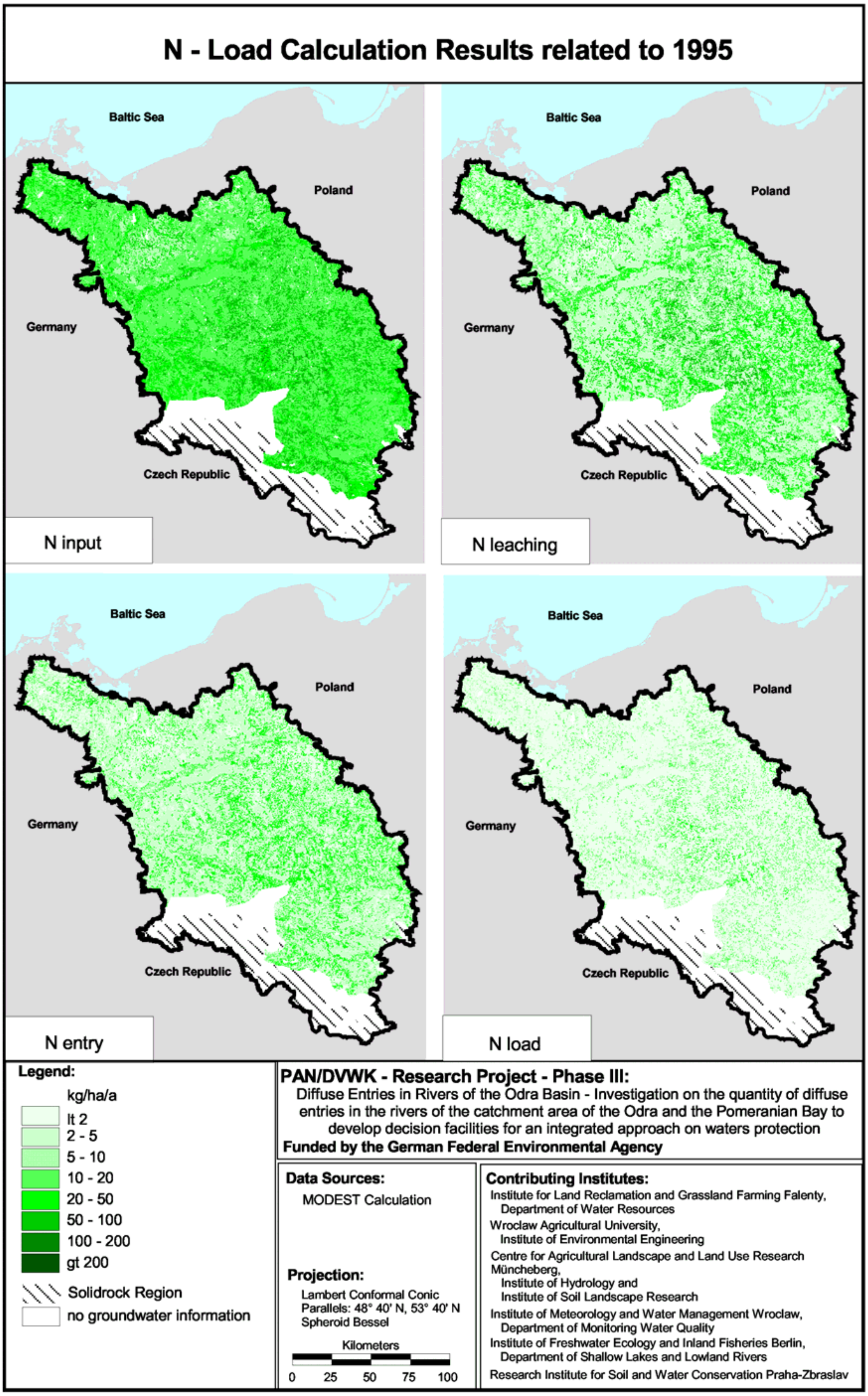
Map 5.20: Specific N load (N_3) received by the Odra river system in 1995.



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Data Sources:
MODEST Calculation

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

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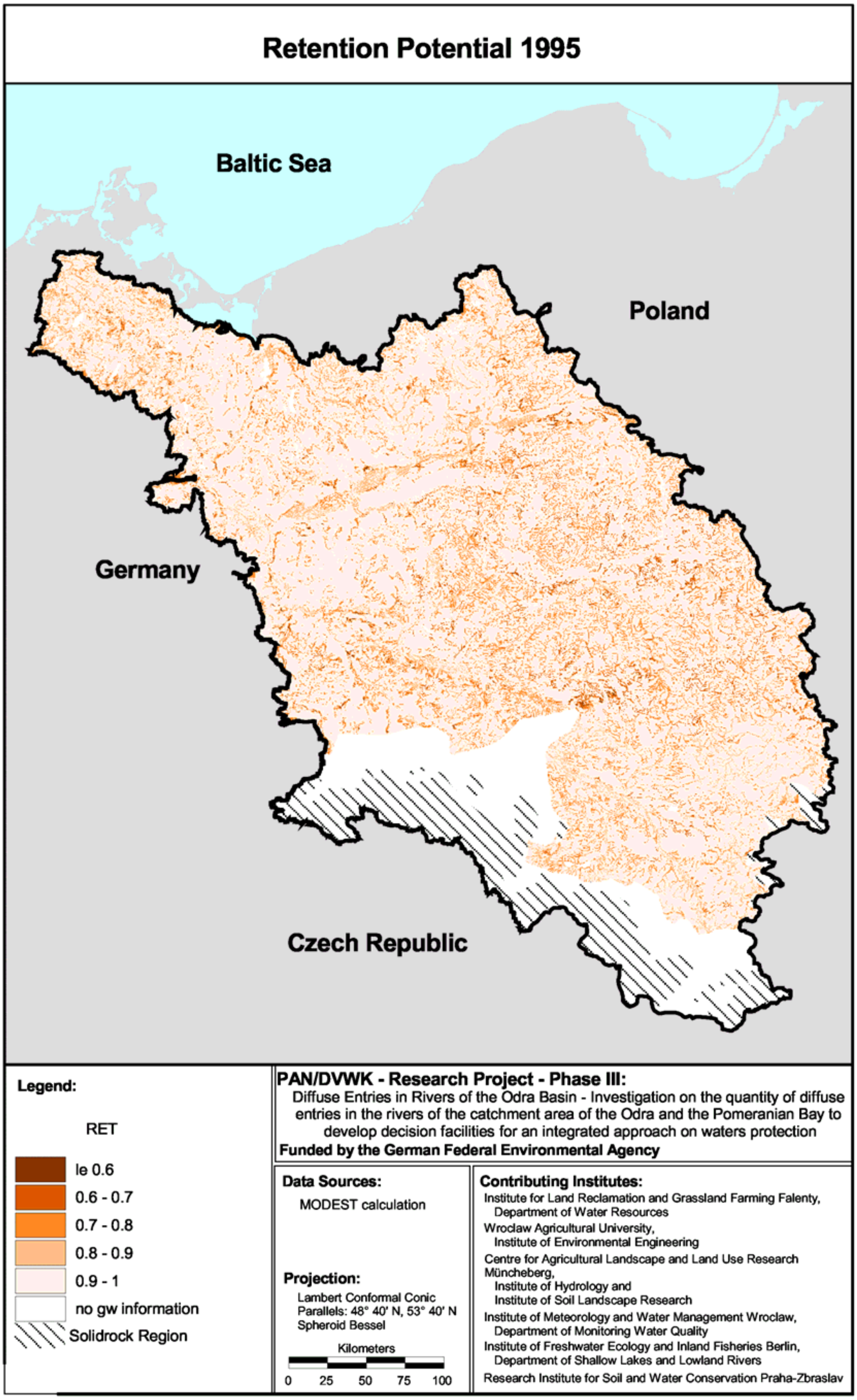
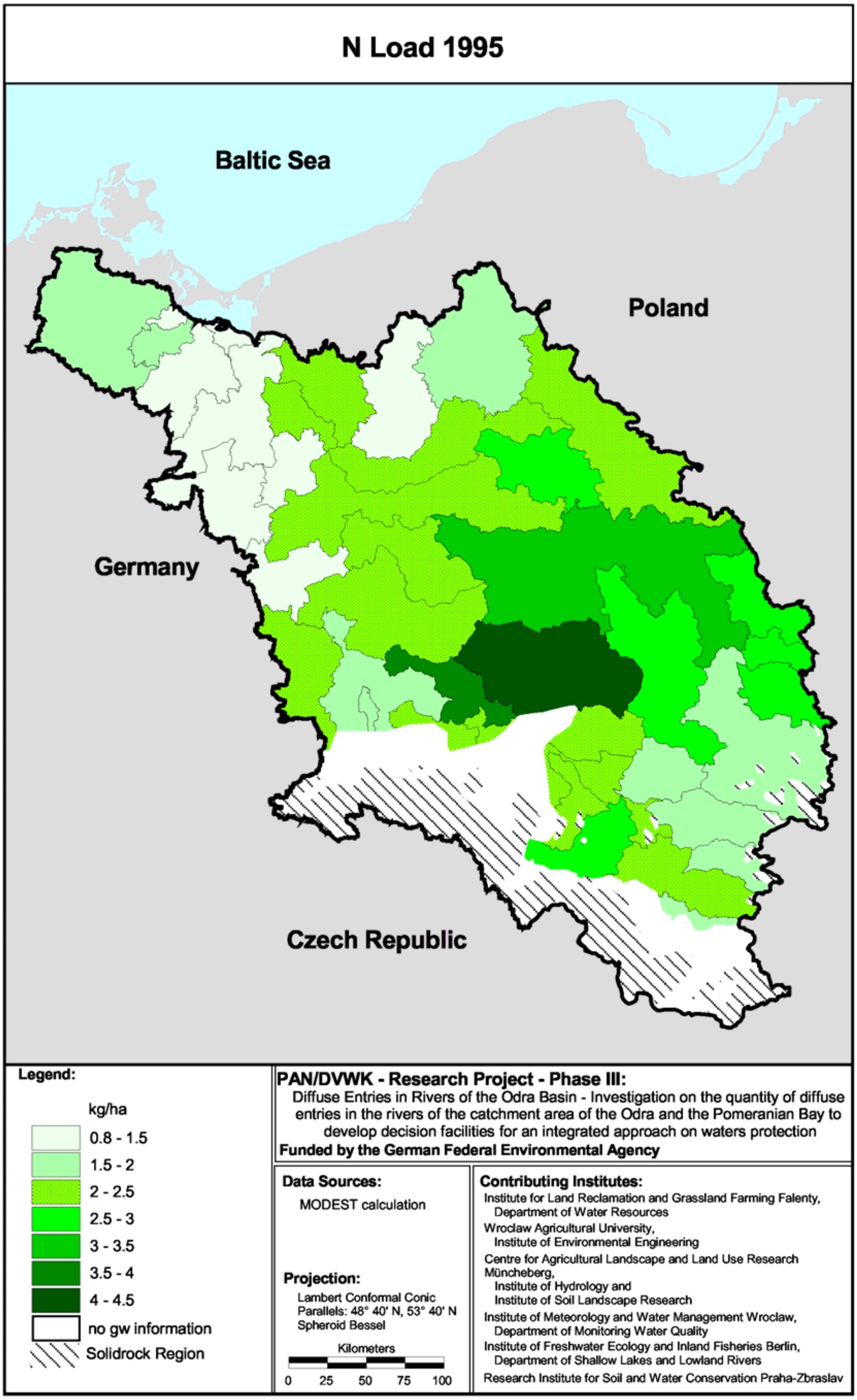
Map 5.21: Interim specific N loads (N_x, $x = 0\ldots3$) related to 1995.



Map 5.22 : Spatial distribution of the retention potential RET as calculated for 1995.



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Data Sources:
MODEST calculation

Projection:
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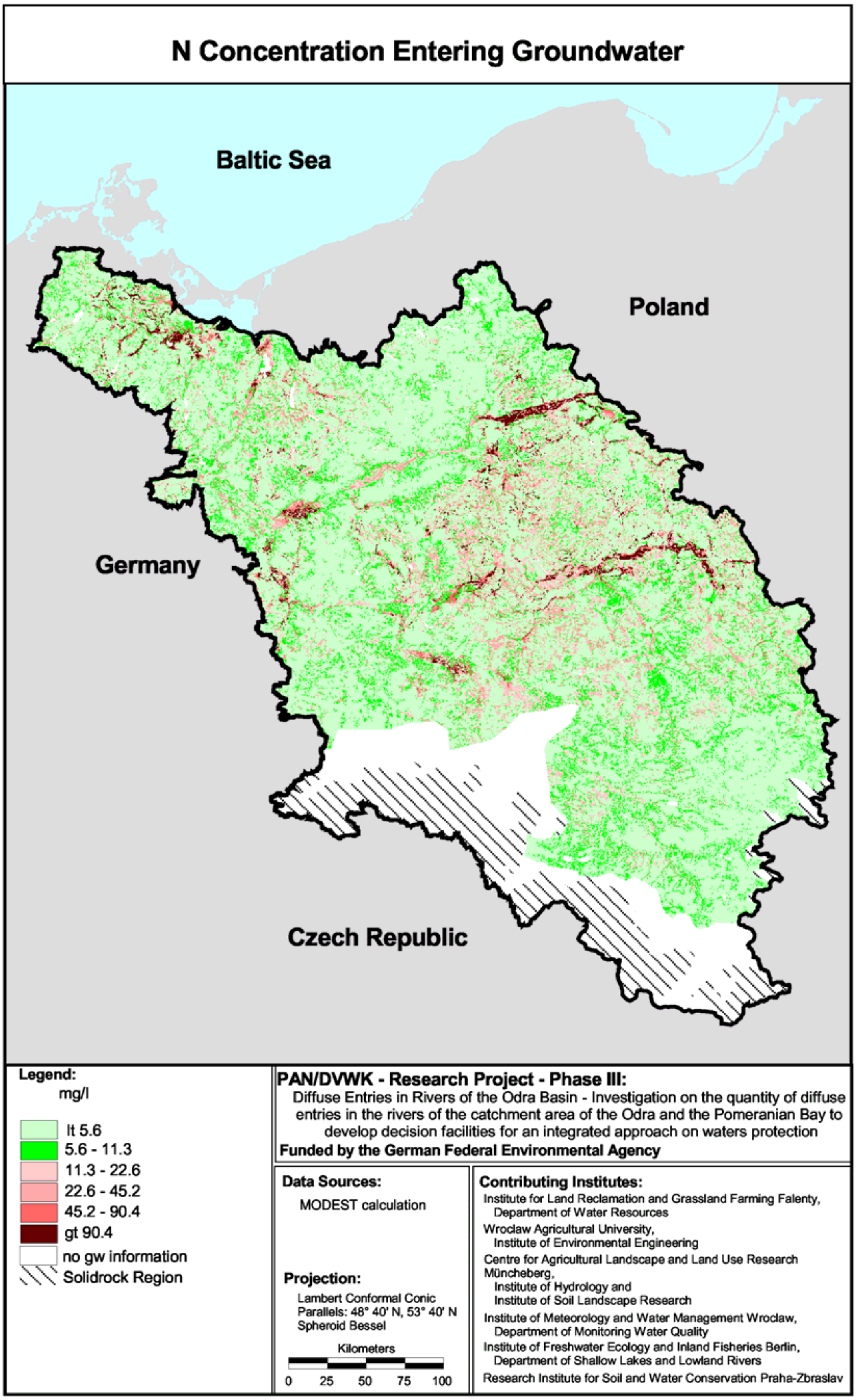
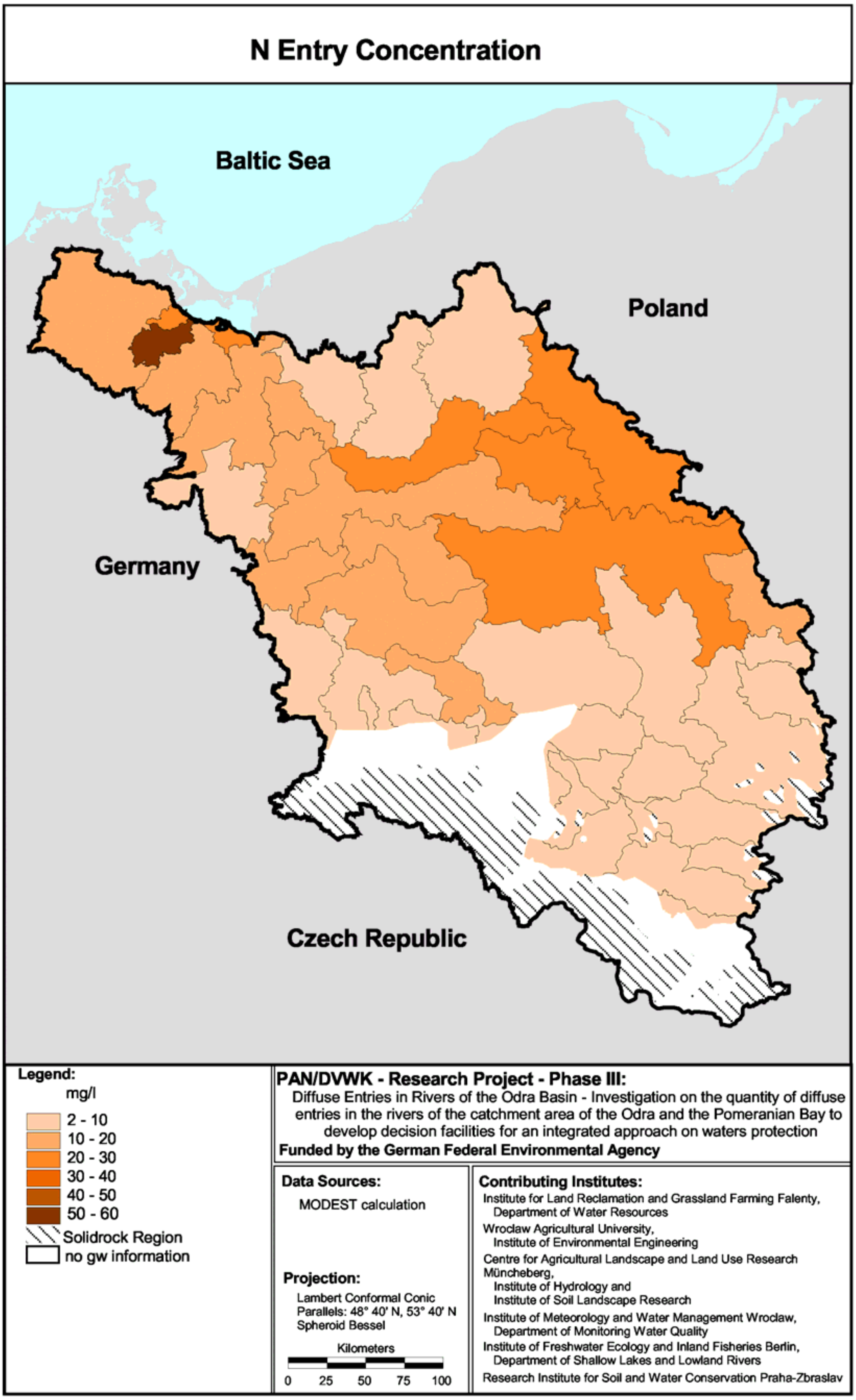
Map 5.23 Specific N load (N_3) aggregated for evaluated catchments.



Map 5.24: Mean N concentration (c_{N2}) entering the groundwater.



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Data Sources:
MODEST calculation

Projection:
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Map 5.25: Mean N concentration (c_{N2}) aggregated for evaluated catchments.

5.2.6.2 Results for the MONERIS approach

Phosphorus and nitrogen inputs by groundwater and natural interflow were calculated with MONERIS for the consolidated and unconsolidated rock region of the Odra basin. For this calculation the model parameter were not changed or adapted to the situation in the Odra.

As shown in Table 5.24 and Figure 5.15 the P-inputs by groundwater into the Odra were about 1170 tP/a for the period 1993-1997. The portion of the countries to the P-inputs by groundwater does not differ very much from the portion of the countries to the total area. The Map 5.24 shows the spatial distribution of the specific phosphorus inputs by groundwater. The highest values of more than 30 kgP/(km²·a) were found for the catchments of Grabia and Ner. The specific groundwater P-input is moderate or low for the other areas.

According to Figure 5.15 and Table 5.25 the total nitrogen inputs by groundwater into the river systems of the Odra calculated with the MONERIS approach was 33640 tN/a. 20.7 % and 4.2 % of this inputs are due to the emissions within the Czech and German part of the Odra. The rest of 75.1 % is caused by the Polish part of the Odra basin. As shown in Map 2.26 a large variance of the specific nitrogen inputs via groundwater were found. But this is not caused by the differences for the estimated nitrogen surplus in the Odra as shown by Map 2.25. The highest specific nitrogen inputs via groundwater occur within the consolidated rock region. The specific nitrogen inputs via groundwater are moderate or low for the unconsolidated rock region of the Odra. The variance in the specific N-inputs leads to significant differences in the N-inputs via groundwater of the catchments of Odra and Wartha upstream Kostrin, where the N-inputs are in the part of Odra 3 times higher (Table.5.27).

If the nitrogen surplus within the sub catchments (Map 2.25) is compared with the specific N-inputs by groundwater (Map 2.26) the summarized nitrogen retention (mainly denitrification) within the soil, the unsaturated zone and the groundwater can be estimated. The result is shown in Map 5.27. One main reason for the high N-inputs in the consolidated rock region seems to be the relative low N-retention of only 60 to 90%. In contrast the N-retention in the unconsolidated region is often in a range of more than 95%.

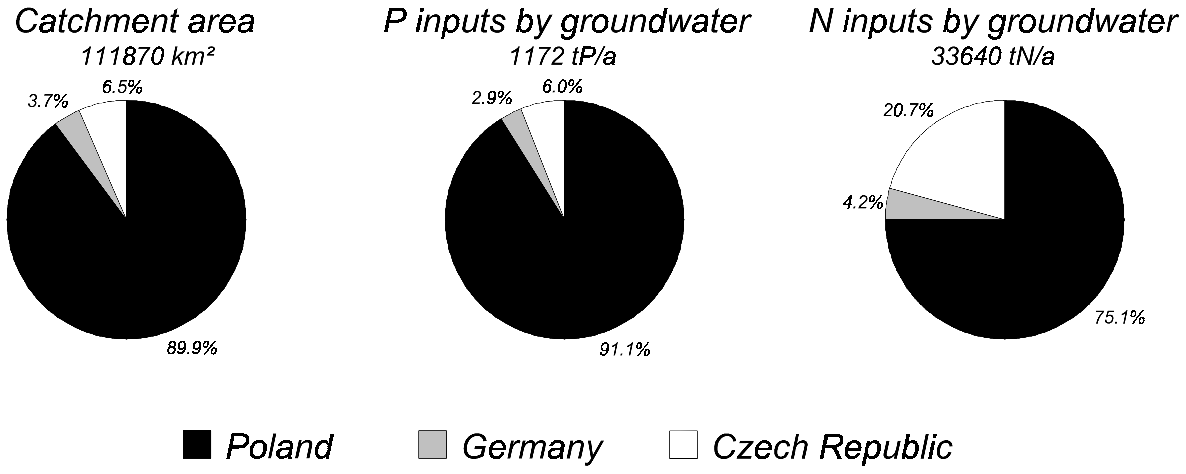


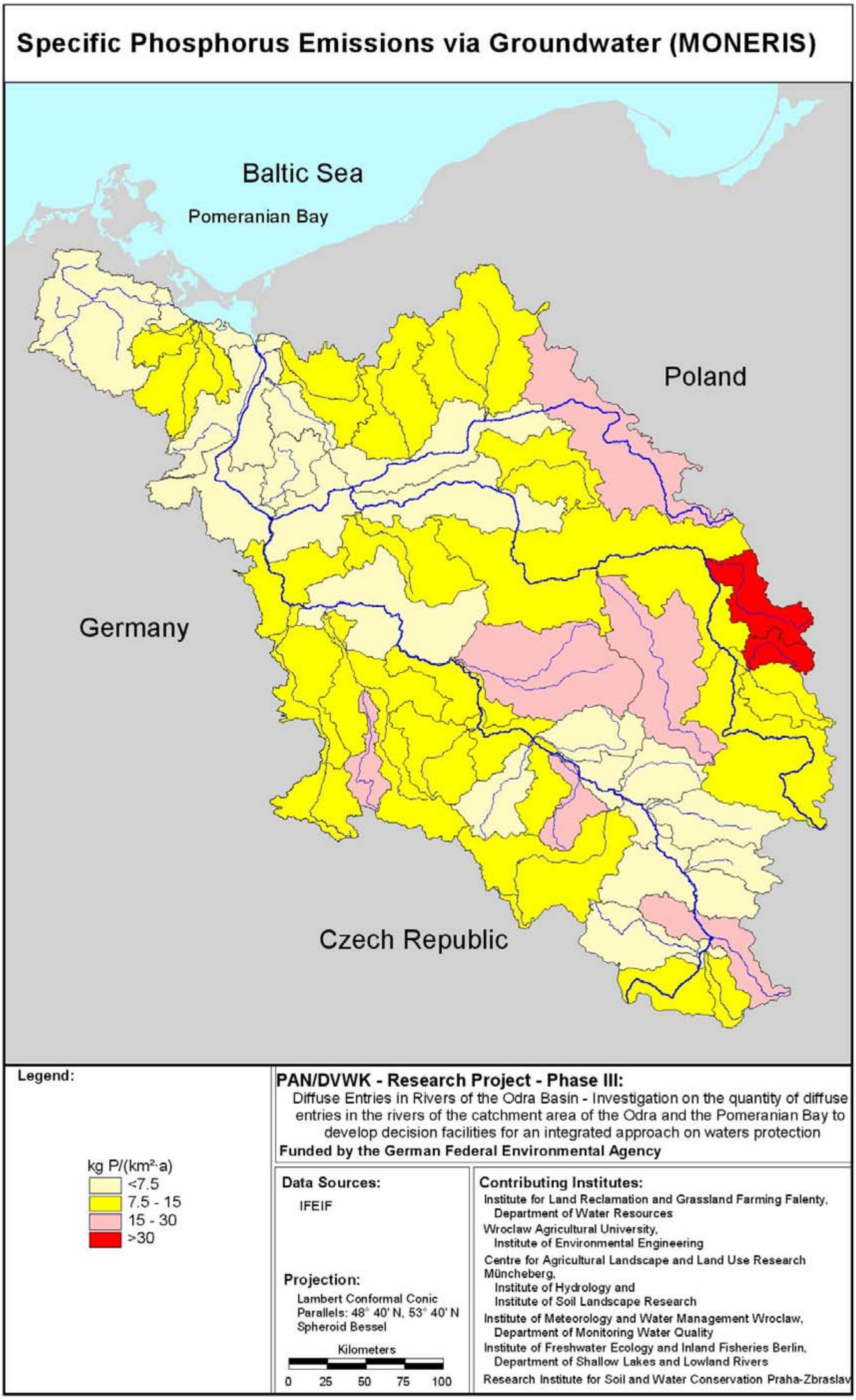
Figure 5.15: Portion of the countries to the total catchment area of the Odra and the total phosphorus and nitrogen emissions by groundwater.

Table 5.24: Phosphorus emissions via groundwater (EGW_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EGW_P	EGW_P-PL	EGW_P-GE	EGW_P-CZ	EGW_P-PL	EGW_P-GE	EGW_P-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	12.7	0.0	0.0	12.7	0.0	0.0	100.0
Opava	2,091	15.2	1.1	0.0	14.1	7.0	0.0	93.0
Ostravice	824	8.0	0.0	0.0	8.0	0.0	0.0	100.0
Odra-Chal	4,666	36.5	1.1	0.0	35.4	3.0	0.0	97.0
Odra-Raci	6,684	78.8	27.9	0.0	50.9	35.4	0.0	64.6
Klodnica	1,085	6.0	6.0	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	100.7	48.5	0.0	52.2	48.2	0.0	51.8
Mala Panew	2,123	15.0	15.0	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	42.0	33.8	0.0	8.2	80.6	0.0	19.4
Stobrawa	1,601	5.7	5.7	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	166.8	106.5	0.0	60.4	63.8	0.0	36.2
Olawa	1,167	18.5	18.5	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	11.1	11.1	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	10.6	10.6	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	23.7	23.7	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	260.4	200.0	0.0	60.4	76.8	0.0	23.2
Barycz	5,535	90.8	90.8	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	373.5	313.2	0.0	60.4	83.8	0.0	16.2
Kwisa	1,026	15.7	15.3	0.0	0.4	97.3	0.0	2.7
Bobr	5,869	70.9	70.4	0.0	0.6	99.2	0.0	0.8
Odra-Pole	47,152	457.5	396.6	0.0	61.0	86.7	0.0	13.3
Ny Lu-Zgor	1,609	19.5	4.1	6.1	9.3	21.1	31.1	47.8
Ny Lu-Gubi	3,974	40.6	20.4	10.9	9.3	50.3	26.8	23.0
Odra-Kost	53,532	520.0	429.4	20.4	70.3	82.6	3.9	13.5
Grabia	813	23.9	23.9	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	41.7	41.7	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	107.7	107.7	0.0	0.0	100.0	0.0	0.0
Ner	1,867	61.4	61.4	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	79.1	79.1	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	366.8	366.8	0.0	0.0	100.0	0.0	0.0
Welna	2,621	22.8	22.8	0.0	0.0	100.0	0.0	0.0
Obra	2,758	34.2	34.2	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	110.9	110.9	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	41.1	41.1	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	27.8	27.8	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	182.4	182.4	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	642.8	642.8	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	3.7	3.7	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	1173.1	1,077.5	25.3	70.3	91.9	2.2	6.0
Plonia	1,101	2.9	2.9	0.0	0.0	100.0	0.0	0.0
Ina	2,163	32.1	32.1	0.0	0.0	100.0	0.0	0.0
Odra-Mouth	118,861	1230.4	1,125.6	34.5	70.3	91.5	2.8	5.7
Peene	5,110	28.4	0.0	28.4	0.0	0.0	100.0	0.0
Zarow	748	9.2	0.0	9.2	0.0	0.0	100.0	0.0
Uecker	2,401	22.3	0.1	22.1	0.0	0.6	99.4	0.0
Odra Haff	8,885	62.3	0.9	61.5	0.0	1.4	98.6	0.0

Table 5.25: Nitrogen emissions via groundwater (EGW_N) in the period 1993-1997 for the whole catchment and for the countries.

Shortname	Area	EGW_N	EGW_N-PL	EGW_N-GE	EGW_N-CZ	EGW_N-PL	EGW_N-GE	EGW_N-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	1,794	0	0	1,794	0.0	0.0	100.0
Opava	2,091	2,418	170	0	2,248	7.0	0.0	93.0
Ostravice	824	591	0	0	591	0.0	0.0	100.0
Odra-Chal	4,666	4,901	171	0	4,729	3.5	0.0	96.5
Odra-Raci	6,684	7,151	1,600	0	5,551	22.4	0.0	77.6
Klodnica	1,085	371	371	0	0	100.0	0.0	0.0
Odra-Gros	10,989	8,387	2,764	0	5,623	33.0	0.0	67.0
Mala Panew	2,123	821	821	0	0	100.0	0.0	0.0
Nysa Klod	4,515	3,358	2,705	0	652	80.6	0.0	19.4
Stobrawa	1,601	203	204	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	12,897	6,622	0	6,275	51.3	0.0	48.7
Olawa	1,167	170	170	0	0	100.0	0.0	0.0
Bystrzyca	1,760	636	636	0	0	100.0	0.0	0.0
Widawa	1,716	258	258	0	0	100.0	0.0	0.0
Kaczawa	2,261	920	920	0	0	100.0	0.0	0.0
Odra-Scin	29,584	15,905	9,630	0	6,275	60.5	0.0	39.5
Barycz	5,535	985	985	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	17,192	10,917	0	6,275	63.5	0.0	36.5
Kwisa	1,026	817	795	0	22	97.3	0.0	2.7
Bobr	5,869	3,815	3,784	0	31	99.2	0.0	0.8
Odra-Pole	47,152	21,416	15,109	0	6,307	70.6	0.0	29.4
Ny Lu-Zgor	1,609	1,370	289	426	655	21.1	31.1	47.8
Ny Lu-Gubi	3,974	2,344	1,041	648	655	44.4	27.6	28.0
Odra-Kost	53,532	24,725	16,696	1,066	6,962	67.5	4.3	28.2
Grabia	813	179	179	0	0	100.0	0.0	0.0
Widawka	2,355	580	580	0	0	100.0	0.0	0.0
Warta-Sier	8,140	2,335	2,335	0	0	100.0	0.0	0.0
Ner	1,867	422	422	0	0	100.0	0.0	0.0
Prosna	4,825	701	701	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	4,243	4,243	0	0	100.0	0.0	0.0
Welna	2,621	142	142	0	0	100.0	0.0	0.0
Obra	2,758	241	241	0	0	100.0	0.0	0.0
Notec-Osie	5,508	697	697	0	0	100.0	0.0	0.0
Gwda	4,943	1,014	1,014	0	0	100.0	0.0	0.0
Drawa	3,296	839	839	0	0	100.0	0.0	0.0
Notec-Sant	17,330	2,618	2,618	0	0	100.0	0.0	0.0
Warta-Kost	54,518	7,596	7,596	0	0	100.0	0.0	0.0
Mysla	1,334	113	113	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	32,748	24,485	1,301	6,962	74.8	4.0	21.3
Plonia	1,101	16	16	0	0	100.0	0.0	0.0
Ina	2,163	594	594	0	0	100.0	0.0	0.0
Odra-Mout	118,861	33,638	25,259	1,417	6,962	75.1	4.2	20.7
Peene	5,110	1,272	0	1,272	0	0.0	100.0	0.0
Zarow	748	123	0	123	0	0.0	100.0	0.0
Uecker	2,401	301	2	299	0	0.6	99.4	0.0
Odra Haff	8,885	1,771	24	1,747	0	1.3	98.7	0.0



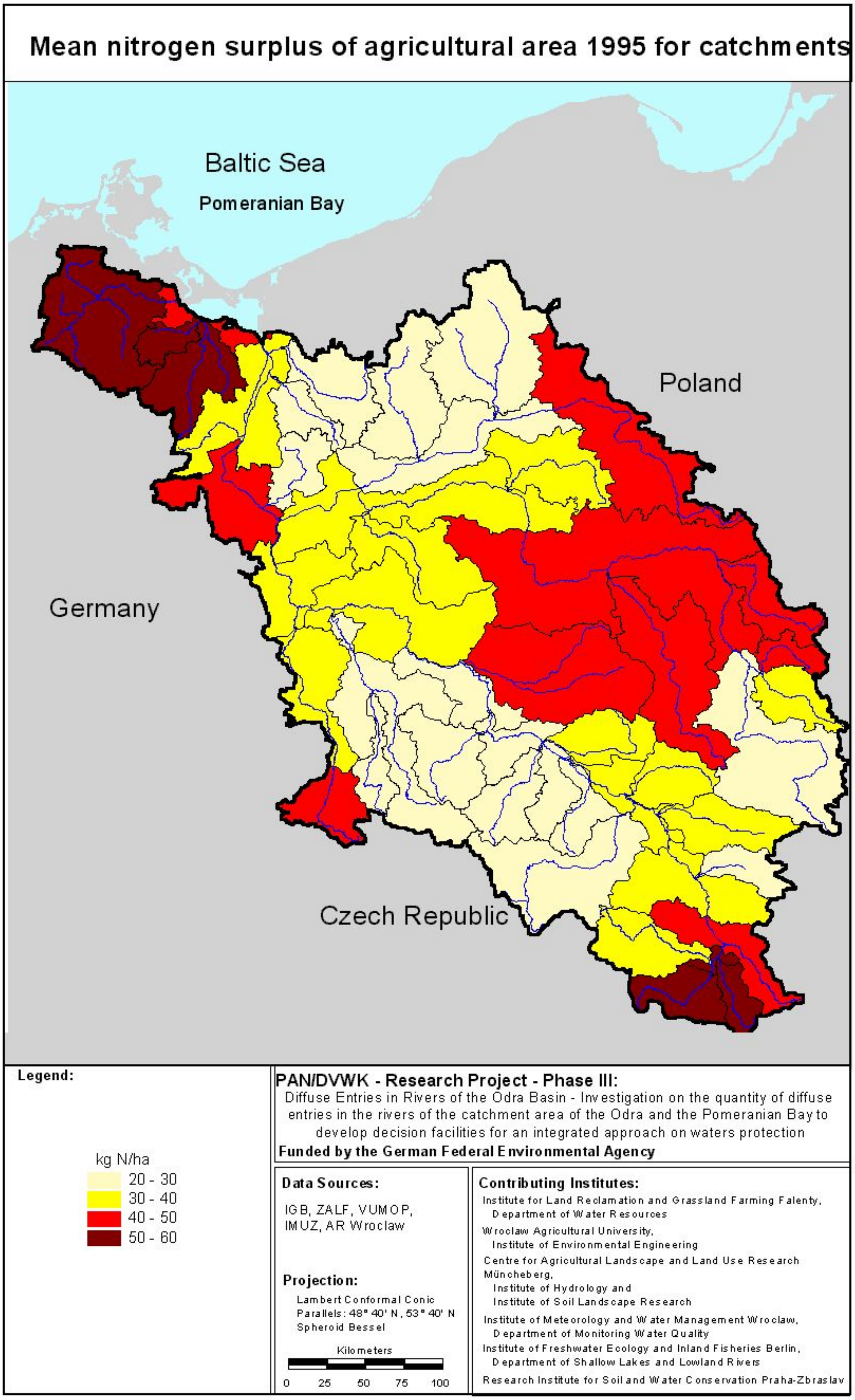
PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.26: Specific phosphorus emissions via groundwater in the period 1993-1997.



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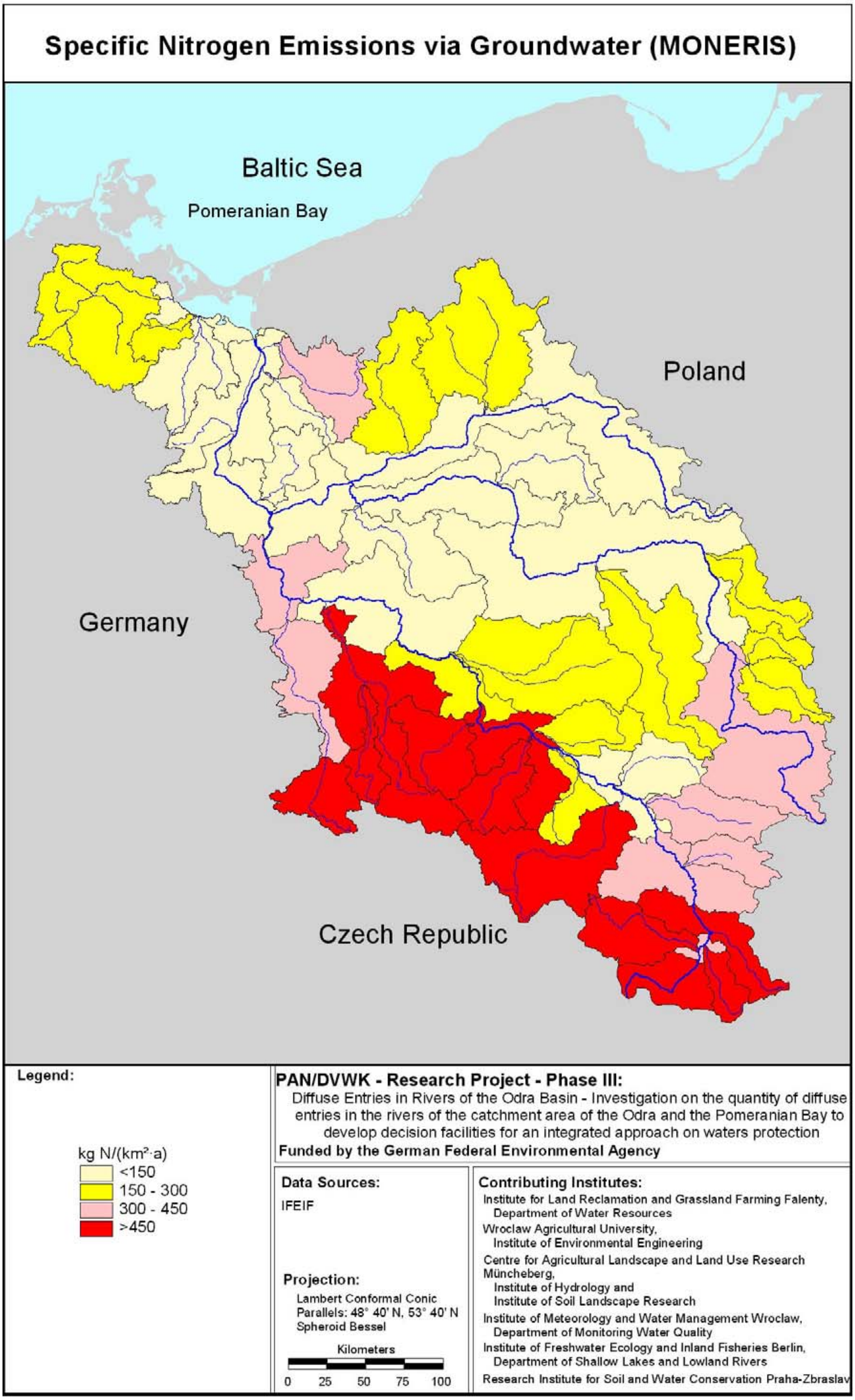
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IGB, ZALF, VUMOP,
IMUZ, AR Wroclaw

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research
Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.27: Specific nitrogen surplus of agricultural areas within the catchments of the Odra in 1995.



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Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
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Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
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Institute of Hydrology and
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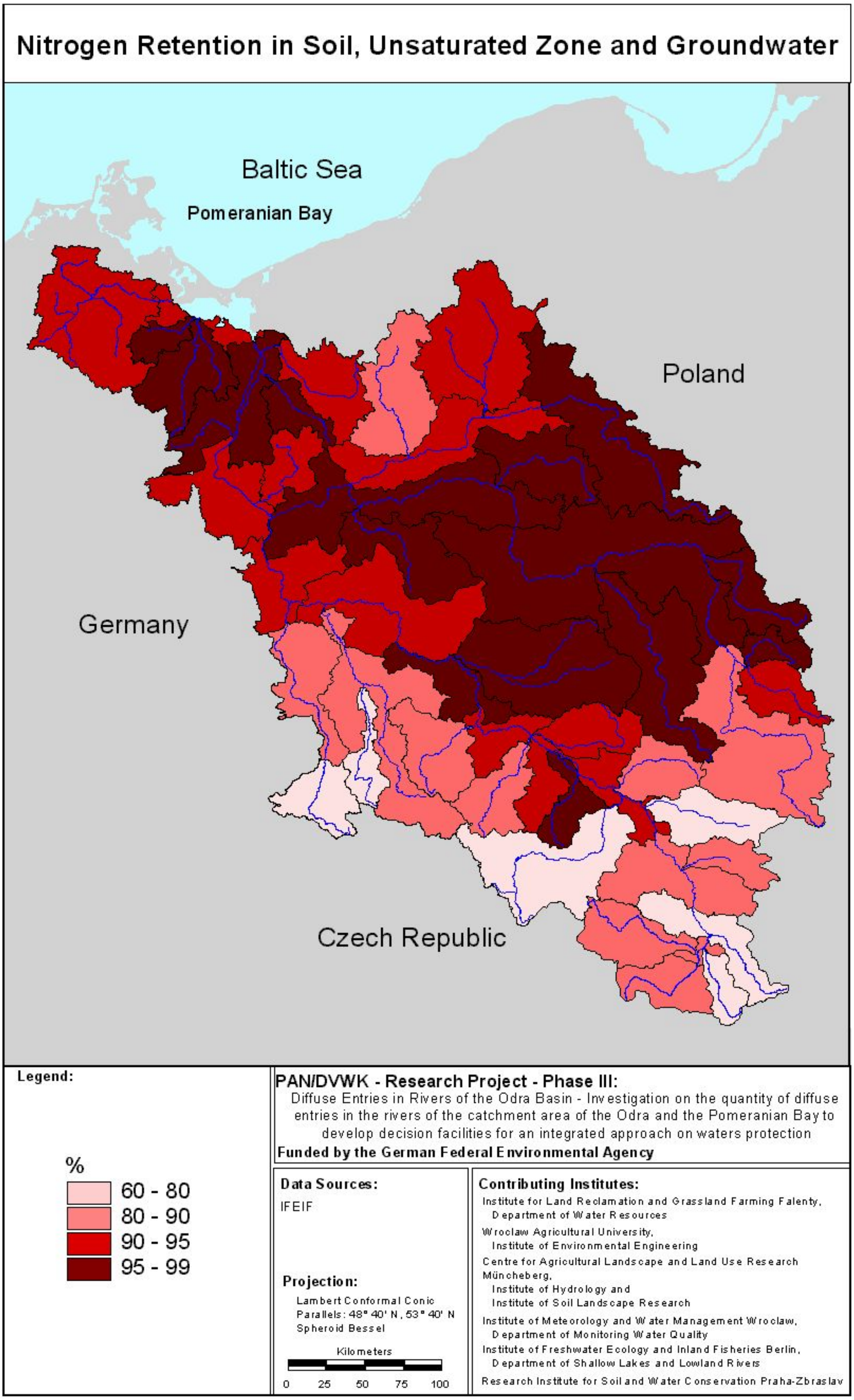
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.28: Specific nitrogen emissions via groundwater in the period 1993-1997.



Nitrogen Retention in Soil, Unsaturated Zone and Groundwater

Legend:

%

🟥 60 - 80
🟥 80 - 90
🟥 90 - 95
🟥 95 - 99

PAN/DVWK - Research Project - Phase III:

Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

Funded by the German Federal Environmental Agency

Data Sources:

IFEIF

Projection:

Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:

Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
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Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
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Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.29: Nitrogen retention in soil, unsaturated zone and groundwater in the period 1993-1997.

5.2.6.3 Comparison of the MODEST and MONERIS results

With the results of the application of the MODEST model and MONERIS module for groundwater inputs different values were estimated for the nitrogen inputs via groundwater into the sub catchments of the Odra. The difference in the model approaches is on the one hand the spatial resolution. MODEST calculates the N-inputs for individual grid cells of 0,25 km² and MONERIS only for gauged catchments. As shown by Venohr (2000) the spatial resolution for MONERIS application is limited for catchment size of about 50 km². On the other hand MONERIS describes the process of N-retention as a conceptional box model and the function between the N-retention and its main driving forces (geological conditions, leakage rate and N-concentration in the top soil) is derived empirically from the comparison of the N-concentrations in topsoil with the regionalized groundwater concentration. Thus the spatial resolution for MONERIS application is also limited by the availability of measurement data of stream flows and matter concentration in the groundwater and the rivers of the small catchments. In contrast MODEST is caused by a mechanistic model describing the main processes of transport and retention so that the requirements on input data especially on the spatial resolution are respectively higher as in case of MONERIS.

To compare the results of both approaches the first step is to find out an independent and observable parameters representing the situation of N-inputs by groundwater within the catchments.

One parameter which can be used for the comparison is the concentration of dissolved inorganic nitrogen (DIN = NO_3-N+NO_2-N+NH_4-N) in groundwater. Because the individual data of one monitoring station are not representative for a catchment, the data of a large data set of groundwater monitoring stations have to be regionalized by means of GIS-tools (see BEHRENDT et al., 2000). For the Odra basin data of 105 stations of groundwater monitoring can be used as the base for this procedure (see Map 5.28). The data were collected by the different environmental institutions of the countries. Based on the data of the 105 stations a grid with 20 km cell size as derived for the whole Odra basin as presented in Map 5.28. If this regionalized data on DIN in groundwater are overlayed with the catchments the mean DIN concentration in the groundwater of the catchments can be estimated and used for the comparison with the results of the models.

Because the regionalized groundwater concentrations can not compensate the effect of some individual stations on the grid value especially if only a limited number of observations is available, the comparison can show large differences caused by only one groundwater monitoring station. Therefore an other parameter representing the integral effects for a catchment would be useful.

Behrendt et al. (2001a and 2001b) has shown that such a parameter can be derived from the dataset of the normal monitoring data of river observation. The hypothesis for selection of this parameter are:

- nitrate concentration is the main indicator for the level of groundwater N-inputs,

- at low flow conditions the observed nitrate concentration is caused by groundwater inputs and point source discharges and
- at low temperature the effect of denitrification in the surface waters is low or neglecting.

Consequently the observed nitrate concentrations in rivers can be an indicator for the groundwater concentration if the point source influence is not dominant and only the concentrations at low flow conditions and low water temperature are selected from the whole set of measurements. As criteria for the selection procedure the following assumptions were used by BEHRENDT et al. (2001a; b). The point source contribution to the total N-inputs should not be larger than one third, the flow should be lower than two third of the average flow and the temperature should be lower than 10 °C.

Table 5.26 and Figure 5.16 shows the mean of the selected nitrate concentration in rivers, the mean nitrogen concentrations derived from groundwater monitoring and the mean nitrogen concentration of groundwater inputs estimated by MONERIS and MODEST. Additionally the relative deviation of the model results and the indicators for nitrogen concentration in groundwater are presented.

The average relative deviation of the nitrogen concentrations of groundwater inputs estimated with MONERIS to the mean nitrate concentration in the rivers at low flow and low

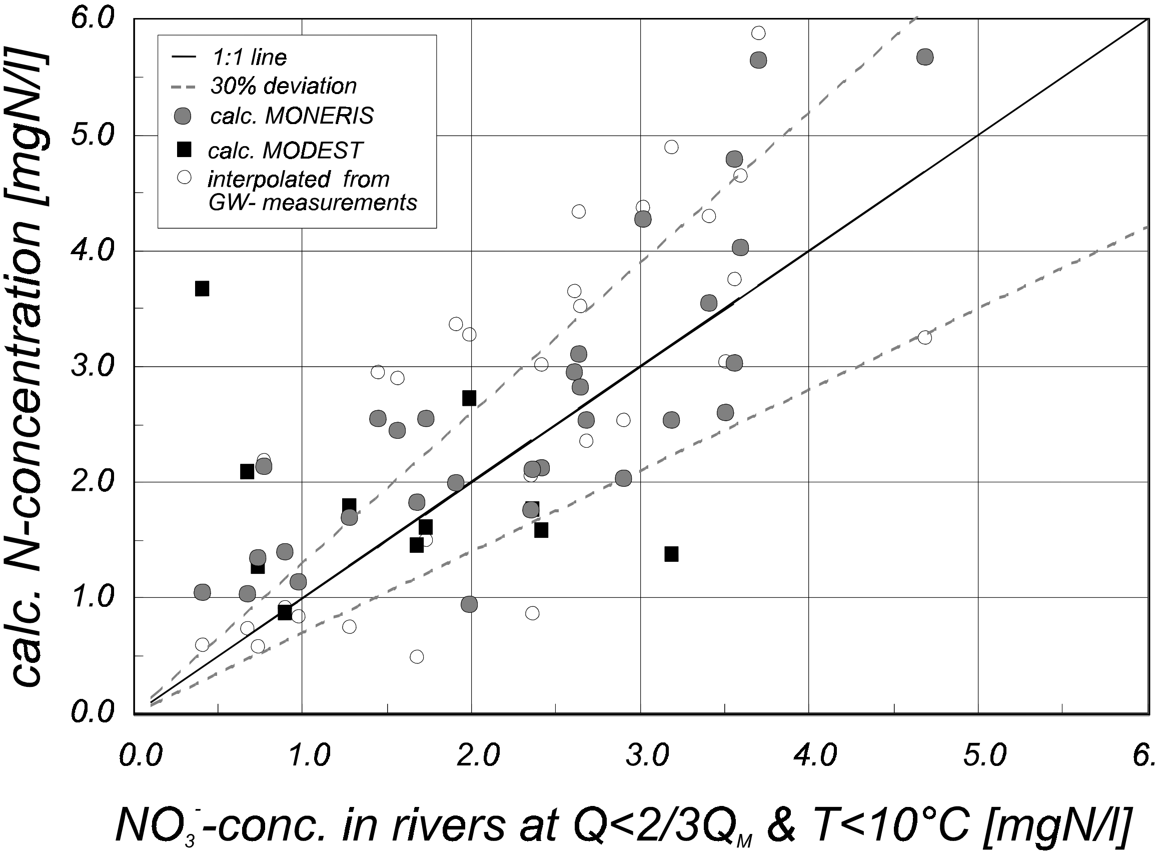


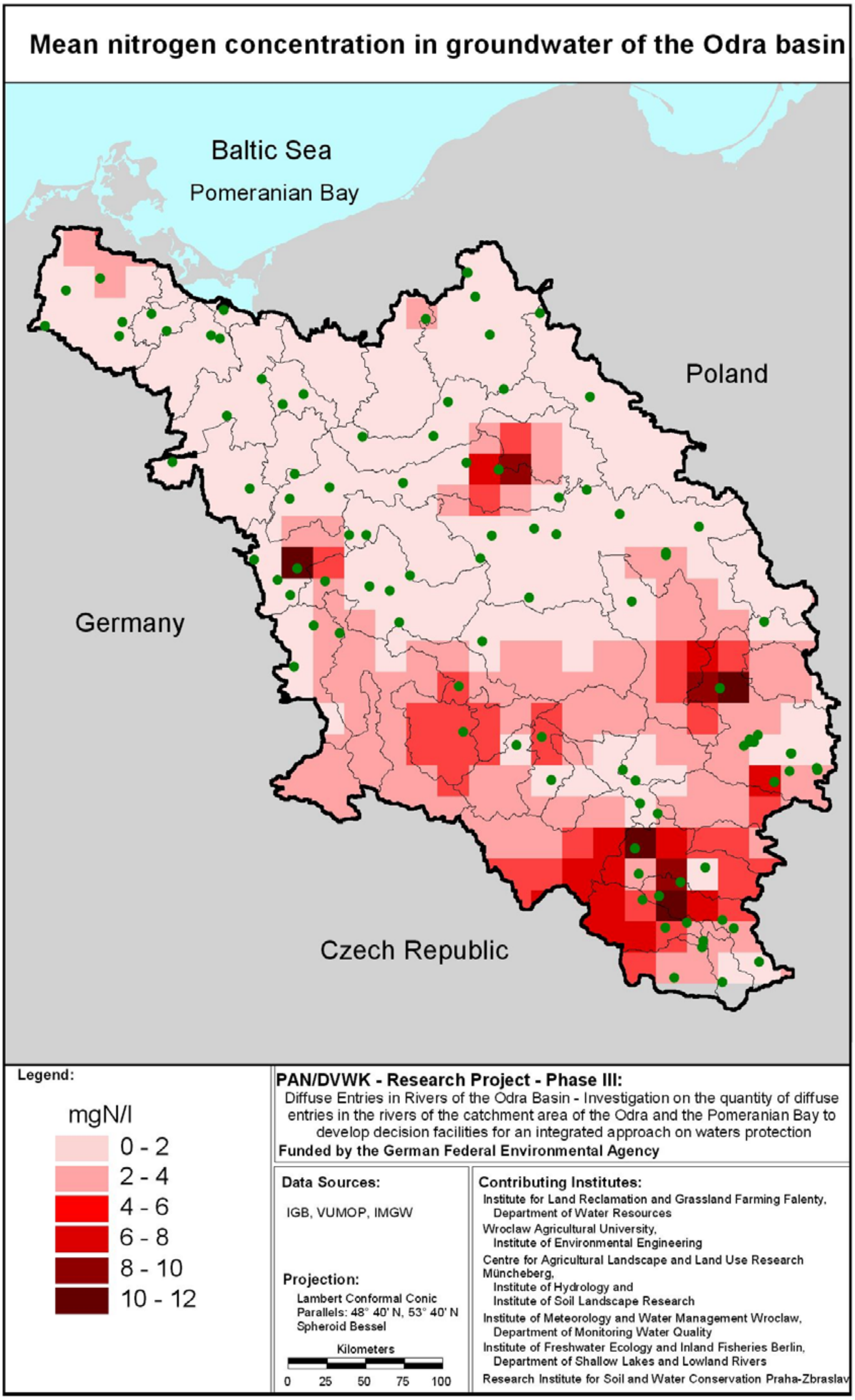
Figure 5.16: Comparison of the nitrate concentration in rivers at low flow conditions and low temperature with the regionalized nitrogen concentration in groundwater and this concentration estimated with MONERIS and MODEST..

Table 5.26: Nitrogen emissions via groundwater (EGW_N) in the period 1993-1997 for the whole catchment and for the countries.

Shortname	1	2	3	4	5	6	7	8	9
	N-conc. river	N-conc. GW	rel. Dev. to 1	N-conc. MONERIS	rel. Dev. to 1	rel. Dev. to 2	N-conc. MODEST	rel. Dev. to 1	rel. Dev. to 2
	[mgN /l]	[mgN /l]	[%]	[mgN /l]	[%]	[%]	[mgN /l]	[%]	[%]
Odra-Pola	4.7	3.3	30.5	5.68	21.4	74.5			
Opava	3.7	5.9	59.1	5.66	52.8	3.9			
Odra-Chal	3.6	3.8	6.0	4.80	35.1	27.4			
Odra-Raci	3.0	4.4	45.4	4.28	41.9	2.4			
Odra-Gros	3.6	4.7	29.6	4.03	12.3	13.4			
Mala Panew	3.5	3.1	12.9	2.61	25.5	14.5			
Nysa Klod	2.6	4.3	65.1	3.12	18.4	28.3			
Odra-Wroc	3.4	4.3	26.5	3.55	4.4	17.4			
Olawa	2.9	2.5	12.4	2.04	29.8	19.9			
Widawa	1.9	3.4	77.4	2.00	5.5	40.6			
Kaczawa	3.2	4.9	54.1	2.54	20.2	48.2	1.39	56.4	71.7
Barycz	0.8	2.2	184.7	2.15	179.4	1.9			
Kwisa	1.4	3.0	106.1	2.55	77.6	13.8			
Bobr	1.6	2.9	86.2	2.46	57.4	15.5			
Odra-Pole	2.6	3.7	40.9	2.96	13.6	19.4			
Ny Lu-Zgor	3.6	3.1	14.2	3.04	14.6	0.5			
Ny Lu-Gubi	2.7	2.4	11.6	2.55	4.8	7.6			
Odra-Kost	2.6	3.5	33.9	2.83	7.1	20.0			
Grabia	1.3	0.8	40.4	1.70	33.5	123.9	1.81	41.8	137.8
Widawka	2.4	2.1	11.8	1.76	24.9	14.9			
Prosna	2.4	3.0	25.3	2.13	11.8	29.6	1.60	33.7	47.1
Welna	2.0	3.3	65.6	0.96	51.8	70.9	2.74	38.0	16.7
Obra	0.7	0.7	10.7	1.04	55.9	40.8	2.11	215.9	185.4
Notec-Osie	1.0	0.9	12.1	1.14	17.6	33.8			
Gwda	0.9	0.9	3.9	1.40	56.7	50.8	0.89	0.56	4.3
Mysla	0.7	0.6	19.5	1.35	85.3	130.3	1.29	77.1	120.1
Plonia	0.4	0.6	48.7	1.06	163.2	77.0	3.69	816.8	516.3
Peene	1.7	1.5	12.7	2.55	48.2	69.7	1.62	6.0	7.7
Zarow	2.4	0.9	63.2	2.12	10.2	143.8	1.78	24.6	104.8
Uecker	1.7	0.5	70.2	1.83	9.3	266.9	1.47	12.4	194.2
Mean of all catchments			42.7 (42.5)*		39.7 (35.4)*	42.9 (42.1)*			
Mean of flat-land catchments			37.7 (36.6)*		49.7 (38.3)*	95.6 (97.5)*		120.3 (50.6)*	127.8 (89.0)*

* Numbers in brackets represent the mean deviation without the data set of Plonia.

temperature is 40 % for all considered catchments 40 % and nearly equal to the relative deviation of the regionalized nitrogen concentrations in groundwater to this nitrogen concentrations in rivers.



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Lambert Conformal Conic
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Contributing Institutes:
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Wroclaw Agricultural University,
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Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.30 : Regionalized Nitrogen concentration in groundwater within the Odra basin in the period 1993-1997.

For the catchments in the unconsolidated rock region the deviation of MONERIS results is about 50 % and 10 % higher as deviation between groundwater and selected river concentrations.

As shown in Figure 5.16 the MONERIS N-concentrations are higher as the both proposed indicators for this region, which is mainly characterized by low concentrations. Regarding MODEST the deviation to both indicators is 120 and 128 %, respectively. This is mainly caused by one very large deviation for the catchments of Plonia.

If this data are excluded from the data set of Table 5.26 deviations comparable with whose of MONERIS are realized by the MODEST model. The deviation between both model results was found to 42.9 % and lays in the same range than the deviation between the both indicators for evaluation of model results.

From the comparison it can be concluded, that the conceptual MONERIS box approach does not estimate results with more errors as the spatial distributed mechanistic approach of the MODEST model. In general, the deviation between the model results of MONERIS and the indicators as well as the MODEST results is not larger as the deviation between the indicators itself. For the evaluation of the model results it is to consider that the error of the estimated groundwater N-inputs is up to now in a range lower than 40 %.

Especially for the unconsolidated rock region, where the nitrogen concentrations in groundwater are in general low, the derivation of regionalized groundwater concentration can due to overestimations if individual data of groundwater monitoring are characterized by high values (see Map 5.28).

The model results regarding the N-transports from groundwater to the rivers within the catchments can not be directly compared, because the MODEST approach does not consider the tile drainage as a separate pathway.

5.2.7 Nutrient Emissions via Urban Areas

A comparison of estimated nutrient inputs via the various pathways in urban areas with other research projects as well as the literature was done by Behrendt et al. (2000). Overall, the comparison had shown that the mean deviation between the results of detailed German studies and MONERIS calculations were reduced from 40% to below 20% for nitrogen and phosphorus by introduction of the dependence of the days of combined sewer overflow on precipitation.

Maps 5.31 and 5.32 show the summarised results of the calculations of N- and P- inputs from paved urban areas and from inhabitants via separated sewers, combined sewer overflows and without any sewer connection for the period 1993-1997. The specific emissions shown in the Maps refer to the whole urban area in the particular catchments.

The highest specific emissions are found in the catchments of Ner, Klodnica, Bystrica and Kwisa. The cause of the high specific nutrient emissions lies in the high proportion of combined sewer systems and in the high proportion of the population which is connected to sewers but not to a wastewater treatment plant.

Tables 5.27 to 5.28 and Figure 5.17 present the results for the nutrient input from urban areas for the investigated catchments in the period 1993-1997. Totally 1495 tP/a and 7680 tN/a were emitted by urban areas into the catchments of the Odra. The portion of German part of Odra is with 1 and 1.9% very low, which is caused on the one hand by the dominance of separate sewer systems and for phosphorus that the inhabitant specific P-emissions are lower as in Czech Republic and Poland, because P-free detergents are used in Germany.

Unclear is the finding in Figure 5.17 that the urban area in Poland is much lower as in Czech Republic and Germany, because for the analysis the harmonized CORINE map was used

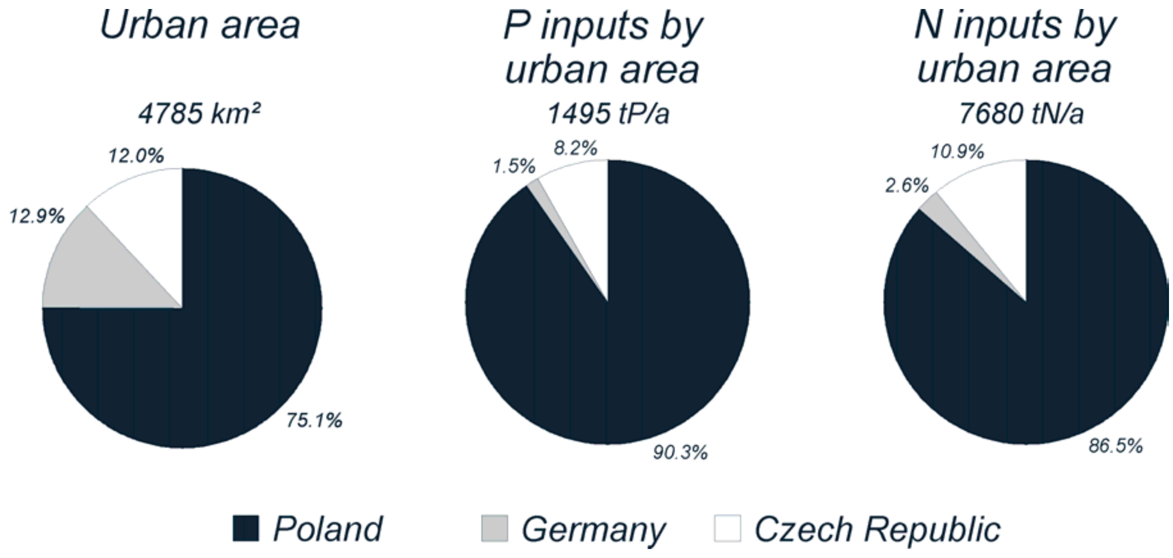


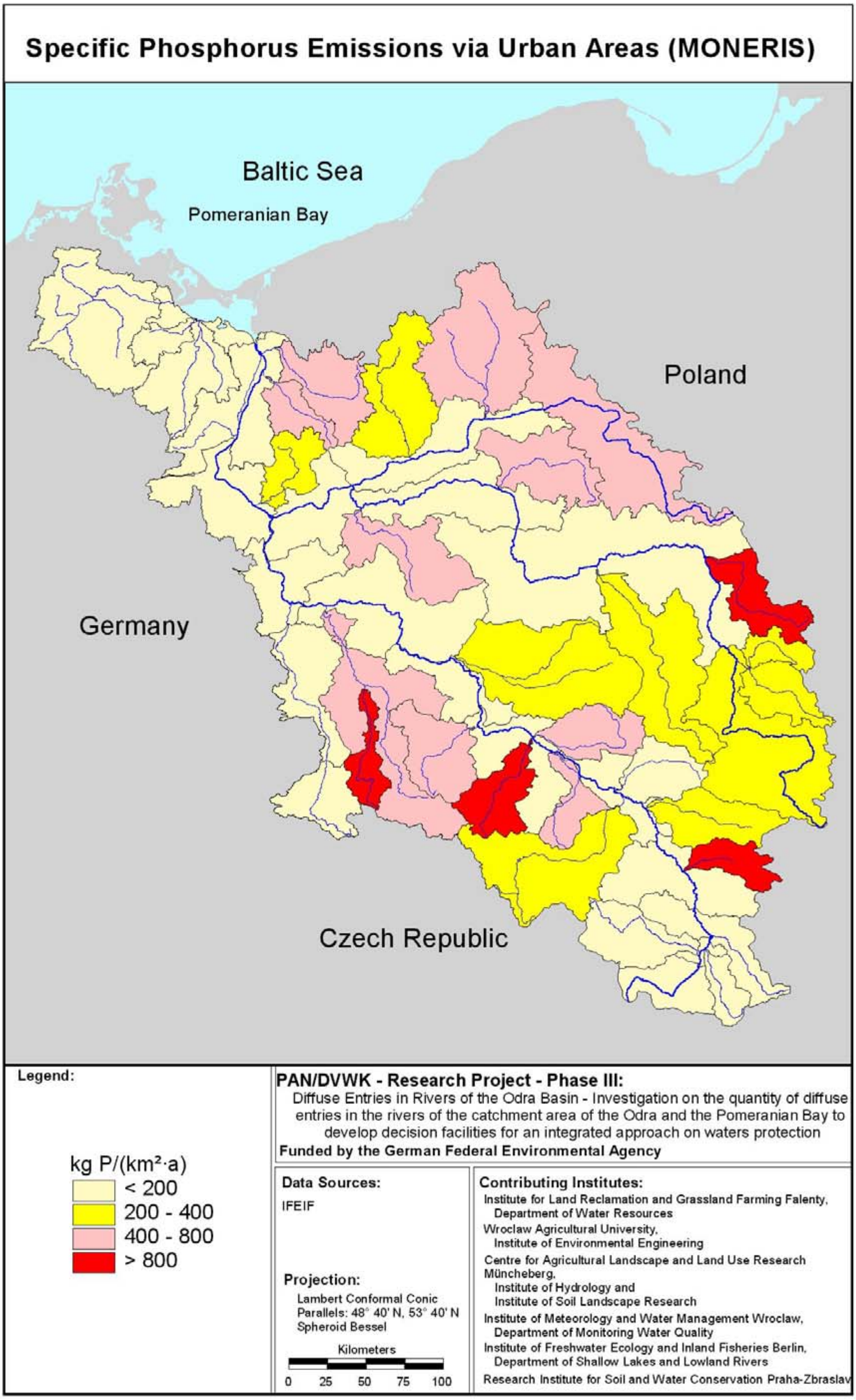
Figure 5.17: Portion of the countries to the total urban area and the total phosphorus and nitrogen discharges by urban areas.

Table 5.27: Phosphorus emissions via urban areas (EUR_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EUR_P	EUR_P-PL	EUR_P-GE	EUR_P-CZ	EUR_P-PL	EUR_P-GE	EUR_P-CZ
	[km^2]	[t P/a]				[%]		
Odra-Pola	1,570	7.7	0.0	0.0	7.7	0.0	0.0	100.0
Opava	2,091	10.7	0.0	0.0	10.7	0.0	0.0	100.0
Ostravice	824	31.0	0.0	0.0	31.0	0.0	0.0	100.0
Odra-Chal	4,666	82.2	0.0	0.0	82.2	0.0	0.0	100.0
Odra-Raci	6,684	119.3	25.1	0.0	94.2	21.0	0.0	79.0
Klodnica	1,085	158.2	158.2	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	337.0	242.3	0.0	94.6	71.9	0.0	28.1
Mala Panew	2,123	24.2	24.2	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	45.1	43.9	0.0	1.2	97.3	0.0	2.7
Stobrawa	1,601	6.3	6.3	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	426.9	331.1	0.0	95.8	77.6	0.0	22.4
Olawa	1,167	11.0	11.0	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	38.1	38.1	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	10.3	10.3	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	17.8	17.8	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	606.5	510.6	0.0	95.8	84.2	0.0	15.8
Barycz	5,535	28.5	28.5	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	679.8	584.0	0.0	95.8	85.9	0.0	14.1
Kwisa	1,026	7.2	7.2	0.0	0.0	99.5	0.0	0.5
Bobr	5,869	49.1	49.0	0.0	0.0	99.9	0.0	0.1
Odra-Pole	47,152	760.0	664.2	0.0	95.9	87.4	0.0	12.6
Ny Lu-Zgor	1,609	33.6	2.8	4.9	26.0	8.2	14.4	77.4
Ny Lu-Gubi	3,974	44.8	10.9	7.9	26.0	24.3	17.6	58.0
Odra-Kost	53,532	814.9	677.8	15.3	121.9	83.2	1.9	15.0
Grabia	813	5.6	5.6	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	23.5	23.5	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	74.7	74.7	0.0	0.0	100.0	0.0	0.0
Ner	1,867	118.9	118.9	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	41.5	41.5	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	427.5	427.5	0.0	0.0	100.0	0.0	0.0
Welna	2,621	20.7	20.7	0.0	0.0	100.0	0.0	0.0
Obra	2,758	14.0	14.0	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	31.2	31.2	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	35.6	35.6	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	8.6	8.6	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	88.8	88.8	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	596.0	596.0	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	5.9	5.9	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	1424.7	1,282.1	20.7	121.9	90.0	1.5	8.6
Plonia	1,101	5.0	5.0	0.0	0.0	100.0	0.0	0.0
Ina	2,163	9.6	9.6	0.0	0.0	100.0	0.0	0.0
Odra-Mout	118,861	1494.8	1,350.4	22.5	121.9	90.3	1.5	8.2
Peene	5,110	15.1	0.0	15.1	0.0	0.0	100.0	0.0
Zarow	748	1.8	0.0	1.8	0.0	0.0	100.0	0.0
Uecker	2,401	5.9	0.0	5.9	0.0	0.0	100.0	0.0
Odra Haff	8,885	24.7	0.6	24.1	0.0	2.5	97.5	0.0

Table 5.28: Nitrogen emissions via urban areas (EUR_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	EUR_N	EUR_N-PL	EUR_N-GE	EUR_N-CZ	EUR_N-PL	EUR_N-GE	EUR_N-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	32	0	0	32	0.0	0.0	100.0
Opava	2,091	45	0	0	44	0.9	0.0	99.1
Ostravice	824	140	0	0	140	0.0	0.0	100.0
Odra-Chal	4,666	372	0	0	371	0.1	0.0	99.9
Odra-Raci	6,684	622	138	0	483	22.3	0.0	77.7
Klodnica	1,085	593	593	0	0	100.0	0.0	0.0
Odra-Gros	10,989	1638	1,021	0	617	62.3	0.0	37.7
Mala Panew	2,123	123	123	0	0	100.0	0.0	0.0
Nysa Klod	4,515	298	204	0	94	68.4	0.0	31.6
Stobrawa	1,601	44	44	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	2197	1,486	0	711	67.6	0.0	32.4
Olawa	1,167	70	70	0	0	100.0	0.0	0.0
Bystrzyca	1,760	177	177	0	0	100.0	0.0	0.0
Widawa	1,716	69	69	0	0	100.0	0.0	0.0
Kaczawa	2,261	102	102	0	0	100.0	0.0	0.0
Odra-Scin	29,584	3044	2,333	0	711	76.6	0.0	23.4
Barycz	5,535	194	194	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	3434	2,723	0	711	79.3	0.0	20.7
Kwisa	1,026	63	39	0	25	61.1	0.0	38.9
Bobr	5,869	279	254	0	25	91.2	0.0	8.8
Odra-Pole	47,152	3889	3,153	0	736	81.1	0.0	18.9
Ny Lu-Zgor	1,609	151	18	30	102	12.1	19.9	68.0
Ny Lu-Gubi	3,974	238	68	68	102	28.5	28.5	43.0
Odra-Kost	53,532	4207	3,240	128	838	77.0	3.1	19.9
Grabia	813	36	36	0	0	100.0	0.0	0.0
Widawka	2,355	121	121	0	0	100.0	0.0	0.0
Warta-Sier	8,140	410	410	0	0	100.0	0.0	0.0
Ner	1,867	493	493	0	0	100.0	0.0	0.0
Prosna	4,825	237	237	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	2054	2,054	0	0	100.0	0.0	0.0
Welna	2,621	111	111	0	0	100.0	0.0	0.0
Obra	2,758	83	83	0	0	100.0	0.0	0.0
Notec-Osie	5,508	192	192	0	0	100.0	0.0	0.0
Gwda	4,943	168	168	0	0	100.0	0.0	0.0
Drawa	3,296	49	49	0	0	100.0	0.0	0.0
Notec-Sant	17,330	490	490	0	0	100.0	0.0	0.0
Warta-Kost	54,518	3009	3,009	0	0	100.0	0.0	0.0
Mysla	1,334	33	33	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	7325	6,303	184	838	86.1	2.5	11.4
Plonia	1,101	33	33	0	0	100.0	0.0	0.0
Ina	2,163	61	61	0	0	100.0	0.0	0.0
Odra-Mout	118,861	7678	6,639	201	838	86.5	2.6	10.9
Peene	5,110	119	0	119	0	0.0	100.0	0.0
Zarow	748	15	0	15	0	0.0	100.0	0.0
Uecker	2,401	51	0	50	0	0.6	99.4	0.0
Odra Haff	8,885	197	3	194	0	1.7	98.3	0.0



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Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
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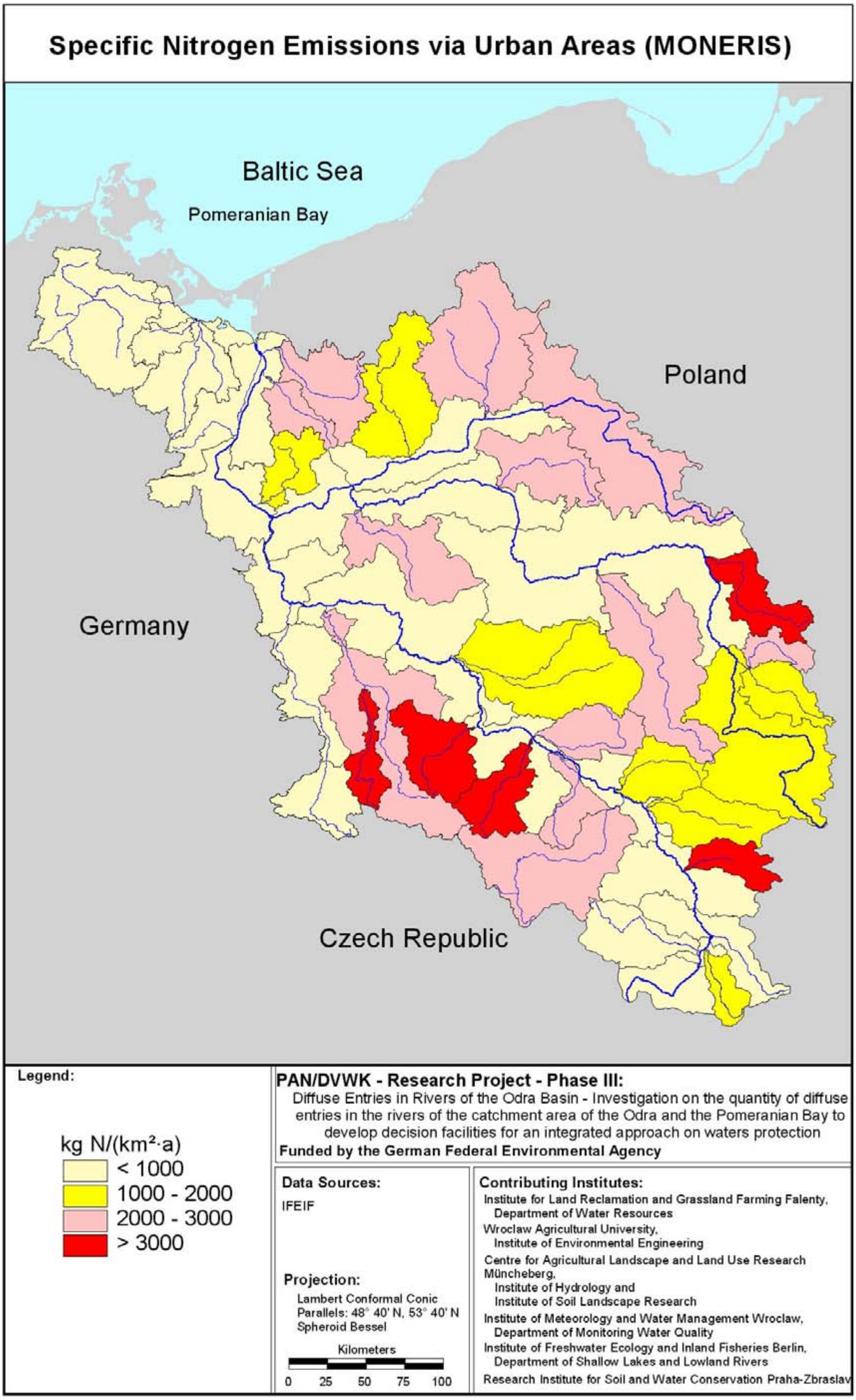
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.31: Specific phosphorus emissions via urban areas in the period 1993-1997.



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Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.32: Specific nitrogen emissions via urban areas in the period 1993-1997.

5.2.8 Total Diffuse Nutrient Emissions

An overview on the total diffuse nutrient emissions into the river system of Odra and the main tributaries is given in the Tables 5.29 and 5.30. Additionally the Maps 5.33 and 5.34 shows the spatial distribution of the total diffuse emissions.

The total diffuse P-inputs were about 4870 tP/a in the period 1993-1997 (see also Figure 5.18). The part of Czech Republic to the total diffuse emissions was 10% which is about the double of the portion of Czech part to the total catchment area of Odra. As shown in Map 5.31 the reason for this result is that the Czech part of Odra is mainly characterized by moderate and high specific P-inputs from diffuse pathways. In general the highest diffuse P-emissions occur in sub catchments with high portion of urban areas. As shown in Figure 5.20 the contribution of P-inputs by urban area is higher than 45 % only in the three sub catchments of Ostravice, Klodnica and Ner, where the highest agglomerations of populations are located. For the whole Odra basin the contribution of this pathway to the total diffuse P-inputs is 30.7 % (see Figure 5.19). Together with erosion (31.2%) the highest P-emissions are erosion are caused by this two pathways followed by the P-inputs via groundwater (24.1%). Within the catchment of the Warta the P-inputs by groundwater are in general higher than the inputs by erosion. But as shown in Figure 5.20 the contribution of the individual pathways to the total diffuse emissions varies in a wide range. The consequence is that possible measures against diffuse P-emissions have to be different in the individual sub catchments. If the results of the NIIRS model regarding erosion is taken into account the portion of erosion to the total P-emissions by diffuse sources is reduced to lower than 25% for the whole Odra basin. For this case the P-inputs by urban area and groundwater would be larger as the inputs by erosion.

TONDERSKI (1997) found that the diffuse P-inputs into the Odra upstream Krajnik Dony was 2400 tP/a for the period 1992-1994, which is substantially lower as estimated here (4600 tP/a). On the other hand the diffuse P-inputs estimated by BEHRENDT et al. (1999) varies between 3320 and 3870 tP/a depending on the method used for the analysis.

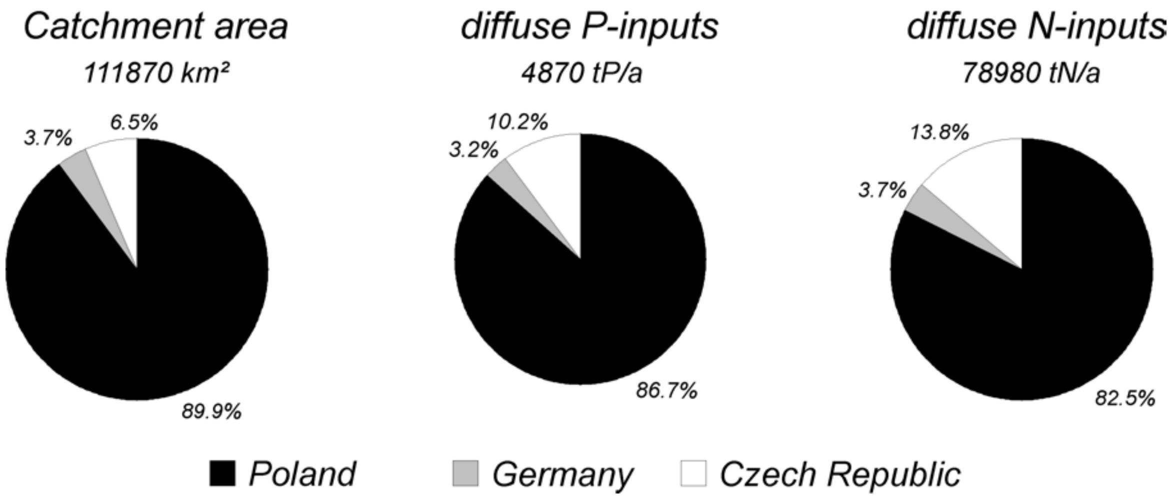


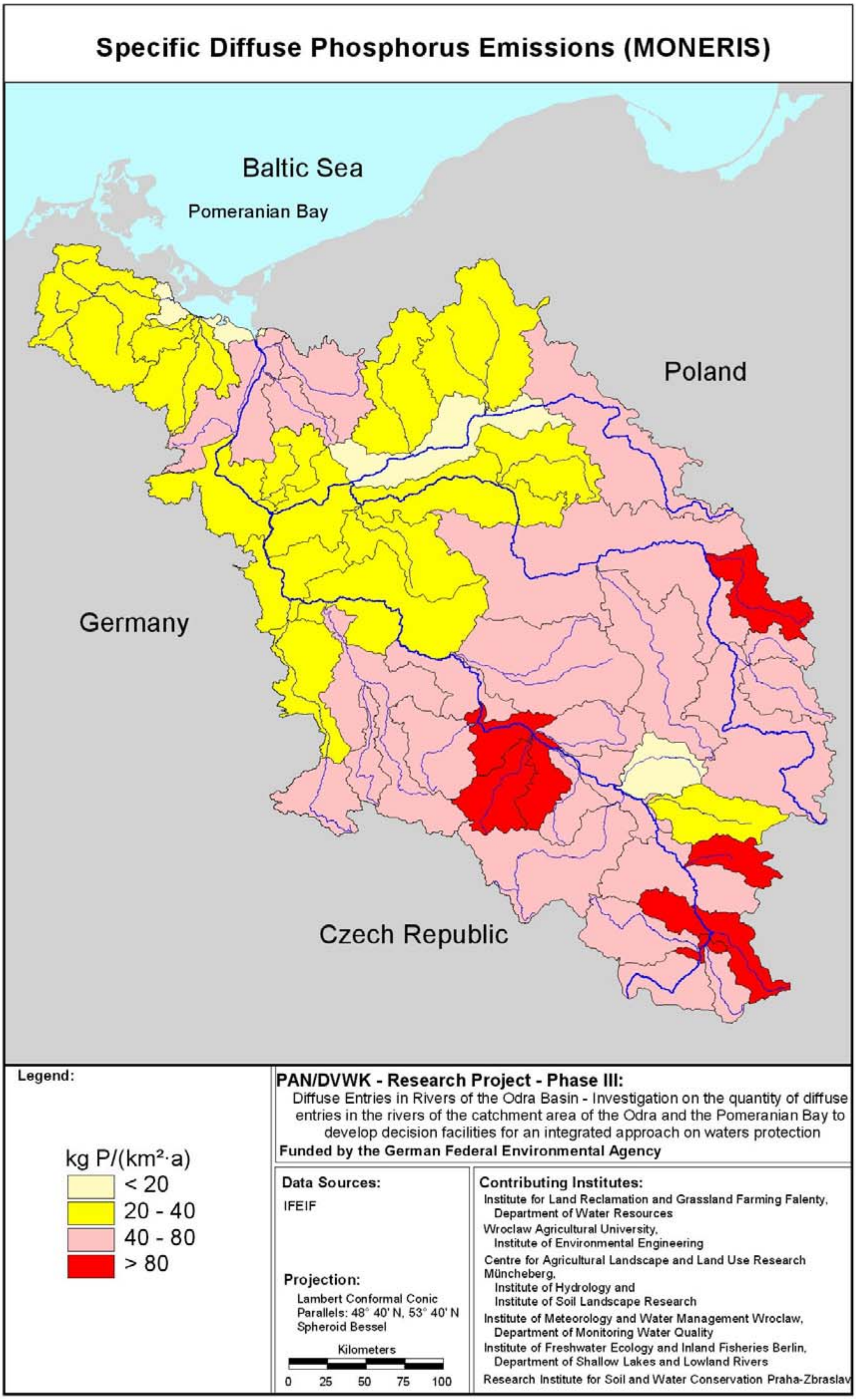
Figure 5.18: Portion of the countries to the total catchment area and the total phosphorus and nitrogen discharges by diffuse pathways.

Table 5.29: Diffuse phosphorus emissions (ED_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ED_P	ED_P-PL	ED_P-GE	ED_P-CZ	ED_P-PL	ED_P-GE	ED_P-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	106.2	0.0	0.0	106.2	0.0	0.0	100.0
Opava	2,091	103.6	6.5	0.0	97.0	6.3	0.0	93.7
Ostravice	824	67.9	0.0	0.0	67.9	0.0	0.0	100.0
Odra-Chal	4,666	317.8	6.6	0.0	311.1	2.1	0.0	97.9
Odra-Raci	6,684	493.4	119.6	0.0	373.8	24.2	0.0	75.8
Klodnica	1,085	180.0	180.0	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	838.1	455.1	0.0	383.0	54.3	0.0	45.7
Mala Panew	2,123	53.9	53.9	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	233.0	195.3	0.0	37.7	83.8	0.0	16.2
Stobrawa	1,601	24.2	24.2	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	1,181.2	760.5	0.0	420.7	64.4	0.0	35.6
Olawa	1,167	58.5	58.5	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	103.7	103.7	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	51.6	51.6	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	112.6	112.6	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	1,707.4	1,286.8	0.0	420.7	75.4	0.0	24.6
Barycz	5,535	233.8	233.8	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	2,041.5	1,620.9	0.0	420.7	79.4	0.0	20.6
Kwisa	1,026	51.2	50.0	0.0	1.2	97.7	0.0	2.3
Bobr	5,869	237.2	235.5	0.0	1.7	99.3	0.0	0.7
Odra-Pole	47,152	2,368.3	1,945.9	0.0	422.3	82.2	0.0	17.8
Ny Lu-Zgor	1,609	132.9	23.7	35.7	73.5	17.8	26.9	55.3
Ny Lu-Gubi	3,974	181.1	60.4	47.2	73.5	33.4	26.1	40.6
Odra-Kost	53,532	2,594.9	2,029.2	70.0	495.8	78.2	2.7	19.1
Grabia	813	36.2	36.2	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	82.4	82.4	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	258.9	258.9	0.0	0.0	100.0	0.0	0.0
Ner	1,867	204.1	204.1	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	165.5	165.5	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	1,156.5	1,156.5	0.0	0.0	100.0	0.0	0.0
Welna	2,621	93.5	93.5	0.0	0.0	100.0	0.0	0.0
Obra	2,758	70.6	70.6	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	243.0	243.0	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	117.6	117.6	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	61.2	61.2	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	454.4	454.4	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	1,915.1	1,915.1	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	22.2	22.2	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	4,597.0	3,983.3	117.8	495.8	86.7	2.6	10.8
Plonia	1,101	41.8	41.8	0.0	0.0	100.0	0.0	0.0
Ina	2,163	95.5	95.5	0.0	0.0	100.0	0.0	0.0
Odra-Mout	118,861	4,871.6	4,222.2	153.5	495.8	86.7	3.2	10.2
Peene	5,110	145.5	0.0	145.5	0.0	0.0	100.0	0.0
Zarow	748	23.8	0.0	23.8	0.0	0.0	100.0	0.0
Uecker	2,401	87.4	0.5	86.9	0.0	0.6	99.4	0.0
Odra Haff	8,885	264.8	2.9	261.9	0.0	1.1	98.9	0.0

Table 5.30: Diffuse nitrogen emissions (ED_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ED_N	ED_N-PL	ED_N-GE	ED_N-CZ	ED_N-PL	ED_N-GE	ED_N-CZ
	[km²]	[t N/a]				[%]		
Odra-Pola	1,570	2,899	0	0	2,899	0.0	0.0	100.0
Opava	2,091	3,079	214	0	2,865	6.9	0.0	93.1
Ostravice	824	1,067	0	0	1,067	0.0	0.0	100.0
Odra-Chal	4,666	7,384	217	0	7,168	2.9	0.0	97.1
Odra-Raci	6,684	10,879	2,414	0	8,465	22.2	0.0	77.8
Klodnica	1,085	1,126	1,126	0	0	100.0	0.0	0.0
Odra-Gros	10,989	14,219	5,471	0	8,748	38.5	0.0	61.5
Mala Panew	2,123	1,374	1,374	0	0	100.0	0.0	0.0
Nysa Klod	4,515	4,736	3,780	0	956	79.8	0.0	20.2
Stobrawa	1,601	599	599	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	21,524	11,820	0	9,704	54.9	0.0	45.1
Olawa	1,167	655	655	0	0	100.0	0.0	0.0
Bystrzyca	1,760	1,312	1,312	0	0	100.0	0.0	0.0
Widawa	1,716	913	913	0	0	100.0	0.0	0.0
Kaczawa	2,261	1,474	1,474	0	0	100.0	0.0	0.0
Odra-Scin	29,584	28,101	18,397	0	9,704	65.5	0.0	34.5
Barycz	5,535	4,449	4,449	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	33,391	23,688	0	9,704	70.9	0.0	29.1
Kwisa	1,026	1,183	1,129	0	54	95.4	0.0	4.6
Bobr	5,869	5,078	5,012	0	66	98.7	0.0	1.3
Odra-Pole	47,152	40,065	30,296	0	9,770	75.6	0.0	24.4
Ny Lu-Zgor	1,609	2,298	471	697	1,130	20.5	30.3	49.2
Ny Lu-Gubi	3,974	3,677	1,517	1,030	1,130	41.3	28.0	30.7
Odra-Kost	53,532	45,037	32,521	1,617	10,900	72.2	3.6	24.2
Grabia	813	504	504	0	0	100.0	0.0	0.0
Widawka	2,355	1,359	1,359	0	0	100.0	0.0	0.0
Warta-Sier	8,140	4,709	4,709	0	0	100.0	0.0	0.0
Ner	1,867	1,860	1,860	0	0	100.0	0.0	0.0
Prosna	4,825	3,623	3,623	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	18,027	18,027	0	0	100.0	0.0	0.0
Welna	2,621	1,059	1,059	0	0	100.0	0.0	0.0
Obra	2,758	989	989	0	0	100.0	0.0	0.0
Notec-Osie	5,508	2,424	2,424	0	0	100.0	0.0	0.0
Gwda	4,943	2,118	2,118	0	0	100.0	0.0	0.0
Drawa	3,296	1,330	1,330	0	0	100.0	0.0	0.0
Notec-Sant	17,330	6,602	6,602	0	0	100.0	0.0	0.0
Warta-Kost	54,518	29,134	29,133	0	0	100.0	0.0	0.0
Mysla	1,334	459	459	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	75,654	62,374	2,380	10,900	82.4	3.1	14.4
Plonia	1,101	510	510	0	0	100.0	0.0	0.0
Ina	2,163	1,332	1,332	0	0	100.0	0.0	0.0
Odra-Mout	118,861	78,976	65,173	2,904	10,900	82.5	3.7	13.8
Peene	5,110	4,599	0	4,599	0	0.0	100.0	0.0
Zarow	748	434	0	434	0	0.0	100.0	0.0
Uecker	2,401	1,524	9	1,515	0	0.6	99.4	0.0
Odra Haff	8,885	6,815	83	6,732	0	1.2	98.8	0.0



PAN/DVWK - Research Project - Phase III:
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection

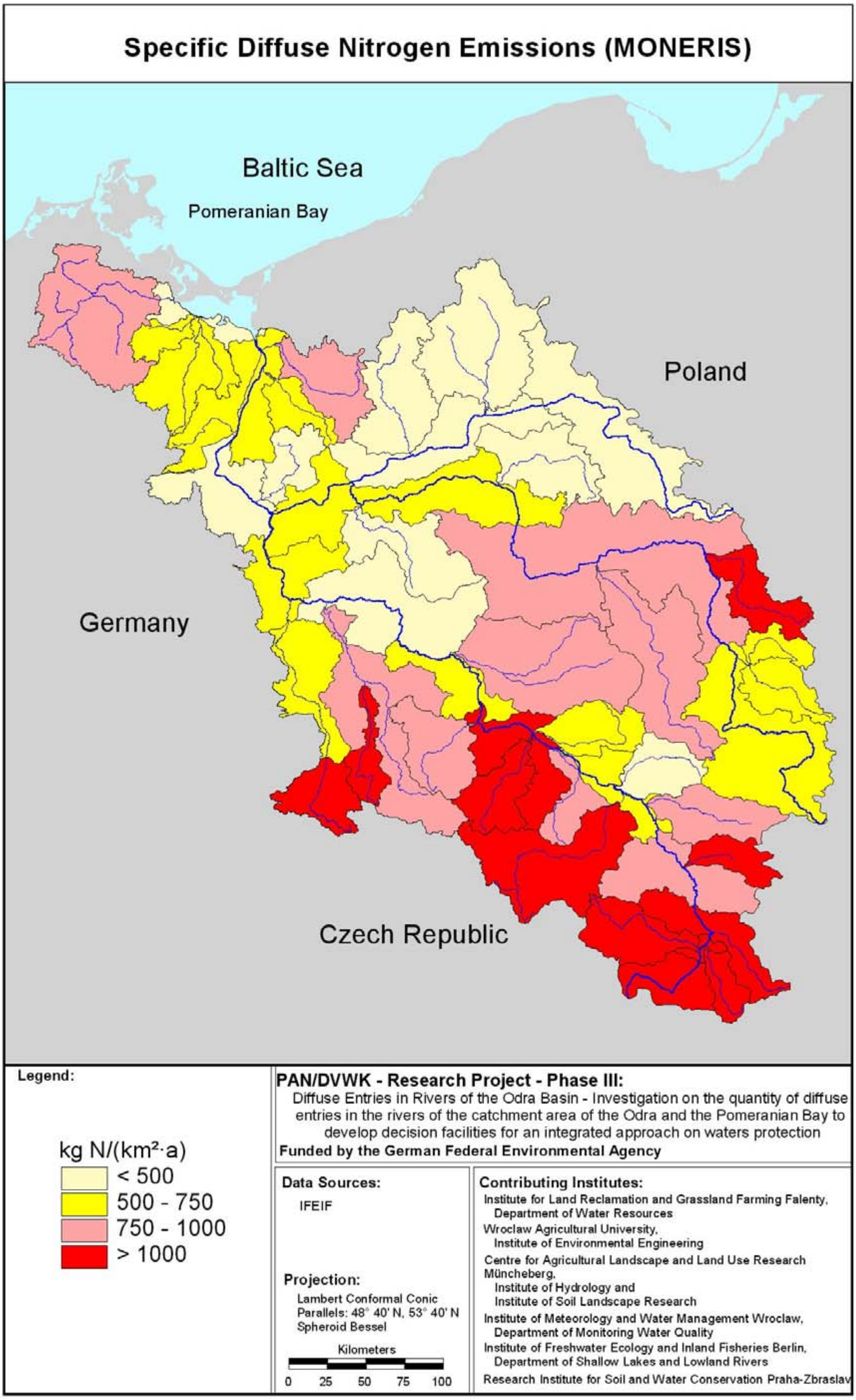
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty, Department of Water Resources
Wroclaw Agricultural University, Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg, Institute of Hydrology and Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw, Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.33: Specific diffuse phosphorus emissions in the period 1993-1997.



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Institute of Freshwater Ecology and Inland Fisheries Berlin, Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.34: Specific diffuse nitrogen emissions in the period 1993-1997.

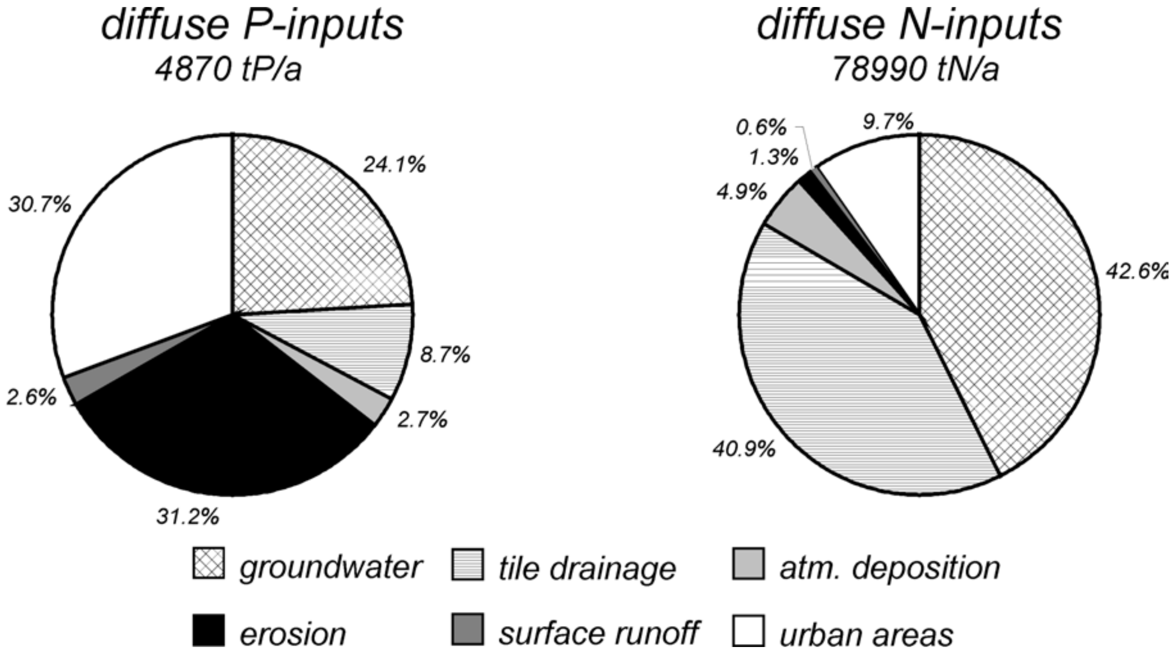


Figure 5.19: Portion of the different pathways to the total diffuse P- and N-inputs into the river systems of the Odra .

Also these results lay below the estimations within this study. In contrast to this KORNMILCH (1997) has found that the diffuse P-inputs into the Odra basins were 6540 tP/a.

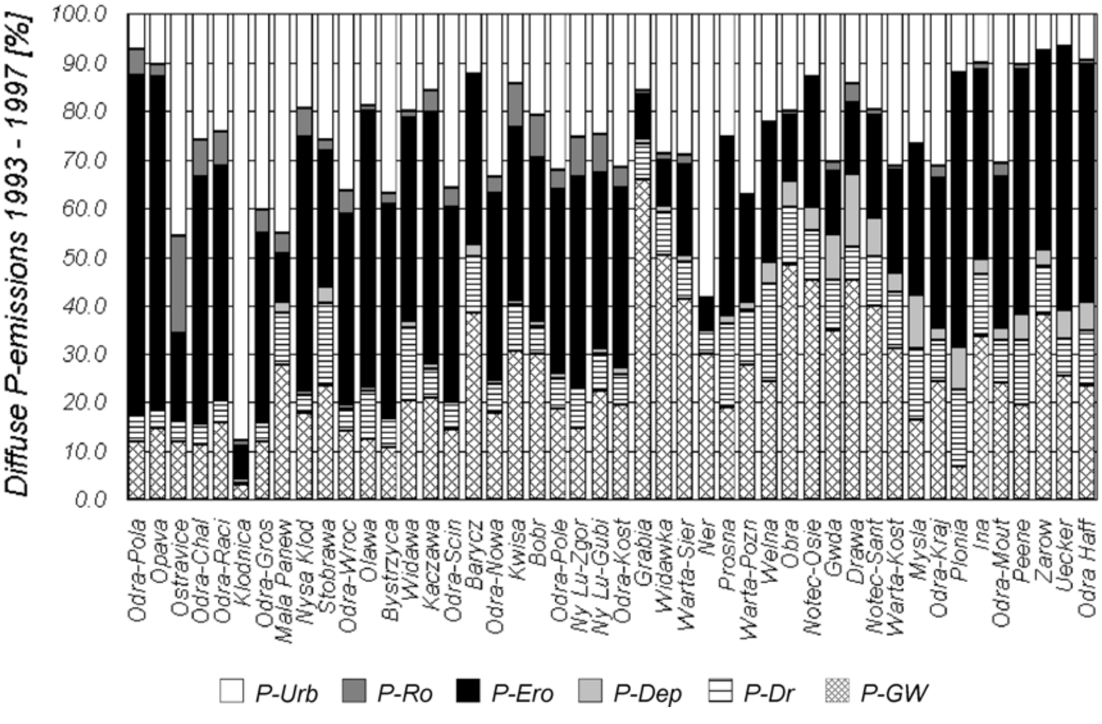


Figure 5.20: Portion of the different pathways to the total diffuse P-inputs into the river systems of the Odra and its main tributaries.

The total N-emissions by diffuse sources were about 79000 tN/a (Figure 5.18). Also for nitrogen the contribution of diffuse emissions from the Czech part of Odra are about the double in comparison to the contribution to the total catchment area. The highest specific nitrogen emissions from diffuse sources occur in the sub catchments of the consolidated rock region and in the area of Ner.

In contrast to phosphorus the diffuse nitrogen inputs are dominated by two pathways only. The portion of groundwater to the total diffuse N-emissions is estimated to 42.6 % and only 2% higher than the portion of N-inputs by tile drainage. The other pathways contribute to the total diffuse N-emissions with a percentage of minor than 10%. As presented in Figure 5.21 a higher portion of the N-inputs by urban areas was only found in the catchments of Ostravice, Klodnica and Ner. Within the consolidated rock region the nitrogen inputs by groundwater are clearly higher than the inputs by tile drainage. If only this two pathways are taken into account the portion of groundwater is there about 72%. Tile drainage causes only 28% of the diffuse subsurface N-inputs. In the unconsolidated rock region the relation is completely different. Tile drainage causes about 64% and groundwater about 36% of the total subsurface inputs.

If the results of the MODEST model are taken into account as the N-inputs by all subsurface pathways (MODEST model includes only groundwater and does not consider tile drainage) within the calculated areas of the unconsolidated rock region a total amount of 23020 tN/a was estimated (see Table 5.21). In contrast, the groundwater N-inputs calculated with the MONERIS model were 17500 tN/a for the unconsolidated rock region, if tile drainage was

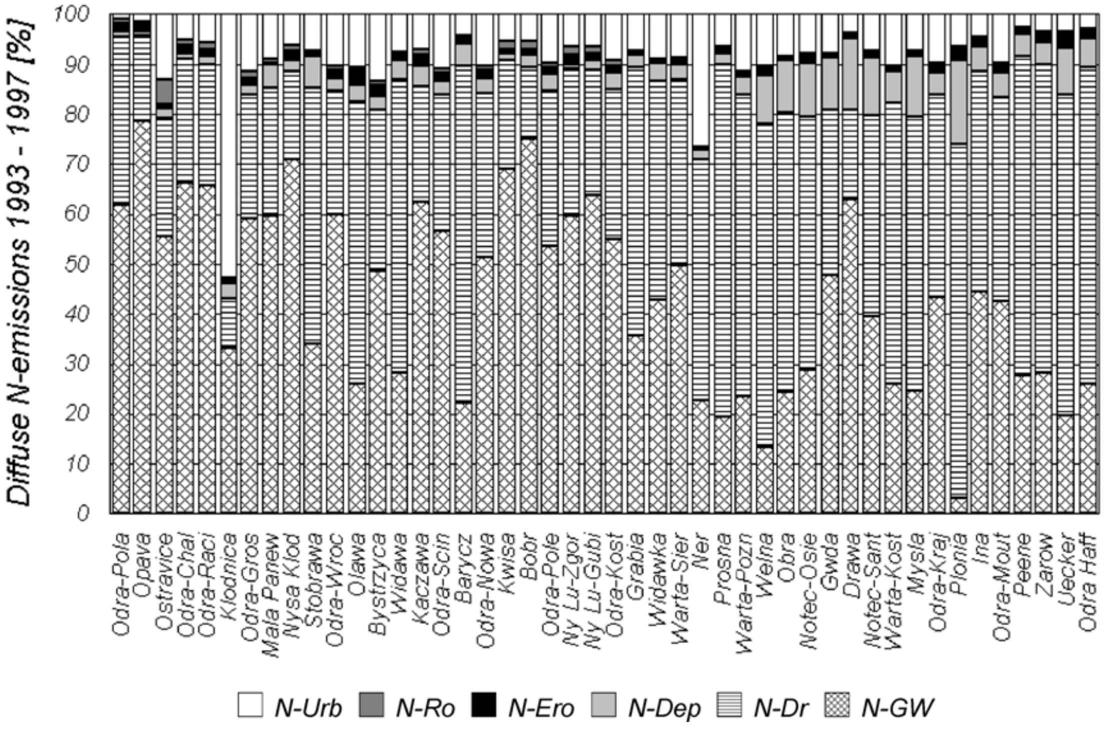


Figure 5.21: Portion of the different pathways to the total diffuse N-inputs into the river systems of the Odra and its main tributaries.

Table 5.31: Diffuse phosphorus and nitrogen inputs into the Odra and other large river basins in Central Europe.

	area	Diffus P-input	Specific diffuse P-input	Diffus N-input	Specific diffuse N-input	Reference
	[km²]	[tP/a]	[kgP/(ha·a)]	[tN/a]	[kgN/(ha·a)]	
Odra 93/97	118860	4870	0.41	78980	6.65	this study
Vistula 92/94	194480	4500	0.23	114000	5.87	Tonderski (1997)
Odra 92/94	110070	2400	0.22	55000	5.04	Tonderski (1997)
Rhine 83/87	159700	12070	0.76	285090	17.85	Behrendt et al. (2000)
Rhine 93/97	159700	10200	0.64	250890	15.71	Behrendt et al. (2000)
Elbe 83/87	134850	9260	0.69	198300	14.70	Behrendt et al. (2000)
Elbe 93/97	134850	6580	0.49	168550	12.50	Behrendt et al. (2000)
Danube 83/87	77100	5310	0.69	135300	17.54	Behrendt et al. (2000)
Danube 93/97	77100	4760	0.62	123200	15.98	Behrendt et al. (2000)
Seine 1991	73800			71000	9.66	Billen/Garnier (1999)
Seine 1994	73800			108000	14.69	Billen/Garnier (1999)

assumed as zero. The deviation for both estimations is 25 %, which can be assumed as the mean error of the calculated results of the groundwater pathway. But if the N-inputs by tile drainage (24700 tN/a) are additionally taken into account the sum of the N-inputs by both pathways were 38700 tN/a, which is much higher as the result of the MODEST model. From this one can conclude that a high portion of the estimated subsurface N-inputs estimated by MODEST is caused in the reality by tile drained areas.

If the results of this study are compared with that of other authors it can be concluded for nitrogen that estimated diffuse N-inputs are within the range of earlier studies. The diffuse N-inputs estimated by TONDERSKI (1997) were 55000 tN/a. KORNMILCH (1998) found that the diffuse N-inputs was for the period 1992-1994 about 130000 tN/a. Based on the immission and emission method a diffuse N-input into the Odra upstream Krajnik Dolny was calculated to 96200 tN/a and 67900 tN/a, respectively (BEHRENDT et al. (1999).

If the diffuse P- and N-inputs are compared with the results of other river systems in Central Europe (see Table 5.31), it can be concluded that beside a lot of methodological problems the diffuse P-emissions into the Odra basin are in the same order of magnitude or lower than in the other river basins. In contrast to this the nitrogen emissions are only a half of the that given by other studies.

This phenomenon is mainly caused by the fact that the Odra basin is characterized by a high portion of unconsolidated rock region to the total size of the basin which is 86.2%. In contrast to this the portion of unconsolidated rock region to the total size of the catchment is 24% in the Rhine and 41% in the Elbe.

5.3 Total Nutrient Emissions

An overview on the total nutrient emissions (point and diffuse sources) into the river system of Odra and Warta is given in the Tables 5.32 and 5.33. Figure 5.22 shows the summarized picture for the Odra and the contribution of the three countries to these total emissions.

For phosphorus a total emission by point and non-point sources of 12800 tP/a was estimated for the time period 1993-1997. The origin of 89 % of this total p-emissions is located in Poland. 8% of the total P-emissions are caused by sources within the Czech part of Odra and the rest of 3% is emitted by point and diffuse sources within the German part of Odra basin.

Tonderski (1997) found that 16800 tP/a are emitted into the Odra river system upstream of Krajnik Dolny for the period 1992-1994. According to BEHRENDT et al.(1999) the total P-emissions were about 14000 tP/a in same period, which is only 10% higher than the results of this study for the period 1993-1997.

As shown in Map 5.35 the highest P-inputs occur in the sub catchments of the upper part of Odra and Warta. The catchments located in the lowlands have in general P-emissions lower than 2.0 kgP/(km²·a).

The Figures 5.23 to 5.24 presents the portion of the different pathways to the total P-emissions. For the whole Odra catchment a portion of point sources of 64% was found. This is lower than the portion of point sources of 72 to 76 % published by BEHRENDT et al. (1999). The result of TONDERSKI (1997) that 86% of the P-emissions are caused by point sources seems to be about 10% to high, if it is compared to the result of this study and BEHRENDT et al. (1999). As shown in Figure 5.24 the highest portion of point sources occurs in the Klodnica and the Ner with 75% to about 80%. In contrast point source emissions are lower than 20% in the Drava and and the German rivers flowing directly into the Oder Haff.

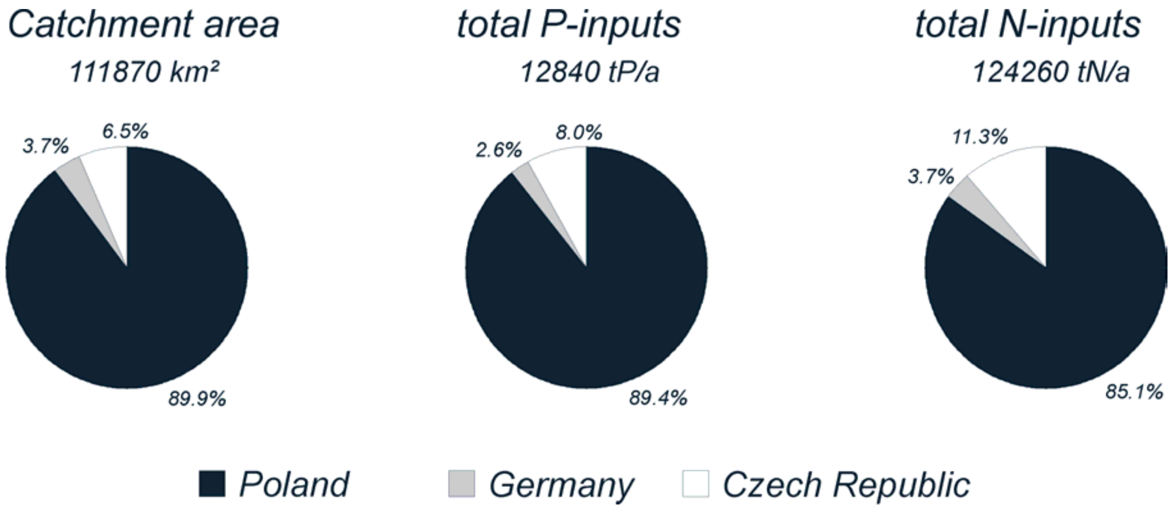


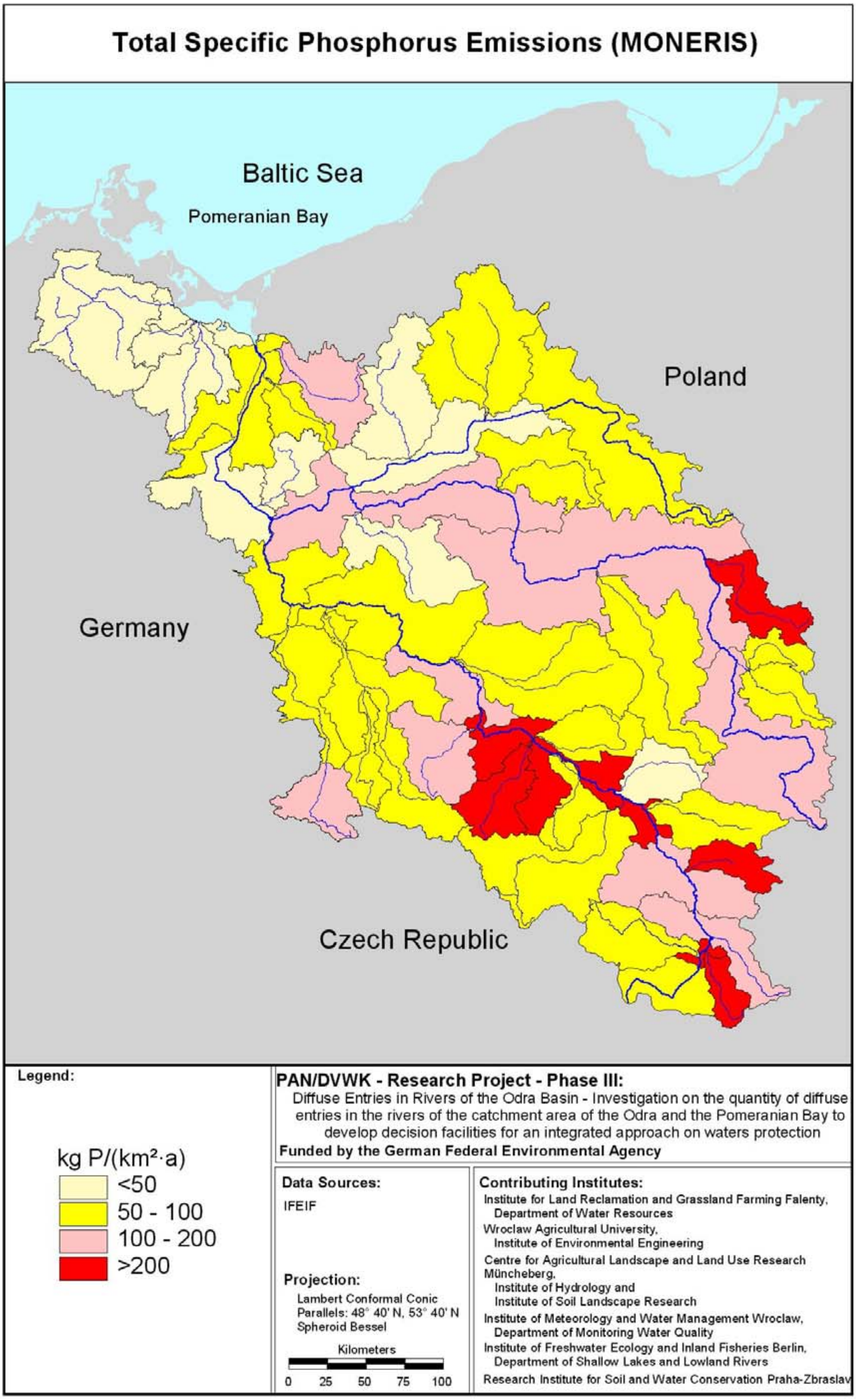
Figure 5.22: Portion of the countries to the total catchment area and the phosphorus and nitrogen discharges by point and diffuse pathways.

Table 5.32: Total phosphorus emissions (ET_P) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ET_P	ET_P-PL	ET_P-GE	ET_P-CZ	ET_P-PL	ET_P-GE	ET_P-CZ
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	152.3	0.0	0.0	152.3	0.0	0.0	100.0
Opava	2,091	170.0	6.5	0.0	163.4	3.8	0.0	96.2
Ostravice	824	196.3	0.0	0.0	196.3	0.0	0.0	100.0
Odra-Chal	4,666	714.3	6.6	0.0	707.6	0.9	0.0	99.1
Odra-Raci	6,684	998.5	163.0	0.0	835.6	16.3	0.0	83.7
Klodnica	1,085	724.6	724.6	0.0	0.0	100.0	0.0	0.0
Odra-Gros	10,989	2,206.4	1,359.2	0.0	847.2	61.6	0.0	38.4
Mala Panew	2,123	151.4	151.4	0.0	0.0	100.0	0.0	0.0
Nysa Klod	4,515	357.0	308.6	0.0	48.4	86.4	0.0	13.6
Stobrawa	1,601	42.1	42.1	0.0	0.0	100.0	0.0	0.0
Odra-Wroc	20,397	3,038.9	2,143.3	0.0	895.6	70.5	0.0	29.5
Olawa	1,167	75.1	75.1	0.0	0.0	100.0	0.0	0.0
Bystrzyca	1,760	444.6	444.6	0.0	0.0	100.0	0.0	0.0
Widawa	1,716	103.3	103.3	0.0	0.0	100.0	0.0	0.0
Kaczawa	2,261	252.4	252.4	0.0	0.0	100.0	0.0	0.0
Odra-Scin	29,584	4,910.2	4,014.6	0.0	895.6	81.8	0.0	18.2
Barycz	5,535	377.8	377.8	0.0	0.0	100.0	0.0	0.0
Odra-Nowa	36,780	5,590.5	4,694.9	0.0	895.6	84.0	0.0	16.0
Kwisa	1,026	69.6	68.4	0.0	1.2	98.3	0.0	1.7
Bobr	5,869	479.5	477.8	0.0	1.7	99.7	0.0	0.3
Odra-Pole	47,152	6,304.5	5,407.3	0.0	897.2	85.8	0.0	14.2
Ny Lu-Zgor	1,609	230.2	55.4	43.6	131.3	24.0	18.9	57.0
Ny Lu-Gubi	3,974	337.2	109.9	96.0	131.3	32.6	28.5	38.9
Odra-Kost	53,532	6,792.2	5,551.5	212.2	1,028.5	81.7	3.1	15.1
Grabia	813	64.2	64.2	0.0	0.0	100.0	0.0	0.0
Widawka	2,355	153.2	153.1	0.0	0.0	100.0	0.0	0.0
Warta-Sier	8,140	671.8	671.8	0.0	0.0	100.0	0.0	0.0
Ner	1,867	1,031.2	1,031.2	0.0	0.0	100.0	0.0	0.0
Prosna	4,825	328.0	328.0	0.0	0.0	100.0	0.0	0.0
Warta-Pozn	25,911	3,270.7	3,270.7	0.0	0.0	100.0	0.0	0.0
Welna	2,621	158.4	158.4	0.0	0.0	100.0	0.0	0.0
Obra	2,758	92.9	92.9	0.0	0.0	100.0	0.0	0.0
Notec-Osie	5,508	353.8	353.8	0.0	0.0	100.0	0.0	0.0
Gwda	4,943	238.9	238.9	0.0	0.0	100.0	0.0	0.0
Drawa	3,296	73.0	73.0	0.0	0.0	100.0	0.0	0.0
Notec-Sant	17,330	758.9	758.9	0.0	0.0	100.0	0.0	0.0
Warta-Kost	54,518	5,227.8	5,227.8	0.0	0.0	100.0	0.0	0.0
Mysla	1,334	50.0	50.0	0.0	0.0	100.0	0.0	0.0
Odra-Kraj	110,074	12,170.7	10,855.7	286.6	1,028.5	89.2	2.4	8.5
Plonia	1,101	79.4	79.4	0.0	0.0	100.0	0.0	0.0
Ina	2,163	329.3	329.3	0.0	0.0	100.0	0.0	0.0
Odra-Mout	118,861	12,842.1	11,483.2	330.3	1,028.5	89.4	2.6	8.0
Peene	5,110	173.1	0.0	173.1	0.0	0.0	100.0	0.0
Zarow	748	25.9	0.0	25.9	0.0	0.0	100.0	0.0
Uecker	2,401	102.6	0.5	102.1	0.0	0.5	99.5	0.0
Odra Haff	8,885	311.5	3.2	308.3	0.0	1.0	99.0	0.0

Table 5.33: Total nitrogen emissions (ET_N) in the period 1993-1997 for the whole catchment and for the countries.

Short name	Area	ET_N	ET_N-PL	ET_N-GE	ET_N-CZ	ET_N-PL	ET_N-GE	ET_N-CZ
	[km^2]	[t N/a]				[%]		
Odra-Pola	1,570	3,138	0	0	3,138	0.0	0.0	100.0
Opava	2,091	3,405	214	0	3,191	6.3	0.0	93.7
Ostravice	824	1,739	0	0	1,739	0.0	0.0	100.0
Odra-Chal	4,666	9,528	217	0	9,311	2.3	0.0	97.7
Odra-Raci	6,684	13,690	2,643	0	11,047	19.3	0.0	80.7
Klodnica	1,085	3,945	3,945	0	0	100.0	0.0	0.0
Odra-Gros	10,989	21,344	10,002	0	11,342	46.9	0.0	53.1
Mala Panew	2,123	1,878	1,878	0	0	100.0	0.0	0.0
Nysa Klod	4,515	5,476	4,466	0	1,010	81.6	0.0	18.4
Stobrawa	1,601	707	707	0	0	100.0	0.0	0.0
Odra-Wroc	20,397	31,297	18,945	0	12,352	60.5	0.0	39.5
Olawa	1,167	728	728	0	0	100.0	0.0	0.0
Bystrzyca	1,760	2,931	2,931	0	0	100.0	0.0	0.0
Widawa	1,716	1,146	1,146	0	0	100.0	0.0	0.0
Kaczawa	2,261	2,025	2,025	0	0	100.0	0.0	0.0
Odra-Scin	29,584	44,843	32,492	0	12,352	72.5	0.0	27.5
Barycz	5,535	5,119	5,119	0	0	100.0	0.0	0.0
Odra-Nowa	36,780	51,494	39,142	0	12,352	76.0	0.0	24.0
Kwisa	1,026	1,303	1,249	0	54	95.8	0.0	4.2
Bobr	5,869	6,345	6,279	0	66	99.0	0.0	1.0
Odra-Pole	47,152	60,328	47,910	0	12,418	79.4	0.0	20.6
Ny Lu-Zgor	1,609	3,085	640	841	1,604	20.7	27.3	52.0
Ny Lu-Gubi	3,974	4,917	1,762	1,551	1,604	35.8	31.5	32.6
Odra-Kost	53,532	67,382	50,432	2,929	14,022	74.8	4.3	20.8
Grabia	813	641	641	0	0	100.0	0.0	0.0
Widawka	2,355	1,953	1,953	0	0	100.0	0.0	0.0
Warta-Sier	8,140	7,805	7,805	0	0	100.0	0.0	0.0
Ner	1,867	5,850	5,850	0	0	100.0	0.0	0.0
Prosna	4,825	4,975	4,975	0	0	100.0	0.0	0.0
Warta-Pozn	25,911	30,072	30,072	0	0	100.0	0.0	0.0
Welna	2,621	1,350	1,350	0	0	100.0	0.0	0.0
Obra	2,758	1,103	1,103	0	0	100.0	0.0	0.0
Notec-Osie	5,508	2,916	2,916	0	0	100.0	0.0	0.0
Gwda	4,943	2,888	2,888	0	0	100.0	0.0	0.0
Drawa	3,296	1,384	1,384	0	0	100.0	0.0	0.0
Notec-Sant	17,330	8,243	8,243	0	0	100.0	0.0	0.0
Warta-Kost	54,518	49,425	49,425	0	0	100.0	0.0	0.0
Mysla	1,334	583	583	0	0	100.0	0.0	0.0
Odra-Kraj	110,074	118,698	100,744	3,932	14,022	84.9	3.3	11.8
Plonia	1,101	680	680	0	0	100.0	0.0	0.0
Ina	2,163	2,436	2,436	0	0	100.0	0.0	0.0
Odra-Mout	118,861	124,258	105,693	4,543	14,022	85.1	3.7	11.3
Peene	5,110	5,185	0	5,185	0	0.0	100.0	0.0
Zarow	748	451	0	451	0	0.0	100.0	0.0
Uecker	2,401	1,678	9	1,669	0	0.6	99.4	0.0
Odra Haff	8,885	7,620	85	7,535	0	1.1	98.9	0.0



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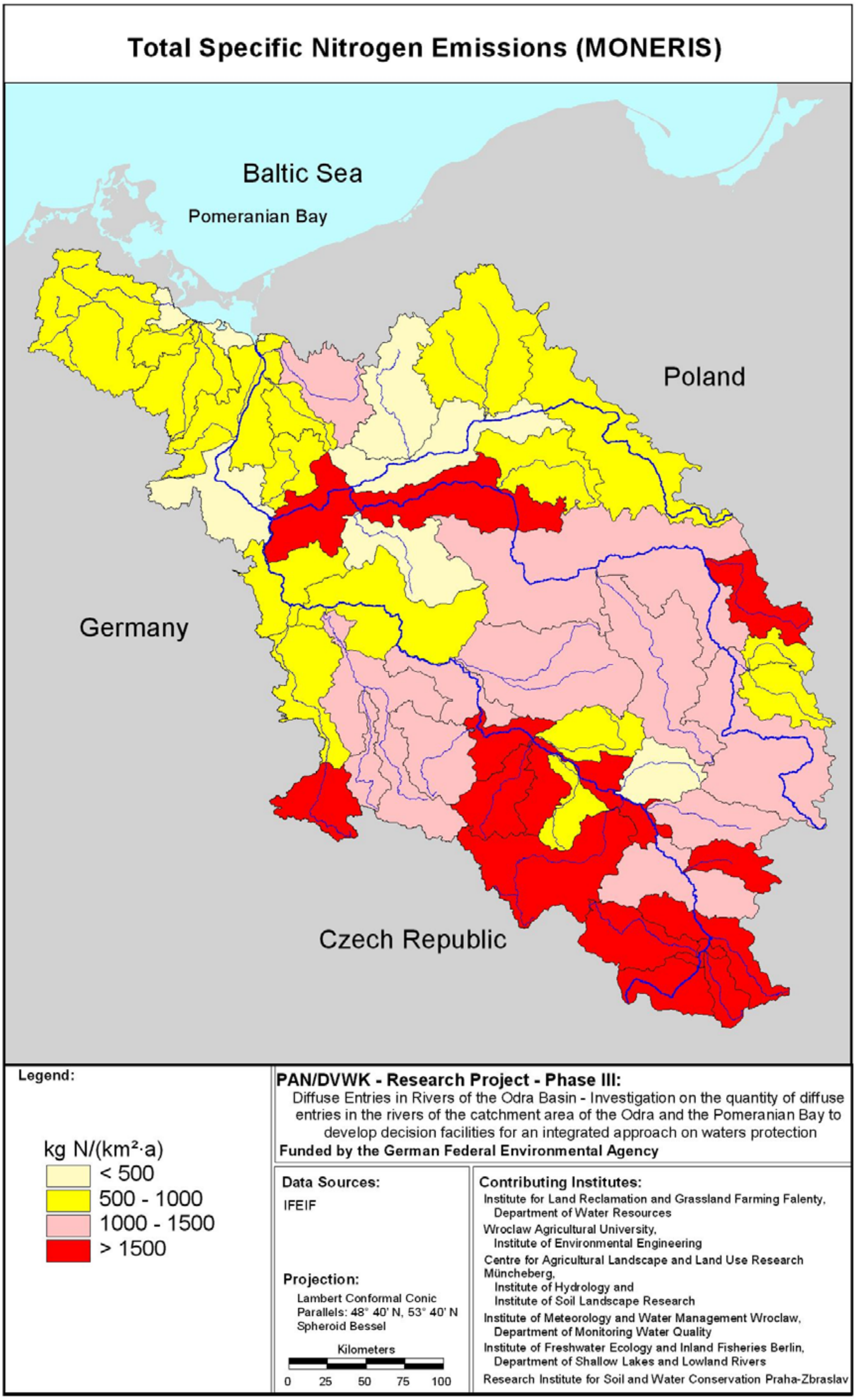
Diffuse Entries in Rivers of the Odra Basin - Investigation on the quantity of diffuse entries in the rivers of the catchment area of the Odra and the Pomeranian Bay to develop decision facilities for an integrated approach on waters protection
Funded by the German Federal Environmental Agency

Data Sources:
IFEIF

Projection:
Lambert Conformal Conic
Parallels: 48° 40' N, 53° 40' N
Spheroid Bessel

Contributing Institutes:
Institute for Land Reclamation and Grassland Farming Falenty,
Department of Water Resources
Wroclaw Agricultural University,
Institute of Environmental Engineering
Centre for Agricultural Landscape and Land Use Research Müncheberg,
Institute of Hydrology and
Institute of Soil Landscape Research
Institute of Meteorology and Water Management Wroclaw,
Department of Monitoring Water Quality
Institute of Freshwater Ecology and Inland Fisheries Berlin,
Department of Shallow Lakes and Lowland Rivers
Research Institute for Soil and Water Conservation Praha-Zbraslav

Map 5.35: Total specific phosphorus emissions in the period 1993-1997.



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Map 5.36: Total specific nitrogen emissions in the period 1993-1997.

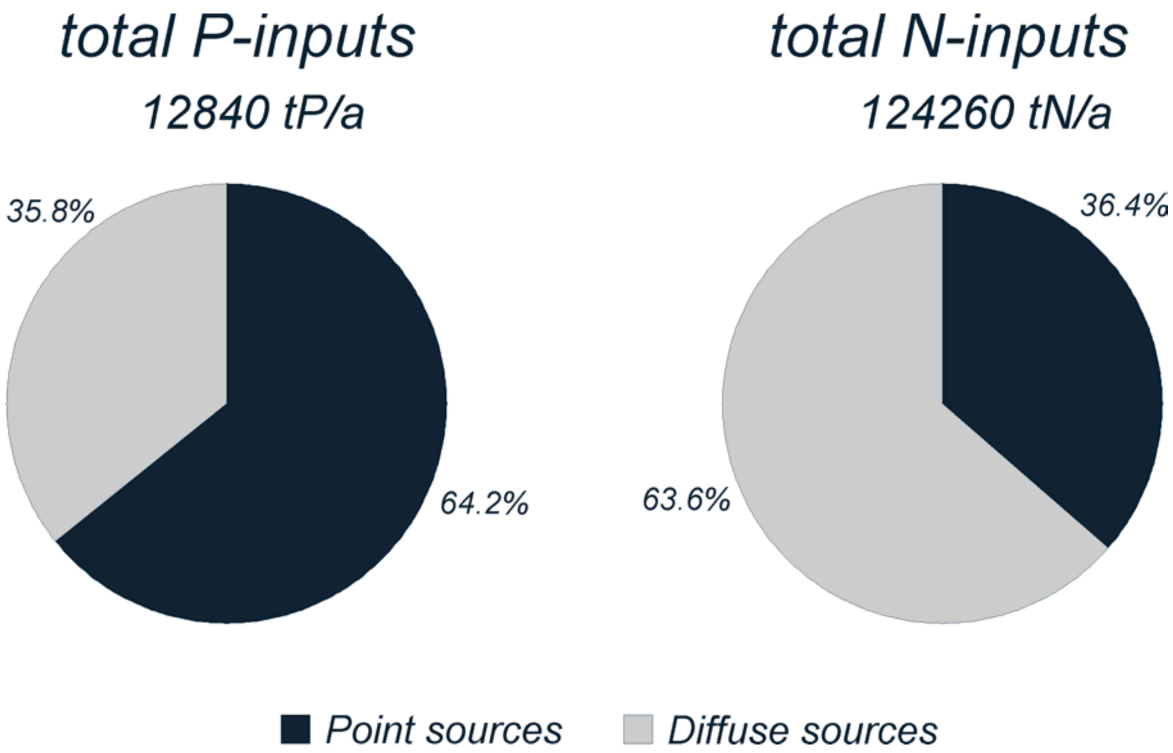

Figure 5.23: Portion of the diffuse and point sources to the total nutrient emissions into the river systems of the Odra in the period 1993 to 1997.

Compared to other river basins in Central Europe the portion of point sources to the total P-emissions into the Odra is high for the recent period and in comparison with the situation in German rivers in the period 1983-1987 (see Table 5.34).

The analysis of P-emissions into the river system of the Odra shows clearly that a further demand exists to reduce especially the P-inputs from point sources.

For nitrogen we found that the total emission into the Odra river system by point and diffuse sources amounts about 124300 tN/a in the period 1993-1997. The results estimated by TONDERSKI (1997) (Odra at Krajnik Dolny 115700 tN/a for the Period 1992-1994) and BEHRENDT (1999) (Odra at Krajnik Dolny 122400 to 144000 tN/a for the period 1992-1994) are very similar to the result of this study.

Within the Czech part 11% of the total N-inputs are emitted which is about the double of the portion the Czech area to the whole basin of Odra (see Figure 5.22). The contribution of the German part is about the same than the portion to the whole area. 85% of the total Nitrogen emissions are caused by point and diffuse sources within the Polish part of Odra.

The portion of point sources to the total N-emissions is for the Odra only 36%. About 64% of the N-inputs are caused by diffuse sources, where the inputs from groundwater and tile drainage is about 85% of this rest. BEHRENDT et al. (1999) estimated a portion of point sources to the total N-emissions of Odra upstream Krajnik Dolny between 32 and 34%. In comparison to this the portion of point sources calculated by TONDERSKI (1997) is 52% and probably to high.

The highest portion of point sources to the total N-emissions was indicated for the catchments of Klodnica and Ner, where about 70% of the total emissions are originated by this pathway. In contrast to this some river systems in the Czech part of Odra, in the Warta and German rivers flowing directly into the Odra Haff are characterized by a point source input of about or less than 10%.

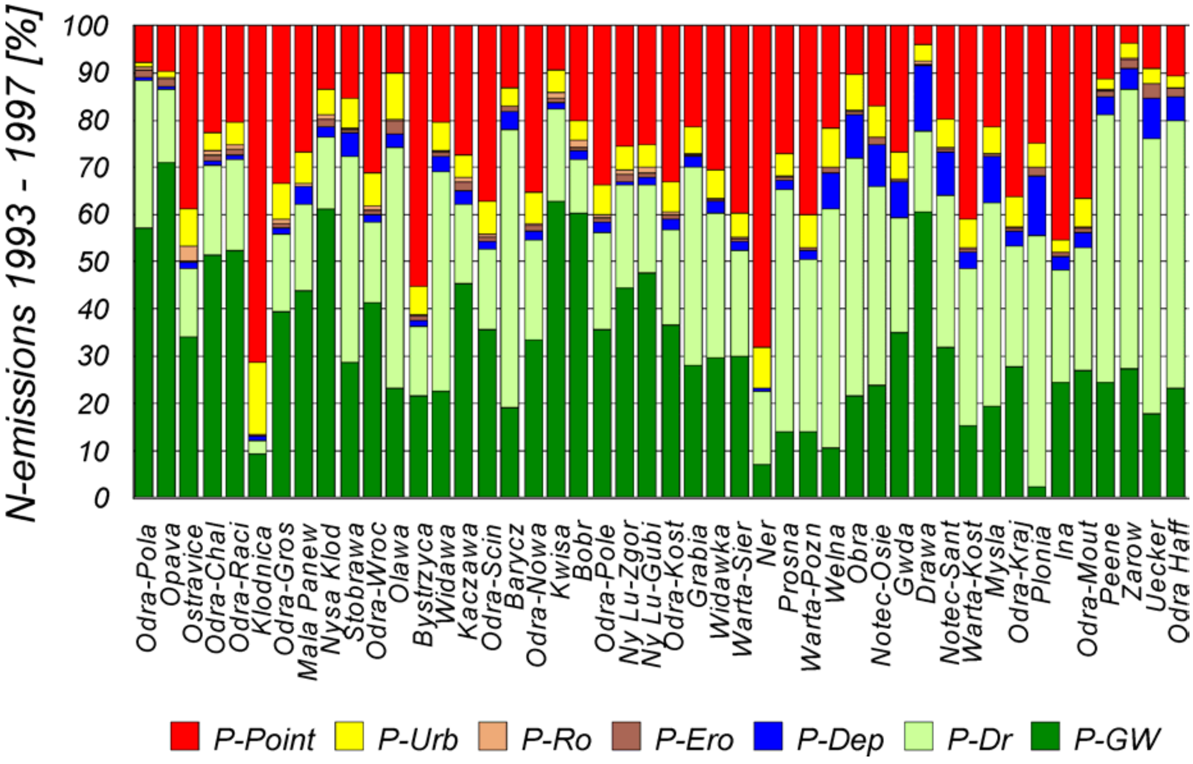

Figure 5.24: Proportions of different pathways to the total phosphorus emissions in the Odra catchment in the period 1993-1997.

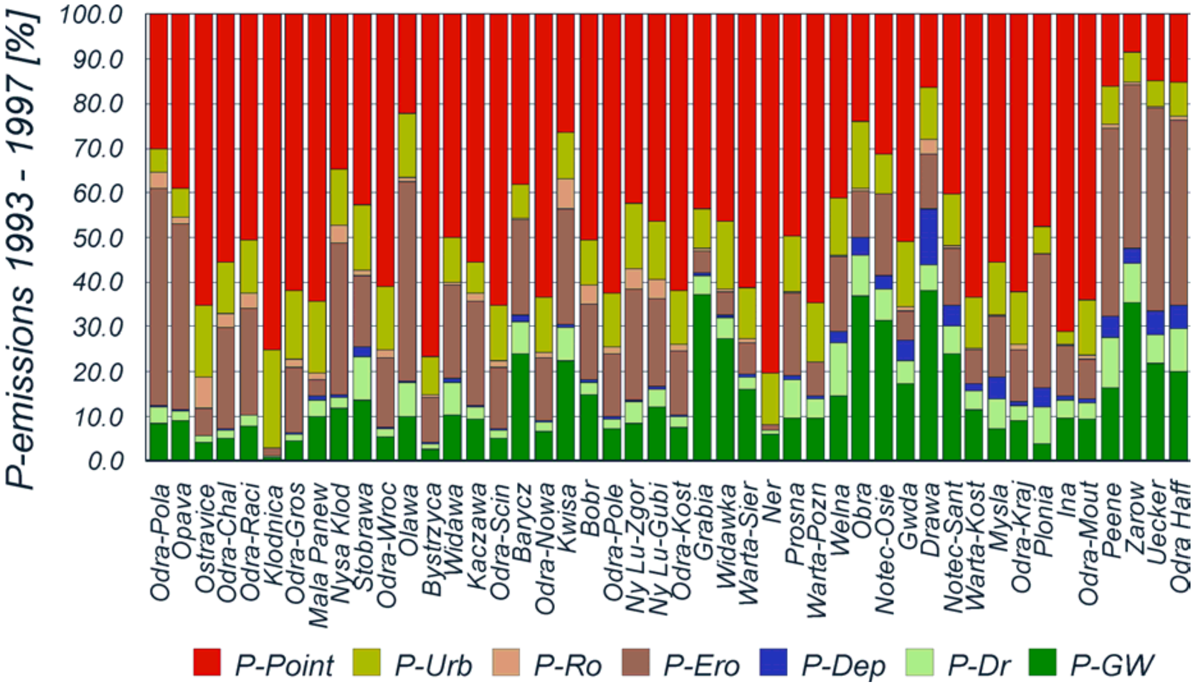

Figure 5.25: Proportions of different pathways to the total nitrogen emissions in the Odra

Table 5.34: Diffuse phosphorus and nitrogen inputs into the Odra and other large river basins in Central Europe.

	area	Total P-input	Portion of point sources to P-input	Diffus N-input	Portion of point sources to N-input	Reference
	[km²]	[tP/a]	[%]	[tN/a]	[%]	
Odra 93/97	118860	12840	64	124260	36	this study
Vistula 92/94	194480	22860	79	204000	44	Tonderski (1997)
Odra 92/94	110070	16800	86	115700	52	Tonderski (1997)
Rhine 83/87	159700	50550	76	567800	50	Behrendt et al. (2000)
Rhine 93/97	159700	20160	49	398800	37	Behrendt et al. (2000)
Elbe 83/87	134850	24660	63	315600	37	Behrendt et al. (2000)
Elbe 93/97	134850	11470	43	231200	27	Behrendt et al. (2000)
Danube 83/87	77100	13220	60	179400	25	Behrendt et al. (2000)
Danube 93/97	77100	6740	29	153100	20	Behrendt et al. (2000)
Seine 1991	73800			127000	44	Billen/Garnier (1999)
Seine 1994	73800			164000	34	Billen/Garnier (1999)

As mentioned above the portion of point sources to the total nutrient emissions into the Odra is for phosphorus high and corresponds with the situation in other river systems in the period 1983 to 1987 (see Table 5.33). For nitrogen the Table shows that the point source contribution is also for the period 1993 to 1997 comparable with situation in Rhine and Seine. But within these basins the population density is about two to three times higher than in the Odra.

5.4 River Nutrient Loads

An overview on the calculated nutrient and heavy metal loads in the period 1993-1997 is given in Table 5.35. The specific loads at each monitoring station are compared in the Figures 5.26 and 5.27.

Fgure 5.26 presents the mean specific load of total phosphorus (TP) derived from the observed data of discharge and concentrations according to the Equation (4.73) in Chapter 4.3. In general the measured specific loads are below 0.5 kgP/(ha·a). But there exists a number of exceptions with higher specific P-load. A part of these can be explained by the fact that large cities are located within these sub catchments (e.g.Ostravice, Klodnica, Nysa Luzycka, Ner, Ina). For other as the Bobr, Bystriza and Nysa Klodska the reason for this high specific P-load can not be derived from the measurements and a simple comparison to land use or population data.

For nitrogen a clear tendency exists that the specific N-load is decreasing from the spring to the mouth of Odra and Warta and the sub catchments located along this line. This behaviour is only broken by the Nysa Luzycka and the Ner.

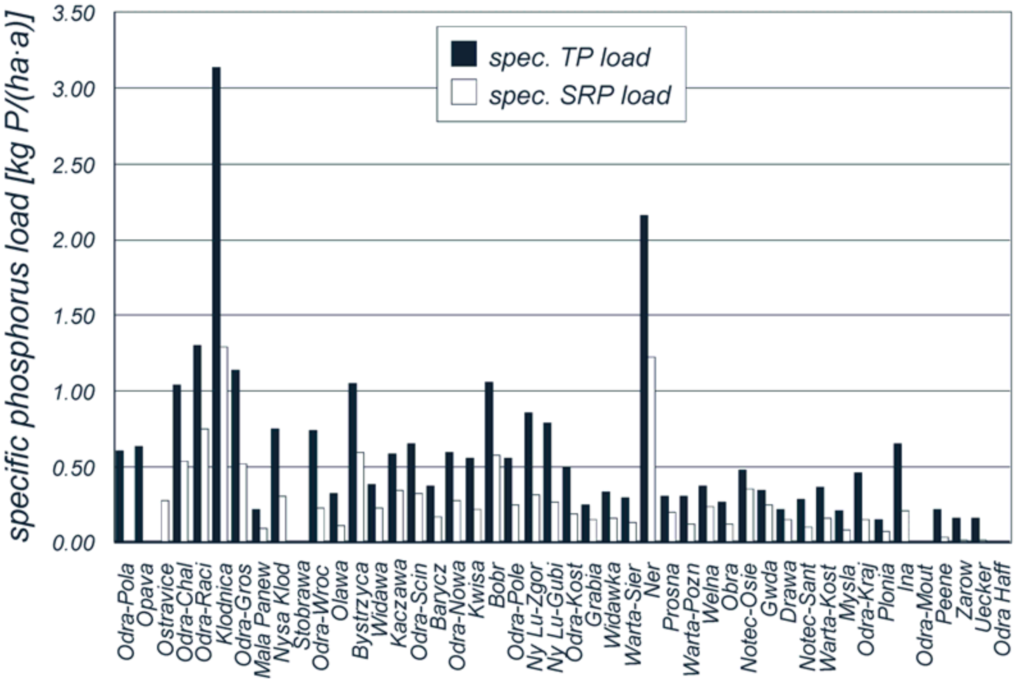

Figure 5.26: Specific phosphorus loads in the Odra sub catchments in the period 1993-1997.

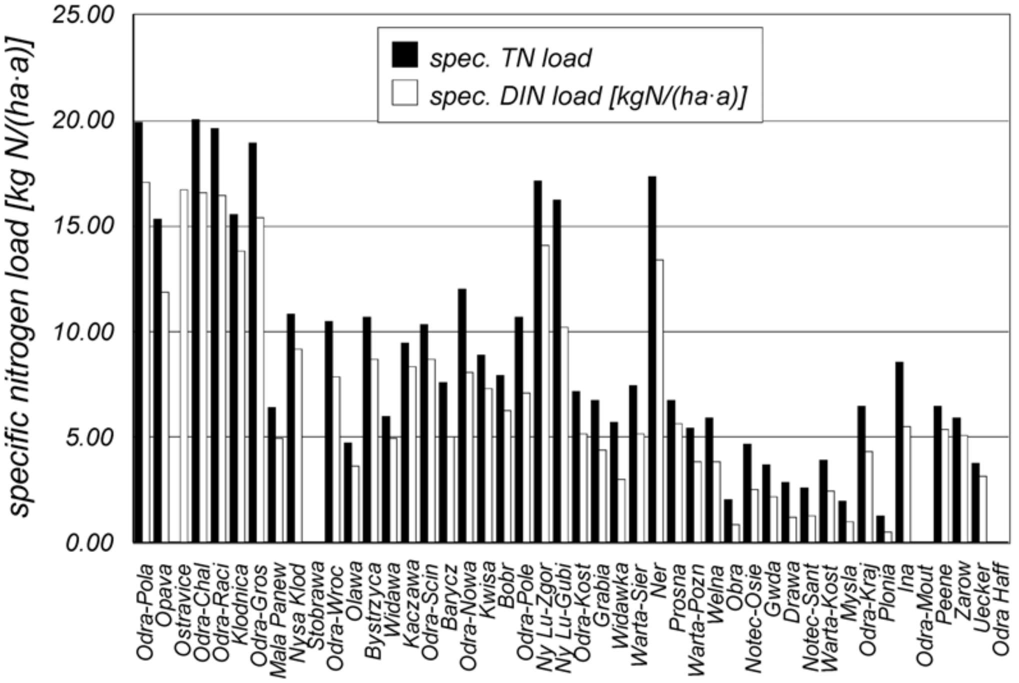

Figure 5.27: Specific nitrogen loads in the Odra sub catchments in the period 1993-1997.

Table 5.35: Mean annual discharge and calculated river loads for ammonium, nitrate, dissolved inorganic nitrogen (DIN), total nitrogen (TN), soluble reactive phosphorus (SRP) and total phosphorus (TP).

River	Station	Discharge	NH^-_4	NO^-_3	DIN	TN	SRP	TP
		[m^3/s]	[tN/a]	[tN/a]	[tN/a]	[tN/a]	[tP/a]	[tP/a]
Odra	Polanka	12.5	290	2,357	2,675	3,130		95
Opawa	Mouth	15.1	327	2,130	2,481	3,212		132
Ostravice	Mouth	10.5	475	864	1,377		23	
Odra	Chalupki	45.4	1,595	5,899	7,728	9,355	249	483
Odra	above Raciborz	69.2	3,394	7,340	11,011	13,146	503	870
Klodnica	mouth	5.6	836	508	1,495	1,688	140	340
Odra	above Groszowic	86.3	5,326	10,585	16,953	20,798	564	1,252
Mala Panew	Czarnowasy	11.4	150	822	1,052	1,358	19	46
Nysa Klodzka	Skorogoszcz	38.1	559	2,792	4,132	4,894	140	337
Odra	Wroclaw	131.1	2,615	13,044	15,974	21,458	455	1,512
Olawa	Malgorzata	3.9	79	335	424	554	13	38
Bystrzyca	mouth	8.5	556	926	1,524	1,882	105	184
Widawa	mouth	5.6	132	710	852	1,026	39	66
Kaczawa	Kwiatkowice	13.4	304	1,522	1,887	2,134	78	133
Odra	above Scinawa	179.4	4,613	21,017	25,738	30,604	957	1,923
Barycz	Wyszanow	20.3	374	2,358	2,780	4,179	92	205
Odra	above Nowa Sol	206.2	5,850	23,479	29,565	44,221	996	2,170
Kwisa	Trzebow	11.4	137	602	750	911	22	57
Bobr	St. Raduszec	53.9	897	2,748	3,695	4,647	336	619
Odra	Polecko	270.0	6,223	27,098	33,551	50,390	1,160	2,601
Nysa Luzycka	above Zgorzelec	17.3	232	2,003	2,269	2,759	50	138
Nysa Luzycka	Gubin	33.3	640	3,383	4,055	6,462	106	315
Odra	Kostrzyn	322.4	2,745	24,510	27,527	38,303	1,016	2,691
Grabia	mouth	4.0	61	426	359	546	12	20
Widawka	Podgorze	11.9	109	645	711	1,341	38	78
Warta	below Sieradz	42.2	491	3,678	4,222	6,045	104	241
Ner	Chelmno	9.8	1,802	676	2,506	3,234	229	404
Prosna	Ruda Komnorow.	15.7	404	2,246	2,738	3,248	94	148
Warta	Poznan	97.4	1,443	8,404	10,038	14,135	316	794
Welna	Kowanowko	7.8	141	855	1,005	1,555	63	98
Obra	mouth	8.8	53	182	241	560	33	72
Notec	Osiek	23.3	464	909	1,402	2,556	194	263
Gwda	mouth	25.6	233	818	1,070	1,844	124	169
Drawa	Lekacz Wlkp.	21.3	85	331	407	942	50	70
Notec	Santok	73.3	287	1,942	2,263	4,511	168	489
Warta	Kostrzyn	199.6	1,585	11,612	13,362	21,489	874	1,989
Mysla	mouth	3.4	22	112	137	260	11	27
Odra	Krajnik Dolny	524.2	4,732	42,022	48,005	71,193	1,640	5,072
Plonia	mouth	1.8	23	31	56	140	8	17
Ina	Goleniow	13.6	110	1,065	1,192	1,843	44	141
Peene	Anklam	20.9	280	2,442	2,759	3,307	17	113
Zarow	Grambin	2.3	43	332	380	445	1	12
Uecker	Ueckermuende	6.9	132	612	759	912	4	39

Regarding the load of nutrients it must be considered that these calculated loads is based on measurements of discharges and concentrations and the measurements of both parameters includes errors. As shown different authors (e.g. Behrendt et al.,2000; zzzzz) these error depends among other on the frequency of monitoring and the size of the catchment. For sub catchments with a size of more than 1000 km² these error is in general low for dissolved transported substances as nitrate, ammonia and soluble reactive phosphorus. But for parameters including particulate material as total nitrogen and phosphorus the deviation can be in a range of 20% and more.

For the Odra a direct comparison is possible for some stations along the Polish German Border where measurements were done independently from both sides. One example shows Figure 5.28, where the discharge and the nutrient load for the Odra stations Krajnik Dolny and Schwedt are shown since 1980. Both stations have approximately the same catchments size (Schwedt: 112950 km²; Krajnik Dolny: 111870 km²). The Figure shows clearly that especially in the last years a difference between the observed loads at Krjnik Dolny and Schwedt exists. As assumed before, this difference is larger for total nitrogen and especially total phosphorus. Table 5.36 gives a summarized overview on the deviation between the discharge and load observed at these stations.

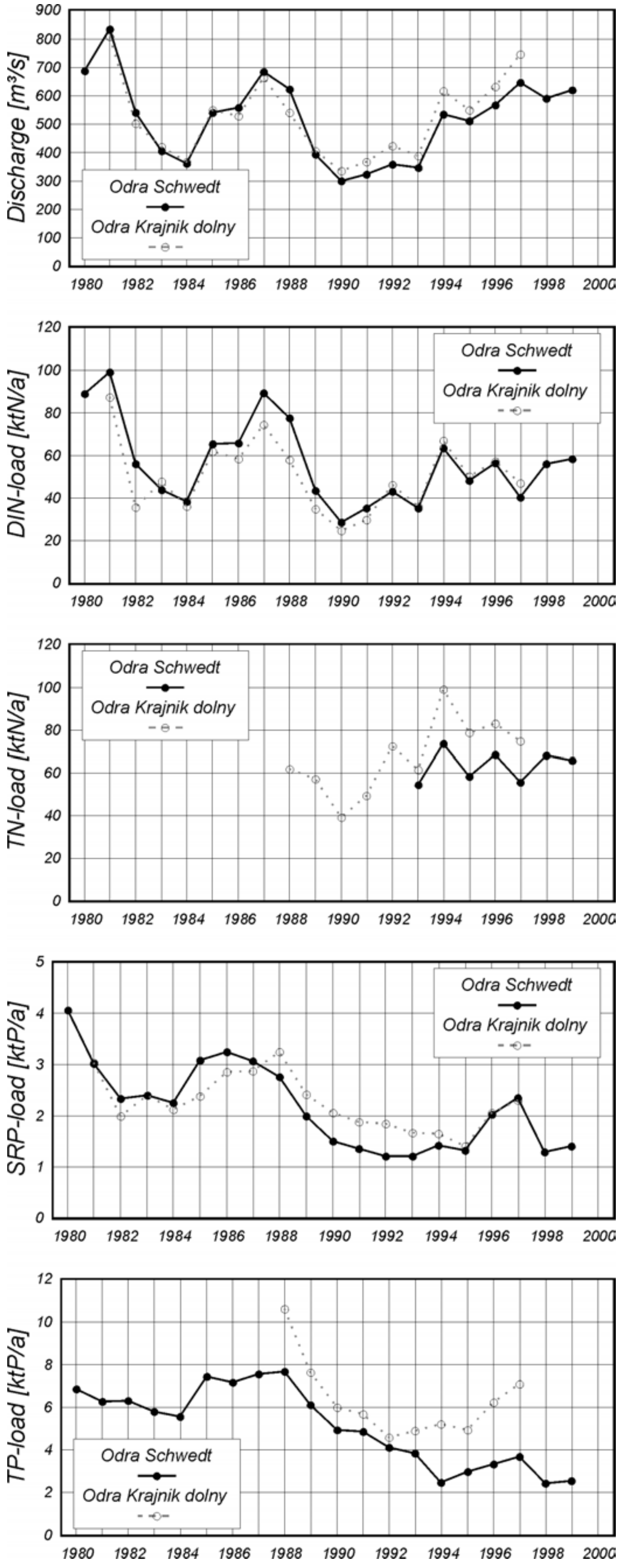

Figure 5.28: Comparison of the measured discharge and nutrient loads for the Odra stations Krajnik Dolny and Schwedt

Table 5.36: Mean deviation between the observed discharge and nutrient loads for the Odra stations Krajnik Dolny and Schwedt for different time periods

	Q	SRP	TP	DIN	TN
	[%]	[%]	[%]	[%]	[%]
83-87	3.1	11.2		10.8	
88-92	11.2	24.3	18.1	20.0	
93-97	10.8	9.8	41.6	5.4	21.3

For discharge this deviation is for the different period between 3 and 11%. For the dissolved parameters SRP and DIN the deviation vary between 10 and 20%. But for the total nitrogen and phosphorus a deviation of more than 20% can be assumed. Especially for these parameters the deviation seems to be systematically, because the load at Krajnik Dolny is larger as at Schwedt. But also for the other stations along the Nysa Luzycka and the lower Odra differences of the same order of magnitude can be estimated.

The reason for the differences of the load can be manifold and can not be discussed here in detail. With regard to the following chapter it is only important that we have to consider that the observed nutrient loads include errors which are probably for dissolved substances and total nutrient loads in a range of 10% and more than 20%, respectively.

Regarding Figure 5.28 an other point is important. A clear tendency exist for the reduction of phosphorus if the 80ties are compared with the 90ties. The reduction is for both station on average about 35 %. For nitrogen a low tendency of load reduction can be observed from Figure 5.28 and the comparison of both time periods results in a decrease of about 14%. In general, the tendency of reduction is for both nutrient loads at Krajnik Dolny lower as at the station Schwedt.

5.5 Comparison of the calculated with the observed nutrient loads

As shown by Alexander et al. (1999), Billen & Garnier (1999) and Behrendt &Opitz (1999) the nutrient emissions into a river system can not be directly compared with the observed load, because retention processes within the system of surface waters have to taken into account. The model MONERIS includes the possibility to calculated this retention for phosphorus and nitrogen based on river parameters as specific runoff and hydraulic load (see Chapter 4.3).

If this retention formulas are applied to the Odra and its sub catchments the phosphorus and nitrogen load can be estimated for the period 1993-1997 and compared with the observed loads given above. The result of this comparison is presented in Figure 5.29 for total phosphorus, dissolved inorganic nitrogen and total nitrogen.

Especially for the both nitrogen components the calculated loads agree well with the results of the measurements. The deviation between the measured and calculated loads exceeds a deviation of 30% for 9 to 10 sub catchments (see Table 5.37).

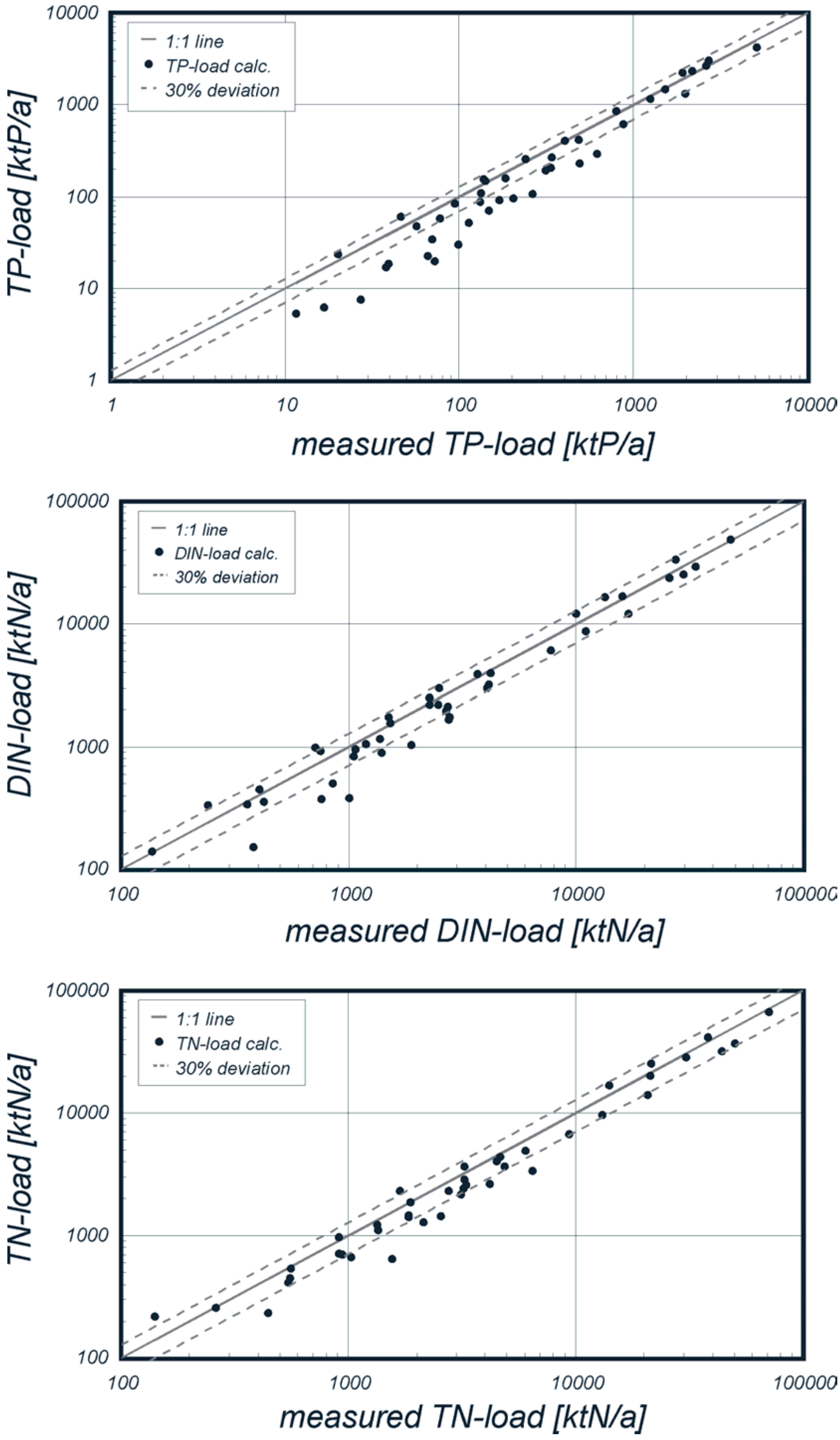

Figure 5.29: Comparison of measured and observed nutrient loads.

The mean deviation is for DIN and TN load below 22%. If the possible error of the observed load is taken into account (see Chapter 5.1.4) the real deviation can be assumed to be less than 20%. For total nitrogen a tendency exists that the calculated TN-loads are lower than the observed loads especially for smaller catchments. The reason for this can be on the one hand an underestimation of the nitrogen emissions or of the transfer process of dissolved nitrogen to particulate material due to phytoplankton growth. On the other hand the frequency of measurements of total nitrogen is lower for smaller catchments and this can causes higher observed loads.

For phosphorus the Figure 5.27 shows that the deviation between calculated and observed loads is higher than for nitrogen. The mean deviation between calculated and observed loads was estimated as 31.5%, which is about 10% higher than for nitrogen. In contrast to nitrogen for 13 catchments the deviation is higher than 50% and for the half of the catchments higher than 30% (see Table 5.37). Additionally a clear tendency exists that the calculated P-loads are below the observed loads.

Because the possible error of the measurements of total phosphorus is higher than for nitrogen (see Table 5.37) this can be one reason for the higher deviation between calculated and observed TP-loads. But this would not explain the systematical underestimation of calculated TP-loads for a sub set of catchments.

A more detailed analysis of the catchments with the high underestimation of the phosphorus load shows that all of these catchments are characterized by high area of surface waters and low specific runoff. Consequently the hydraulic load within these river systems is in the most case lower than 5 m/a. A similar behaviour of river systems with such high area of surface waters (mainly caused by lakes) and low specific runoff was found for the river Havel (see BEHRENDT et al. (2001). The main reason for this underestimation of TP-load based on the Equation (4.81) seems to be that especially in eutroph polymixtic lakes the P-desorption from the sediment during anoxic conditions is an additional source of phosphorus, which is up to now not included within the retention approach.

Based on the results of this study and other analysis it is an important task for the next future to adapt the retention approach for phosphorus that possible effects of P-desorption in shallow lakes can be taken into account.

Table 5.37: Results of the comparison between measured and observed nutrient loads for the Odra river system in the period 1993-1997.

	TP	TN	DIN
Number of rivers with deviation >50%	13	1	2
Number of rivers with deviation >50%	20	9	10
Number of stations with load measurements	41	41	41
Mean deviation [%]	31.5	21.4	21.9

5.6 Comparison with the results of the Immission Method

Beside the comparison of the different models and between calculated and observed loads an additional possibility exists to evaluate the results for the nutrient emissions. That is the comparison between the percentages of point and diffuse sources at the total emissions estimated by the MONERIS approach with these percentages estimated by means of the immission approach as described in Chapter 4.4. This approach is similar to the Polish method to estimate the point source load within a river system. The difference between the results of emission and the immission approach is that the immission method estimates the percentage of the point and diffuse sources at the observed load and therefore the results should be only comparable with these of the emission method, if the retention of the substance within the river system is equally or at least similar for the point and diffuse sources.

The comparison of the results of both methods is shown for the Odra and its main tributaries in the Figures 5.30 and 5.31. The Figures include additionally the lines of a deviation between the both estimations of plus and minus 15 %.

For phosphorus (Figure 5.30) the comparison shows that there is the same tendency regarding the contribution of point sources to the total load or emission of sub catchments but for 18 of the analysed 43 catchments the deviation between the results of the emission and immission method is larger than 15%. That is a further indication that the errors of the model and or load calculation are high for phosphorus. The catchments with very high deviations between the point source percentage at the total emissions or load (Drawa, Bobr, Mala Panew and Nysa Luzycka at Gubin) are identical with catchments of high deviation between the observed and calculated phosphorus loads (see Chapter 5.1.5). But the other are characterized by relative low deviation regarding the comparison between observed and calculated P-loads. This can be an indication that the observed loads for these 4 catchments are probably wrong.

In contrast to phosphorus the estimated point source percentages at the nitrogen emissions or loads are mostly within the range of 15% deviation as shown in Figure 5.31. Only for three catchments a deviation larger than 15% was estimated. For nitrogen, with the immission method, there is a tendency for a portion of point sources at. This is also applies for German rivers (Behrendt et al., 2000). The reason of this may be in particular related to inputs from municipal wastewater treatment plants which includes a fraction of storm water runoff from paved urban areas. That means that these inputs are not always the same but climb with increasing flows. Through this behaviour, especially where there is a high proportion of point source discharges in the loads, the immission method yields a higher estimated proportion of diffuse inputs than the emission method. This behaviour is particularly applicable to areas with a high proportion of combined sewer systems in urban areas. Because the database was not sufficient for the sewer systems a similar correction as for German rivers could not be done for the catchments of the Odra.

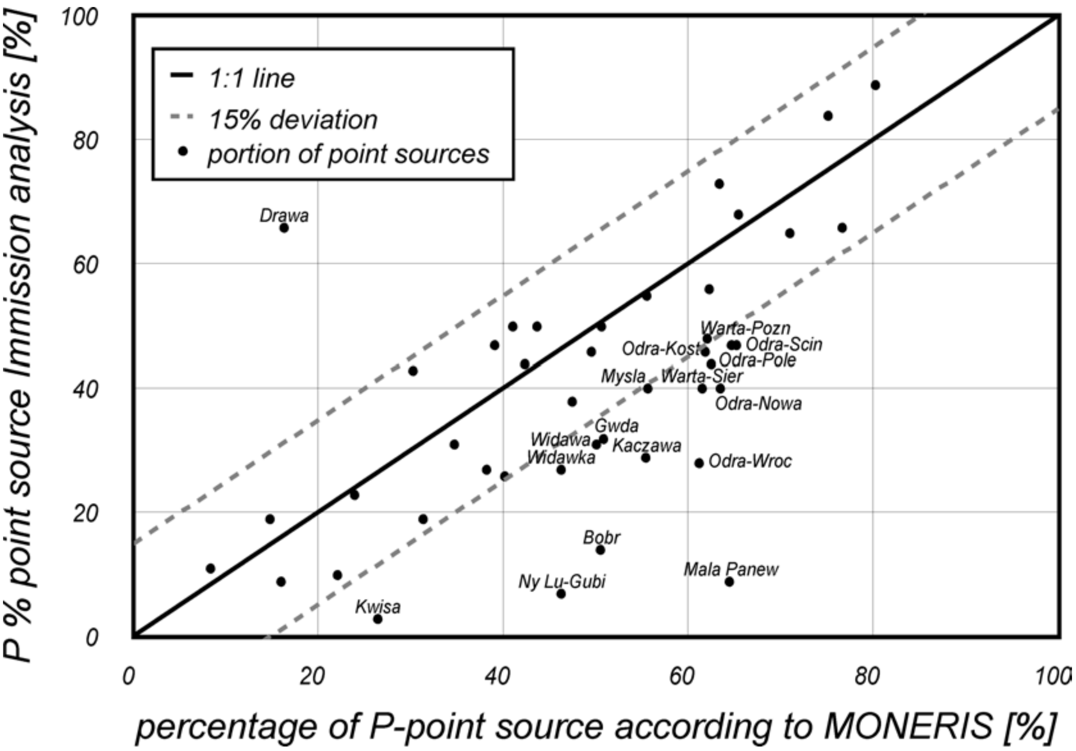

Figure 5.30: Comparison of percentage of point sources at the phosphorus load estimated by the emission and immission approach for the Odra and its main tributaries.

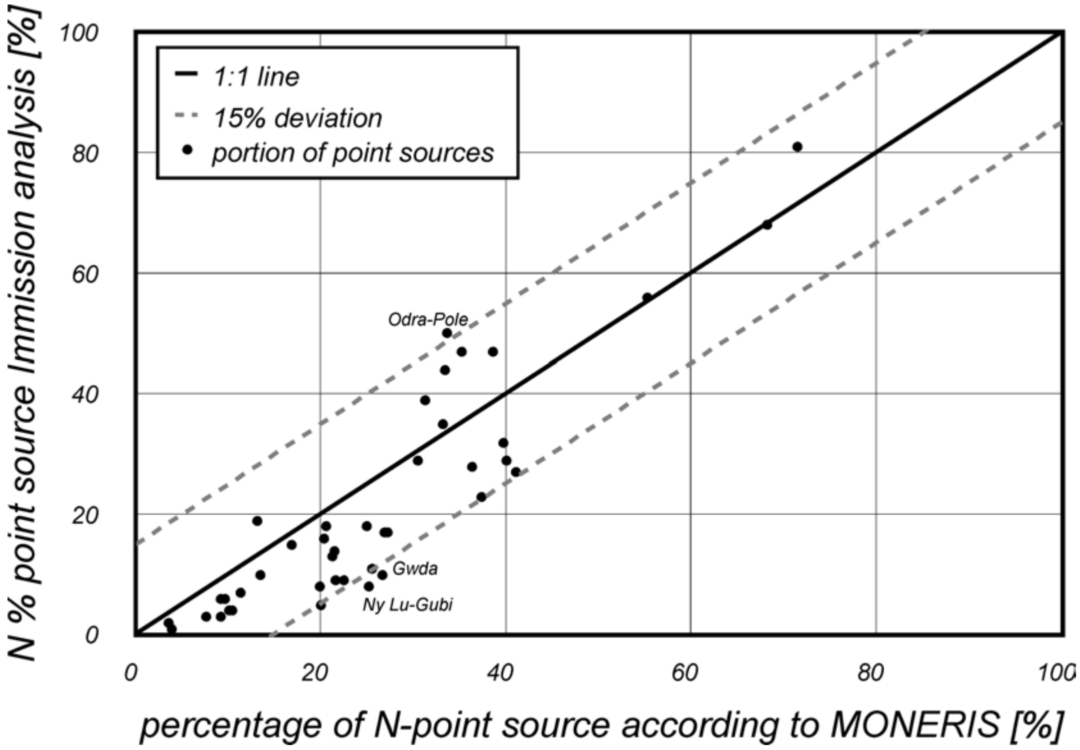

Figure 5.31: Comparison of percentage of point sources at the nitrogen load estimated by the emission and immission approach for the Odra and its main tributaries.

5.7 Present state of Heavy Metal Inputs in the Odra Basin

5.7.1 Heavy Metal Emissions

The successful application of the MONERIS approach for the estimation of heavy metal inputs in German rivers (Vink, 2002, Vink & Behrendt, 2001a and b; Fuchs et al., 2002) was the reason to try a similar transfer for the Odra basin. For this the specific emission data for German rivers given by Fuchs et al. (2002) were applied to the Odra river system with small changes considering the specific conditions of the Odra basin (see Chapter 4.2). For the application of these specific parameters to the Odra the GIS data base with the same spatial resolution was used as for the nutrients. But with regard to the probable high sources of errors we present in the following only the results for the larger basins, because there the errors seem to be lower than for the smaller catchments.

The Figures 5.32 to 5.35 show the total emissions of cadmium, copper, lead and zinc for the three main sub catchments of the Odra (Odra upstream Polecko, Warta upstream Kostrzyn and Odra upstream Krajnik Dolny). The Table 5.38 includes additionally the catchments of the Odra at Chalupki (Czech-Polish border) and of the Odra before entering the Haff.

The total emissions of cadmium into the river systems of Odra were estimated to about 10 t/a for the period 1993-1997. The discharges by municipal waste water treatment plants are the dominant source of emissions for cadmium. This pathway causes totally about 71% of the cadmium inputs into the Odra river system. The direct industrial discharges which was as-

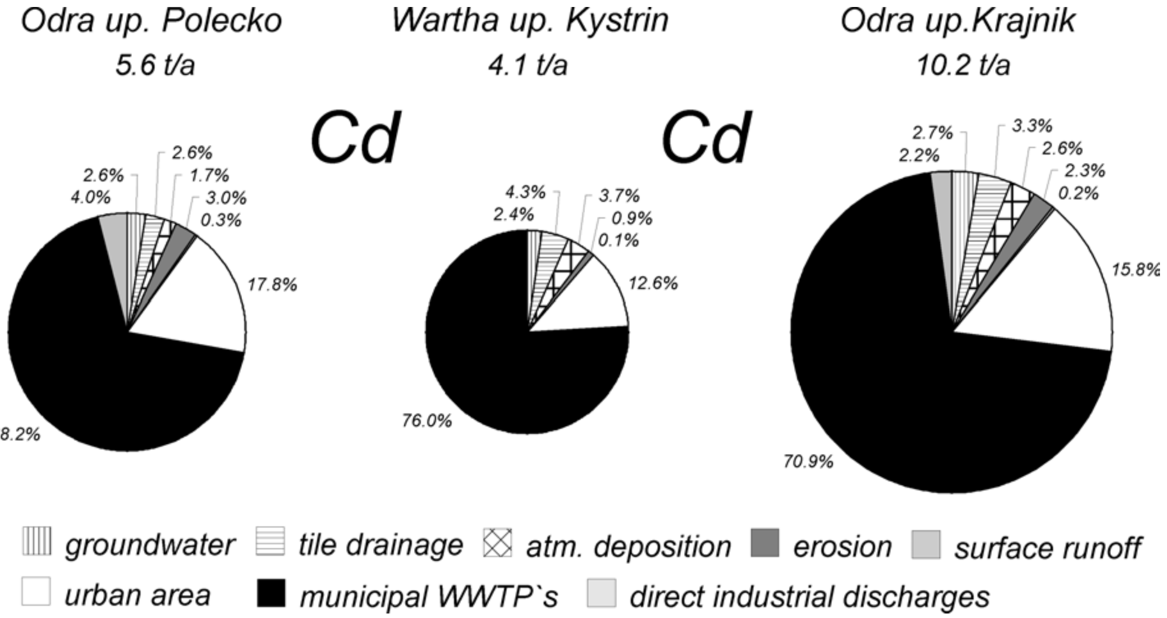

Figure 5.32: Total cadmium emissions into the main sub basins of the Odra and contribution of the pathways to this total inputs in the period 1993-1997.

sumed to be 10% of the discharges given by BCEOM (1992), contribute to the total emissions to about 2%. Based on this results it is to assume that specific cadmium discharges of WWTP given for few examples in the Czech Republic and applied to whole Polish and Czech part of Odra are probably too high. But this can be changed only on the base of a better data base especially for the WWTP`s in Poland.

The diffuse source contribution is only 29% and from this more than a half is caused by cadmium emissions from urban areas (mainly from inhabitants and urban areas not connected to a municipal WWTP. Only 13% of the total cadmium emissions are caused by the sum of the other diffuse pathways as groundwater, tile drainage, atmospheric deposition, erosion and surface runoff.

If it is taken into account that the assumed cadmium concentrations for the WWTP effluents represent the mean of all German WWTP`s and these are probably lower than on Poland or Czech Republic the result is more an underestimation with regard to the total emissions and the portion of WWTP`s to the total inputs of cadmium.

The cadmium inputs into the Warta are lower than the inputs into the upper Odra, which is mainly caused by a lower input from urban areas and that the industrial discharges are probably neglecting in this catchment.

As shown in Figure 5.33 the situation regarding the emissions of copper is different. The copper emissions from point source are about 34% of the total inputs of 167 t/a. From this one third is probably caused by direct industrial discharges. For this pathway it was assumed that discharges in the period 1993 to 1997 are only 50% of the discharges given by BCEOM (1992), but the location of the discharges within the river system is the same.

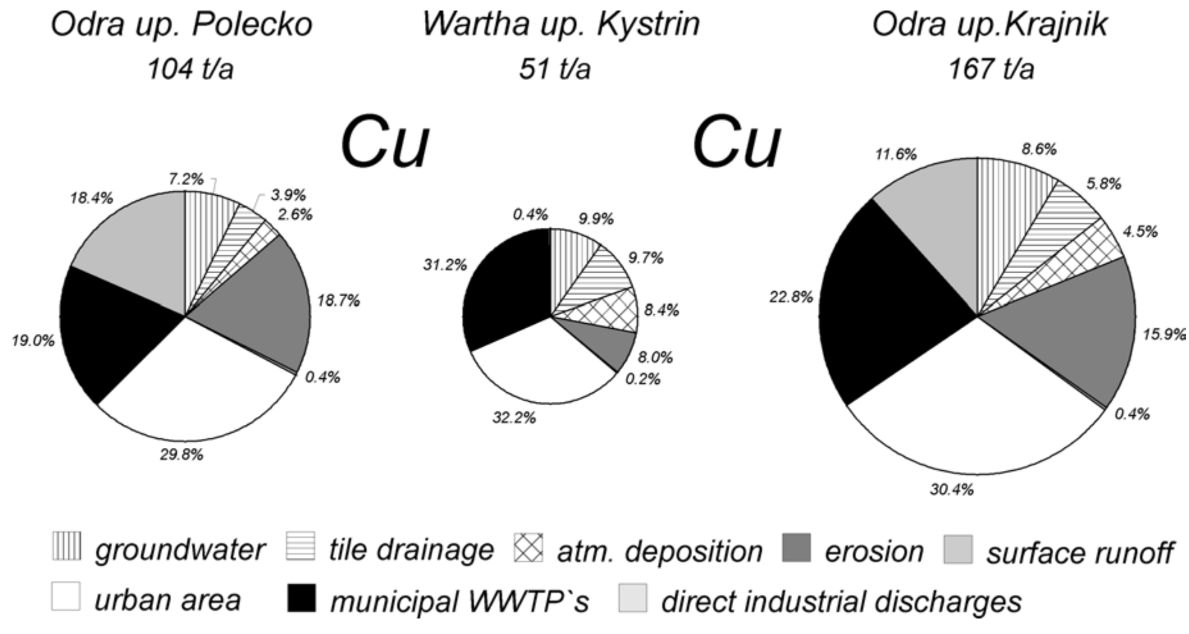

Figure 5.33: Total cupper emissions into the main sub basins of the Odra and contribution of the pathways to this total inputs in the period 1993-1997.

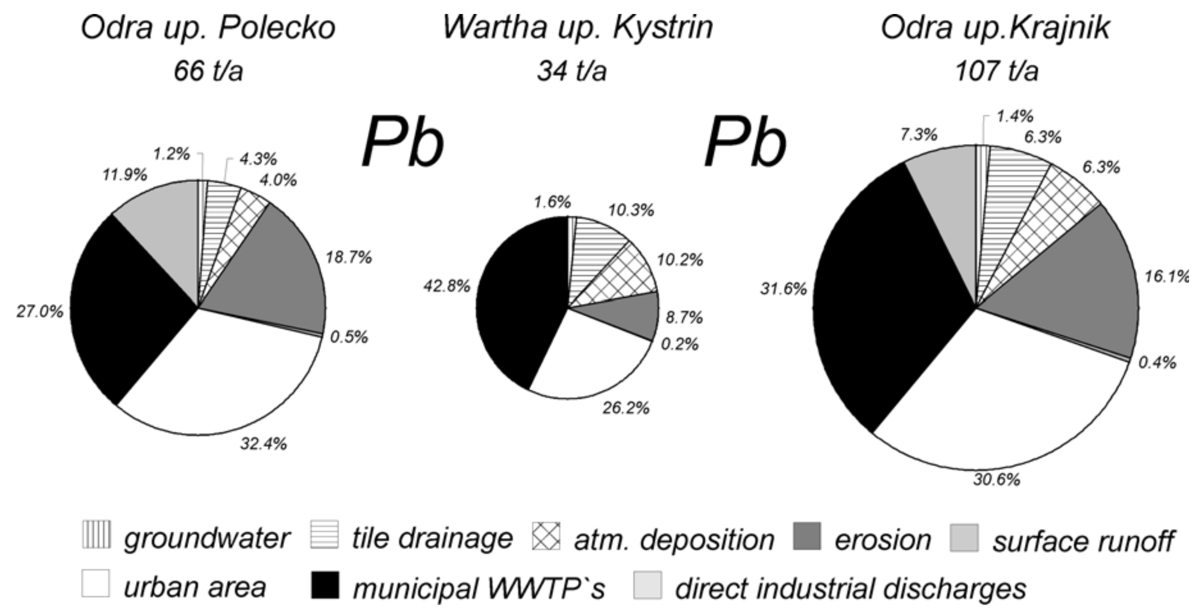

Figure 5.34: Total lead emissions into the main sub basins of the Odra and contribution of the pathways to this total inputs in the period 1993-1997.

The diffuse entries from urban areas represent the dominant pathway and cause about 31% of the total emissions. 16% of the emissions are caused by erosion. Each of the other diffuse pathways contributes less than 10% to the emissions.

Because the sources of industrial discharges are only located in the upper Odra it is obvious that the total inputs of copper are within this tributary about the double of that in the Warta.

It is possible that the estimated copper inputs from urban area are overestimated for the Odra basin, because these inputs are dependent on the area of copper surfaces especially on roofs, and this area is probably in Poland and Czech Republic smaller than in Germany. But the data base is missing for an adaptation of the specific emission parameters for copper.

The Figure 5.34 shows the situation in the Odra basin regarding the emissions of lead. The point source discharges amount 39% of the total inputs. The proportion caused by municipal WWTP`s is with 32% higher than for copper.

The emissions from urban areas are 31% of the total emissions of 107 t/a. This is clear because the main source of lead pollution is traffic and the highest deposition rates can be assumed within urban areas. Further the high deposition rates of lead are the reason that the direct inputs by atmospheric deposition for lead are 6% higher than for cadmium and copper (Unklare Aussage). In the Warta this pathway causes 10% of the total lead emissions, because the area of surface waters is in the Warta much higher than in the upper Odra.

Regarding the spatial differences of the lead emissions the situation is similar as for copper. The total emissions within the Warta are only about a half compared to the upper Odra. Thus industrial sources seem to be unimportant in the Warta and that in this river system the erosion and also the emissions of heavy metals by this pathway are much lower than in the upper Odra.

For Zinc we could calculate total emissions of about 1120 t/a. The point sources causes 51% of this emissions. The contribution of direct industrial discharges to the total zinc emissions is only 8 %. The rest of the point source inputs is caused by municipal WWTP`s (43%).

With regard to the dominant source of diffuse emission the situation for Zinc is similar to the other heavy metals. Also for this metal the emissions from urban areas represent more than a half of the total diffuse entries. In relation to the total zinc emissions 28% were caused by this pathway. In contrast to copper and lead the input by erosion are lower and amounts only 5% of the total zinc emissions. Therefore the difference between the total zinc emissions into the Warta and the upper Odra are not so large than for copper and lead.

In general the presented results for the heavy metal emissions by point and diffuse source into the Odra are only a first raw estimation, because the specific database for a more detailed study for the Odra is missing up to now. Further the used emission coefficients for the heavy metals are related to German river systems and also for these the database is raw in comparison to the nutrients. On the other hand this analysis of the emission situation of heavy metals in the Odra gives the possibility to evaluate the results of the immission analysis for the heavy metals.

Furthermore it can be concluded from this preliminary analysis that the main sources of heavy metal inputs in the Odra basin are the discharges by municipal WWTP`s and the emissions from urban areas, which is similar to the results of other river systems (Behrendt, 1993, Vink & Behrendt, 2001; Fuchs et al. 2002). This situation can be changed by reduction of the inputs to the urban area especially by traffic and corrosion and by increasing elimination rates of heavy metals within the WWTP`s. Further special measures have to be established to

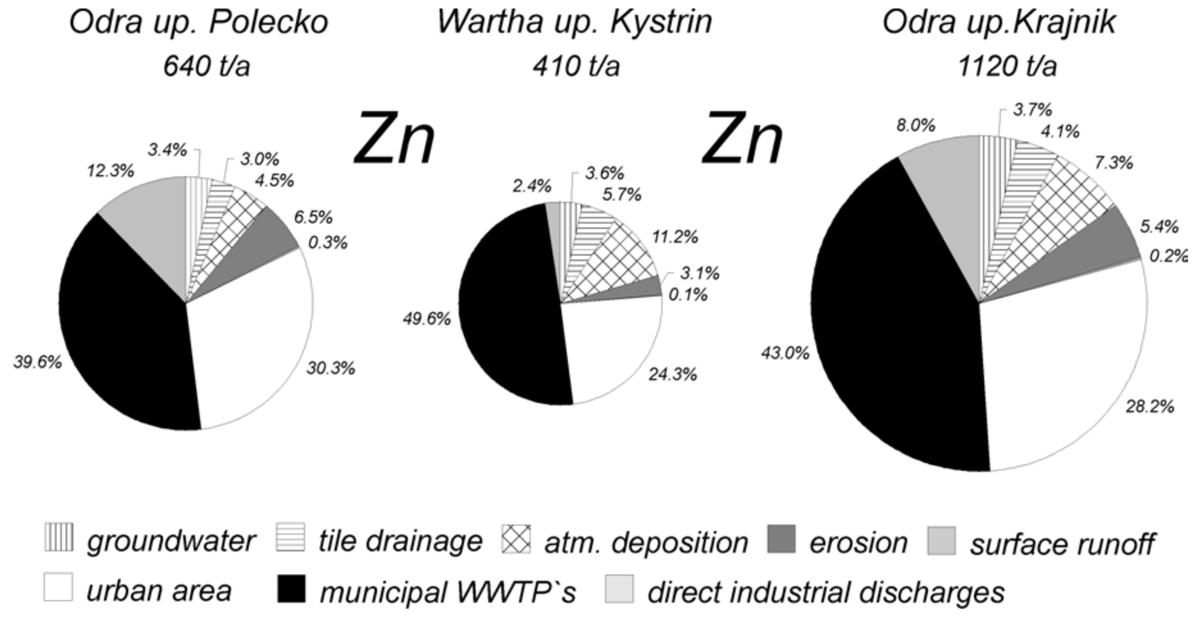

Figure 5.35: Total zinc emissions into the main sub basins of the Odra and contribution of the pathways to this total inputs in the period 1993-1997.

Table 5.38: Heavy metal emissions by point and diffuse sources into larger river basins of the Odra in the period 1993-1997.

Catchment	Gw	Dr	Dep	Ero	Ro	Urb	WWTP	Ind	Sum
	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]	[kg/a]
Cadmium (Cd)									
Odra-Chal	20	19	7	49	5	147	405	33	684
Odra-Pole	145	143	94	167	18	995	3820	223	5604
Warta-Kost	98	174	149	39	4	510	3081	0	4054
Odra-Kraj	278	336	261	231	23	1612	7209	223	10174
Odra-Mout	289	357	286	240	24	1701	7707	223	10826
Copper (Cu)									
Odra-Chal	1100	500	200	5900	100	4400	2100	1300	15600
Odra-Pole	7500	4100	2700	19400	400	31000	19800	19200	104100
Warta-Kost	5100	5000	4300	4100	100	16500	16000	200	51200
Odra-Kraj	14300	9600	7600	26600	600	50800	38200	19400	167000
Odra-Mout	14900	10200	8300	27500	600	53600	40800	19400	175200
Lead (Pb)									
Odra-Chal	100	400	400	3600	100	5000	1900	1200	12600
Odra-Pole	800	2900	2700	12400	300	21400	17900	7900	66200
Warta-Kost	500	3500	3500	2900	100	8800	14400	0	33700
Odra-Kraj	1500	6700	6700	17300	400	32800	34000	7900	107300
Odra-Mout	1600	7100	7400	17900	400	34700	36300	7900	113300
Zinc (Zn)									
Odra-Chal	3100	2500	2200	10800	500	28200	27000	64500	138900
Odra-Pole	21700	19400	29200	41800	2000	194700	254700	79000	642600
Warta-Kost	14700	23600	46600	12900	400	100500	205400	10100	414300
Odra-Kraj	41700	45700	81600	60900	2700	315800	482500	90000	1120900
Odra-Mout	43300	48400	89200	63800	2700	333400	515900	90000	1186700

reduce the inputs by combined and separate sewer systems to reduce the events of combined sewer overflows and the direct flow of rain water via separate sewers to the river.

For the Odra it is important that such measures are to establish parallel to measures related to an increase of population connected to sewer systems and WWTP`s, because otherwise the total emissions of heavy metals will increase in the next years.

5.7.2 Heavy Metal Loads

Measurements of heavy metal concentrations in the Odra and its tributaries were available only for one third of the selected stations for the nutrients. With regard to the quality of these data it must be pointed out that especially for cadmium and lead a high portion of the concentration data were marked as below detection limit. For this data the half of the detection limit was used to fill the lack in the set of measurements.

An overview on the calculated heavy metal loads in the period 1993-1997 is given in Table 5.39. The specific loads for the areas upstream of each of the selected monitoring station are presented in the Figures 5.36 to 5.39.

The figures show for all heavy metals that the specific loads are high in the upper part of the Odra and the sub catchments within this area but very low at the downstream station Krajnik Dolny. Additionally, the total heavy metal loads are decreasing at least in the lower part of Odra from the station Scinava to Krajnik Dolny (Table 5.29). Because the monitoring at Krajnik Dolny is characterized by the highest frequency this phenomenon can only be explained by high retention processes of heavy metals within the river system of Odra.

In comparison to the heavy metal loads of Rhine and Elbe (see Table 5.40) the specific loads of the sub catchments of upper Odra are very high for cadmium and lead.

Table 5.39: Mean annual discharge and calculated river loads for Cd, Cu, Pb, Zn for selected monitoring stations in the Odra and its main tributaries in the period 1993-1997.

River	**Station**	**Discharge**	**Load [t/a]**			
		[m³/s]	**Cd**	**Cu**	**Pb**	**Zn**
Odra	Polanka	12.5	0.7	4.6	8.2	24
Opawa	mouth	15.1	0.8	3.8	9.2	28
Ostravice	mouth	10.5	1.9	2.9	6.5	51
Odra	Chalupki	45.4	5.2	20	33	296
Odra	Wroclaw	131.1	15.0	24	51	395
Kaczawa	Kwiatkowice	13.4	0.9	6.9	8.6	37
Odra	above Scinawa	179.4	12.2	44	99	568
Barycz	Wyszanow	20.3	5.7	3.5	18	12
Nysa Luzycka	Gubin	33.3	2.5	9.9	24	109
Prosna	Ruda Komnorowska	15.7		4.9	2.8	44
Warta	Poznan	97.4	1.1	31	6.1	79
Odra	Krajnik Dolny	524.2	3.1	67	40	331
Ina	Goleniow	13.6	0.06	1.3	0.8	7
Peene	Anklam	20.9	0.09	3.0	0.9	2.7
Uecker	Ueckermuende	6.9	0.04	0.7	0.2	0.5

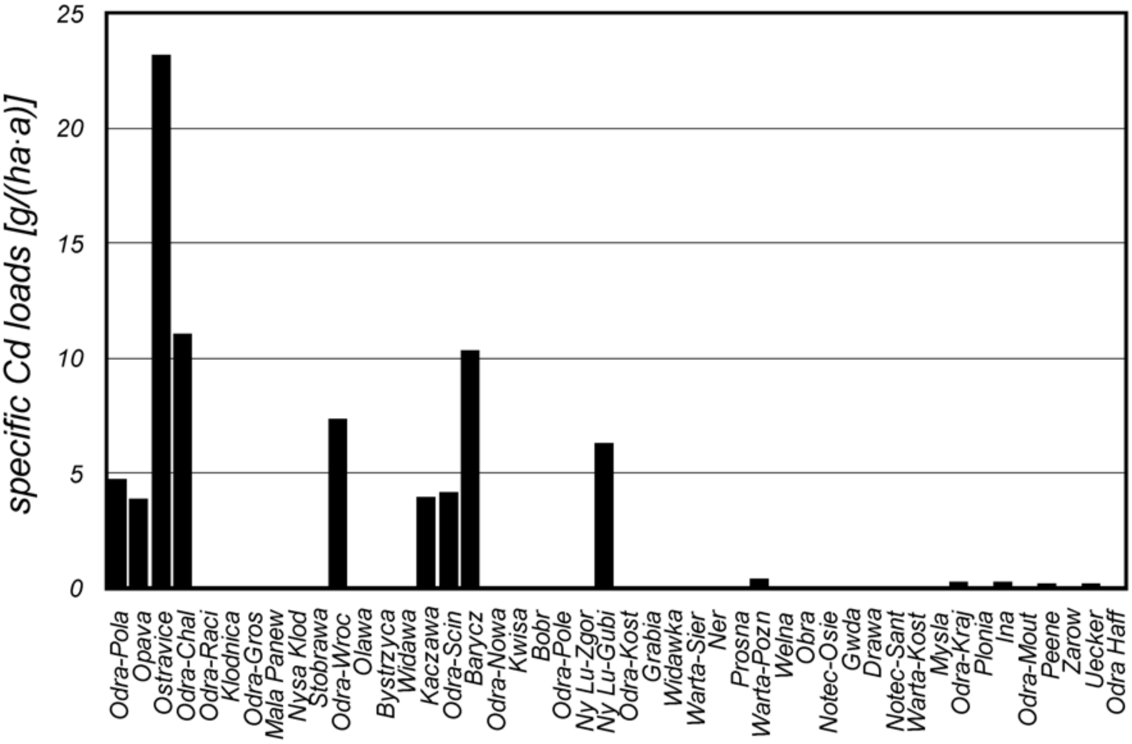

Figure 5.36: Specific cadmium loads in the period 1993-1997

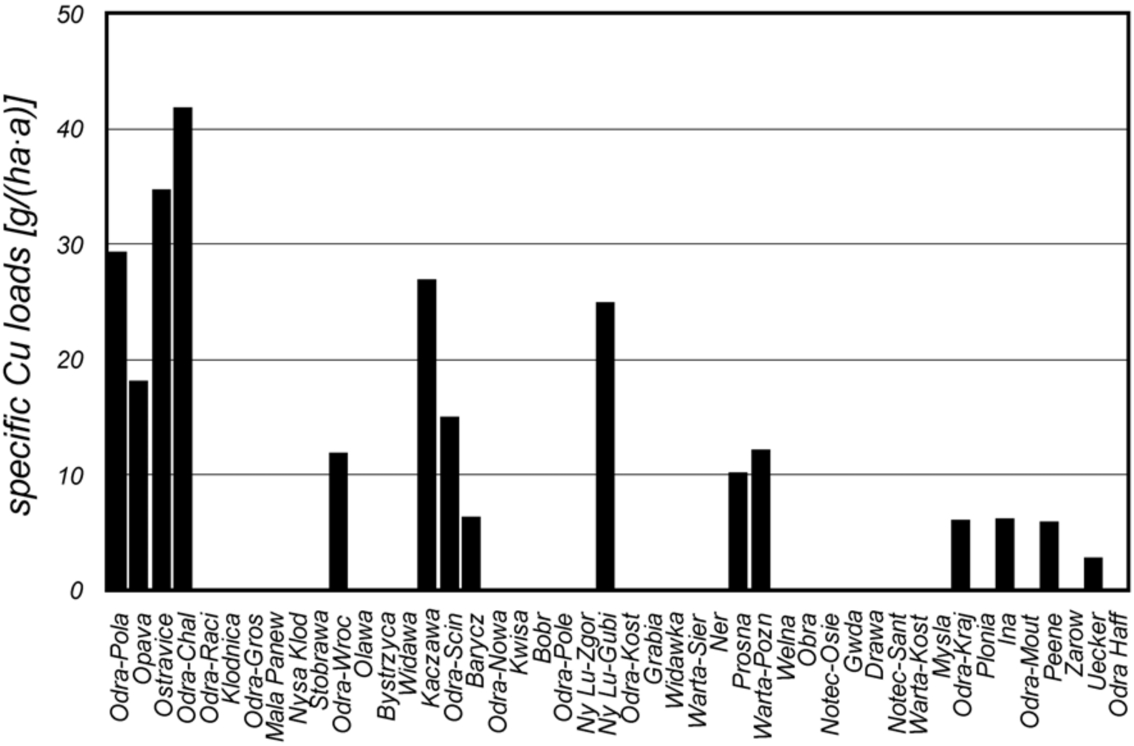

Figure 5.37: Specific copper loads in the period 1993-1997.

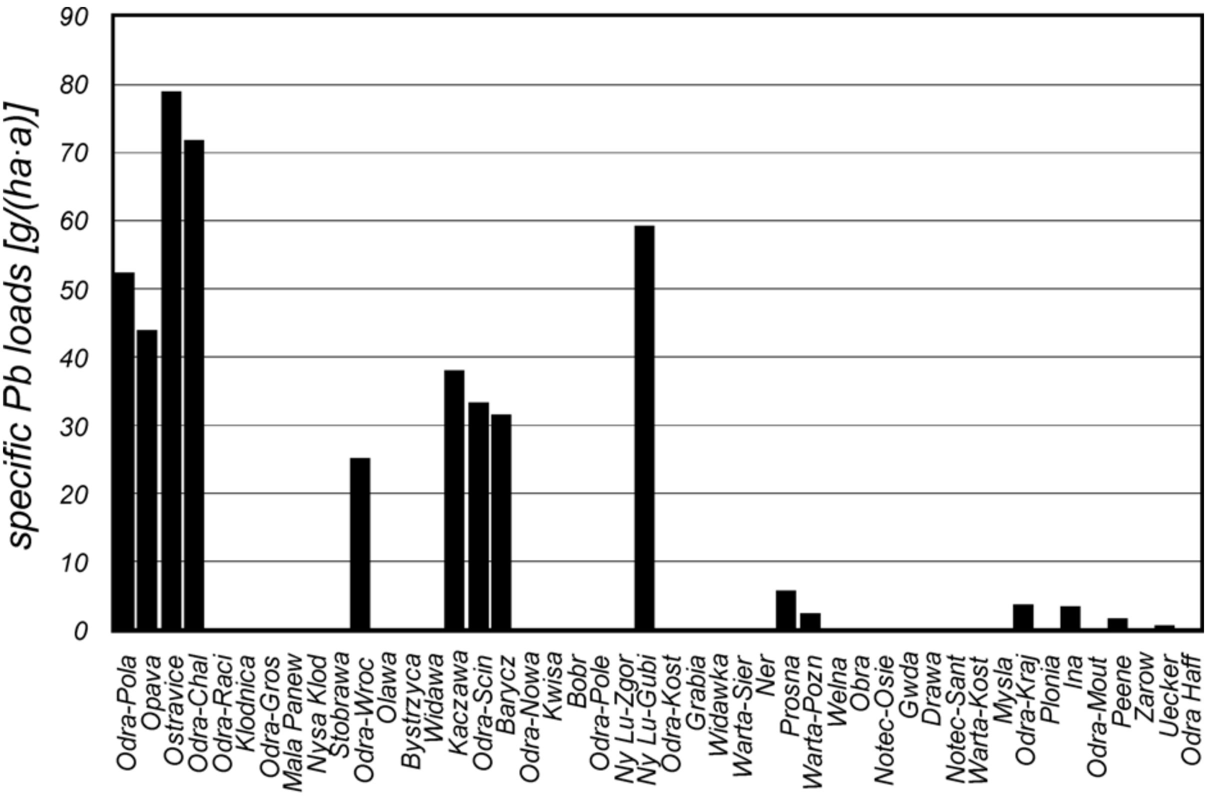

Figure 5.38: Specific lead loads in the period 1993-1997

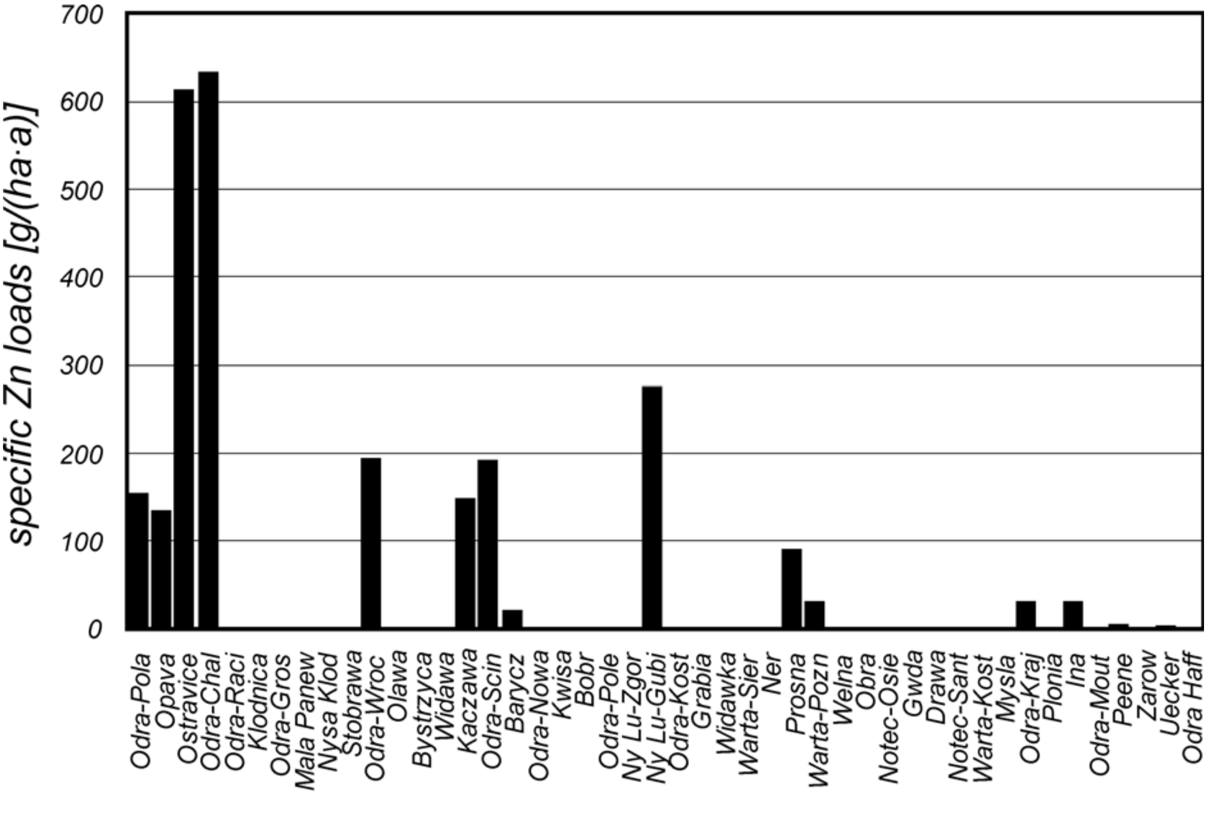

Figure 5.39: Specific zinc loads in the period 1993-1997.

Table 5.40: Specific heavy metal loads of the Elbe, Odra and Rhine.

	area	Cd	Cu	Pb	Zn	Reference
	[km²]	[g/(ha·a)]	[g/(ha·a)]	[g/(ha·a)]	[g/(ha·a)]	
Odra 93/97	118860	0.3	6	3	28	this study
Rhine 83/87	159700	1.4	55	41	308	Vink & Behrendt (2001)
Rhine 93/97	159700	0.4	29	17	130	Vink & Behrendt (2001)
Elbe 83/87*	125160	1.2	36	11	212	Vink et al. (2000)
Elbe 93/97*	125160	0.4	9	7	105	Vink (2001)

* data for Elbe from the station Schnackenburg

For Zinc the specific load is only very high in the catchments of Ostravice and the Odra upstream of Chalupki. The specific loads of copper are in the upper Odra in the same order of magnitude than in the Rhine.

In contrast to this the specific loads of heavy metals are for the station Krajnik Dolny much lower than in the Rhine and the Elbe with the exception of Cadmium.. Especially for lead and zinc the specific load in the Odra is lower than 50% (Pb) or about 25% (Zn) in comparison to the Elbe. For cadmium the level of specific load of the Odra is at the same level as in Rhine and Elbe in the period 1993-1997.

5.7.3 Comparison of the measured with the calculated heavy metal loads

Vink & Behrendt (2002) derived retention functions for the heavy metals in river systems based on the results of an emission analysis in the basins of Rhine and Elbe and the comparison with measured loads for different time periods. These functions were used to calculate the heavy metal loads from the estimated emissions (see Chapter 5.7.1) within the Odra basin and its main tributaries. The calculated loads were in the next step compared with the measured loads for the time period 1993 to 1997 (see Table 5.39).

The results of this comparison are shown in the Figure 5.40 A to D. The table 5.41 shows the calculated and observed loads of heavy metals for the station Krajnik Dolny.

Table 5.41: Comparison of calculated and observed loads of heavy metals for the Odra at the station Krajnik Dolny for the period 1993-1997.

	Cd	Cu	Pb	Zn
	[t/a]	[t/a]	[t/a]	[t/a]
observed load	3.1	67	40	331
calculated load	5.0	78	36	651

The results of this comparison can be distinguished in two groups. For copper and zinc the calculated loads are comparable with the observed loads at the different stations. The deviation between calculated and observed loads is higher than for the nutrients. This can be explained by the lower quality of database for both emission estimation and measurements within the river. But the differences do not show systematical deviations especially for zinc. For copper the load of two stations is only above the 1:1 line, indicating that the emissions of copper are perhaps underestimated or the retention is overestimated. But which pathway is underestimated can be analysed only on the base of a more detailed study and better emissions coefficients.

The second group is represented by cadmium and lead. For both metals the deviation between calculated and observed loads is about one order of magnitude for a subset of the stations. Especially for cadmium the impression exists that this subset of stations is parallel shifted to the 1:1 line. This would indicate that for this stations the observed load and is approximately one order of magnitude to high. It is assumed that the measured concentrations of cadmium for these stations are one order of magni-

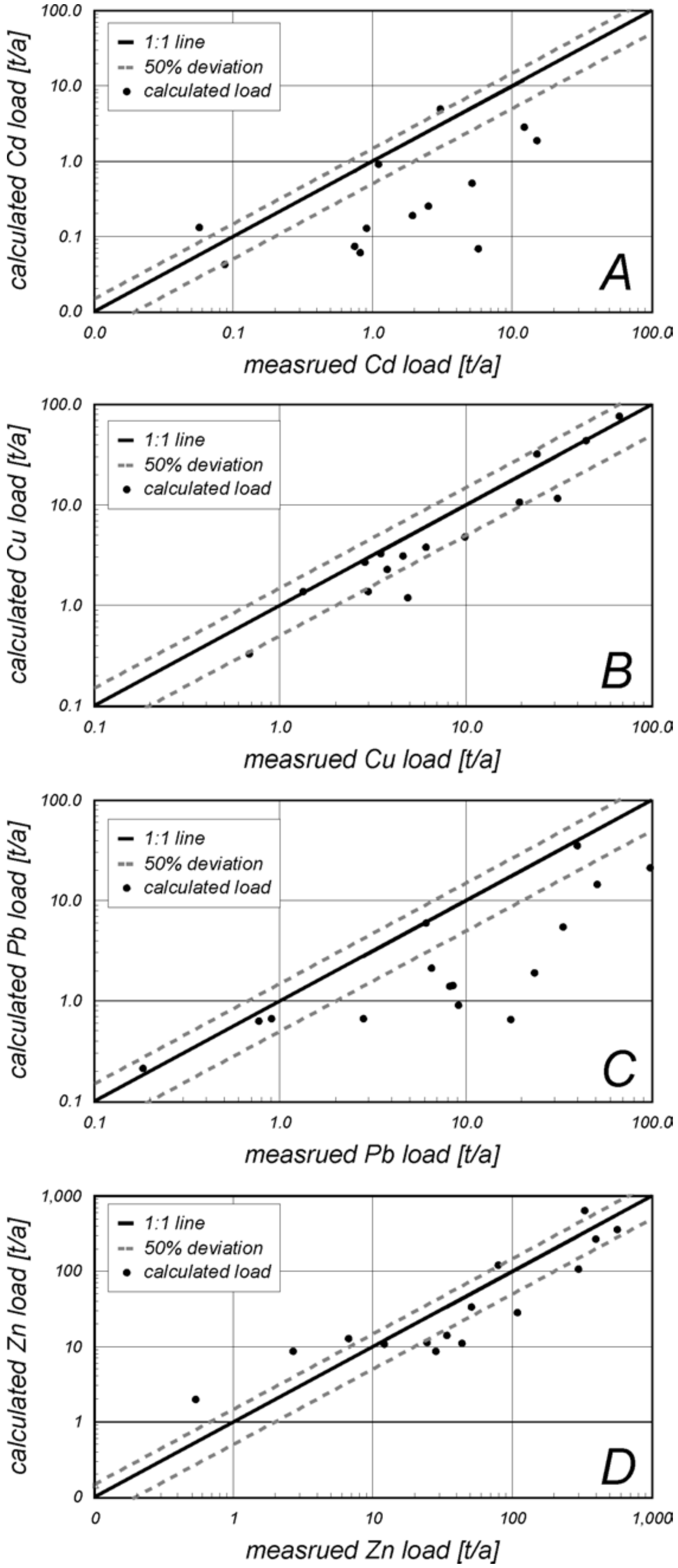

Figure 5.40: *Comparison of calculated and observed load of heavy metals in the Odra for the period 1993-1997.*

tude to high. On the other hand it is possible that one or more sources of emissions are underestimated. But then the load of the four station which are now within or near the 50% deviation range would be overestimated.

For lead it is also to see from Figure 5.40 that differences of more than 100% occur for a high number of stations. But this difference are not so unique as for cadmium. An underestimation of the emissions is less probably, because this would lead to an overestimation of the load for those stations which are now within the tolerable range of deviation. We assume that also for lead the measured concentrations for the stations with high deviation seem to be to high which is perhaps due to high detection limits.

5.7.4 Comparison of the results of immission and emission method for heavy metals

Also for heavy metals an estimation of the portion of point and diffuse sources at the observed loads was done for the stations given in Table 5.39. Based on the results of the immission approach a further comparison can be done relating the portion of point sources to the total emissions and loads. The results of this comparison are shown in Figure 5.41 to 5.44.

For all heavy metals it is to see that in the most cases the portion of point sources estimated with the immission approach is in the most cases lower than the result of the emission method. If it is considered that the main sources of heavy metal inputs are WWTP`s and urban areas this behaviour can be expected, because the immission analysis does not take into account that the emissions from WWTP`s are at high flow conditions often higher than dry wether conditions. This portion of WWTP emissions will be indicated at the immission method as an diffuse part. The influence of this problem within the immission method is increasing with the increased influenced of sources which are emitted from urban areas.

For cadmium and lead the number of stations which could use for an immission analysis was very low, because for these heavy metals the lower limit of about 50 datasets needed for the application of the immission analysis was not reached for most of the stations.

As already pointed out before the results of the comparison of immission and emission method support the thesis that the quality and density of measurements of Cadmium and lead within the Odra catchment are not sufficient for a load calculation with low error. On the other hand also the data base for the emission method was very limited.

For copper and zinc we found a much better results, which is due to the fact that the concentrations of these both heavy metals can be better measured and therefore the portion of values below detection limit was much lower than for cadmium and lead.

Especially the good agreement between the result of immission and emission method for copper can be an indication for the fact that both the emissions and the loads are in a realistic range. The same can be assumed for zinc, but there exist for some stations large deviations (see Figure 5.44), which can be not explained at the present level of data base.

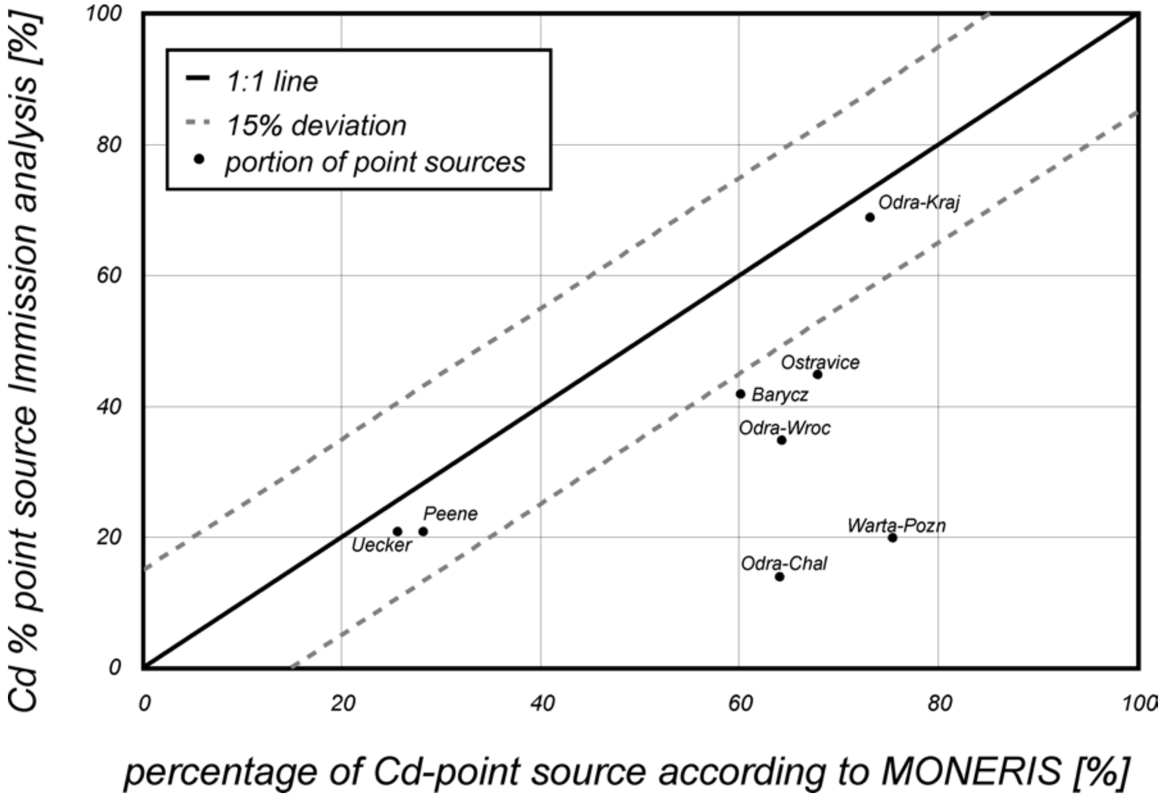

Figure 5.41: Comparison of the estimates portion of point sources at the Cd loads and emissions for different monitoring stations in the Odra basins for the period 1993-1997

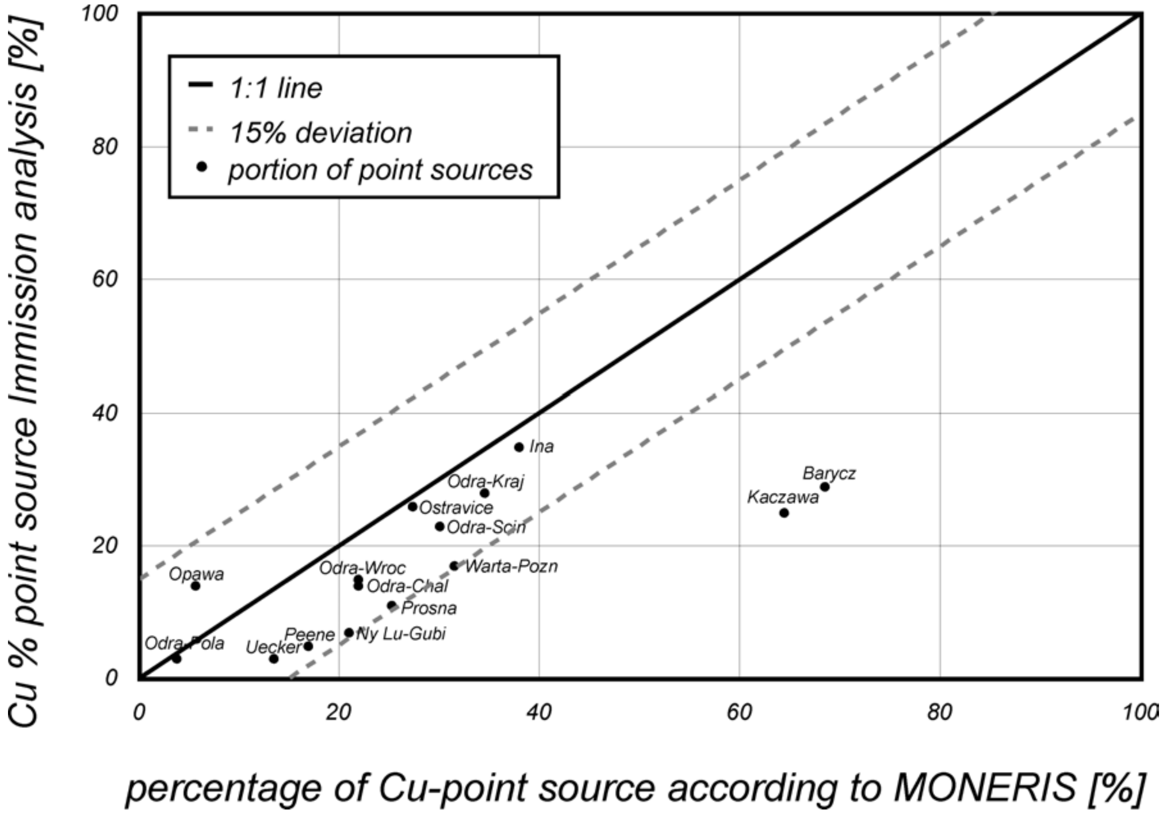

Figure 5.42: Comparison of the estimates portion of point sources at the Cu loads and emissions for different monitoring stations in the Odra basins for the period 1993-1997

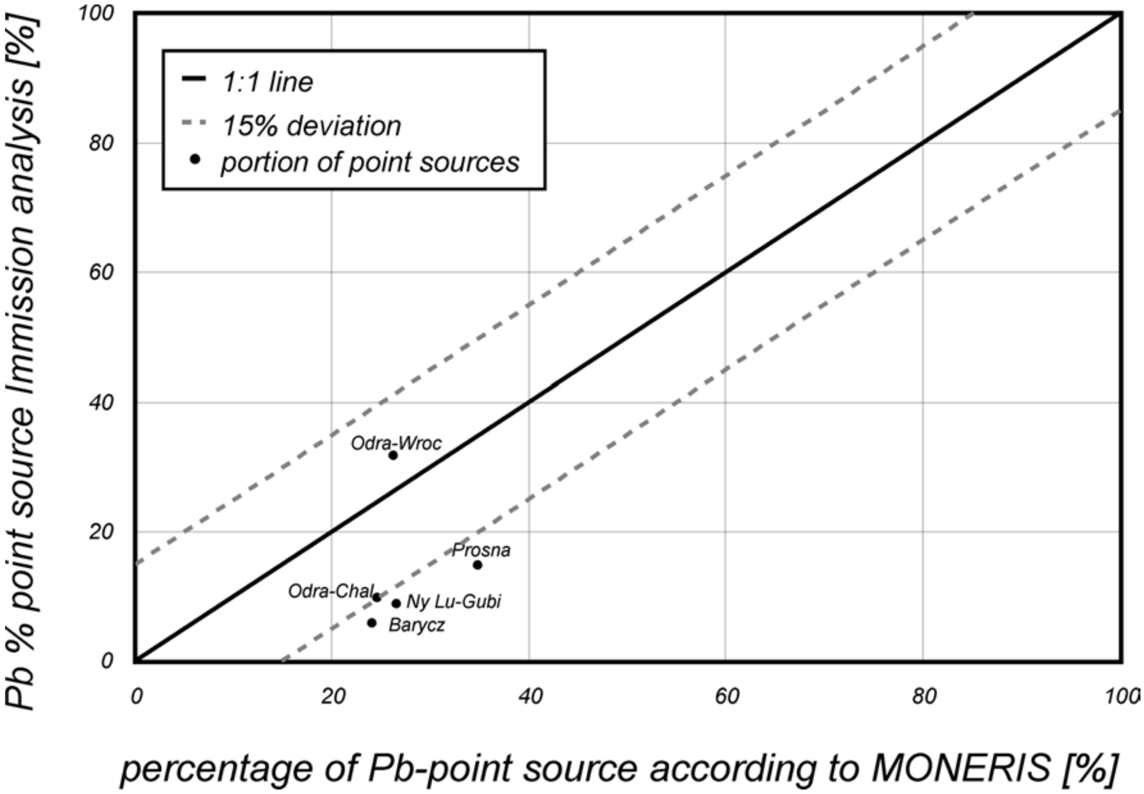

Figure 5.43: Comparison of the estimates portion of point sources at the Pb loads and emissions for different monitoring stations in the Odra basins for the period 1993-1997

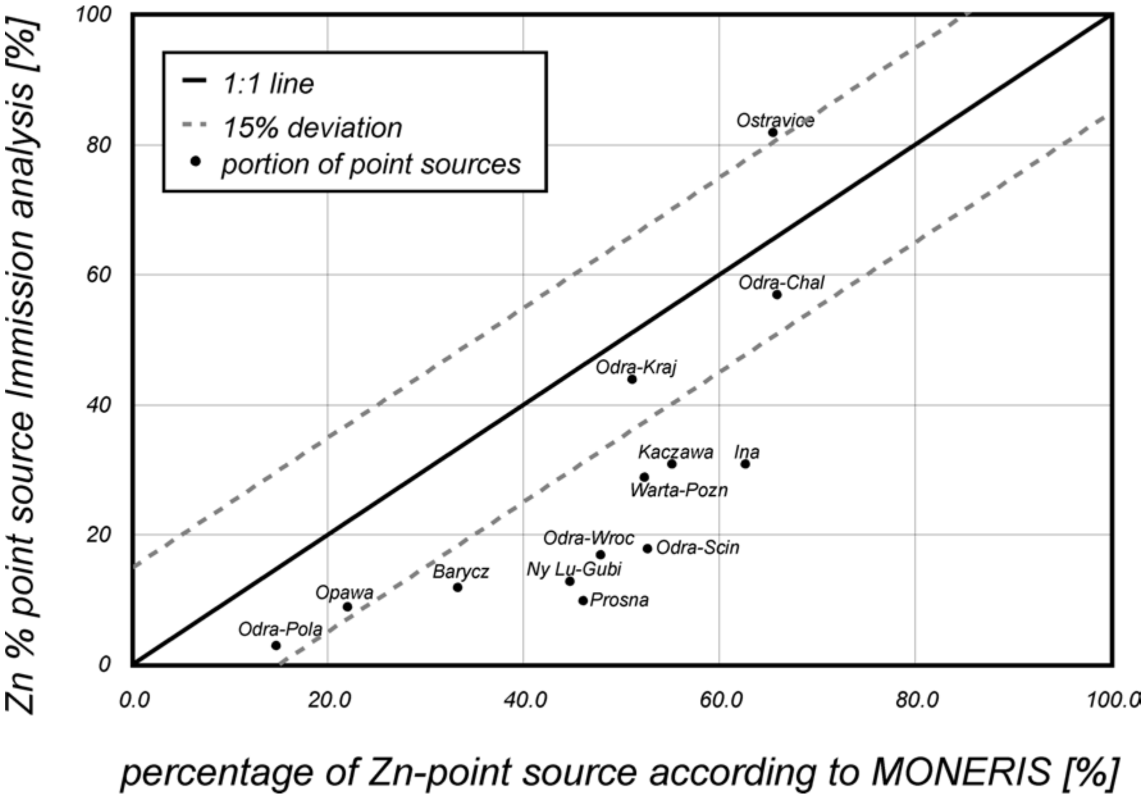

Figure 5.44: Comparison of the estimates portion of point sources at the Zn loads and emissions for different monitoring stations in the Odra basins for the period 1993-1997

6 Scenario Calculations for Nutrients

6.1 Point Source Scenarios

6.1.1 Definition of the Point source Scenarios

General assumptions

The point source scenarios have in some cases also consequences on the inputs from urban area. Therfore within this set of scenarios we calculate the effects of different measures on the point source emissions as well as the emissions by urban areas.

Further assumptions are:

- The Odra Basin carries eutrophication-prone waters.
- By the year 2005 only point sources listed in “The quick operation programme on Odra river pollution protection” will have been changed.

Detailed assumptions

Scenario P0

In Scenario P0 the effect of the indroduction of phosphorus free detergents in Poland and Czech Republic. Based on this assumption the specific P-emissions per inhabitant are reduced from 3.26 (Poland) and 2.5 gP/(Inh.·d) (Czech Republic) to the present emission in Germany (1.8 gP/(Inh.·d). It is assumed that the elimination rates of WWTP`s within Poland and Czech Republic are the same than in the period 1993-1997.

Scenario P1:

Municipalities with a population of ≥ 10,000 will have been completely to sewer systems and WWTP`s by the year 2000.

- The subset of municipalities with ≥ 10,000 inhabitants has been established.
- The percentage of the population making use of the sewer system has been verified.
- The factor by which the raw sewage volume will increase when the number of sewerage users reaches 100% has been calculated on assuming the following pollution load per caput:
    - BOD = 60 mg O_2/l, P = -0.2532 Ln (inhabitants) + 3.2632 and
    - N = -0.9266 Ln (inhabitants) + 15.95.
    - For the WWTP in the German part of Odra the point source emissions for the year 2000 were considered.

Scenario P1a:

Additionally to Scenario P2 in Scenario P2a it is assumed the indroduction of phosphorus free detergents in Poland and Czech Republic according to Scenario P1a.

Scenario P2

By the year 2005 or later, also municipalities with a population of ≥ 2,000 will be completely connected to sewer systems and WWTP`s.

- The subset of municipalities with the number of inhabitants ranging between ≥ 2,000 and 10,000 has been established.
- The percentage of the population making use of the sewer system has been verified.
- The factor by which the raw sewage volume will increase when the number of sewerage users reaches 100% has been calculated on assuming the following pollution load per caput:
    - **BOD = 60 mg O_2/l P = -0.2532 Ln (inhabitants) + 3.2632 and**
    - **N = -0.9266 Ln (inhabitants) + 15.95.**
    - Scenario P2a:

Additionally to Scenario P2 in Scenario P2a it is assumed the indroduction of phosphorus free detergents in Poland and Czech Republic according to Scenario P1a.

Scenario P3 :

According to the 91/271/EEC Directive, the concentrations of water pollutants after treatment of “sensitive” recipients (beyond 2005) should take the following values:

- BOD = 25 mg O_2/l, COD = 125 mg O_2/l, SS = 35 mg/l, P = 2 mg/l, N = 15 mg/l for municipalities with a population ranging between 10,000 and 100,000;
- 1 mg P/l and 10 mg N/l for municipalities with more than 100,000 inhabitants.
- Data for the population range 2,000–10,000 are lacking; the values adopted for calculations were those for 10,000 inhabitants.

For the WWTP`s in the German part of the Odra the results of the scenario calculations of Behrendt et al. (2000) were taken into account for the scenario that the elimination rates of all WWTP`s are in agreement with the EU waste water directive.

For the Czech part of Odra we assumed the same effluent concentrations as for the Polish part.

Scenario P3a:

Additionally to Scenario P3 in Scenario P3a it is assumed the indroduction of phosphorus free detergents in Poland and Czech Republic according to Scenario P1a.

Scenario P4:

According to Polish water quality standards (beyond 2000), the concentration of water pollutants after treatment should take the following values for discharge greater than 2000 m^3/d:

- BOD = 15 mg O_2/l; Total Phosphorus = 1.5 mg P/l and Total Nitrogen = 30 mg N/l.

For discharge lower than 2,000 m^3/d the recommended final concentrations are:

- BOD = 30 mg O_2/l; Total Phosphorus = 5.0 mg P/l and Total Nitrogen = 30 mg N/l.

For the WWTP`s in the Czech and the German part of Odra the WWTP emissions of scenario 3 were taken into account.

Scenario P4a:

Additionally to Scenario P4 in Scenario P4a it is assumed the indroduction of phosphorus free detergents in Poland and Czech Republic according to Scenario P1a.

Scenario P5:

Scenario 5 is a special scenario related to the emissions from urban areas. Additionally to the scenario P3a it is assumed that in locations with combined sewer systems the storage volume within the combined sewers is increased to 23.3 m^3/ha paved urban area. According to the investigations of Hamm et al. (1991) this storage volume would guarantee that the pollution concentrations in the combined sewer overflows are not higher than in the separate sewer system.

6.1.2 Results of Point Source Scenario Calculations

The results of the different scenarios P0 to P5 are shown in the Tables 6.1 to 6.14 for all sub catchments within the Odra. Additionally the changes of point source nutrient discharges and the emissions by urban areas in relation to the state in the time period 1993-1997 are presented.

From the scenario calculations it can be concluded that already the scenario P0 (ban of phosphorus in detergents) leads to substantial decrease of the P-emissions in the Odra river system. Without further measures the P-discharges by point sources would reduced by 43%. Additionally the P-emissions by urban areas would reduced by 48 %. If the other sources are assumed as constant this scenario results in a reduction of the total P-emissions into the Odra basin of 32 % compared to the situation in the period 1993-1997. If the situation in the eighties of the last century is additionally taken into account, where it can be assumed that the specific P-emission per inhabitant was in all three countries 4 gP/(Inh.·d) or more, the existing reduction of the observed P-load (see Figure 5.3..) can be explained mainly by the reduction of the specific P-emissions in the countries. Compared to the late eighties a complete replacement of P in detergents would lead to a reduction of the P-emissions and P-load of the Odra of about 43%, which is neary by the target given by HELCOM.

The scenarios P1 and P2 show that the connection of all inhabitants of the cities with more than 10,000 (P1) and 2000 (P2) people to sewers and WWTP`s leads to a significant increase of the P-discharges by point sources. This increase can not be compensated by the corresponding reduction of P-emissions from urban areas in the most of the sub catchments. As shown in the Tables 6.2 and 6.4 the total inputs into the Odra will be increase by 7 % to 10 % compared to the period 1993-1997. If additional P-free detergents will be introduced the point discharges and the emissions by urban areas will decrease in the most of the catchments. For the total basin of the Odra the scenarios P1a and P2a result in a reduction of total P-emissions by 28 and 27% (see Table 6.3 and 6.5).

If the targets of the EU waste water directive are completely established in the countries of the Odra, a reduction of the P-discharges by point sources and urban areas will be reduced of about 77 and 63 %, respectively (see Table 6.6). If a constant amount of the other diffuse sources is assumed these measures would lead to a reduction of the total P-emissions into the river system of Odra of 55 % compared with the situation in 1993-1997. That means, the implementation of the EU waste water directive would guarantee that the HELCOM targets will be full filled for the Odra basin.

Scenario 3a shows (Table 6.7) that for this case the introduction of P-free detergents would lead only to further reduction of P-emissions from urban areas and the total reduction of P-emissions in the Odra would reach 57%.

Scenario 4 and 4a (realization of polish targets for the waste water discharges result in a

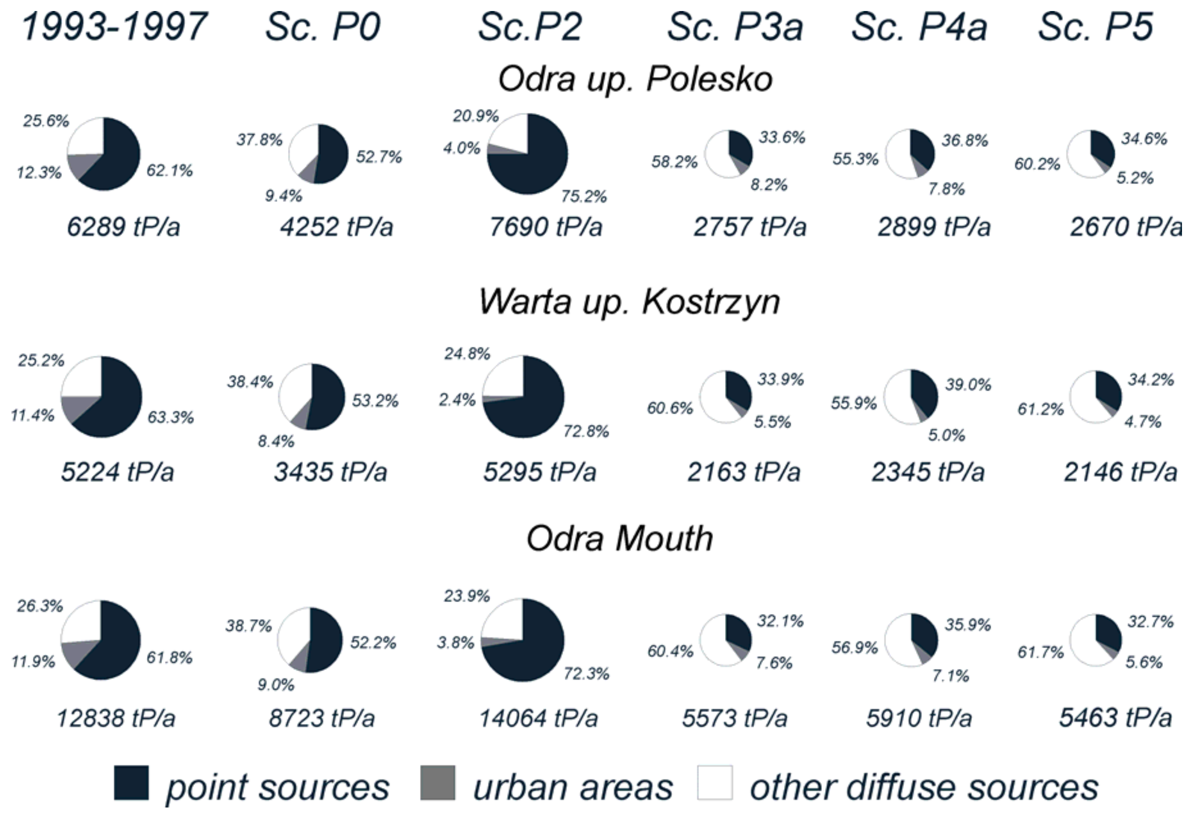

Figure 6.1: Results of selected point source scenarios for phosphorus for the upper Odra, the Warta and the total Odra.

reduction of the total P-emissions of 51% and 54%, which would be also sufficient to manage the HELCOM target.

The highest reduction of P-emissions would be possible if the set of measures regarding Scenario 5 is realized. In this case the P-emissions of point sources and from urban areas are reduced by 77% and 80%, respectively. The total P-emissions would be in that case 57 % than in the period 1993-1997.

The point source scenarios P1 to P5 for nitrogen show that a similar reduction is not possible for nitrogen due to the higher portion of diffuse sources at the total N-inputs into the river system of Odra (see Tables 6.11 to 6.15 and Figure 6.2).

For the scenarios P1 and P2 it can be also expected an increase of the point source N-discharges and the total emissions into the Odra. The highest reduction is possible with the scenarios P3 (measures according EU waste water directive) and P5, which leads to decrease of the N-discharges by point sources of 64% and for the inputs from urban areas by 49 and 56 %, respectively. But by realization of these measures a reduction of the total N-emissions into the river system of Odra of 26 and 27% seems to be possible.

In contrast to phosphorus the implementation of the Polish targets for waste water (Scenario P4) results only in a low reduction of the N-discharges of point sources (13%) and the total N-emissions can only reduced by 8%.

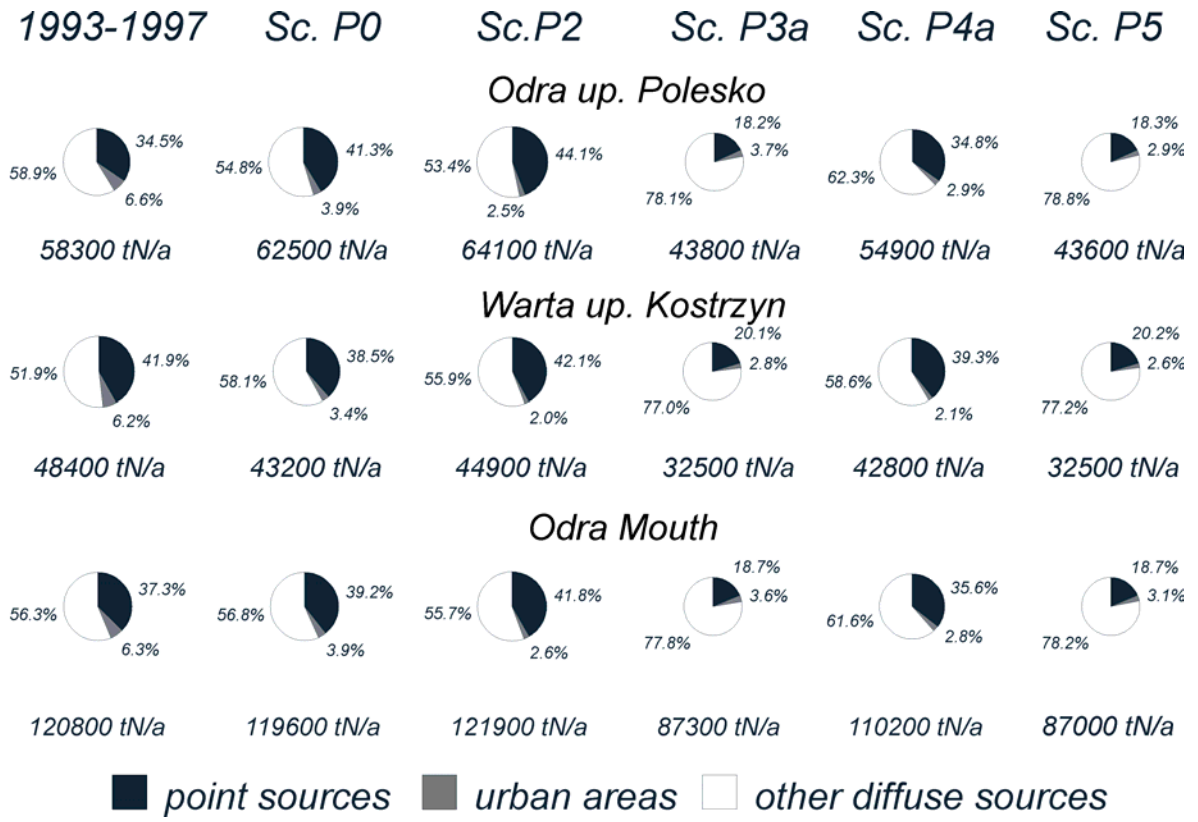

Figure 6.2: Results of selected point source scenarios for nitrogen for the upper Odra, the Warta and the total Odra.

Table 6.1: Phosphorus emissions in the Odra by realisation of the scenario P0 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_P *P0*	EUR_P *P0*	ED_P *P0*	ET_P *P0*	Red EP_P *P0*	Red EUR_P *P0*	Red.ET_P *P0*	Red.ET_P *P0*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	33.6	6.4	104.9	138.5	27.0	30.7	2.6	9.9
Opava	48.2	8.4	101.3	149.5	27.4	32.5	3.9	13.0
Ostravice	96.8	22.8	59.8	156.5	24.6	29.6	13.8	20.8
Odra-Chal	290.8	60.5	296.1	586.9	26.7	31.6	8.6	18.5
Odra-Raci	362.0	86.9	461.0	823.0	28.3	36.4	9.7	19.0
Klodnica	300.7	75.9	97.7	398.4	44.8	52.0	45.7	45.0
Odra-Gros	839.0	192.3	693.4	1532.4	38.7	45.8	19.0	31.1
Mala Panew	52.3	11.7	41.3	93.6	44.8	51.8	23.3	37.0
Nysa Klod	69.9	22.9	210.8	280.7	43.3	51.7	10.4	21.7
Stobrawa	9.9	2.8	20.7	30.6	44.8	55.1	14.3	27.3
Odra-Wroc	1109.1	237.8	992.0	2101.0	40.2	46.8	17.4	31.2
Olawa	9.1	6.2	53.7	62.8	44.8	43.7	8.2	16.3
Bystrzyca	188.2	20.1	85.7	273.9	44.8	47.3	17.4	38.4
Widawa	28.6	5.6	46.9	75.5	44.8	45.5	9.1	27.0
Kaczawa	75.4	9.5	104.4	179.8	44.8	46.5	7.3	27.9
Odra-Scin	1850.0	328.0	1428.9	3278.9	42.1	47.7	17.3	33.4
Barycz	68.6	14.7	220.0	288.6	44.8	48.4	5.9	19.4
Odra-Nowa	2030.2	364.2	1725.9	3756.1	42.4	48.0	16.3	32.7
Kwisa	10.2	3.4	47.3	57.5	44.8	54.1	7.8	17.5
Bobr	132.1	24.6	212.6	344.8	44.8	50.1	10.4	27.7
Odra-Pole	2242.2	404.9	2013.1	4255.3	42.6	48.1	15.7	32.4
Ny Lu-Zgor	67.2	33.0	132.3	199.5	30.9	31.7	10.4	18.6
Ny Lu-Gubi	118.0	41.7	178.0	296.0	24.4	32.6	10.2	16.5
Odra-Kost	2460.0	456.0	2236.1	4696.0	41.0	46.6	15.1	30.9
Grabia	15.5	2.8	33.3	48.8	44.8	50.7	7.9	24.0
Widawka	39.1	10.9	69.8	108.9	44.8	53.6	15.3	28.9
Warta-Sier	228.0	35.5	219.8	447.7	44.8	52.4	15.1	33.3
Ner	456.7	57.4	142.6	599.2	44.8	51.7	30.1	41.9
Prosna	89.7	19.9	143.8	233.6	44.8	52.1	13.1	28.8
Warta-Pozn	1167.3	203.1	932.0	2099.3	44.8	52.5	19.4	35.8
Welna	35.5	9.9	82.6	118.1	44.8	52.4	11.6	25.1
Obra	12.2	6.7	63.3	75.5	44.8	52.4	10.4	18.6
Notec-Osie	60.9	15.3	227.1	288.1	44.8	50.8	6.5	18.5
Gwda	67.0	17.4	99.4	166.4	44.8	51.1	15.5	30.4
Drawa	6.6	4.3	56.8	63.3	44.8	50.7	7.2	13.3
Notec-Sant	166.9	43.7	409.4	576.3	44.8	50.7	9.9	23.8
Warta-Kost	1827.2	288.6	1607.7	3434.9	44.8	51.6	16.1	34.3
Mysla	15.3	3.0	19.3	34.6	44.8	49.4	13.2	30.7
Odra-Kraj	4334.3	755.8	3928.1	8262.4	42.5	48.4	15.3	32.1
Plonia	20.8	3.0	39.8	60.6	44.8	38.8	4.6	23.6
Ina	129.1	5.6	91.6	220.7	44.8	41.3	4.1	33.0
Odra-Mouth	4556.9	796.9	4173.7	8730.6	42.6	48.1	15.0	32.1
Peene	27.6	15.1	145.5	173.1	0.0	0.0	0.0	0.0
Zarow	2.2	1.8	23.8	25.9	0.0	0.0	0.0	0.0
Uecker	15.2	5.9	87.4	102.6	0.0	0.4	0.0	0.0
Odra Haff	46.6	24.6	264.7	311.3	0.3	2.2	0.2	0.2

Table 6.2: Phosphorus emissions in the Odra by realisation of the scenario P1 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_P$ *P1*	EUR$_P$ *P1*	ED$_P$ *P1*	ET$_P$ *P1*	Red EP$_P$ *P1*	Red EUR$_P$ *P1*	Red.ET$_P$ *P1*	Red.ET$_P$ *P1*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	54.0	4.9	103.4	157.4	-17.2	46.9	4.0	-2.3
Opava	78.0	5.4	98.2	176.2	-17.4	56.7	6.7	-2.6
Ostravice	148.5	22.1	59.1	207.6	-15.7	31.7	14.8	-5.0
Odra-Chal	463.6	45.1	280.8	744.4	-16.9	49.0	13.4	-3.3
Odra-Raci	717.1	72.5	446.5	1163.6	-42.0	46.9	12.6	-14.6
Klodnica	977.9	145.8	167.7	1145.5	-79.5	7.8	6.9	-58.1
Odra-Gros	2124.8	243.2	743.9	2868.8	-55.3	31.4	13.1	-29.0
Mala Panew	165.2	11.4	41.0	206.2	-74.5	52.9	24.0	-38.8
Nysa Klod	249.0	18.3	206.2	455.1	-102.0	61.4	12.4	-26.9
Stobrawa	20.1	4.3	22.1	42.2	-12.2	32.1	8.6	-0.2
Odra-Wroc	2741.5	285.7	1039.3	3780.7	-47.9	36.1	13.5	-23.7
Olawa	115.5	6.8	54.3	169.8	-597.8	38.3	7.2	-126.3
Bystrzyca	476.8	66.5	132.0	608.8	-39.9	-74.2	-27.3	-36.9
Widawa	144.8	6.8	48.0	192.8	-179.8	34.1	6.9	-86.6
Kaczawa	204.2	10.3	105.1	309.4	-49.5	42.1	6.7	-24.1
Odra-Scin	4213.2	459.6	1559.8	5773.0	-31.8	26.7	9.7	-17.3
Barycz	188.0	18.7	223.3	411.4	-51.3	34.2	4.5	-14.9
Odra-Nowa	4636.5	512.3	1872.5	6509.0	-31.6	26.8	9.2	-16.6
Kwisa	43.8	3.9	47.8	91.6	-138.4	47.2	6.9	-31.4
Bobr	397.8	24.6	212.6	610.5	-66.2	50.0	10.4	-28.1
Odra-Pole	5288.2	552.5	2159.2	7447.4	-35.4	29.2	9.6	-18.3
Ny Lu-Zgor	134.1	19.9	119.2	253.3	-37.7	58.8	19.3	-3.4
Ny Lu-Gubi	230.3	26.9	163.2	393.5	-47.5	56.5	17.7	-11.1
Odra-Kost	5627.4	587.8	2366.3	7993.6	-35.0	31.1	10.1	-17.5
Grabia	33.8	3.0	33.4	67.2	-20.7	46.2	7.7	-4.7
Widawka	100.0	8.4	67.0	167.1	-41.4	64.2	18.6	-9.1
Warta-Sier	469.0	36.3	219.8	688.8	-13.6	51.3	15.1	-2.5
Ner	707.3	165.7	250.8	958.1	14.5	-39.4	-22.9	7.1
Prosna	231.7	17.8	141.3	373.0	-42.6	57.2	14.6	-13.7
Warta-Pozn	2171.0	272.5	998.8	3169.7	-2.7	36.2	13.6	3.1
Welna	96.0	8.2	80.8	176.8	-49.2	60.3	13.5	-12.0
Obra	69.3	6.9	63.4	132.7	-213.8	50.8	10.3	-43.1
Notec-Osie	202.0	16.6	227.9	429.9	-83.0	46.9	6.2	-21.6
Gwda	204.6	10.7	92.6	297.2	-68.7	70.0	21.2	-24.4
Drawa	44.4	4.1	56.6	101.0	-274.2	52.5	7.5	-38.3
Notec-Sant	541.8	38.8	403.9	945.7	-79.2	56.2	11.1	-25.0
Warta-Kost	3399.1	379.5	1694.9	5094.1	-2.7	36.3	11.5	2.5
Mysla	36.3	2.7	19.0	55.2	-30.7	54.6	14.6	-10.6
Odra-Kraj	9104.3	978.5	4145.5	13249.8	-20.7	33.2	10.6	-8.8
Plonia	77.8	4.7	41.5	119.3	-106.7	4.5	0.5	-50.3
Ina	123.7	6.3	92.3	215.9	47.1	33.9	3.4	34.4
Odra-Mouth	9305.8	1107.7	4479.2	13785.0	-17.2	27.9	8.8	-7.3
Peene	27.6	11.8	142.3	169.8	0.0	21.8	2.3	1.9
Zarow	2.2	1.4	23.4	25.5	0.0	21.7	1.6	1.5
Uecker	15.2	5.3	86.8	102.0	0.0	10.7	0.7	0.6
Odra Haff	46.4	19.8	259.9	306.3	0.7	21.2	2.0	1.8

Table 6.3: Phosphorus emissions in the Odra by realisation of the scenario P1a and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_P *P1a*	EUR_P *P1a*	ED_P *P1a*	ET_P *P1a*	Red EP_P *P1a*	Red EUR_P *P1a*	Red.ET_P *P1a*	Red.ET_P *P1a*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	28.8	3.7	102.2	131.0	37.6	59.7	5.1	14.8
Opava	41.1	4.2	97.0	138.1	38.1	66.6	7.9	19.6
Ostravice	84.4	16.9	53.8	138.2	34.3	47.8	22.4	30.1
Odra-Chal	249.5	34.7	270.3	519.8	37.1	60.8	16.6	27.9
Odra-Raci	387.3	52.3	426.2	813.6	23.3	61.7	16.5	19.9
Klodnica	539.9	70.7	92.5	632.4	0.9	55.3	48.6	12.7
Odra-Gros	1164.5	139.4	640.1	1804.6	14.9	60.7	25.2	18.9
Mala Panew	91.2	7.3	36.9	128.1	3.6	69.8	31.6	13.8
Nysa Klod	137.0	11.0	198.9	335.9	-11.2	76.8	15.5	6.3
Stobrawa	11.0	2.6	20.4	31.4	38.6	59.2	15.6	25.4
Odra-Wroc	1504.5	166.0	919.5	2424.0	18.9	62.9	23.5	20.7
Olawa	63.8	4.4	51.9	115.7	-285.3	59.9	11.2	-54.2
Bystrzyca	263.2	32.0	97.6	360.8	22.8	16.1	5.9	18.8
Widawa	79.9	4.4	45.7	125.6	-54.5	57.3	11.5	-21.5
Kaczawa	112.8	6.5	101.3	214.1	17.4	63.4	10.0	14.1
Odra-Scin	2317.1	254.2	1354.4	3671.5	27.5	59.4	21.6	25.4
Barycz	103.8	12.4	217.0	320.8	16.5	56.4	7.2	10.4
Odra-Nowa	2550.8	283.6	1643.9	4194.6	27.6	59.5	20.3	24.9
Kwisa	24.2	2.1	46.0	70.2	-31.6	71.0	10.3	-0.8
Bobr	219.7	14.8	202.8	422.5	8.2	69.9	14.5	11.4
Odra-Pole	2910.6	308.4	1915.1	4825.7	25.5	60.5	19.8	23.3
Ny Lu-Zgor	75.7	14.8	114.1	189.8	22.2	69.4	22.7	22.5
Ny Lu-Gubi	147.2	20.5	156.8	303.9	5.7	66.9	20.9	14.2
Odra-Kost	3159.7	336.5	2115.0	5274.7	24.2	60.6	19.7	22.4
Grabia	18.7	2.1	32.5	51.2	33.4	62.2	10.2	20.3
Widawka	55.2	5.4	64.0	119.3	21.9	77.0	22.3	22.1
Warta-Sier	259.0	23.0	206.5	465.4	37.3	69.2	20.2	30.7
Ner	390.5	77.1	162.2	552.7	52.8	35.2	20.5	46.4
Prosna	128.0	12.3	135.8	263.7	21.3	70.4	17.9	19.6
Warta-Pozn	1198.7	147.7	873.9	2072.6	43.3	65.5	24.4	36.6
Welna	53.0	5.1	77.7	130.7	17.6	75.3	16.9	17.2
Obra	38.3	4.2	60.7	99.0	-73.3	70.0	14.1	-6.7
Notec-Osie	111.5	10.6	221.9	333.4	-1.0	66.0	8.7	5.6
Gwda	113.0	7.1	89.1	202.1	6.9	80.0	24.2	15.4
Drawa	24.5	2.8	55.2	79.8	-106.6	68.2	9.7	-9.2
Notec-Sant	299.2	25.2	390.2	689.4	1.0	71.7	14.1	8.9
Warta-Kost	1876.8	210.8	1526.2	3403.0	43.3	64.6	20.3	34.9
Mysla	20.0	1.8	18.1	38.1	27.8	69.1	18.5	23.7
Odra-Kraj	5091.4	557.2	3724.2	8815.6	32.5	62.0	19.7	27.6
Plonia	43.0	2.9	39.7	82.7	-14.1	40.7	4.8	-4.2
Ina	68.3	4.3	90.2	158.5	70.8	55.5	5.6	51.9
Odra-Mouth	5202.6	622.9	3994.3	9197.0	34.5	59.4	18.7	28.4
Peene	27.6	11.8	142.3	169.8	0.0	21.8	2.3	1.9
Zarow	2.2	1.4	23.4	25.5	0.0	21.7	1.6	1.5
Uecker	15.2	5.3	86.8	102.0	0.0	10.9	0.7	0.6
Odra Haff	46.4	19.7	259.9	306.3	0.7	21.5	2.0	1.8

Table 6.4: Phosphorus emissions in the Odra by realisation of the scenario P2 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_P *P2*	EUR_P *P2*	ED_P *P2*	ET_P *P2*	Red EP_P *P2*	Red EUR_P *P2*	Red.ET_P *P2*	Red.ET_P *P2*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	59.8	4.9	103.4	163.2	-29.7	46.9	4.0	-6.1
Opava	86.4	5.4	98.2	184.6	-30.1	56.9	6.8	-7.5
Ostravice	163.2	22.1	59.1	222.3	-27.1	31.7	14.8	-12.4
Odra-Chal	512.7	45.1	280.7	793.5	-29.3	49.0	13.4	-10.1
Odra-Raci	808.6	73.4	447.2	1255.8	-60.1	46.2	12.4	-23.6
Klodnica	1029.9	48.0	69.9	1099.7	-89.1	69.7	61.2	-51.8
Odra-Gros	2355.1	146.0	646.5	3001.6	-72.1	58.9	24.5	-35.0
Mala Panew	198.4	11.3	40.8	239.2	-109.6	53.5	24.3	-61.0
Nysa Klod	283.4	18.3	206.1	489.5	-129.9	61.4	12.4	-36.5
Stobrawa	22.5	3.7	21.6	44.0	-25.2	40.2	10.9	-4.5
Odra-Wroc	3057.4	186.7	939.7	3997.1	-64.9	58.3	21.8	-30.8
Olawa	122.1	5.9	53.3	175.4	-637.4	46.5	8.9	-133.7
Bystrzyca	497.4	17.3	82.9	580.2	-45.9	54.6	20.1	-30.5
Widawa	151.9	5.7	46.8	198.8	-193.7	44.9	9.2	-92.3
Kaczawa	211.1	9.4	104.1	315.2	-54.5	47.1	7.6	-26.5
Odra-Scin	4598.2	244.7	1344.0	5942.2	-43.9	61.0	22.2	-20.7
Barycz	228.6	15.9	219.9	448.5	-83.9	44.1	5.9	-25.3
Odra-Nowa	5071.0	268.4	1627.0	6698.0	-44.0	61.7	21.1	-19.9
Kwisa	55.0	4.1	48.0	102.9	-199.0	44.6	6.5	-47.7
Bobr	455.9	23.9	211.7	667.7	-90.5	51.4	10.8	-40.1
Odra-Pole	5804.0	305.6	1910.3	7714.3	-48.6	60.8	20.0	-22.5
Ny Lu-Zgor	149.1	16.8	116.1	265.2	-53.2	65.2	21.3	-8.3
Ny Lu-Gubi	214.6	23.4	159.6	374.3	-37.5	62.1	19.4	-5.6
Odra-Kost	6050.1	337.3	2113.7	8163.8	-45.2	60.5	19.7	-20.0
Grabia	37.5	2.6	32.9	70.3	-33.6	53.7	9.2	-9.5
Widawka	106.9	7.5	66.0	172.9	-51.1	67.9	19.9	-12.9
Warta-Sier	572.9	34.2	217.3	790.2	-38.7	54.2	16.1	-17.6
Ner	748.3	22.1	107.3	855.6	9.5	81.4	47.4	17.0
Prosna	275.5	15.7	139.0	414.5	-69.5	62.1	16.0	-26.4
Warta-Pozn	2477.3	116.7	840.8	3318.2	-17.2	72.7	27.3	-1.5
Welna	122.6	6.6	79.0	201.7	-90.6	68.0	15.4	-27.8
Obra	79.0	5.4	61.7	140.8	-257.9	61.3	12.6	-51.8
Notec-Osie	238.4	13.4	224.3	462.7	-116.0	57.0	7.7	-30.9
Gwda	218.7	9.0	90.8	309.5	-80.3	74.8	22.8	-29.6
Drawa	51.2	3.6	56.0	107.2	-331.1	58.6	8.4	-46.8
Notec-Sant	615.5	31.9	396.3	1011.8	-103.6	64.1	12.8	-33.7
Warta-Kost	3857.5	183.1	1494.9	5352.3	-16.6	69.3	21.9	-2.4
Mysla	38.5	2.3	18.5	57.0	-38.5	61.2	16.5	-14.1
Odra-Kraj	9983.0	531.2	3692.5	13675.5	-32.4	63.7	20.4	-12.3
Plonia	81.1	3.1	39.8	120.9	-115.5	37.3	4.7	-52.3
Ina	126.7	5.3	91.2	217.9	45.8	44.2	4.5	33.9
Odra-Mouth	10190.8	574.5	3940.0	14130.7	-28.4	62.6	19.8	-10.0
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	3.0	1.4	23.4	26.4	-39.5	21.7	1.6	-1.8
Uecker	18.0	5.3	86.8	104.8	-18.7	10.7	0.7	-2.1
Odra Haff	47.0	19.8	259.9	306.9	-0.6	21.2	2.0	1.6

Table 6.5: Phosphorus emissions in the Odra by realisation of the scenario P2a and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_P$ *P2a*	EUR$_P$ *P2a*	ED$_P$ *P2a*	ET$_P$ *P2a*	Red EP$_P$ *P2a*	Red EUR$_P$ *P2a*	Red.ET$_P$ *P2a*	Red.ET$_P$ *P2a*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	31.8	3.7	102.2	134.0	31.1	59.7	5.1	12.9
Opava	45.5	4.2	97.0	142.5	31.5	66.4	7.9	17.0
Ostravice	92.0	16.9	53.8	145.9	28.3	47.8	22.4	26.2
Odra-Chal	274.9	34.7	270.3	545.3	30.7	60.8	16.6	24.3
Odra-Raci	435.9	53.5	427.3	863.2	13.7	60.8	16.3	15.0
Klodnica	568.6	29.6	51.5	620.1	-4.4	81.3	71.4	14.4
Odra-Gros	1289.7	100.5	601.1	1890.8	5.7	71.7	29.8	15.0
Mala Panew	109.6	7.8	37.3	146.8	-15.7	68.0	30.9	1.2
Nysa Klod	156.0	12.4	200.1	356.1	-26.6	73.9	15.0	0.7
Stobrawa	12.3	2.7	20.5	32.8	31.5	56.7	15.2	22.1
Odra-Wroc	1676.9	129.3	882.4	2559.3	9.6	71.1	26.5	16.2
Olawa	67.4	4.6	52.0	119.4	-307.1	58.3	11.1	-59.1
Bystrzyca	274.6	11.9	77.4	352.1	19.4	68.8	25.4	20.8
Widawa	83.9	4.5	45.7	129.6	-62.2	55.9	11.4	-25.4
Kaczawa	116.6	6.9	101.6	218.2	14.7	61.1	9.8	12.5
Odra-Scin	2527.6	172.0	1271.3	3798.9	20.9	72.6	26.4	22.8
Barycz	126.2	13.0	217.0	343.2	-1.6	54.3	7.2	4.1
Odra-Nowa	2788.7	191.5	1550.1	4338.8	20.8	72.6	24.8	22.3
Kwisa	30.3	2.5	46.4	76.7	-65.1	66.3	9.7	-10.0
Bobr	251.7	16.4	204.2	456.0	-5.2	66.7	13.9	4.3
Odra-Pole	3193.4	218.2	1822.9	5016.3	18.3	72.0	23.7	20.3
Ny Lu-Zgor	85.3	13.7	113.0	198.3	12.3	71.6	23.5	19.0
Ny Lu-Gubi	122.5	19.7	155.9	278.4	21.5	68.2	21.3	21.4
Odra-Kost	3339.3	245.8	2022.2	5361.5	19.9	71.2	23.2	21.2
Grabia	20.7	2.2	32.4	53.1	26.2	61.5	10.4	17.3
Widawka	59.0	5.6	64.0	123.1	16.6	76.4	22.3	19.6
Warta-Sier	316.3	23.9	207.0	523.3	23.4	67.9	20.0	22.1
Ner	413.2	16.7	101.9	515.1	50.0	85.9	50.1	50.0
Prosna	152.1	12.5	135.8	287.9	6.4	69.9	17.9	12.2
Warta-Pozn	1367.9	89.3	813.4	2181.2	35.3	79.1	29.7	33.3
Welna	67.7	5.2	77.6	145.3	-5.2	74.9	17.0	7.9
Obra	43.6	4.2	60.5	104.2	-97.6	69.9	14.3	-12.3
Notec-Osie	131.6	10.6	221.5	353.1	-19.3	66.0	8.9	0.1
Gwda	120.7	7.3	89.2	209.9	0.5	79.5	24.2	12.1
Drawa	28.3	3.0	55.4	83.7	-138.0	65.5	9.4	-14.6
Notec-Sant	339.8	25.5	390.0	729.8	-12.4	71.2	14.2	3.6
Warta-Kost	2129.9	142.0	1453.8	3583.6	35.6	76.2	24.1	31.4
Mysla	21.2	1.9	18.2	39.4	23.5	67.4	18.1	21.1
Odra-Kraj	5519.8	398.1	3559.3	9079.1	26.8	72.8	23.2	25.4
Plonia	44.8	2.6	39.3	84.0	-19.0	48.5	6.0	-5.9
Ina	70.0	4.5	90.3	160.2	70.1	53.4	5.5	51.3
Odra-Mouth	5634.5	428.4	3793.9	9428.4	29.0	72.1	22.8	26.6
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	3.0	1.4	23.4	26.4	-39.5	21.7	1.6	-1.8
Uecker	18.0	5.3	86.8	104.8	-18.7	10.8	0.7	-2.1
Odra Haff	47.0	19.8	259.9	306.9	-0.6	21.4	2.0	1.6

Table 6.6: Phosphorus emissions in the Odra by realisation of the scenario P3 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_P$ *P3*	EUR$_P$ *P3*	ED$_P$ *P3*	ET$_P$ *P3*	Red EP$_P$ *P3*	Red EUR$_P$ *P3*	Red.ET$_P$ *P3*	Red.ET$_P$ *P3*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	11.9	4.9	103.4	115.3	74.1	46.9	4.0	25.0
Opava	16.5	5.4	98.2	114.7	75.2	56.9	6.8	33.2
Ostravice	41.6	22.1	59.1	100.7	67.6	31.7	14.8	49.1
Odra-Chal	106.7	45.1	280.7	387.4	73.1	49.0	13.4	46.2
Odra-Raci	141.3	73.4	447.2	588.5	72.0	46.2	12.4	42.1
Klodnica	121.1	48.0	69.9	190.9	77.8	69.7	61.2	73.6
Odra-Gros	326.7	146.0	646.5	973.2	76.1	58.9	24.5	56.2
Mala Panew	34.6	11.3	40.8	75.4	63.4	53.5	24.3	49.2
Nysa Klod	35.1	18.3	206.1	241.2	71.5	61.4	12.4	32.7
Stobrawa	4.5	3.7	21.6	26.1	74.9	40.2	10.9	38.1
Odra-Wroc	462.0	186.7	939.7	1401.8	75.1	58.3	21.8	54.1
Olawa	3.7	5.9	53.3	57.0	78.0	46.5	8.9	24.1
Bystrzyca	89.1	17.3	82.9	172.0	73.9	54.6	20.1	61.3
Widawa	21.3	5.7	46.8	68.1	58.8	44.9	9.2	34.1
Kaczawa	39.4	9.4	104.1	143.5	71.2	47.1	7.6	42.4
Odra-Scin	776.8	244.7	1344.0	2120.8	75.7	61.0	22.2	56.9
Barycz	33.4	15.9	219.9	253.3	73.1	44.1	5.9	29.2
Odra-Nowa	841.8	268.4	1627.0	2468.9	76.1	61.7	21.1	55.8
Kwisa	4.8	4.1	48.0	52.8	73.7	44.6	6.5	24.3
Bobr	67.7	23.9	211.7	279.5	71.7	51.4	10.8	41.4
Odra-Pole	943.5	305.6	1910.3	2853.8	75.8	60.8	20.0	54.7
Ny Lu-Zgor	31.1	16.8	116.1	147.2	68.0	65.2	21.3	39.9
Ny Lu-Gubi	42.4	23.4	159.6	202.1	72.8	62.1	19.4	43.0
Odra-Kost	1000.9	337.3	2113.7	3114.6	76.0	60.5	19.7	54.2
Grabia	15.4	2.6	32.9	48.3	45.0	53.7	9.2	24.8
Widawka	28.0	7.5	66.0	94.0	60.4	67.9	19.9	38.6
Warta-Sier	162.4	34.2	217.3	379.7	60.7	54.2	16.1	43.5
Ner	109.4	22.1	107.3	216.7	86.8	81.4	47.4	79.0
Prosna	46.9	15.7	139.0	185.9	71.1	62.1	16.0	43.3
Warta-Pozn	490.7	116.7	840.8	1331.5	76.8	72.7	27.3	59.3
Welna	10.8	6.6	79.0	89.8	83.2	68.0	15.4	43.1
Obra	6.9	5.4	61.7	68.7	68.6	61.3	12.6	26.0
Notec-Osie	34.3	13.4	224.3	258.6	68.9	57.0	7.7	26.8
Gwda	34.2	9.0	90.8	125.1	71.8	74.8	22.8	47.6
Drawa	1.1	3.6	56.0	57.1	90.8	58.6	8.4	21.8
Notec-Sant	81.9	31.9	396.3	478.2	72.9	64.1	12.8	36.8
Warta-Kost	778.1	183.1	1494.9	2272.9	76.5	69.3	21.9	56.5
Mysla	7.1	2.3	18.5	25.6	74.6	61.2	16.5	48.8
Odra-Kraj	1797.8	531.2	3692.5	5490.3	76.2	63.7	20.4	54.9
Plonia	8.8	3.1	39.8	48.6	76.5	37.3	4.7	38.7
Ina	44.2	5.3	91.2	135.4	81.1	44.2	4.5	58.9
Odra-Mouth	1850.9	574.5	3940.0	5790.9	76.7	62.6	19.8	54.9
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	0.4	1.4	23.4	23.8	81.4	21.7	1.6	8.3
Uecker	9.9	5.3	86.8	96.7	34.7	10.7	0.7	5.8
Odra Haff	36.3	19.8	259.9	296.2	22.3	21.2	2.0	5.1

Table 6.7: Phosphorus emissions in the Odra by realisation of the scenario P3a and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_P *P3a*	EUR_P *P3a*	ED_P *P3a*	ET_P *P3a*	Red EP_P *P3a*	Red EUR_P *P3a*	Red.ET_P *P3a*	Red.ET_P *P3a*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	14.4	3.7	102.2	116.6	68.8	59.7	5.1	24.2
Opava	20.1	4.2	97.0	117.1	69.8	66.4	7.9	31.8
Ostravice	47.8	16.9	53.8	101.7	62.8	47.8	22.4	48.6
Odra-Chal	127.3	34.7	270.3	397.6	67.9	60.8	16.6	44.8
Odra-Raci	163.6	53.5	427.3	590.9	67.6	60.8	16.3	41.8
Klodnica	120.4	29.6	51.5	171.8	77.9	81.3	71.4	76.3
Odra-Gros	346.5	100.5	601.1	947.5	74.7	71.7	29.8	57.4
Mala Panew	31.6	7.8	37.3	68.8	66.6	68.0	30.9	53.7
Nysa Klod	30.3	12.4	200.1	230.4	75.4	73.9	15.0	35.7
Stobrawa	4.1	2.7	20.5	24.6	77.2	56.7	15.2	41.5
Odra-Wroc	471.2	129.3	882.4	1353.6	74.6	71.1	26.5	55.7
Olawa	3.3	4.6	52.0	55.3	79.9	58.3	11.1	26.3
Bystrzyca	86.3	11.9	77.4	163.7	74.7	68.8	25.4	63.2
Widawa	16.3	4.5	45.7	62.0	68.5	55.9	11.4	40.0
Kaczawa	37.5	6.9	101.6	139.1	72.6	61.1	9.8	44.2
Odra-Scin	774.6	172.0	1271.3	2045.9	75.8	72.6	26.4	58.4
Barycz	29.3	13.0	217.0	246.3	76.4	54.3	7.2	31.2
Odra-Nowa	835.3	191.5	1550.1	2385.3	76.3	72.6	24.8	57.3
Kwisa	4.1	2.5	46.4	50.5	77.5	66.3	9.7	27.5
Bobr	62.2	16.4	204.2	266.5	74.0	66.7	13.9	44.1
Odra-Pole	929.4	218.2	1822.9	2752.3	76.2	72.0	23.7	56.3
Ny Lu-Zgor	34.1	13.7	113.0	147.0	65.0	71.6	23.5	40.0
Ny Lu-Gubi	45.0	19.7	155.9	200.9	71.2	68.2	21.3	43.3
Odra-Kost	988.7	245.8	2022.2	3010.8	76.3	71.2	23.2	55.7
Grabia	15.4	2.2	32.4	47.9	45.0	61.5	10.4	25.5
Widawka	27.5	5.6	64.0	91.6	61.1	76.4	22.3	40.2
Warta-Sier	158.0	23.9	207.0	365.0	61.7	67.9	20.0	45.7
Ner	106.7	16.7	101.9	208.6	87.1	85.9	50.1	79.8
Prosna	42.9	12.5	135.8	178.7	73.6	69.9	17.9	45.5
Warta-Pozn	464.3	89.3	813.4	1277.6	78.0	79.1	29.7	60.9
Welna	10.5	5.2	77.6	88.1	83.6	74.9	17.0	44.2
Obra	6.4	4.2	60.5	66.9	71.0	69.9	14.3	27.8
Notec-Osie	30.6	10.6	221.5	252.1	72.3	66.0	8.9	28.7
Gwda	32.4	7.3	89.2	121.6	73.3	79.5	24.2	49.1
Drawa	0.6	3.0	55.4	56.0	94.9	65.5	9.4	23.3
Notec-Sant	72.5	25.5	390.0	462.4	76.0	71.2	14.2	38.9
Warta-Kost	733.1	142.0	1453.8	2186.8	77.8	76.2	24.1	58.1
Mysla	7.1	1.9	18.2	25.2	74.6	67.4	18.1	49.5
Odra-Kraj	1739.8	398.1	3559.3	5299.2	76.9	72.8	23.2	56.5
Plonia	8.5	2.6	39.3	47.7	77.5	48.5	6.0	39.9
Ina	42.5	4.5	90.3	132.8	81.8	53.4	5.5	59.7
Odra-Mouth	1790.8	428.4	3793.9	5584.7	77.4	72.1	22.8	56.5
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	0.4	1.4	23.4	23.8	81.4	21.7	1.6	8.3
Uecker	9.9	5.3	86.8	96.7	34.7	10.8	0.7	5.8
Odra Haff	36.3	19.8	259.9	296.2	22.3	21.4	2.0	5.1

Table 6.8: Phosphorus emissions in the Odra by realisation of the scenario P4 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_P$ *P4*	EUR$_P$ *P4*	ED$_P$ *P4*	ET$_P$ *P4*	Red EP$_P$ *P4*	Red EUR$_P$ *P4*	Red.ET$_P$ *P4*	Red.ET$_P$ *P4*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	14.8	4.9	103.4	118.2	67.8	46.9	4.0	23.1
Opava	20.8	5.4	98.2	119.0	68.7	56.9	6.8	30.7
Ostravice	49.0	22.1	59.1	108.1	61.8	31.7	14.8	45.3
Odra-Chal	131.4	45.1	280.7	412.1	66.9	49.0	13.4	42.8
Odra-Raci	170.9	73.4	447.2	618.1	66.2	46.2	12.4	39.1
Klodnica	141.5	48.0	69.9	211.4	74.0	69.7	61.2	70.8
Odra-Gros	380.8	146.0	646.5	1027.3	72.2	58.9	24.5	53.8
Mala Panew	23.5	11.3	40.8	64.3	75.2	53.5	24.3	56.7
Nysa Klod	48.4	18.3	206.1	254.5	60.7	61.4	12.4	29.0
Stobrawa	5.6	3.7	21.6	27.2	68.7	40.2	10.9	35.5
Odra-Wroc	529.8	186.7	939.7	1469.5	71.4	58.3	21.8	51.9
Olawa	5.6	5.9	53.3	58.9	65.9	46.5	8.9	21.5
Bystrzyca	100.6	17.3	82.9	183.5	70.5	54.6	20.1	58.7
Widawa	23.8	5.7	46.8	70.6	54.0	44.9	9.2	31.6
Kaczawa	48.5	9.4	104.1	152.6	64.5	47.1	7.6	38.8
Odra-Scin	926.6	244.7	1344.0	2270.7	71.0	61.0	22.2	53.9
Barycz	51.4	15.9	219.9	271.3	58.7	44.1	5.9	24.2
Odra-Nowa	1013.2	268.4	1627.0	2640.3	71.2	61.7	21.1	52.7
Kwisa	12.4	4.1	48.0	60.3	32.8	44.6	6.5	13.4
Bobr	98.7	23.9	211.7	310.4	58.8	51.4	10.8	34.9
Odra-Pole	1152.8	305.6	1910.3	3063.1	70.5	60.8	20.0	51.3
Ny Lu-Zgor	35.2	16.8	116.1	151.3	63.8	65.2	21.3	38.2
Ny Lu-Gubi	46.5	23.4	159.6	206.1	70.2	62.1	19.4	41.8
Odra-Kost	1219.9	337.3	2113.7	3333.6	70.7	60.5	19.7	51.0
Grabia	13.3	2.6	32.9	46.1	52.7	53.7	9.2	28.2
Widawka	27.7	7.5	66.0	93.7	60.9	67.9	19.9	38.8
Warta-Sier	183.3	34.2	217.3	400.6	55.6	54.2	16.1	40.4
Ner	176.3	22.1	107.3	283.6	78.7	81.4	47.4	72.5
Prosna	68.5	15.7	139.0	207.5	57.8	62.1	16.0	36.7
Warta-Pozn	629.0	116.7	840.8	1469.8	70.2	72.7	27.3	55.1
Welna	14.9	6.6	79.0	94.0	76.8	68.0	15.4	40.5
Obra	11.6	5.4	61.7	73.3	47.5	61.3	12.6	20.9
Notec-Osie	44.1	13.4	224.3	268.3	60.1	57.0	7.7	24.1
Gwda	46.5	9.0	90.8	137.3	61.7	74.8	22.8	42.5
Drawa	8.1	3.6	56.0	64.1	32.0	58.6	8.4	12.2
Notec-Sant	134.1	31.9	396.3	530.4	55.6	64.1	12.8	29.9
Warta-Kost	1050.3	183.1	1494.9	2545.2	68.3	69.3	21.9	51.3
Mysla	5.7	2.3	18.5	24.2	79.6	61.2	16.5	51.5
Odra-Kraj	2292.1	531.2	3692.5	5984.5	69.6	63.7	20.4	50.9
Plonia	13.9	3.1	39.8	53.7	63.1	37.3	4.7	32.4
Ina	51.8	5.3	91.2	143.0	77.8	44.2	4.5	56.6
Odra-Mouth	2357.7	574.5	3940.0	6297.7	70.3	62.6	19.8	51.0
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	0.4	1.4	23.4	23.8	81.4	21.7	1.6	8.3
Uecker	9.9	5.3	86.8	96.7	34.7	10.7	0.7	5.8
Odra Haff	36.3	19.8	259.9	296.2	22.3	21.2	2.0	5.1

Table 6.9: Phosphorus emissions in the Odra by realisation of the scenario P4a and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_{P}$ *P4a*	EUR$_{P}$ *P4a*	ED$_{P}$ *P4a*	ET$_{P}$ *P4a*	Red EP$_{P}$ *P4a*	Red EUR$_{P}$ *P4a*	Red.ET$_{P}$ *P4a*	Red.ET$_{P}$ *P4a*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	16.8	3.7	102.2	119.1	63.5	59.7	5.1	22.6
Opava	23.7	4.2	97.0	120.7	64.4	66.4	7.9	29.7
Ostravice	54.1	16.9	53.8	108.0	57.9	47.8	22.4	45.4
Odra-Chal	148.3	34.7	270.3	418.6	62.6	60.8	16.6	41.9
Odra-Raci	187.5	53.5	427.3	614.8	62.9	60.8	16.3	39.5
Klodnica	141.4	29.6	51.5	192.9	74.0	81.3	71.4	73.4
Odra-Gros	392.9	100.5	601.1	993.9	71.3	71.7	29.8	55.3
Mala Panew	23.5	7.8	37.3	60.8	75.2	68.0	30.9	59.1
Nysa Klod	36.7	12.4	200.1	236.8	70.2	73.9	15.0	34.0
Stobrawa	4.7	2.7	20.5	25.2	74.0	56.7	15.2	40.2
Odra-Wroc	522.7	129.3	882.4	1405.1	71.8	71.1	26.5	54.0
Olawa	4.1	4.6	52.0	56.1	75.3	58.3	11.1	25.2
Bystrzyca	93.8	11.9	77.4	171.2	72.5	68.8	25.4	61.5
Widawa	19.2	4.5	45.7	64.9	62.8	55.9	11.4	37.2
Kaczawa	38.6	6.9	101.6	140.2	71.8	61.1	9.8	43.7
Odra-Scin	891.2	172.0	1271.3	2162.5	72.1	72.6	26.4	56.1
Barycz	37.8	13.0	217.0	254.8	69.6	54.3	7.2	28.8
Odra-Nowa	960.3	191.5	1550.1	2510.4	72.7	72.6	24.8	55.0
Kwisa	7.9	2.5	46.4	54.3	56.9	66.3	9.7	22.1
Bobr	79.6	16.4	204.2	283.9	66.7	66.7	13.9	40.4
Odra-Pole	1072.4	218.2	1822.9	2895.3	72.5	72.0	23.7	54.0
Ny Lu-Zgor	36.3	13.7	113.0	149.3	62.7	71.6	23.5	39.0
Ny Lu-Gubi	46.3	19.7	155.9	202.2	70.3	68.2	21.3	42.9
Odra-Kost	1136.1	245.8	2022.2	3158.3	72.7	71.2	23.2	53.6
Grabia	12.5	2.2	32.4	44.9	55.4	61.5	10.4	30.0
Widawka	24.3	5.6	64.0	88.4	65.6	76.4	22.3	42.3
Warta-Sier	167.2	23.9	207.0	374.2	59.5	67.9	20.0	44.3
Ner	167.5	16.7	101.9	269.4	79.8	85.9	50.1	73.9
Prosna	55.3	12.5	135.8	191.1	66.0	69.9	17.9	41.7
Warta-Pozn	561.2	89.3	813.4	1374.6	73.5	79.1	29.7	58.0
Welna	11.7	5.2	77.6	89.3	81.9	74.9	17.0	43.4
Obra	8.3	4.2	60.5	68.9	62.2	69.9	14.3	25.7
Notec-Osie	34.3	10.6	221.5	255.7	69.0	66.0	8.9	27.6
Gwda	38.0	7.3	89.2	127.2	68.7	79.5	24.2	46.8
Drawa	4.5	3.0	55.4	59.9	62.4	65.5	9.4	18.0
Notec-Sant	97.9	25.5	390.0	487.8	67.6	71.2	14.2	35.5
Warta-Kost	915.3	142.0	1453.8	2369.1	72.3	76.2	24.1	54.7
Mysla	5.5	1.9	18.2	23.7	80.2	67.4	18.1	52.6
Odra-Kraj	2070.4	398.1	3559.3	5629.7	72.5	72.8	23.2	53.8
Plonia	10.4	2.6	39.3	49.6	72.5	48.5	6.0	37.5
Ina	47.0	4.5	90.3	137.3	79.9	53.4	5.5	58.3
Odra-Mouth	2127.8	428.4	3793.9	5921.7	73.2	72.1	22.8	53.9
Peene	25.0	11.8	142.3	167.3	9.3	21.8	2.3	3.4
Zarow	0.4	1.4	23.4	23.8	81.4	21.7	1.6	8.3
Uecker	9.9	5.3	86.8	96.7	34.7	10.8	0.7	5.8
Odra Haff	36.3	19.8	259.9	296.2	22.3	21.4	2.0	5.1

Table 6.10: Phosphorus emissions in the Odra by realisation of the scenario P5 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_P *P5*	EUR_P *P5*	ED_P *P5*	ET_P *P5*	Red EP_P *P5*	Red EUR_P *P5*	Red.ET_P *P5*	Red.ET_P *P5*
	[t P/a]	[t P/a]	[tP/a]	[t P/a]	[%]	[%]	[%]	[%]
Odra-Pola	14.4	2.0	100.5	114.9	68.8	78.7	6.7	25.3
Opava	20.1	2.0	94.8	114.9	69.8	84.3	10.0	33.1
Ostravice	47.8	5.1	42.2	90.0	62.8	84.1	39.2	54.5
Odra-Chal	127.3	12.4	248.3	375.6	67.9	86.0	23.4	47.9
Odra-Raci	163.6	19.0	393.6	557.2	67.6	86.1	22.9	45.1
Klodnica	120.4	15.2	37.4	157.8	77.9	90.4	79.2	78.2
Odra-Gros	346.5	42.4	544.3	890.8	74.7	88.1	36.4	60.0
Mala Panew	31.6	3.1	32.7	64.3	66.6	87.2	39.3	56.7
Nysa Klod	30.3	5.6	193.5	223.8	75.4	88.1	17.8	37.6
Stobrawa	4.1	1.9	19.8	23.9	77.2	69.1	18.2	43.3
Odra-Wroc	471.2	58.6	813.3	1284.6	74.6	86.9	32.3	58.0
Olawa	3.3	3.9	51.4	54.7	79.9	64.4	12.2	27.1
Bystrzyca	86.3	6.1	71.8	158.1	74.7	84.0	30.8	64.4
Widawa	16.3	4.4	45.6	61.8	68.5	57.4	11.7	40.2
Kaczawa	37.5	4.8	99.6	137.1	72.6	72.8	11.5	45.0
Odra-Scin	774.6	88.4	1189.9	1964.5	75.8	85.9	31.1	60.1
Barycz	29.3	12.6	216.6	245.9	76.4	55.9	7.3	31.3
Odra-Nowa	835.3	107.3	1468.1	2303.4	76.3	84.7	28.8	58.8
Kwisa	4.1	0.9	44.8	48.9	77.5	88.4	12.8	29.8
Bobr	62.2	9.2	197.2	259.5	74.0	81.3	16.9	45.6
Odra-Pole	929.4	125.5	1732.7	2662.0	76.2	83.9	27.5	57.7
Ny Lu-Zgor	34.1	7.7	107.1	141.2	65.0	84.1	27.4	42.4
Ny Lu-Gubi	45.0	13.4	149.8	194.8	71.2	78.3	24.4	45.0
Odra-Kost	988.7	146.3	1925.3	2914.0	76.3	82.9	26.9	57.2
Grabia	15.4	2.1	32.4	47.8	45.0	62.1	10.5	25.5
Widawka	27.5	3.7	62.3	89.8	61.1	84.1	24.4	41.3
Warta-Sier	158.0	11.8	195.5	353.5	61.7	84.2	24.5	47.4
Ner	106.7	14.6	100.2	206.9	87.1	87.7	50.9	79.9
Prosna	42.9	10.8	134.2	177.1	73.6	74.0	18.9	46.0
Warta-Pozn	464.3	72.0	797.3	1261.6	78.0	83.2	31.1	61.4
Welna	10.5	5.2	77.6	88.1	83.6	75.1	17.0	44.2
Obra	6.4	4.2	60.5	66.9	71.0	70.2	14.4	27.9
Notec-Osie	30.6	10.5	221.4	252.0	72.3	66.3	8.9	28.7
Gwda	32.4	7.2	89.1	121.5	73.3	79.7	24.2	49.1
Drawa	0.6	3.0	55.4	56.0	94.9	65.8	9.4	23.3
Notec-Sant	72.5	25.3	389.8	462.2	76.0	71.5	14.2	38.9
Warta-Kost	733.1	123.8	1436.8	2169.9	77.8	79.2	25.0	58.5
Mysla	7.1	1.9	18.2	25.2	74.6	67.7	18.2	49.5
Odra-Kraj	1739.8	280.3	3445.5	5185.3	76.9	80.9	25.7	57.4
Plonia	8.5	2.4	39.1	47.6	77.5	51.4	6.3	40.0
Ina	42.5	4.4	90.2	132.7	81.8	53.8	5.5	59.7
Odra-Mouth	1790.8	308.5	3678.1	5468.9	77.4	79.9	25.1	57.4
Peene	25.0	11.2	141.6	166.6	9.3	26.0	2.7	3.7
Zarow	0.4	1.4	23.3	23.7	81.4	24.1	1.8	8.4
Uecker	9.9	5.1	86.7	96.6	34.7	13.4	0.9	5.9
Odra Haff	36.3	18.9	259.0	295.3	22.3	24.9	2.4	5.3

Table 6.11: Nitrogen emissions in the Odra by realisation of the scenario P1and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_N$ *P1*	EUR$_N$ *P1*	ED$_N$ *P1*	ET$_N$ *P1*	Red EP$_N$ *P1*	Red EUR$_N$ *P1*	Red.ET$_N$ *P1*	Red.ET$_N$ *P1*
	[t N/a]	[t N/a]	[t Na]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	249	34	2902	3151	-4.2	38.3	0.7	0.3
Opava	341	36	3070	3410	-4.3	48.6	1.1	0.6
Ostravice	695	110	1038	1733	-3.5	31.9	4.7	1.6
Odra-Chal	2226	254	7268	9494	-3.9	45.8	2.8	1.3
Odra-Raci	3546	397	10561	14107	-26.1	41.5	2.7	-3.2
Klodnica	4784	550	1085	5869	-69.7	7.2	3.7	-48.7
Odra-Gros	10432	1099	13537	23969	-46.4	30.2	3.5	-13.3
Mala Panew	808	61	1306	2114	-66.0	50.9	5.0	-13.6
Nysa Klod	1213	116	4508	5721	-65.0	46.9	2.3	-6.9
Stobrawa	112	30	579	692	-3.6	31.1	2.7	1.7
Odra-Wroc	13458	1380	20502	33960	-38.0	32.8	3.3	-9.7
Olawa	565	56	634	1199	-666.4	20.1	2.2	-66.2
Bystrzyca	2333	274	1386	3718	-44.1	-54.8	-7.5	-27.9
Widawa	708	56	898	1607	-203.5	19.0	1.6	-40.2
Kaczawa	999	75	1424	2423	-87.8	26.5	1.9	-22.1
Odra-Scin	20658	2206	26972	47630	-23.7	23.9	2.6	-7.3
Barycz	920	154	4414	5334	-67.3	21.0	1.1	-6.4
Odra-Nowa	22729	2519	32188	54917	-26.7	23.4	2.5	-7.8
Kwisa	214	23	1138	1352	-79.2	42.8	1.6	-6.0
Bobr	1946	167	4941	6887	-55.8	36.2	1.9	-9.5
Odra-Pole	25918	2806	38675	64593	-29.1	24.7	2.5	-8.1
Ny Lu-Zgor	923	130	2276	3199	-17.4	32.7	2.7	-2.4
Ny Lu-Gubi	1571	199	3635	5206	-26.7	28.0	2.1	-5.1
Odra-Kost	28355	3089	43620	71975	-27.9	24.6	2.4	-7.7
Grabia	166	25	493	659	-20.5	31.5	2.6	-2.4
Widawka	489	57	1294	1783	17.6	52.7	4.9	8.8
Warta-Sier	2295	212	4548	6842	25.9	48.3	4.5	12.9
Ner	3461	652	2027	5487	13.3	-32.3	-8.5	6.3
Prosna	1134	133	3528	4662	16.2	44.0	3.2	6.7
Warta-Pozn	10622	1418	17451	28073	11.8	31.0	3.7	6.9
Welna	470	65	1016	1486	-63.3	41.5	4.4	-10.0
Obra	339	54	965	1304	-197.8	34.4	3.0	-17.7
Notec-Osie	988	130	2375	3364	-102.1	32.2	2.7	-14.8
Gwda	1001	83	2082	3083	-29.9	50.8	4.0	-4.9
Drawa	217	33	1379	1597	-306.5	33.0	1.2	-10.1
Notec-Sant	2651	304	6545	9196	-62.9	38.1	2.9	-9.9
Warta-Kost	16631	2138	28472	45102	18.0	29.0	3.1	9.2
Mysla	178	22	452	629	-43.6	34.8	2.6	-7.1
Odra-Kraj	45477	5350	73600	119077	-6.2	26.1	2.6	-0.5
Plonia	381	33	510	891	-124.4	2.2	0.1	-30.9
Ina	605	50	1350	1955	45.2	17.9	0.8	20.7
Odra-Mouth	47031	5870	77126	124157	-4.3	22.8	2.3	-0.1
Peene	586	131	4679	5265	0.0	15.3	0.5	0.4
Zarow	16	16	440	456	0.0	14.0	0.6	0.6
Uecker	154	64	1544	1698	0.0	6.1	0.3	0.2
Odra Haff	803	225	6925	7728	0.2	12.7	0.5	0.4

Table 6.12: Nitrogen emissions in the Odra by realisation of the scenario P2 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_N *P2*	EUR_N *P2*	ED_N *P2*	ET_N *P2*	Red EP_N *P2*	Red EUR_N *P2*	Red.ET_N *P2*	Red.ET_N *P2*
	[t N/a]	[t N/a]	[t Na]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	275	34	2902	3177	-15.0	38.3	0.7	-0.5
Opava	376	35	3069	3445	-15.2	49.4	1.1	-0.4
Ostravice	754	110	1038	1792	-12.2	31.9	4.7	-1.7
Odra-Chal	2435	253	7267	9702	-13.6	45.9	2.8	-0.8
Odra-Raci	3962	388	10547	14509	-40.9	42.8	2.8	-6.2
Klodnica	5039	214	751	5790	-78.7	63.9	33.4	-46.7
Odra-Gros	11527	738	13166	24694	-61.8	53.1	6.2	-16.7
Mala Panew	971	53	1296	2267	-99.3	56.9	5.7	-21.8
Nysa Klod	1380	98	4481	5862	-87.8	55.4	2.9	-9.6
Stobrawa	125	25	573	698	-15.7	43.3	3.9	0.9
Odra-Wroc	14972	982	20080	35052	-53.5	52.2	5.3	-13.2
Olawa	597	50	625	1223	-709.9	28.8	3.4	-69.5
Bystrzyca	2433	98	1206	3640	-50.3	44.8	6.4	-25.2
Widawa	743	49	889	1633	-218.5	28.8	2.6	-42.4
Kaczawa	1033	65	1410	2442	-94.1	36.4	2.9	-23.1
Odra-Scin	22511	1385	26112	48623	-34.8	52.3	5.7	-9.5
Barycz	1118	136	4389	5508	-103.4	29.8	1.6	-9.9
Odra-Nowa	24824	1592	31213	56037	-38.4	51.6	5.4	-10.0
Kwisa	269	19	1133	1402	-124.7	51.7	2.0	-9.9
Bobr	2231	141	4905	7136	-78.6	46.0	2.7	-13.5
Odra-Pole	28411	1834	37641	66052	-41.5	50.8	5.1	-10.6
Ny Lu-Zgor	969	127	2271	3240	-23.2	34.4	2.9	-3.7
Ny Lu-Gubi	1383	194	3627	5009	-11.5	29.9	2.3	-1.2
Odra-Kost	30116	2111	42576	72692	-35.9	48.5	4.7	-8.8
Grabia	183	22	490	673	-33.4	39.0	3.2	-4.6
Widawka	523	48	1282	1805	12.0	60.4	5.7	7.6
Warta-Sier	2803	178	4507	7310	9.5	56.5	5.4	7.0
Ner	3661	163	1538	5200	8.3	66.8	17.6	11.2
Prosna	1348	116	3507	4855	0.3	51.0	3.7	2.8
Warta-Pozn	12121	824	16835	28956	-0.6	59.9	7.1	4.0
Welna	600	54	1004	1604	-108.5	51.2	5.5	-18.8
Obra	387	44	954	1340	-239.7	46.5	4.1	-20.9
Notec-Osie	1166	109	2350	3517	-138.5	43.5	3.7	-20.1
Gwda	1070	70	2068	3138	-38.8	58.1	4.6	-6.8
Drawa	250	30	1375	1625	-368.3	39.5	1.5	-12.1
Notec-Sant	3011	255	6489	9500	-85.0	48.0	3.7	-13.6
Warta-Kost	18873	1358	27653	46526	6.9	54.9	5.9	6.3
Mysla	188	19	449	637	-52.1	42.3	3.3	-8.4
Odra-Kraj	49470	3591	71735	121206	-15.5	50.4	5.1	-2.3
Plonia	397	25	502	899	-134.0	24.4	1.7	-32.1
Ina	620	44	1341	1961	43.9	28.7	1.4	20.4
Odra-Mouth	51059	3867	75016	126075	-13.3	49.1	5.0	-1.6
Peene	416	131	4679	5095	29.0	15.3	0.5	3.7
Zarow	16	16	440	456	1.0	14.0	0.6	0.6
Uecker	141	64	1544	1685	8.2	6.1	0.3	1.0
Odra Haff	617	225	6925	7542	23.3	12.7	0.5	2.8

Table 6.13: Nitrogen emissions in the Odra by realisation of the scenario P3 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_N$ *P3*	EUR$_N$ *P3*	ED$_N$ *P3*	ET$_N$ *P3*	Red EP$_N$ *P3*	Red EUR$_N$ *P3*	Red.ET$_N$ *P3*	Red.ET$_N$ *P3*
	[t N/a]	[t N/a]	[t Na]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	94	34	2902	2996	60.5	38.3	0.7	5.2
Opava	126	35	3069	3194	61.5	49.4	1.1	6.9
Ostravice	339	110	1038	1377	49.5	31.9	4.7	21.8
Odra-Chal	966	253	7267	8233	54.9	45.9	2.8	14.4
Odra-Raci	1314	388	10547	11861	53.3	42.8	2.8	13.2
Klodnica	1076	214	751	1827	61.8	63.9	33.4	53.7
Odra-Gros	2912	738	13166	16079	59.1	53.1	6.2	24.0
Mala Panew	260	53	1296	1556	46.6	56.9	5.7	16.4
Nysa Klod	264	98	4481	4745	64.1	55.4	2.9	11.3
Stobrawa	41	25	573	614	62.2	43.3	3.9	12.8
Odra-Wroc	3980	982	20080	24060	59.2	52.2	5.3	22.3
Olawa	27	50	625	653	62.9	28.8	3.4	9.5
Bystrzyca	741	98	1206	1948	54.2	44.8	6.4	33.0
Widawa	160	49	889	1049	31.6	28.8	2.6	8.5
Kaczawa	295	65	1410	1705	44.5	36.4	2.9	14.1
Odra-Scin	6699	1385	26112	32811	59.9	52.3	5.7	26.1
Barycz	251	136	4389	4640	54.4	29.8	1.6	7.4
Odra-Nowa	7201	1592	31213	38414	59.9	51.6	5.4	24.6
Kwisa	36	19	1133	1169	69.7	51.7	2.0	8.4
Bobr	548	141	4905	5453	56.1	46.0	2.7	13.3
Odra-Pole	8003	1834	37641	45644	60.1	50.8	5.1	23.6
Ny Lu-Zgor	360	127	2271	2631	54.3	34.4	2.9	15.8
Ny Lu-Gubi	532	194	3627	4158	57.1	29.9	2.3	16.0
Odra-Kost	8781	2111	42576	51358	60.4	48.5	4.7	23.2
Grabia	116	22	490	606	15.7	39.0	3.2	5.9
Widawka	210	48	1282	1492	64.7	60.4	5.7	23.7
Warta-Sier	1319	178	4507	5826	57.4	56.5	5.4	25.9
Ner	1079	163	1538	2617	73.0	66.8	17.6	55.3
Prosna	379	116	3507	3885	72.0	51.0	3.7	22.2
Warta-Pozn	4123	824	16835	20958	65.8	59.9	7.1	30.5
Welna	81	54	1004	1085	71.9	51.2	5.5	19.7
Obra	52	44	954	1006	54.3	46.5	4.1	9.3
Notec-Osie	257	109	2350	2608	47.4	43.5	3.7	11.0
Gwda	273	70	2068	2341	64.5	58.1	4.6	20.3
Drawa	8	30	1375	1383	84.6	39.5	1.5	4.6
Notec-Sant	631	255	6489	7119	61.2	48.0	3.7	14.9
Warta-Kost	6551	1358	27653	34204	67.7	54.9	5.9	31.1
Mysla	53	19	449	502	57.2	42.3	3.3	14.6
Odra-Kraj	15541	3591	71735	87277	63.7	50.4	5.1	26.3
Plonia	66	25	502	569	60.9	24.4	1.7	16.5
Ina	365	44	1341	1706	67.0	28.7	1.4	30.8
Odra-Mouth	16331	3867	75016	91347	63.8	49.1	5.0	26.4
Peene	396	131	4679	5075	32.4	15.3	0.5	4.0
Zarow	7	16	440	447	56.7	14.0	0.6	2.6
Uecker	129	64	1544	1673	15.9	6.1	0.3	1.7
Odra Haff	572	225	6925	7497	28.9	12.7	0.5	3.4

Table 6.14: Nitrogen emissions in the Odra by realisation of the scenario P4 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP_N *P4*	EUR_N *P4*	ED_N *P4*	ET_N *P4*	Red EP_N *P4*	Red EUR_N *P4*	Red.ET_N *P4*	Red.ET_N *P4*
	[t N/a]	[t N/a]	[t Na]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	214	34	2902	3116	10.4	38.3	0.7	1.4
Opava	292	35	3069	3361	10.6	49.4	1.1	2.0
Ostravice	615	110	1038	1653	8.5	31.9	4.7	6.2
Odra-Chal	1941	253	7267	9208	9.4	45.9	2.8	4.3
Odra-Raci	2626	388	10547	13173	6.6	42.8	2.8	3.6
Klodnica	2827	214	751	3578	-0.3	63.9	33.4	9.3
Odra-Gros	6677	738	13166	19843	6.3	53.1	6.2	6.2
Mala Panew	470	53	1296	1766	3.5	56.9	5.7	5.1
Nysa Klod	572	98	4481	5053	22.2	55.4	2.9	5.5
Stobrawa	96	25	573	668	11.6	43.3	3.9	5.1
Odra-Wroc	9038	982	20080	29118	7.3	52.2	5.3	6.0
Olawa	65	50	625	690	12.5	28.8	3.4	4.4
Bystrzyca	1800	98	1206	3006	-11.2	44.8	6.4	-3.4
Widawa	333	49	889	1222	-42.7	28.8	2.6	-6.6
Kaczawa	660	65	1410	2069	-24.0	36.4	2.9	-4.3
Odra-Scin	16089	1385	26112	42200	3.7	52.3	5.7	5.0
Barycz	603	136	4389	4992	-9.6	29.8	1.6	0.4
Odra-Nowa	17275	1592	31213	48488	3.7	51.6	5.4	4.8
Kwisa	109	19	1133	1241	9.2	51.7	2.0	2.7
Bobr	1378	141	4905	6283	-10.3	46.0	2.7	0.1
Odra-Pole	19207	1834	37641	56848	4.4	50.8	5.1	4.8
Ny Lu-Zgor	688	127	2271	2960	12.5	34.4	2.9	5.3
Ny Lu-Gubi	934	194	3627	4560	24.7	29.9	2.3	7.9
Odra-Kost	20418	2111	42576	62995	7.9	48.5	4.7	5.8
Grabia	242	22	490	731	-75.9	39.0	3.2	-13.6
Widawka	449	48	1282	1732	24.4	60.4	5.7	11.4
Warta-Sier	3163	178	4507	7670	-2.2	56.5	5.4	2.4
Ner	3250	163	1538	4789	18.6	66.8	17.6	18.3
Prosna	957	116	3507	4464	29.2	51.0	3.7	10.6
Warta-Pozn	10462	824	16835	27296	13.1	59.9	7.1	9.5
Welna	197	54	1004	1201	31.6	51.2	5.5	11.1
Obra	130	44	954	1084	-14.3	46.5	4.1	2.2
Notec-Osie	575	109	2350	2925	-17.6	43.5	3.7	0.1
Gwda	665	70	2068	2733	13.7	58.1	4.6	7.0
Drawa	48	30	1375	1423	9.4	39.5	1.5	1.8
Notec-Sant	1549	255	6489	8038	4.8	48.0	3.7	3.9
Warta-Kost	16786	1358	27653	44439	17.2	54.9	5.9	10.5
Mysla	108	19	449	557	12.5	42.3	3.3	5.2
Odra-Kraj	37492	3591	71735	109228	12.5	50.4	5.1	7.8
Plonia	168	25	502	670	1.1	24.4	1.7	1.6
Ina	887	44	1341	2228	19.6	28.7	1.4	9.6
Odra-Mouth	39321	3867	75016	114337	12.8	49.1	5.0	7.8
Peene	396	131	4679	5075	32.4	15.3	0.5	4.0
Zarow	7	16	440	447	56.7	14.0	0.6	2.6
Uecker	129	64	1544	1673	15.9	6.1	0.3	1.7
Odra Haff	572	225	6925	7497	28.9	12.7	0.5	3.4

Table 6.15: Nitrogen emissions in the Odra by realisation of the scenario P5 and changes in relation to the period 1993-1997 (negative values = increase of emissions).

Short name	EP$_N$ *P5*	EUR$_N$ *P5*	ED$_N$ *P5*	ET$_N$ *P5*	Red EP$_N$ *P5*	Red EUR$_N$ *P5*	Red.ET$_N$ *P5*	Red.ET$_N$ *P5*
	[t N/a]	[t N/a]	[t Na]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	94	28	2902	2997	60.5	48.6	0.7	5.2
Opava	126	28	3069	3194	61.5	60.5	1.1	6.9
Ostravice	339	58	995	1334	49.5	64.4	8.7	24.3
Odra-Chal	966	155	7208	8175	54.9	66.8	3.6	15.1
Odra-Raci	1314	236	10456	11769	53.3	65.2	3.7	13.9
Klodnica	1076	148	707	1783	61.8	75.0	37.3	54.8
Odra-Gros	2912	481	13007	15920	59.1	69.5	7.3	24.8
Mala Panew	260	33	1283	1543	46.6	73.0	6.7	17.1
Nysa Klod	264	69	4464	4728	64.1	68.6	3.3	11.6
Stobrawa	41	22	570	611	62.2	50.1	4.2	13.1
Odra-Wroc	3980	671	19887	23867	59.2	67.3	6.2	22.9
Olawa	27	47	623	651	62.9	32.8	3.8	9.8
Bystrzyca	741	71	1190	1932	54.2	59.7	7.7	33.6
Widawa	160	49	889	1049	31.6	29.7	2.6	8.5
Kaczawa	295	55	1403	1698	44.5	45.9	3.4	14.4
Odra-Scin	6699	1016	25881	32580	59.9	65.0	6.6	26.6
Barycz	251	135	4388	4639	54.4	30.8	1.7	7.4
Odra-Nowa	7201	1221	30980	38181	59.9	62.9	6.1	25.1
Kwisa	36	11	1126	1163	69.7	72.5	2.6	8.9
Bobr	548	107	4880	5428	56.1	59.1	3.1	13.7
Odra-Pole	8003	1424	37380	45383	60.1	61.8	5.7	24.0
Ny Lu-Zgor	360	101	2255	2615	54.3	47.7	3.5	16.3
Ny Lu-Gubi	532	167	3610	4142	57.1	39.6	2.8	16.4
Odra-Kost	8781	1672	42297	51078	60.4	59.2	5.3	23.6
Grabia	116	22	490	606	15.7	39.4	3.3	5.9
Widawka	210	40	1277	1487	64.7	66.6	6.1	23.9
Warta-Sier	1319	127	4471	5790	57.4	69.0	6.1	26.3
Ner	1079	155	1532	2611	73.0	68.6	18.0	55.4
Prosna	379	109	3502	3880	72.0	54.0	3.9	22.3
Warta-Pozn	4123	751	16784	20907	65.8	63.4	7.4	30.7
Welna	81	54	1004	1085	71.9	51.3	5.6	19.7
Obra	52	44	953	1005	54.3	46.7	4.1	9.3
Notec-Osie	257	108	2350	2607	47.4	43.7	3.7	11.0
Gwda	273	70	2068	2341	64.5	58.2	4.6	20.4
Drawa	8	30	1375	1383	84.6	39.7	1.5	4.6
Notec-Sant	631	254	6488	7119	61.2	48.1	3.7	14.9
Warta-Kost	6551	1281	27598	34150	67.7	57.4	6.1	31.2
Mysla	53	19	449	502	57.2	42.5	3.3	14.6
Odra-Kraj	15541	3076	71402	86943	63.7	57.5	5.5	26.6
Plonia	66	25	502	568	60.9	26.1	1.8	16.5
Ina	365	43	1341	1706	67.0	28.9	1.4	30.8
Odra-Mouth	16331	3344	74677	91008	63.8	56.0	5.4	26.6
Peene	396	129	4678	5074	32.4	16.5	0.5	4.1
Zarow	7	16	440	447	56.7	14.6	0.6	2.6
Uecker	129	64	1544	1673	15.9	6.8	0.3	1.7
Odra Haff	572	223	6923	7496	28.9	13.7	0.5	3.4

6.2 Diffuse Source Scenarios

6.2.1 Definition of the Diffuse Source Scenarios

6.2.1.1 Scenarios for Nutrient Emissions via Erosion

Basics:

There were no scenario calculations designed for nutrient emissions via surface runoff. The very rough calculation method applied and also the data base cannot provide new or better results compared with the basic method described in Chapter 4.1.2.3.

Scenario E0 documents the basic situation linking all the data described for soil, topography, soil cover and management, and long-term average annual rainstorm conditions. The calculation was performed with the original data sets for all the three countries which came from VUMOP, IMUZ, and ZALF. Several assumptions were necessary: for substituting missing data on arable land, a portion of 80 % of the agricultural land was assumed (in case of the MMK for the German part). Soils with management or cultivation difficulties are the first ones to be set aside or to be subject to land use changes in the case of economical changes in agriculture. The municipality-oriented GIS database available in this study has hindered such calculations. The following assumptions were made for scenario calculations to demonstrate the effects of changed land use and management practices on sediment yields and nutrient loads caused by water erosion:

Scenario E1 – “Status Quo”

Intention for Scenario 1:	Simulating the erosion-induced processes for actual agricultural conditions at arable land using the statistical land use data collected by IGB.
Initial condition:	Because of missing values of factors R and L for the Czech part, adapting to the Czech database and filling the gaps in data was necessary. The R factor was assumed to 40 N/h/a, the LS factor to 2.5. Doing so, an additional factor was needed to arrive a similar level of soil loss.

An insignificantly higher portion of mono-cultures and crop rotations without catch crops, assuming unchanged agricultural conditions, is simulated by increasing the C factor by 10 % for the entire basin. Also a portion of 10 % of arable land was taken away for permanent land use change (sealing or afforesting, see remarks at the end of this chapter). This scenario calculation is nearly comparable with Scenario 0.

Scenario E2 – “Initiation of Best Management Practices – step 1”

Intention for Scenario 2:	Simulating a reduction of soil erosion at arable land using “Best management practices” and an assumed loss of arable land by 10 %.
Initial condition:	Factors and area as from scenario 1

Assumption:	The initiation of conservation tillage and certain changes in crop rotation causing improved soil covering by plants and their residues at a part of each catchment is represented by a C factor reduced by 10 %.

Scenario E3 – "Initiation of Best Management Practices at the entire arable land – step 2"

Intention for Scenario 3:	Simulating a strong reduction of soil erosion using "Best management practices" at arable land as a whole
Initial condition:	Factors and area as from scenario 1
Assumption:	A strong reduction of the basic C factor by 50 %. This means, conservation tillage is applied at the entire arable land in the Odra basin in general. Also the effect of set-aside fields is included.

A particular reduction of arable land was not yet integrated into the scenarios. The loss of arable land by permanent changes, in this case by sealing or by taking out and changing into forest, is difficult to be localised but may get up to 20 % for Poland (see Chapter 4.2.2.2). The effect of those possible changes is indirectly integrated into the reduced C factors.

6.2.1.2 Scenarios for Subsurface Nitrogen Emissions

Basics:

The sum from agricultural N surplus and atmospheric N deposition at the soil surface, $N_0(i,j)$, is taken as "N surplus" and "N input" once related to a reference year, respectively. For areas of forests and gardens, omitting detailed analyses of surplus/deposition/denitrification, lumped N leakage values were specified to 5 kg/ha/a and 35 kg/ha/a, respectively. Atmospheric N deposition is left constant after the year 2000. The spatial distribution of N input is based on estimates for the year 1995 and retained unchanged afterwards. Travelling and residence times for vertical resp. lateral transport have been previously determined and stored in 250 m grids. N reduction k_v in the aeration zone and the reaction constant k_l of nitrate decomposition in the aquifer are assessed and regionalised as preliminarily calibrated for the validation catchments (Chapter 5.1.2.6).

Scenario assumptions:

Scenario S0 – "Business as usual"

Intention for Scenario 0:	Simulating the N load development beyond the year 2000, assuming unmodified agricultural nutrient management and constant atmospheric N deposition
Initial condition:	Agricultural N surplus extrapolated from the known distribution and development (1995) to the year 2000, resulting in a scaling factor of 1.02.

Assumption: Constant N input distribution between 2000 and 2020

Scenario S1 – "Increase of N surplus"

Intention for Scenario 1: Simulating the N load development beyond the year 2000, assuming increasing N input but constant N deposition

Initial condition: N input for 2000 (such as Scenario 0)

Assumption: Increase of N surplus (agricultural area only) by a factor of 1.2 and 1.3 until 2010 and 2020, respectively

Scenario S2 – "Decrease of N surplus"

Intention for Scenario 2: Simulating the N load development beyond the year 2000, assuming decrease of N input but constant N deposition

Initial condition: N input for 2000 (such as Scenarios 0/1)

Assumption: Reduction of N surplus (agricultural area only) multiplying by 0.8 and 0.7 until 2010 and 2020, respectively

The above scenarios were elaborated taking into consideration the predicted use of nitrogen and decreasing agricultural land. According to the official strategies for agricultural development elaborated by the *Polish Ministry of Agriculture* (1999), the weak and very weak soils should not be used for agricultural purposes because of conceivable economical problems. As well some agricultural land is required to be afforested from the nature protection point of view (Siuta et al. 1999). It means that in the Odra catchment about 20 % of the land may be withdrawn from agricultural use.

The change of the surplus of nitrogen has been analysed for the next 20 years (Michna et al. 1998). All predictions show the use of nitrogen to be increasing, because of very low application nowadays. In some areas with good soils and big farms, the increased level of fertiliser application can be even 50 to 70 % higher than present.

On the other hand, implementation of the best agricultural practice and increasing of the yield allowed one to assume that increasing of the resulting nitrogen surplus will not be very high. With higher yields more nitrogen will be exported outside the farm area.

As the analysis has shown, it is not possible to give an exact estimation of the changes of agriculture. Therefore, for scenario calculations was assumed in a simplified manner, as stated above, that the final (2020) surplus at agricultural land will be increased by 30 % for scenario 1, and decreased by 30 % for scenario 2 in comparison to scenario 0.

6.2.2 Results of the Diffuse Source Scenario Calculations

6.2.2.1 Results of the Scenarios for Erosion

The results of the NIIRS model relating the present state and the Scenarios E1, E2, E3 are given as specific data for the sub catchments in the Tables 6.16 and 6.17.

Table 6.18 shows the P-emissions by erosion for the scenarios E1, E2 and E3 estimated by means of MONERIS for the Odra and its sub catchments. Additionally this table includes the reduction of the P-emissions for the total Odra basin and the sub catchments in relation to the present state (basic scenario E0). The starting point for the scenario calculations of NIIRS and MONERIS was the soil losses estimated by NIIRS in the Table 6.16 and 6.17.

A comparison of the model results for the scenario calculations by means of NIIRS and MONERIS is given for three catchments within the Odra basin in the Figure 6.3. Besides the remaining fact that the P-inputs by erosion calculated with MONERIS are about 50% higher than the P-inputs calculated with NIIRS (see Chapter 5.2.4.3) the relative differences between the results of both models for the scenarios are low. Only for the Warta in scenario E3 the deviation between the results of both models is more than 5%.

Regarding the changes of the P-inputs it is shown in Table 6.18 and Figure 6.3 that a substantial reduction of the P-inputs is only possible if the measures of the scenario E3 will be realized.

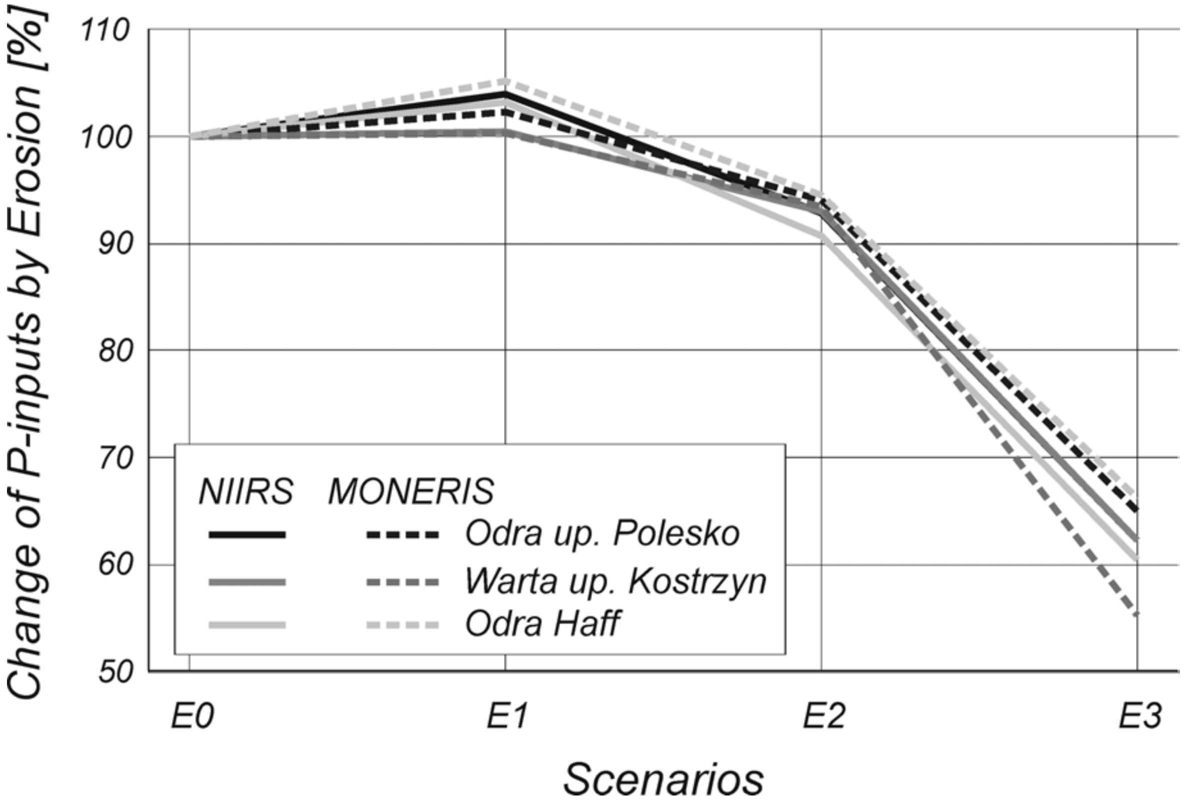

Figure 6.3: Comparison of the scenario results estimated for the Odra upstream Polesko, the Warta upstream Kostrzyn and the Odra Haff by the models NIIRS and MONERIS.

Table 6.16: Soil loss, sediment yield, and nutrient loads estimated for the scenario E0 (basic scenario) and E1 for the evaluated catchments by NIIRS.

Catchment name	Basin area km²	Arable land km²	Basic scenario (Sc E0)					Scenario E1				
			BA_{AL} t/ha	$BA_{\_WF}$ t/ha	BA_{SPEZ} kg/ha	N_{SPEZ} kg/ha	P_{SPEZ} kg/ha	BA_{AL} t/ha	BA_{WF} t/ha	BA_{SPEZ} kg/ha	N_{SPEZ} kg/ha	P_{SPEZ} kg/ha
Odra - Polanka	1569.8	669.3	6.392	2.725	0.145	0.478	0.308	6.685	2.850	0.148	0.493	0.318
Opawa	2066.1	738.2	5.045	1.803	0.118	0.385	0.235	4.805	1.717	0.115	0.372	0.227
Ostravice	816.8	165.6	5.942	1.205	0.102	0.323	0.208	8.223	1.667	0.118	0.402	0.259
Odra - Chalupki	237.6	74.9	6.253	1.972	0.149	0.486	0.298	14.199	4.478	0.209	0.812	0.498
Odra - Raciborz	2092.6	1060.2	4.010	2.032	0.125	0.383	0.245	5.298	2.684	0.143	0.466	0.298
Klodnica	1104.1	486.7	1.013	0.446	0.063	0.159	0.101	1.013	0.446	0.063	0.159	0.101
Odra - Groszowice	2984.1	1733.1	1.851	1.075	0.090	0.286	0.176	1.712	0.995	0.087	0.271	0.167
Mala Panew	2084.8	607.8	0.758	0.221	0.043	0.112	0.071	0.758	0.221	0.043	0.112	0.071
Nysa Klodzka	4500.2	1980.8	2.435	1.072	0.090	0.246	0.158	2.324	1.023	0.088	0.238	0.153
Stobrawa	1592.9	736.3	0.521	0.241	0.046	0.104	0.067	0.521	0.241	0.046	0.104	0.067
Odra - Wroclaw	1357.8	677.6	0.498	0.249	0.048	0.095	0.064	0.498	0.249	0.048	0.095	0.064
Olawa	1166.4	797.9	1.572	1.075	0.094	0.189	0.135	1.572	1.075	0.094	0.189	0.135
Bystrzyca	1750.0	974.5	1.672	0.931	0.086	0.178	0.123	1.848	1.029	0.090	0.191	0.132
Widawa	1707.2	1244.5	0.651	0.475	0.063	0.119	0.083	0.651	0.475	0.063	0.119	0.083
Kaczawa	2247.5	1195.7	1.546	0.822	0.080	0.174	0.131	1.546	0.822	0.080	0.174	0.131
Odra - Scinawa	2352.3	1573.1	1.249	0.835	0.081	0.142	0.108	1.249	0.835	0.081	0.142	0.108
Barycz	5490.4	2826.7	0.644	0.332	0.050	0.147	0.087	0.710	0.366	0.053	0.157	0.093
Odra - Nowa Sol	1642.3	811.6	0.766	0.379	0.057	0.117	0.083	0.766	0.379	0.057	0.117	0.083
Kwisa	1028.3	393.7	2.048	0.784	0.082	0.182	0.136	2.071	0.793	0.083	0.183	0.137
Bobr	4843.7	1436.2	1.285	0.381	0.054	0.123	0.090	1.432	0.425	0.057	0.132	0.097
Odra - Polecko	4715.8	1688.4	0.581	0.208	0.040	0.096	0.064	0.581	0.208	0.040	0.096	0.064
Nysa Luzycka Z	1627.5	569.7	5.218	1.826	0.119	0.441	0.251	5.991	2.043	0.126	0.475	0.271
Nysa Luzycka G	2427.9	569.5	0.718	0.168	0.038	0.107	0.061	0.730	0.170	0.038	0.106	0.061
Odra - Kostrzyn	2228.9	602.9	0.917	0.248	0.045	0.113	0.066	0.964	0.253	0.046	0.115	0.068
Grabia	788.6	419.7	0.517	0.275	0.053	0.085	0.050	0.595	0.317	0.057	0.093	0.054
Widawka	1515.8	733.7	0.540	0.261	0.048	0.075	0.045	0.540	0.261	0.048	0.075	0.045
Warta - Sieradz	5705.8	2808.6	1.045	0.514	0.062	0.113	0.068	1.045	0.514	0.062	0.113	0.068
Ner	1824.3	1085.9	0.478	0.285	0.049	0.086	0.051	0.478	0.285	0.049	0.086	0.051
Prosna	4803.6	2868.6	0.630	0.376	0.054	0.105	0.071	0.630	0.376	0.054	0.105	0.071
Warta - Poznan	11064.4	6700.4	0.593	0.359	0.052	0.114	0.062	0.593	0.359	0.052	0.114	0.062
Welna	2622.7	1526.7	0.445	0.259	0.046	0.083	0.050	0.445	0.259	0.046	0.083	0.050
Obra	2730.4	1040.8	0.397	0.151	0.036	0.071	0.043	0.397	0.151	0.036	0.071	0.043
Notec - Osiek	5491.8	3275.9	0.574	0.342	0.051	0.103	0.062	0.574	0.342	0.051	0.103	0.062
Gwda	4907.6	1751.8	0.499	0.178	0.037	0.052	0.038	0.499	0.178	0.037	0.052	0.038
Drawa	3277.1	1030.2	0.733	0.231	0.043	0.067	0.051	0.790	0.248	0.044	0.071	0.054
Notec - mouth	3516.5	1060.2	0.533	0.161	0.036	0.056	0.036	0.533	0.161	0.036	0.056	0.036
Warta – Kostrzyn	5876.7	2203.5	0.520	0.195	0.039	0.071	0.041	0.520	0.195	0.039	0.071	0.041
Mysla	1330.7	553.1	0.510	0.212	0.044	0.079	0.049	0.510	0.212	0.044	0.079	0.049
Odra - Krajnik	2771.9	1359.0	1.025	0.502	0.063	0.202	0.105	1.106	0.516	0.064	0.207	0.108
Peonia	1065.0	574.2	1.078	0.581	0.071	0.161	0.123	1.078	0.581	0.071	0.161	0.123
Ina	2198.1	1122.1	1.139	0.581	0.068	0.143	0.101	1.139	0.581	0.068	0.143	0.101
Odra - mouth	3447.1	1354.1	1.213	0.476	0.061	0.151	0.095	1.278	0.486	0.061	0.153	0.097
Peene	4990.9	2298.3	0.983	0.453	0.059	0.182	0.087	1.081	0.467	0.059	0.188	0.090
Zarow	739.4	285.2	1.330	0.513	0.070	0.237	0.111	1.464	0.529	0.071	0.245	0.114
Uecker	2436.3	1006.1	1.493	0.617	0.070	0.322	0.125	1.642	0.636	0.071	0.333	0.129
Odra Haff	701.1	183.5	0.541	0.142	0.042	0.248	0.070	0.589	0.146	0.042	0.254	0.072

Table 6.17: Soil loss, sediment yield, and nutrient loads estimated by NIIRS for the scenarios E2 and E3 for the evaluated catchments.

Catchment name	Basin area km²	Arable land km²	Scenario E2					Scenario E3				
			BA_{AL} t/ha	BA_{WF} t/ha	BA_{SPEZ} kg/ha	N_{SPEZ} kg/ha	P_{SPEZ} kg/ha	BA_{AL} t/ha	BA_{WF} t/ha	BA_{SPEZ} kg/ha	N_{SPEZ} kg/ha	P_{SPEZ} kg/ha
Odra - Polanka	1569.8	669.3	5.470	2.186	0.130	0.416	0.268	3.039	1.215	0.098	0.277	0.179
Opawa	2066.1	738.2	3.989	1.350	0.102	0.318	0.195	2.216	0.750	0.077	0.212	0.130
Ostravice	816.8	165.6	6.728	1.279	0.105	0.341	0.220	3.738	0.710	0.080	0.231	0.149
Odra - Chalupki	237.6	74.9	11.601	3.437	0.187	0.695	0.427	6.445	1.910	0.147	0.483	0.296
Odra - Raciborz	2092.6	1060.2	4.492	2.242	0.131	0.412	0.263	2.496	1.246	0.098	0.274	0.175
Klodnica	1104.1	486.7	0.906	0.399	0.060	0.147	0.094	0.503	0.222	0.046	0.101	0.064
Odra - Groszowice	2984.1	1733.1	1.520	0.880	0.082	0.249	0.153	0.845	0.489	0.062	0.166	0.102
Mala Panew	2084.8	607.8	0.679	0.198	0.041	0.104	0.066	0.377	0.110	0.032	0.070	0.045
Nysa Klodzka	4500.2	1980.8	2.034	0.889	0.082	0.216	0.139	1.130	0.494	0.061	0.143	0.092
Stobrawa	1592.9	736.3	0.469	0.217	0.044	0.097	0.062	0.260	0.120	0.034	0.066	0.043
Odra - Wroclaw	1357.8	677.6	0.448	0.224	0.045	0.088	0.060	0.249	0.124	0.035	0.060	0.041
Olawa	1166.4	797.9	1.410	0.965	0.089	0.176	0.126	0.783	0.536	0.068	0.118	0.085
Bystrzyca	1750.0	974.5	1.512	0.842	0.082	0.167	0.115	0.840	0.468	0.062	0.112	0.077
Widawa	1707.2	1244.5	0.576	0.420	0.059	0.109	0.077	0.320	0.233	0.045	0.074	0.052
Kaczawa	2247.5	1195.7	1.377	0.733	0.076	0.161	0.121	0.765	0.407	0.057	0.107	0.081
Odra - Scinawa	2352.3	1573.1	1.122	0.750	0.077	0.132	0.100	0.623	0.417	0.058	0.088	0.067
Barycz	5490.4	2826.7	0.581	0.299	0.048	0.137	0.081	0.323	0.166	0.036	0.091	0.054
Odra - Nowa Sol	1642.3	811.6	0.698	0.345	0.054	0.110	0.078	0.388	0.192	0.041	0.075	0.053
Kwisa	1028.3	393.7	1.877	0.718	0.079	0.171	0.128	1.043	0.399	0.060	0.116	0.087
Bobr	4843.7	1436.2	1.171	0.347	0.052	0.115	0.085	0.651	0.193	0.039	0.077	0.056
Odra - Polecko	4715.8	1688.4	0.523	0.187	0.038	0.089	0.060	0.291	0.104	0.029	0.060	0.040
Nysa Luzycka Z	1627.5	569.7	4.929	1.652	0.114	0.412	0.235	2.738	0.918	0.086	0.275	0.157
Nysa Luzycka G	2427.9	569.5	0.641	0.149	0.036	0.098	0.056	0.356	0.083	0.027	0.066	0.038
Odra - Kostrzyn	2228.9	602.9	0.813	0.214	0.042	0.102	0.060	0.452	0.119	0.032	0.069	0.041
Grabia	788.6	419.7	0.488	0.260	0.052	0.082	0.048	0.271	0.144	0.041	0.057	0.034
Widawka	1515.8	733.7	0.488	0.236	0.046	0.070	0.042	0.271	0.131	0.035	0.048	0.029
Warta - Sieradz	5705.8	2808.6	0.948	0.466	0.059	0.105	0.064	0.526	0.259	0.044	0.070	0.042
Ner	1824.3	1085.9	0.435	0.259	0.047	0.081	0.048	0.242	0.144	0.036	0.055	0.032
Prosna	4803.6	2868.6	0.578	0.345	0.051	0.099	0.067	0.321	0.192	0.039	0.066	0.044
Warta - Poznan	11064.4	6700.4	0.532	0.322	0.049	0.106	0.057	0.296	0.179	0.037	0.070	0.038
Welna	2622.7	1526.7	0.397	0.231	0.044	0.077	0.046	0.220	0.128	0.033	0.052	0.031
Obra	2730.4	1040.8	0.362	0.138	0.034	0.067	0.040	0.201	0.077	0.026	0.045	0.027
Notec - Osiek	5491.8	3275.9	0.521	0.311	0.049	0.096	0.058	0.289	0.173	0.037	0.064	0.039
Gwda	4907.6	1751.8	0.452	0.161	0.036	0.049	0.035	0.251	0.090	0.027	0.033	0.024
Drawa	3277.1	1030.2	0.646	0.203	0.040	0.061	0.047	0.359	0.113	0.031	0.041	0.032
Notec - mouth	3516.5	1060.2	0.486	0.147	0.035	0.052	0.034	0.270	0.081	0.026	0.035	0.023
Warta - Kostrzyn	5876.7	2203.5	0.468	0.176	0.037	0.066	0.038	0.260	0.098	0.028	0.044	0.025
Mysla	1330.7	553.1	0.471	0.196	0.043	0.075	0.047	0.262	0.109	0.033	0.052	0.032
Odra - Krajnik	2771.9	1359.0	0.918	0.428	0.058	0.182	0.095	0.510	0.238	0.044	0.122	0.063
Peonia	1065.0	574.2	0.967	0.521	0.068	0.150	0.115	0.537	0.290	0.052	0.102	0.078
Ina	2198.1	1122.1	1.042	0.532	0.065	0.135	0.095	0.579	0.296	0.049	0.090	0.064
Odra - mouth	3447.1	1354.1	1.077	0.410	0.056	0.136	0.086	0.598	0.228	0.043	0.091	0.058
Peene	4990.9	2298.3	0.884	0.382	0.054	0.163	0.079	0.491	0.212	0.041	0.109	0.052
Zarow	739.4	285.2	1.198	0.433	0.065	0.216	0.101	0.665	0.241	0.051	0.149	0.070
Uecker	2436.3	1006.1	1.344	0.521	0.064	0.290	0.113	0.747	0.289	0.049	0.194	0.075
Odra Haff	701.1	183.5	0.484	0.120	0.039	0.227	0.064	0.269	0.067	0.032	0.162	0.046

Table 6.18: Phosphorus emissions in the Odra by erosion for the period 1993-1995 and the scenarios E1, E2 and E3 (estimated by MONERIS).

Short name	Area	EER$_P$ *E0*	EER$_P$ *E1*	EER$_P$ *E2*	EER$_P$ *E3*	Reduction *E1* to *E0*	Reduction *E2* to *E0*	Reduction *E3* to *E0*
	[km²]	[t P/a]				[%]		
Odra-Pola	1,570	74	76	68	50	-2.4	7.9	32.6
Opava	2,091	71	69	63	46	2.6	11.7	35.3
Ostravice	824	12	14	13	9	-18.8	-6.8	21.8
Odra-Chal	4,666	161	166	149	109	-2.9	7.2	32.1
Odra-Raci	6,684	236	252	229	168	-7.0	3.0	28.9
Klodnica	1,085	12	12	10	6	0.0	10.6	50.3
Odra-Gros	10,989	323	336	307	223	-4.2	4.9	30.9
Mala Panew	2,123	5	5	5	3	0.0	10.4	50.3
Nysa Klod	4,515	122	119	111	81	2.4	9.1	33.4
Stobrawa	1,601	7	7	6	3	0.0	10.0	50.1
Odra-Wroc	20,397	466	477	437	315	-2.2	6.2	32.4
Olawa	1,167	33	33	31	23	0.0	5.6	30.9
Bystrzyca	1,760	45	48	43	31	-5.4	5.2	30.6
Widawa	1,716	22	22	20	13	0.0	6.3	42.1
Kaczawa	2,261	58	58	55	40	0.0	6.0	31.1
Odra-Scin	29,584	677	690	636	459	-1.9	6.0	32.3
Barycz	5,535	80	84	76	42	-5.3	5.3	47.1
Odra-Nowa	36,780	785	802	738	520	-2.2	5.9	33.7
Kwisa	1,026	18	18	17	13	-0.6	4.5	30.1
Bobr	5,869	80	84	76	47	-4.7	4.7	41.0
Odra-Pole	47,152	895	916	842	582	-2.3	6.0	34.9
Ny Lu-Zgor	1,609	57	62	56	41	-7.6	3.0	29.0
Ny Lu-Gubi	3,974	66	70	63	45	-6.8	4.0	31.7
Odra-Kost	53,532	968	994	911	631	-2.7	5.9	34.8
Grabia	813	3	4	3	2	-15.1	5.6	47.6
Widawka	2,355	8	8	7	4	-6.3	8.0	48.9
Warta-Sier	8,140	48	48	44	24	-1.0	9.1	49.5
Ner	1,867	12	12	11	6	0.0	9.0	49.4
Prosna	4,825	60	60	57	36	0.0	4.5	40.6
Warta-Pozn	25,911	245	246	230	138	-0.2	6.2	43.8
Welna	2,621	27	27	25	14	0.0	5.9	46.4
Obra	2,758	10	10	9	5	0.0	8.8	49.4
Notec-Osie	5,508	64	64	61	38	0.0	5.0	41.7
Gwda	4,943	15	15	14	8	0.0	9.4	49.7
Drawa	3,296	9	10	8	4	-7.8	11.9	51.0
Notec-Sant	17,330	96	97	90	53	-0.7	6.6	44.4
Warta-Kost	54,518	406	407	379	224	-0.3	6.6	44.7
Mysla	1,334	7	7	6	3	0.0	7.6	48.6
Odra-Kraj	110,074	1420	1449	1334	882	-2.0	6.1	37.9
Plonia	1,101	24	24	22	16	0.0	5.6	30.9
Ina	2,163	37	37	35	26	0.0	4.6	30.1
Odra-Mouth	118,861	1522	1552	1430	946	-2.0	6.0	37.8
Peene	5,110	73	77	69	48	-5.2	5.5	34.7
Zarow	748	10	10	9	6	-5.2	5.4	41.0
Uecker	2,401	47	49	44	32	-5.2	5.4	30.7
Odra Haff	8,885	130	136	123	86	-5.2	5.5	33.8

6.2.2.2 Results of the Scenarios for Subsurface Nitrogen Inputs

Groundwater

The Tables 6.19 to 6.23 shows the assumed consequences of the Scenarios S0 to S2 for the nitrogen surplus in the agricultural area within the time period from 2000 to 2020 and the results of the scenario calculation with the model MODEST. Regarding Table 6.19 and 6.20 it is to consider that the given N-surplus on agricultural areas of the sub catchments does not include the atmospheric deposition for this areas and is further not a mean for the N-surplus of the total area which causes nitrogen inputs by groundwater.

The scenarios S1 and S2 result in a changes of the N-surplus in agriculture of 11% increase for scenario S1 and 14% decrease for Scenario S2 within the whole time period from 2000 to 2020. If the N-depositon is additionally considered this changes are both below 10%.

Because both models MODEST and MONERIS take into account the residence time in the unsaturated zone and in groundwater the results of the scenarios does not correspond to the changes in the N-surplus in the considered time period.

For the scenario results by application of MODEST it was found that a reduction of the groundwater N-emissions within the unconsolidated rock region of Odra of 39, 29 and 49% can be expected within the next 20 years compared to the situation in the period 1993-1997. Unfortunately from this results the changes of the total subsurface N-inputs into the Odra can not be extrapolated, because the entries by tile drainage and by groundwater within the region of consolidated rocks is not included

In contrast to the erosion the comparison of the scenario results for the MODEST and MONERIS model shows more differences as shown in Figure 6.4 for three different catchments within the Odra. In general the calculated changes by application of the MONERIS model are lower and do not show so much differences between the scenarios. This is mainly caused by the different model approaches, where MONERIS considers a strong nonlinear dependency of the N-retention on the total N-surplus within the catchments.

On the other hand MODEST does not distinguish between entries by groundwater and tile drainage and so a higher response in relation to the changes of N-surplus can be expected. In contrast to this MONERIS inputs by subsurface flows are separated into the component with fast (tile drainage, see next chapter) and slow (groundwater) response, which can be one further reason for the difference of the model behavior.

As shown in Table 6.24 the calculated changes of groundwater emissions into the river systems of the Odra are only 16, 14 and 19% for the Odra at mouth, if the results of the scenarios S0, S1 and S2, respectively, are compared with the situation in the investigation period 1993-1997. Further the simulated reaction in the different sub catchments of the Odra does not so much vary if the scenarios are calculated by MONERIS than by MODEST (see Figure 6.4).

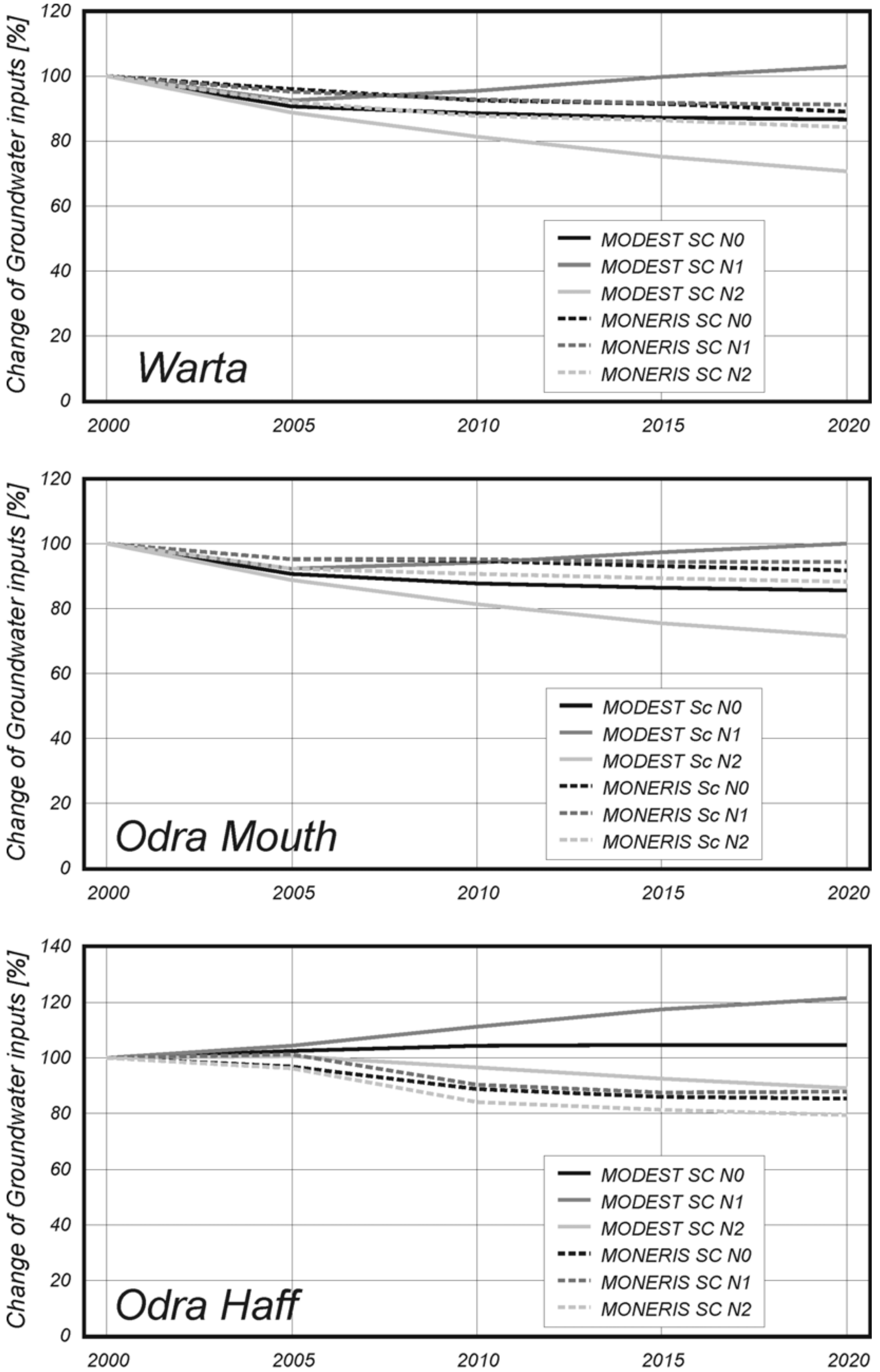

Figure 6.4: Results of the scenario calculations for the changes of nitrogen emissions by groundwater based on the MODEST and MONERIS estimations for different sub catchments within the Odra.

Table 6.19: Specific N surplus at the evaluated sub catchments for the scenario period.

Catchment			Specific N surplus (kg/ha/a)											
Name	Area		Scenario 0				Scenario 1				Scenario 2			
	Total	Evaluated												
	km²	%	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1569.8	0.0												
Opawa	2066.2	0.0												
Ostravice	824.3	0.0												
Odra - Chalupki	237.5	0.0												
Odra - Raciborz	2092.6	21.0	28.0	28.0	28.0	28.0	28.6	29.3	29.7	30.0	27.3	26.6	26.2	25.9
Klodnica	1104.1	81.7	20.4	20.4	20.4	20.4	20.7	21.1	21.2	21.4	20.0	19.7	19.5	19.3
Odra-Groszowice	2984.1	82.7	32.1	32.1	32.1	32.1	33.1	34.1	34.6	35.1	31.1	30.1	29.6	29.1
Mala Panew	2084.8	95.3	24.8	24.8	24.8	24.8	25.4	26.1	26.4	26.7	24.1	23.4	23.1	22.8
Nysa Klodzka	4500.3	38.5	30.0	30.0	30.0	30.0	31.1	32.2	32.8	33.3	28.9	27.8	27.3	26.7
Stobrawa	1593.1	99.9	26.2	26.2	26.2	26.2	27.1	28.1	28.6	29.1	25.2	24.3	23.8	23.3
Odra - Wroclaw	1357.8	99.9	29.8	29.8	29.8	29.8	30.8	31.8	32.2	32.7	28.9	27.9	27.4	26.9
Olawa	1166.4	82.2	26.9	26.9	26.9	26.9	27.7	28.5	28.8	29.2	26.2	25.4	25.0	24.6
Bystrzyca	1750	0.0												
Widawa	1707.2	89.6	28.5	28.5	28.5	28.5	29.6	30.8	31.3	31.9	27.3	26.2	25.6	25.0
Kaczawa	2247.5	25.5	22.1	22.1	22.1	22.1	22.4	22.6	22.8	22.9	21.8	21.5	21.3	21.2
Odra - Scinawa	2352.3	27.3	23.1	23.1	23.1	23.1	23.5	23.9	24.1	24.3	22.7	22.3	22.0	21.8
Barycz	5490.4	96.6	38.2	38.2	38.2	38.2	40.4	42.6	43.7	44.9	36.0	33.7	32.6	31.5
Odra - Nowa Sol	1642.2	99.9	23.3	23.3	23.3	23.3	23.9	24.5	24.8	25.1	22.8	22.2	21.9	21.6
Kwisa	1028.2	18.5	23.1	23.1	23.1	23.1	23.6	24.0	24.2	24.4	22.7	22.3	22.1	21.9
Bobr	4843.8	56.9	23.5	23.5	23.5	23.5	24.0	24.4	24.7	24.9	23.0	22.5	22.3	22.1
Odra - Polecko	4717	99.1	26.1	26.1	26.1	26.1	27.1	28.1	28.6	29.1	25.1	24.2	23.7	23.2
Nysa Luzycka Z	1627.5	0.0												
Nysa Luzycka G	2428	90.1	26.0	26.0	26.0	26.0	26.8	27.5	27.9	28.3	25.3	24.5	24.1	23.8
Odra - Kostrzyn	2229.3	98.9	24.2	24.2	24.2	24.2	24.9	25.7	26.0	26.4	23.5	22.8	22.4	22.1
Grabia	788.6	99.4	34.1	34.1	34.1	34.1	35.9	37.8	38.7	39.6	32.2	30.3	29.4	28.5
Widawka	1517.9	99.6	31.9	31.9	31.9	31.9	33.3	34.8	35.5	36.2	30.4	28.9	28.2	27.5
Warta - Sieradz	5705.7	92.8	25.4	25.4	25.4	25.4	26.4	27.5	28.0	28.5	24.3	23.3	22.7	22.2
Ner	1825.4	99.2	40.4	40.4	40.4	40.4	42.9	45.5	46.8	48.1	37.8	35.2	33.9	32.6
Prosna	4808.1	100.0	34.8	34.8	34.8	34.8	36.8	38.9	39.9	40.9	32.7	30.7	29.7	28.7
Warta - Poznan	11065	99.4	41.6	41.6	41.6	41.6	44.3	47.0	48.4	49.8	38.9	36.2	34.9	33.5
Welna	2623.1	98.4	32.7	32.7	32.7	32.7	34.5	36.3	37.2	38.1	30.8	29.0	28.1	27.2
Obra	2730.3	98.5	27.6	27.6	27.6	27.6	28.8	29.9	30.5	31.1	26.4	25.2	24.6	24.1
Notec - Osiek	5491.8	97.5	40.8	40.8	40.8	40.8	43.5	46.1	47.4	48.8	38.2	35.5	34.2	32.9
Gwda	4908.4	97.2	21.5	21.5	21.5	21.5	22.2	23.0	23.3	23.7	20.8	20.0	19.7	19.3
Drawa	3277.1	95.9	20.0	20.0	20.0	20.0	20.5	21.0	21.3	21.6	19.5	19.0	18.7	18.4
Notec - mouth	3517.8	99.3	21.9	21.9	21.9	21.9	22.7	23.4	23.7	24.1	21.2	20.5	20.1	19.8
Warta - Kostrzyn	5879.1	98.9	27.6	27.6	27.6	27.6	28.8	30.1	30.7	31.3	26.4	25.1	24.5	23.9
Mysla	1330.9	97.6	22.9	22.9	22.9	22.9	23.7	24.5	25.0	25.4	22.0	21.2	20.8	20.4
Odra - Krajnik	2772.1	98.7	31.9	31.9	31.9	31.9	33.5	35.2	36.0	36.9	30.2	28.5	27.7	26.9
Plonia	1065.3	94.5	22.0	22.0	22.0	22.0	22.8	23.5	23.9	24.3	21.2	20.5	20.1	19.7
Ina	2200.8	98.4	21.5	21.5	21.5	21.5	22.3	23.1	23.5	23.9	20.7	19.9	19.5	19.1
Odra - mouth	**3447.8**	**96.7**	**26.2**	**26.2**	**26.2**	**26.2**	**27.3**	**28.4**	**28.9**	**29.5**	**25.1**	**24.0**	**23.4**	**22.9**
Peene	4990.9	97.6	35.2	35.2	35.2	35.2	37.4	39.6	40.7	41.8	33.0	30.9	29.8	28.7
Zarow	739.5	98.4	44.4	44.4	44.4	44.4	47.5	50.6	52.1	53.7	41.3	38.2	36.7	35.1
Uecker	2436.9	96.8	34.6	34.6	34.6	34.6	36.6	38.5	39.5	40.5	32.6	30.6	29.6	28.7
Odra Haff	**718.2**	**98.8**	**28.3**	**28.3**	**28.3**	**28.3**	**29.7**	**31.2**	**31.9**	**32.7**	**26.8**	**25.3**	**24.6**	**23.9**

Table 6.20: Total N surplus at the evaluated catchment area for the scenario period

Catchment			Total N surplus (kt/a)											
Name	Area		Scenario 0				Scenario 1				Scenario 2			
	Total	Eval.												
	(km²)	%	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1569.8	0.0												
Opawa	2066.2	0.0												
Ostravice	824.3	0.0												
Odra - Chalupki	4697.9	0.0												
Odra - Raciborz	6790.5	6.2	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.1
Klodnica	1104.1	79.3	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.8	1.8	1.8	1.8
Odra - Groszowice	10878.7	34.5	11.0	11.0	11.0	11.0	11.3	11.7	11.8	12.0	10.7	10.4	10.3	10.1
Mala Panew	2084.8	94.7	5.0	5.0	5.0	5.0	5.1	5.2	5.3	5.4	4.8	4.7	4.6	4.6
Nysa Klodzka	4500.3	38.3	5.3	5.3	5.3	5.3	5.5	5.7	5.8	5.9	5.1	4.9	4.8	4.7
Stobrawa	1593.1	100.0	4.2	4.2	4.2	4.2	4.3	4.5	4.6	4.6	4.0	3.9	3.8	3.7
Odra - Wroclaw	20414.6	50.9	29.5	29.5	29.5	29.5	30.5	31.4	31.8	32.3	28.6	27.7	27.2	26.8
Olawa	1166.4	79.2	2.6	2.6	2.6	2.6	2.7	2.7	2.8	2.8	2.5	2.4	2.4	2.4
Bystrzyca	1750.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Widawa	1707.2	89.2	4.4	4.4	4.4	4.4	4.5	4.7	4.8	4.9	4.2	4.0	3.9	3.8
Kaczawa	2247.5	23.5	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2
Odra - Scinawa	29638.1	46.9	39.2	39.2	39.2	39.2	40.4	41.7	42.3	42.9	38.0	36.8	36.2	35.6
Barycz	5490.4	89.2	20.4	20.4	20.4	20.4	21.6	22.8	23.3	23.9	19.2	18.0	17.4	16.8
Odra - Nowa Sol	36770.7	54.9	63.4	63.4	63.4	63.4	65.9	68.4	69.7	70.9	60.9	58.4	57.2	55.9
Kwisa	1028.2	18.5	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.4	0.4	0.4	0.4
Bobr	5872.0	49.3	6.9	6.9	6.9	6.9	7.1	7.2	7.3	7.3	6.8	6.7	6.6	6.5
Odra - Polecko	47359.7	57.8	82.7	82.7	82.7	82.7	85.8	88.9	90.4	92.0	79.6	76.5	74.9	73.4
Nysa Luzycka Z	1627.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nysa Luzycka G	4055.5	52.0	5.7	5.7	5.7	5.7	5.8	6.0	6.1	6.2	5.5	5.3	5.3	5.2
Odra - Kostrzyn	53644.5	58.6	93.7	93.7	93.7	93.7	97.2	100.6	102.3	104.0	90.3	86.9	85.2	83.5
Grabia	788.6	89.0	2.7	2.7	2.7	2.7	2.8	3.0	3.0	3.1	2.5	2.4	2.3	2.2
Widawka	2306.4	91.7	7.5	7.5	7.5	7.5	7.8	8.2	8.4	8.6	7.1	6.7	6.6	6.4
Warta - Sieradz	8012.2	91.0	20.9	20.9	20.9	20.9	21.8	22.7	23.2	23.7	20.0	19.1	18.6	18.1
Ner	1825.4	91.1	7.3	7.3	7.3	7.3	7.8	8.2	8.5	8.7	6.8	6.4	6.1	5.9
Prosna	4808.1	95.1	16.7	16.7	16.7	16.7	17.7	18.7	19.2	19.7	15.7	14.8	14.3	13.8
Warta - Poznan	25710.4	91.2	91.0	91.0	91.0	91.0	96.3	101.7	104.4	107.1	85.6	80.2	77.6	74.9
Welna	2623.1	91.0	8.6	8.6	8.6	8.6	9.0	9.5	9.8	10.0	8.1	7.6	7.4	7.1
Obra	2730.3	86.1	7.5	7.5	7.5	7.5	7.9	8.2	8.3	8.5	7.2	6.9	6.7	6.6
Notec - Osiek	5491.8	90.8	22.2	22.2	22.2	22.2	23.7	25.1	25.9	26.6	20.8	19.4	18.6	17.9
Gwda	4908.4	94.4	10.5	10.5	10.5	10.5	10.9	11.2	11.4	11.6	10.2	9.8	9.6	9.4
Drawa	3277.1	92.3	6.5	6.5	6.5	6.5	6.7	6.9	7.0	7.0	6.4	6.2	6.1	6.0
Notec - mouth	17195.1	90.9	47.0	47.0	47.0	47.0	49.2	51.5	52.6	53.7	44.8	42.6	41.5	40.3
Warta - Kostrzyn	54137.9	90.5	170.3	170.3	170.3	170.3	179.4	188.5	193.1	197.6	161.2	152.1	147.5	143.0
Mysla	1330.9	89.2	3.0	3.0	3.0	3.0	3.2	3.3	3.3	3.4	2.9	2.8	2.8	2.7
Odra - Krajnik	111885.4	75.1	275.9	275.9	275.9	275.9	289.0	302.1	308.6	315.2	262.7	249.6	243.1	236.5
Plonia	1065.3	89.1	2.3	2.3	2.3	2.3	2.4	2.5	2.5	2.6	2.3	2.2	2.1	2.1
Ina	2200.8	92.6	4.7	4.7	4.7	4.7	4.9	5.0	5.1	5.2	4.5	4.4	4.3	4.2
Odra - mouth	**118599.2**	**75.8**	**291.9**	**291.9**	**291.9**	**291.9**	**305.6**	**319.4**	**326.2**	**333.1**	**278.1**	**264.4**	**257.5**	**250.7**
Peene	4990.9	94.1	17.5	17.5	17.5	17.5	18.6	19.6	20.2	20.7	16.4	15.3	14.8	14.2
Zarow	739.5	81.2	3.3	3.3	3.3	3.3	3.5	3.7	3.9	4.0	3.1	2.8	2.7	2.6
Uecker	2436.9	85.4	8.4	8.4	8.4	8.4	8.9	9.4	9.6	9.8	7.9	7.4	7.2	7.0
Odra Haff	**8885.5**	**89.3**	**31.1**	**31.1**	**31.1**	**31.1**	**33.0**	**34.9**	**35.9**	**36.8**	**29.2**	**27.3**	**26.4**	**25.4**

Table 6.21: Calculated specific N emissions by groundwater (N_3) for the Scenarios S0, S1 and S2 at the evaluated sub catchments of the unconsolidated rock region (MODEST results)

Catchment			Specific N emission (kg/ha/a)											
Name	Total area	Evaluated area	Scenario 0				Scenario 1				Scenario 2			
	km²	%	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1569.8	0.0												
Opawa	2066.2	0.0												
Ostravice	824.3	0.0												
Odra - Chalupki	237.5	0.0												
Odra - Raciborz	2092.6	21.0	1.13	1.04	0.94	0.92	1.14	1.08	0.99	0.98	1.12	1.01	0.90	0.86
Klodnica	1104.1	81.7	0.94	0.83	0.80	0.79	0.95	0.86	0.84	0.84	0.93	0.81	0.76	0.73
Odra - Groszowice	2984.1	82.7	1.31	1.25	1.20	1.18	1.33	1.32	1.32	1.33	1.28	1.17	1.09	1.04
Mala Panew	2084.8	95.3	1.00	0.98	0.98	0.98	1.02	1.05	1.08	1.11	0.97	0.92	0.88	0.86
Nysa Klodzka	4500.3	38.5	1.89	1.75	1.65	1.59	1.93	1.86	1.83	1.81	1.86	1.64	1.48	1.37
Stobrawa	1593.1	99.9	1.16	1.14	1.14	1.13	1.20	1.25	1.29	1.33	1.12	1.04	0.98	0.95
Odra - Wroclaw	1357.8	99.9	1.31	1.28	1.27	1.27	1.34	1.38	1.43	1.47	1.27	1.18	1.12	1.08
Olawa	1166.4	82.2	1.25	1.15	1.08	1.04	1.26	1.20	1.16	1.15	1.23	1.10	1.00	0.93
Bystrzyca	1750.0	0.0												
Widawa	1707.2	89.6	1.20	1.18	1.17	1.16	1.24	1.28	1.33	1.36	1.17	1.08	1.01	0.97
Kaczawa	2247.5	25.5	0.89	0.86	0.85	0.85	0.90	0.88	0.89	0.91	0.89	0.83	0.81	0.79
Odra - Scinawa	2352.3	27.3	0.88	0.84	0.82	0.81	0.88	0.86	0.86	0.87	0.87	0.81	0.78	0.76
Barycz	5490.4	96.6	2.61	2.54	2.52	2.51	2.67	2.77	2.91	3.02	2.56	2.31	2.13	2.01
Odra - Nowa Sol	1642.2	99.9	1.68	1.47	1.37	1.33	1.69	1.52	1.46	1.46	1.67	1.42	1.28	1.21
Kwisa	1028.2	18.5	1.27	1.25	1.25	1.24	1.29	1.32	1.35	1.37	1.24	1.19	1.15	1.12
Bobr	4843.8	56.9	1.15	1.12	1.11	1.10	1.17	1.18	1.20	1.22	1.13	1.06	1.02	1.00
Odra - Polecko	4717.0	99.1	1.39	1.34	1.32	1.32	1.42	1.43	1.48	1.51	1.37	1.25	1.17	1.12
Nysa Luzycka Z	1627.5	0.0												
Nysa Luzycka G	2428.0	90.1	1.74	1.69	1.67	1.67	1.77	1.79	1.83	1.87	1.71	1.60	1.52	1.47
Odra - Kostrzyn	2229.3	98.9	0.99	0.97	0.96	0.95	1.00	1.02	1.04	1.04	0.98	0.93	0.89	0.86
Grabia	788.6	99.4	1.82	1.77	1.75	1.74	1.86	1.92	2.00	2.07	1.78	1.62	1.50	1.42
Widawka	1517.9	99.6	1.77	1.72	1.71	1.70	1.81	1.85	1.92	1.97	1.73	1.59	1.50	1.44
Warta - Sieradz	5705.7	92.8	1.00	0.98	0.97	0.97	1.02	1.07	1.11	1.14	0.97	0.89	0.84	0.80
Ner	1825.4	99.2	2.02	1.99	1.98	1.98	2.07	2.19	2.32	2.42	1.97	1.80	1.65	1.55
Prosna	4808.1	100.0	2.06	2.01	1.99	1.98	2.12	2.21	2.31	2.39	2.00	1.82	1.68	1.59
Warta - Poznan	11064.7	99.4	2.32	2.28	2.26	2.24	2.36	2.47	2.61	2.72	2.28	2.09	1.91	1.78
Welna	2623.1	98.4	1.58	1.54	1.53	1.52	1.61	1.66	1.75	1.82	1.56	1.43	1.31	1.23
Obra	2730.3	98.5	1.55	1.50	1.48	1.46	1.59	1.62	1.67	1.71	1.51	1.38	1.29	1.22
Notec - Osiek	5491.8	97.5	1.89	1.86	1.84	1.83	1.93	2.02	2.13	2.20	1.85	1.70	1.57	1.47
Gwda	4908.4	97.2	0.97	0.91	0.88	0.87	0.98	0.97	0.97	0.98	0.95	0.86	0.80	0.76
Drawa	3277.1	95.9	0.72	0.67	0.66	0.64	0.73	0.71	0.71	0.71	0.71	0.64	0.60	0.57
Notec - mouth	3517.8	99.3	1.43	1.35	1.31	1.28	1.46	1.43	1.43	1.44	1.41	1.28	1.19	1.13
Warta - Kostrzyn	5879.1	98.9	1.41	1.37	1.35	1.33	1.44	1.47	1.52	1.55	1.39	1.28	1.19	1.12
Mysla	1330.9	97.6	0.80	0.78	0.76	0.74	0.81	0.82	0.83	0.84	0.79	0.73	0.69	0.65
Odra - Krajnik	2772.1	98.7	1.33	1.33	1.32	1.33	1.34	1.39	1.45	1.51	1.33	1.27	1.20	1.16
Plonia	1065.3	94.5	1.29	1.05	1.02	0.98	1.30	1.07	1.05	1.04	1.29	1.04	0.98	0.92
Ina	2200.8	98.4	1.12	1.04	0.99	0.95	1.13	1.08	1.06	1.05	1.11	1.00	0.92	0.86
Odra - mouth	**3447.8**	**96.7**	**1.07**	**1.05**	**1.04**	**1.03**	**1.08**	**1.09**	**1.11**	**1.13**	**1.06**	**1.01**	**0.97**	**0.94**
Peene	4990.9	97.6	2.39	2.41	2.42	2.41	2.44	2.59	2.73	2.81	2.35	2.24	2.13	2.03
Zarow	739.5	98.4	2.12	2.13	2.15	2.16	2.15	2.31	2.47	2.57	2.08	1.96	1.84	1.77
Uecker	2436.9	96.8	1.56	1.62	1.66	1.69	1.57	1.70	1.81	1.89	1.55	1.55	1.51	1.49
Odra Haff	**718.2**	**98.8**	**1.19**	**1.18**	**1.18**	**1.18**	**1.23**	**1.29**	**1.37**	**1.43**	**1.15**	**1.07**	**1.00**	**0.95**

Table 6.22: Calculated N emissions by groundwater (N_3) for the Scenarios S0, S1 and S2 at the evaluated catchments of the unconsolidated rock region (MODEST results)

Gauge Catchment			Total N emissions (kt/a)											
Name	Total area	Eval. area	Szenario 0				Szenario 1				Szenario 2			
	[km²]	%	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1569.8	0.0												
Opawa	2066.2	0.0												
Ostravice	824.3	0.0												
Odra - Chalupki	4697.9	0.0												
Odra - Raciborz	6790.5	6.2	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.04	0.05	0.04	0.04	0.04
Klodnica	1104.1	79.3	0.08	0.08	0.07	0.07	0.09	0.08	0.08	0.08	0.08	0.07	0.07	0.07
Odra - Groszowice	10878.7	34.5	0.46	0.43	0.41	0.40	0.46	0.45	0.45	0.45	0.45	0.41	0.38	0.36
Mala Panew	2084.8	94.7	0.20	0.20	0.20	0.20	0.20	0.21	0.22	0.22	0.19	0.18	0.18	0.17
Nysa Klodzka	4500.3	38.3	0.33	0.30	0.29	0.28	0.33	0.32	0.32	0.31	0.32	0.28	0.26	0.24
Stobrawa	1593.1	100.0	0.18	0.18	0.18	0.18	0.19	0.20	0.21	0.21	0.18	0.17	0.16	0.15
Odra - Wroclaw	20414.6	50.9	1.35	1.28	1.25	1.23	1.38	1.37	1.38	1.39	1.32	1.20	1.12	1.06
Olawa	1166.4	79.2	0.12	0.11	0.10	0.10	0.12	0.12	0.11	0.11	0.12	0.11	0.10	0.09
Bystrzyca	1750.0	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Widawa	1707.2	89.2	0.18	0.18	0.18	0.18	0.19	0.20	0.20	0.21	0.18	0.16	0.15	0.15
Kaczawa	2247.5	23.5	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Odra - Scinawa	29638.1	46.9	1.76	1.68	1.63	1.60	1.79	1.79	1.80	1.82	1.72	1.57	1.46	1.40
Barycz	5490.4	89.2	1.39	1.35	1.34	1.33	1.41	1.47	1.55	1.60	1.36	1.23	1.13	1.07
Odra - Nowa Sol	36770.7	54.9	3.42	3.26	3.19	3.15	3.48	3.50	3.58	3.66	3.35	3.03	2.80	2.66
Kwisa	1028.2	18.5	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.02	0.02	0.02
Bobr	5872.0	49.3	0.34	0.33	0.33	0.33	0.35	0.35	0.36	0.36	0.33	0.31	0.30	0.30
Odra - Polecko	47359.7	57.8	4.41	4.22	4.14	4.09	4.49	4.52	4.63	4.73	4.32	3.93	3.65	3.48
Nysa Luzycka Z	1627.5	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nysa Luzycka G	4055.5	52.0	0.38	0.37	0.37	0.37	0.39	0.39	0.40	0.41	0.37	0.35	0.33	0.32
Odra - Kostrzyn	53644.5	58.6	5.01	4.81	4.71	4.67	5.10	5.14	5.26	5.37	4.91	4.48	4.18	3.99
Grabia	788.6	89.0	0.14	0.14	0.14	0.14	0.15	0.15	0.16	0.16	0.14	0.13	0.12	0.11
Widawka	2306.4	91.7	0.41	0.40	0.40	0.39	0.42	0.43	0.45	0.46	0.40	0.37	0.34	0.33
Warta - Sieradz	8012.2	91.0	0.94	0.92	0.91	0.91	0.96	1.00	1.04	1.07	0.91	0.84	0.79	0.75
Ner	1825.4	91.1	0.37	0.36	0.36	0.36	0.38	0.40	0.42	0.44	0.36	0.33	0.30	0.28
Prosna	4808.1	95.1	0.99	0.97	0.96	0.95	1.02	1.06	1.11	1.15	0.96	0.88	0.81	0.76
Warta - Poznan	25710.4	91.2	4.84	4.75	4.71	4.68	4.95	5.17	5.44	5.64	4.73	4.34	3.99	3.76
Welna	2623.1	91.0	0.41	0.40	0.39	0.39	0.41	0.43	0.45	0.47	0.40	0.37	0.34	0.32
Obra	2730.3	86.1	0.42	0.40	0.40	0.39	0.43	0.43	0.45	0.46	0.41	0.37	0.35	0.33
Notec - Osiek	5491.8	90.8	1.01	1.00	0.99	0.98	1.03	1.08	1.14	1.18	0.99	0.91	0.84	0.79
Gwda	4908.4	94.4	0.46	0.44	0.42	0.41	0.47	0.46	0.46	0.47	0.45	0.41	0.38	0.36
Drawa	3277.1	92.3	0.23	0.21	0.21	0.20	0.23	0.22	0.22	0.22	0.22	0.20	0.19	0.18
Notec - mouth	17195.1	90.9	2.20	2.12	2.07	2.04	2.24	2.26	2.32	2.38	2.16	1.97	1.83	1.72
Warta - Kostrzyn	54137.9	90.5	8.69	8.47	8.36	8.29	8.87	9.15	9.54	9.85	8.51	7.79	7.20	6.78
Mysla	1330.9	89.2	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.10	0.10	0.09	0.08
Odra - Krajnik	111885.4	75.1	14.17	13.74	13.53	13.42	14.45	14.78	15.31	15.73	13.89	12.72	11.80	11.17
Plonia	1065.3	89.1	0.13	0.11	0.10	0.10	0.13	0.11	0.11	0.10	0.13	0.10	0.10	0.09
Ina	2200.8	92.6	0.24	0.23	0.21	0.21	0.24	0.23	0.23	0.23	0.24	0.22	0.20	0.19
Odra - mouth	**118599.2**	**75.8**	**14.90**	**14.42**	**14.20**	**14.07**	**15.18**	**15.48**	**16.02**	**16.44**	**14.61**	**13.38**	**12.42**	**11.76**
Peene	4990.9	94.1	1.17	1.18	1.18	1.18	1.19	1.26	1.33	1.37	1.14	1.09	1.04	0.99
Zarow	739.5	81.2	0.15	0.16	0.16	0.16	0.16	0.17	0.18	0.19	0.15	0.14	0.13	0.13
Uecker	2436.9	85.4	0.37	0.38	0.39	0.40	0.37	0.40	0.43	0.45	0.37	0.36	0.36	0.35
Odra Haff	**8885.5**	**89.3**	**1.77**	**1.80**	**1.81**	**1.81**	**1.80**	**1.92**	**2.03**	**2.10**	**1.74**	**1.67**	**1.60**	**1.54**

Table 6.23: Calculated N retention potential for the scenarios S0, S1 and S2 (Equation 4-16; MODEST results).

Catchment			$RET_{(i,j)}=N_{0(i,j)}-N_{3(i,j)}/ N_{0(i,j)}$											
Name	Total	Evaluated	Scenario 0				Scenario 1				Scenario 2			
	km²	%	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1569.8	0.0												
Opawa	2066.2	0.0												
Ostravice	824.3	0.0												
Odra - Chalupki	237.5	0.0												
Odra – Raciborz	2092.6	21.0	0.963	0.965	0.967	0.968	0.962	0.964	0.966	0.966	0.963	0.966	0.969	0.969
Klodnica	1104.1	81.7	0.963	0.965	0.965	0.964	0.962	0.964	0.963	0.962	0.963	0.966	0.966	0.966
Odra - Groszowice	2984.1	82.7	0.959	0.961	0.962	0.962	0.958	0.958	0.958	0.958	0.959	0.963	0.965	0.966
Mala Panew	2084.8	95.3	0.960	0.960	0.959	0.959	0.959	0.957	0.956	0.954	0.961	0.962	0.963	0.963
Nysa Klodzka	4500.3	38.5	0.945	0.948	0.950	0.950	0.944	0.945	0.946	0.945	0.946	0.951	0.954	0.956
Stobrawa	1593.1	99.9	0.957	0.957	0.957	0.956	0.956	0.954	0.952	0.950	0.958	0.960	0.962	0.962
Odra – Wroclaw	1357.8	99.9	0.956	0.957	0.956	0.956	0.955	0.954	0.952	0.950	0.957	0.959	0.961	0.961
Olawa	1166.4	82.2	0.958	0.961	0.962	0.963	0.958	0.959	0.960	0.960	0.959	0.962	0.965	0.966
Bystrzyca	1750	0.0												
Widawa	1707.2	89.6	0.957	0.958	0.958	0.957	0.956	0.955	0.953	0.951	0.958	0.961	0.962	0.963
Kaczawa	2247.5	25.5	0.965	0.966	0.965	0.965	0.965	0.965	0.964	0.963	0.965	0.966	0.967	0.967
Odra - Scinawa	2352.3	27.3	0.965	0.966	0.967	0.967	0.965	0.965	0.965	0.965	0.965	0.967	0.968	0.968
Barycz	5490.4	96.6	0.923	0.924	0.924	0.924	0.922	0.919	0.916	0.913	0.924	0.929	0.933	0.935
Odra - Nowa Sol	1642.2	99.9	0.946	0.950	0.951	0.951	0.946	0.949	0.949	0.947	0.946	0.951	0.954	0.954
Kwisa	1028.2	18.5	0.945	0.944	0.944	0.943	0.944	0.942	0.940	0.939	0.945	0.947	0.947	0.948
Bobr	4843.8	56.9	0.953	0.953	0.953	0.953	0.952	0.951	0.950	0.949	0.953	0.955	0.956	0.957
Odra - Polecko	4717	99.1	0.945	0.946	0.946	0.946	0.944	0.943	0.941	0.940	0.946	0.949	0.951	0.952
Nysa Luzycka Z	1627.5	0.0												
Nysa Luzycka G	2428	90.1	0.932	0.933	0.933	0.932	0.932	0.930	0.928	0.926	0.933	0.936	0.937	0.938
Odra - Kostrzyn	2229.3	98.9	0.952	0.953	0.953	0.954	0.951	0.951	0.950	0.950	0.952	0.954	0.956	0.957
Grabia	788.6	99.4	0.937	0.939	0.940	0.940	0.936	0.935	0.933	0.932	0.938	0.944	0.947	0.949
Widawka	1517.9	99.6	0.941	0.942	0.943	0.942	0.940	0.939	0.937	0.936	0.942	0.946	0.948	0.949
Warta - Sieradz	5705.7	92.8	0.958	0.959	0.959	0.959	0.957	0.956	0.954	0.953	0.959	0.962	0.964	0.965
Ner	1825.4	99.2	0.934	0.936	0.937	0.938	0.933	0.931	0.929	0.928	0.935	0.941	0.945	0.948
Prosna	4808.1	100.0	0.933	0.935	0.935	0.936	0.932	0.930	0.928	0.926	0.935	0.940	0.943	0.945
Warta - Poznan	11065	99.4	0.927	0.929	0.931	0.932	0.926	0.925	0.923	0.922	0.928	0.934	0.939	0.942
Welna	2623.1	98.4	0.940	0.942	0.943	0.944	0.939	0.939	0.937	0.936	0.940	0.945	0.950	0.952
Obra	2730.3	98.5	0.939	0.941	0.942	0.943	0.938	0.938	0.937	0.936	0.940	0.945	0.948	0.951
Notec - Osiek	5491.8	97.5	0.930	0.932	0.934	0.936	0.929	0.929	0.927	0.927	0.931	0.937	0.942	0.945
Gwda	4908.4	97.2	0.951	0.953	0.955	0.955	0.950	0.951	0.951	0.951	0.952	0.956	0.958	0.960
Drawa	3277.1	95.9	0.961	0.964	0.965	0.966	0.961	0.962	0.962	0.962	0.962	0.965	0.967	0.969
Notec - mouth	3517.8	99.3	0.938	0.940	0.941	0.942	0.937	0.938	0.937	0.937	0.938	0.942	0.945	0.947
Warta - Kostrzyn	5879.1	98.9	0.942	0.944	0.945	0.946	0.941	0.941	0.940	0.939	0.943	0.947	0.950	0.952
Mysla	1330.9	97.6	0.957	0.959	0.960	0.961	0.956	0.957	0.957	0.957	0.957	0.960	0.963	0.965
Odra - Krajnik	2772.1	98.7	0.946	0.947	0.948	0.948	0.946	0.945	0.944	0.944	0.946	0.948	0.951	0.952
Plonia	1065.3	94.5	0.941	0.952	0.955	0.958	0.941	0.952	0.954	0.956	0.941	0.952	0.956	0.959
Ina	2200.8	98.4	0.948	0.952	0.955	0.957	0.948	0.951	0.952	0.953	0.948	0.954	0.957	0.960
Odra - mouth	**3447.8**	**96.7**	**0.947**	**0.948**	**0.949**	**0.951**	**0.947**	**0.947**	**0.947**	**0.948**	**0.947**	**0.949**	**0.952**	**0.954**
Peene	4990.9	97.6	0.909	0.910	0.911	0.913	0.908	0.906	0.905	0.904	0.910	0.914	0.918	0.922
Zarow	739.5	98.4	0.940	0.940	0.940	0.941	0.940	0.938	0.936	0.936	0.940	0.942	0.945	0.946
Uecker	2436.9	96.8	0.932	0.931	0.931	0.932	0.932	0.929	0.928	0.927	0.932	0.933	0.935	0.937
Odra Haff	**718.2**	**98.8**	**0.946**	**0.947**	**0.947**	**0.947**	**0.945**	**0.944**	**0.942**	**0.940**	**0.947**	**0.950**	**0.953**	**0.954**

Table 6.24: Calculated N-emissions by groundwater for the scenarios S0, S1 and S2 for the whole Odra basin and its tributaries (MONERIS results).

Name	EGW_N Scenario *S0* [tN/a]				EGW_N Scenario *S1* [tN/a]				EGW_N Scenario *S2* [tN/a]			
	2005	2010	2015	2020	2005	2010	2015	2020	2005	2010	2015	2020
Odra - Polanka	1330	1349	1349	1349	1404	1433	1433	1434	1270	1263	1263	1263
Opawa	1835	1857	1857	1857	1922	1956	1956	1957	1765	1757	1757	1757
Ostravice	568	574	574	574	592	602	602	602	549	547	547	547
Odra - Chalupki	3826	3876	3876	3876	4018	4092	4092	4093	3675	3655	3656	3657
Odra – Raciborz	5727	5778	5778	5778	5847	6031	6040	6046	5471	5517	5510	5506
Klodnica	356	327	317	317	346	324	313	314	343	319	309	308
Odra - Groszowice	6842	6811	6766	6753	6942	7069	7033	7030	6549	6532	6479	6457
Mala Panew	732	701	702	694	726	697	698	701	716	681	680	677
Nysa Klodzka	2805	2827	2792	2769	2802	2835	2852	2867	2735	2702	2686	2668
Stobrawa	196	200	197	191	191	202	198	193	187	196	193	187
Odra – Wroclaw	10697	10664	10579	10527	10780	10928	10905	10912	10305	10234	10159	10107
Olawa	150	138	128	120	145	139	129	122	142	136	126	118
Bystrzyca	537	479	463	463	527	484	469	473	515	467	450	446
Widawa	237	220	206	194	230	223	207	196	224	214	199	186
Kaczawa	765	722	722	716	758	715	717	718	752	706	705	703
Odra - Scinawa	13173	13009	12875	12790	13215	13268	13210	13206	12704	12518	12396	12316
Barycz	897	821	771	750	884	836	787	776	844	782	731	702
Odra - Nowa Sol	14336	14065	13864	13751	14355	14339	14214	14193	13801	13529	13340	13222
Kwisa	737	791	770	770	761	780	782	783	751	760	758	757
Bobr	3368	3479	3420	3395	3400	3431	3440	3447	3363	3358	3351	3344
Odra - Polecko	18114	17966	17698	17549	18157	18194	18070	18045	17557	17300	17097	16959
Nysa Luzycka Z	1221	1313	1274	1274	1257	1309	1314	1320	1226	1240	1234	1229
Nysa Luzycka G	2111	2229	2177	2169	2158	2215	2224	2233	2115	2123	2113	2105
Odra - Kostrzyn	21128	21135	20798	20628	21233	21333	21221	21208	20577	20321	20105	19957
Grabia	158	150	150	148	158	152	153	155	151	140	139	137
Widawka	515	492	493	486	515	497	500	506	496	466	462	456
Warta - Sieradz	2048	1927	1928	1892	2023	1916	1929	1948	1961	1816	1803	1784
Ner	385	372	372	366	389	379	384	390	368	343	338	331
Prosna	672	637	602	573	666	648	612	589	635	607	573	539
Warta - Poznan	3885	3738	3683	3581	3856	3766	3723	3697	3700	3533	3463	3366
Welna	140	138	129	121	136	141	131	124	130	133	124	115
Obra	231	218	206	197	226	219	207	199	220	212	200	189
Notec - Osiek	635	600	588	588	642	613	605	616	606	561	545	534
Gwda	915	870	870	850	897	850	853	859	880	821	819	813
Drawa	797	770	770	755	786	751	754	757	777	737	735	732
Notec - mouth	2415	2310	2297	2260	2390	2285	2280	2298	2328	2188	2166	2144
Warta - Kostrzyn	7028	6775	6681	6515	6959	6784	6709	6677	6720	6425	6310	6161
Mysla	114	116	111	105	111	116	111	105	108	113	108	102
Odra - Krajnik	28591	28357	27916	27564	28631	28569	28370	28311	27723	27180	26840	26527
Plonia	16	17	16	16	15	17	16	16	15	17	16	15
Ina	475	491	470	456	463	469	473	476	450	443	440	436
Odra - mouth	29371	29162	28695	28319	29398	29355	29153	29087	28468	27929	27581	27254
Peene	1227	1102	1080	1088	1285	1120	1100	1122	1221	1038	1011	1005
Zarow	120	111	104	102	126	114	106	106	119	105	98	95
Uecker	299	294	279	264	312	299	283	270	299	282	267	251
Odra Haff	1722	1582	1533	1521	1801	1608	1560	1566	1714	1497	1445	1415

Tile drainage

Table 6.25 shows the results for the scenario calculation of MONERIS regarding the possible changes of the nitrogen inputs by tile drainage. The Figure 6.5 presents the results for two selected catchment areas within the Odra basin. Depending on the changes of the nitrogen surplus within the next 20 years and the different atmospheric deposition within the sub catchments (see Table 6.19), the estimated nitrogen inputs by tile drainage differ in the individual sub catchments. As shown in Table 6.25, these differences are caused by the different hydrological situation and the different levels of nitrogen surplus in the sub catchments of Odra.

The variation between the scenario results is comparable with that calculated for groundwater with the MODEST model.

The response of the drained areas on the increase or decrease of N-surplus of agriculture areas in the future is only a bit lower than the changes of the N-surplus. In general it is to assume that larger changes of the N-inputs by tile drainage were in the period between 1989 and 1993 Within this years the largest changes of the N-surplus could be observed.

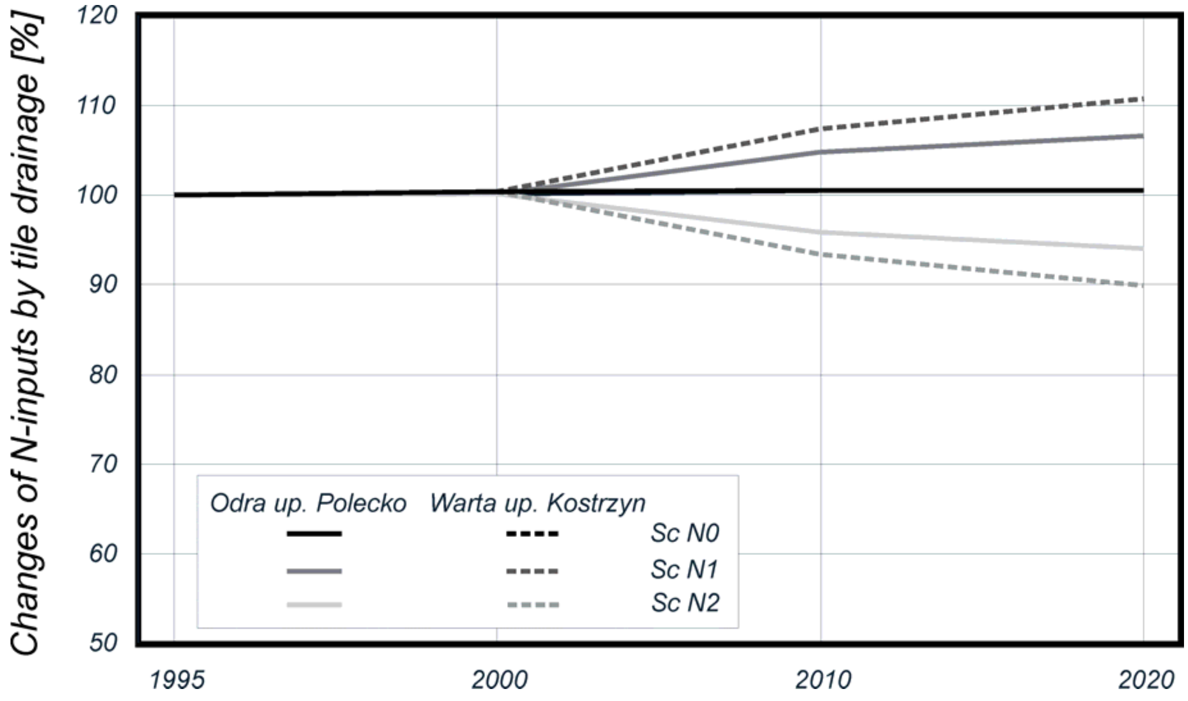

Figure 6.5: Comparison of the scenario results for the N-emissions by tile drainage estimated with MONERIS for the Odra upstream Polesko and the Warta upstream Kostrzyn.

Table 6.25: Nitrogen emissions in the Odra by tile drainage for the period 1993-1995 and the scenarios S1 and S2 (estimated by MONERIS).

Short name	Area	EDR$_N$ *1995*	EDR$_N$ *S1 2010*	EDR$_N$ *S1 2020*	EDR$_N$ *S2 2010*	EDR$_N$ *S2 2020*	Red. *S1 2010/95*	Red. *S1 2020/95*	Red. *S2 2010/95*	Red. *S2 2020/95*
	[km²]	[t N/a]	[t N/a]	[t N/a]	[t N/a]	[t N/a]	[%]	[%]	[%]	[%]
Odra-Pola	1,570	976	1026	1026	909	909	-5,1	-5,1	6,8	6,8
Opava	2,091	526	553	553	490	490	-5,1	-5,1	6,8	6,8
Ostravice	824	254	267	267	236	236	-5,1	-5,1	6,8	6,8
Odra-Chal	4,666	1819	1912	1912	1695	1695	-5,1	-5,1	6,8	6,8
Odra-Raci	6,684	2647	2764	2775	2508	2498	-4,4	-4,8	5,3	5,6
Klodnica	1,085	114	117	117	113	112	-2,4	-3,1	1,0	1,9
Odra-Gros	10,989	3520	3670	3694	3360	3336	-4,3	-4,9	4,6	5,2
Mala Panew	2,123	348	360	365	340	336	-3,4	-4,7	2,4	3,6
Nysa Klod	4,515	835	873	889	806	789	-4,6	-6,6	3,5	5,5
Stobrawa	1,601	307	322	328	297	290	-4,7	-6,8	3,4	5,5
Odra-Wroc	20,397	5324	5551	5607	5107	5049	-4,3	-5,3	4,1	5,2
Olawa	1,167	370	383	388	362	356	-3,6	-4,9	2,3	3,8
Bystrzyca	1,760	423	440	447	410	402	-4,2	-5,8	3,0	4,9
Widawa	1,716	535	562	574	514	502	-5,0	-7,2	3,9	6,3
Kaczawa	2,261	340	346	348	338	336	-2,0	-2,6	0,4	1,1
Odra-Scin	29,584	7649	7957	8044	7383	7290	-4,0	-5,2	3,5	4,7
Barycz	5,535	3009	3238	3349	2802	2692	-7,6	-11,3	6,9	10,5
Odra-Nowa	36,780	10925	11471	11672	10447	10241	-5,0	-6,8	4,4	6,3
Kwisa	1,026	258	265	267	255	253	-2,6	-3,5	1,1	2,0
Bobr	5,869	730	749	756	720	713	-2,6	-3,6	1,4	2,2
Odra-Pole	47,152	12480	13083	13309	11961	11731	-4,8	-6,6	4,2	6,0
Ny Lu-Zgor	1,609	677	705	717	657	645	-4,1	-5,9	3,0	4,7
Ny Lu-Gubi	3,974	920	956	973	894	878	-4,0	-5,8	2,8	4,5
Odra-Kost	53,532	13545	14190	14435	12997	12749	-4,8	-6,6	4,0	5,9
Grabia	813	271	290	299	254	245	-7,1	-10,2	6,2	9,5
Widawka	2,355	596	634	651	564	547	-6,4	-9,2	5,4	8,3
Warta-Sier	8,140	1752	1851	1893	1673	1627	-5,7	-8,1	4,5	7,1
Ner	1,867	899	976	1013	829	791	-8,5	-12,6	7,8	12,0
Prosna	4,825	2556	2755	2845	2381	2289	-7,8	-11,3	6,8	10,5
Warta-Pozn	25,911	10896	11762	12172	10110	9691	-7,9	-11,7	7,2	11,1
Welna	2,621	686	736	759	642	619	-7,2	-10,6	6,4	9,8
Obra	2,758	552	582	596	528	515	-5,4	-7,9	4,4	6,7
Notec-Osie	5,508	1227	1333	1384	1127	1076	-8,6	-12,8	8,1	12,3
Gwda	4,943	700	731	744	677	664	-4,4	-6,2	3,4	5,2
Drawa	3,296	237	245	249	232	228	-3,2	-4,8	2,2	3,8
Notec-Sant	17,330	2651	2816	2892	2508	2432	-6,2	-9,1	5,4	8,3
Warta-Kost	54,518	16380	17584	18147	15309	14736	-7,4	-10,8	6,5	10,0
Mysla	1,334	252	263	269	243	238	-4,6	-6,8	3,4	5,4
Odra-Kraj	110,074	30662	32556	33385	29005	28165	-6,2	-8,9	5,4	8,1
Plonia	1,101	362	377	384	351	344	-4,4	-6,3	2,9	4,9
Ina	2,163	584	612	624	564	552	-4,8	-6,9	3,3	5,4
Odra-Mouth	118,861	32263	34237	35100	30550	29674	-6,1	-8,8	5,3	8,0
Peene	5,110	2940	3181	3296	2722	2604	-8,2	-12,1	7,4	11,4
Zarow	748	268	293	305	243	230	-9,6	-14,1	9,1	13,9
Uecker	2,401	978	1050	1085	913	880	-7,4	-10,9	6,6	10,0
Odra Haff	8,885	4312	4660	4825	3998	3829	-8,1	-11,9	7,3	11,2

6.3 Sum of the Scenarios Results

The Table 6.26 and 6.28 show the results of the sum of the scenario calculations with the highest reduction for point sources (P5), erosion (E3) and the subsurface N-inputs (S2). In the table 6.27 and 6.29 the possible maximum of the reduction in comparison to the period 1993-1997 are presented. These summarized scenario results are also shown in the Figure 6.6 and 6.7. Because the introduction of P-free detergents seems (P0) to be an fast and effective step to reduce the P-inputs into the Odra this scenario result is given additionally in Figure 6.6. In general it can be concluded that a reduction of the P-inputs into the Odra of 62% is possible. This would be sufficient to full fill the HELCOM targets. But within the recent discussions in relation to the EU water framework directive and the establishing of a good ecological status within the river itself, this reduction could be to low. These problems should be discussed and solved in further projects. The applied models can be also used for further scenario analysis in relation to the reference state as well as the good ecological status.

For nitrogen the changes within the point sources, erosion and N-surplus will only result a reduction of 34 % compared to the period 1993-97. It is questionable that these scenarios are sufficient to reach the 50% reduction targets of HELCOM in comparison to the late eighties.

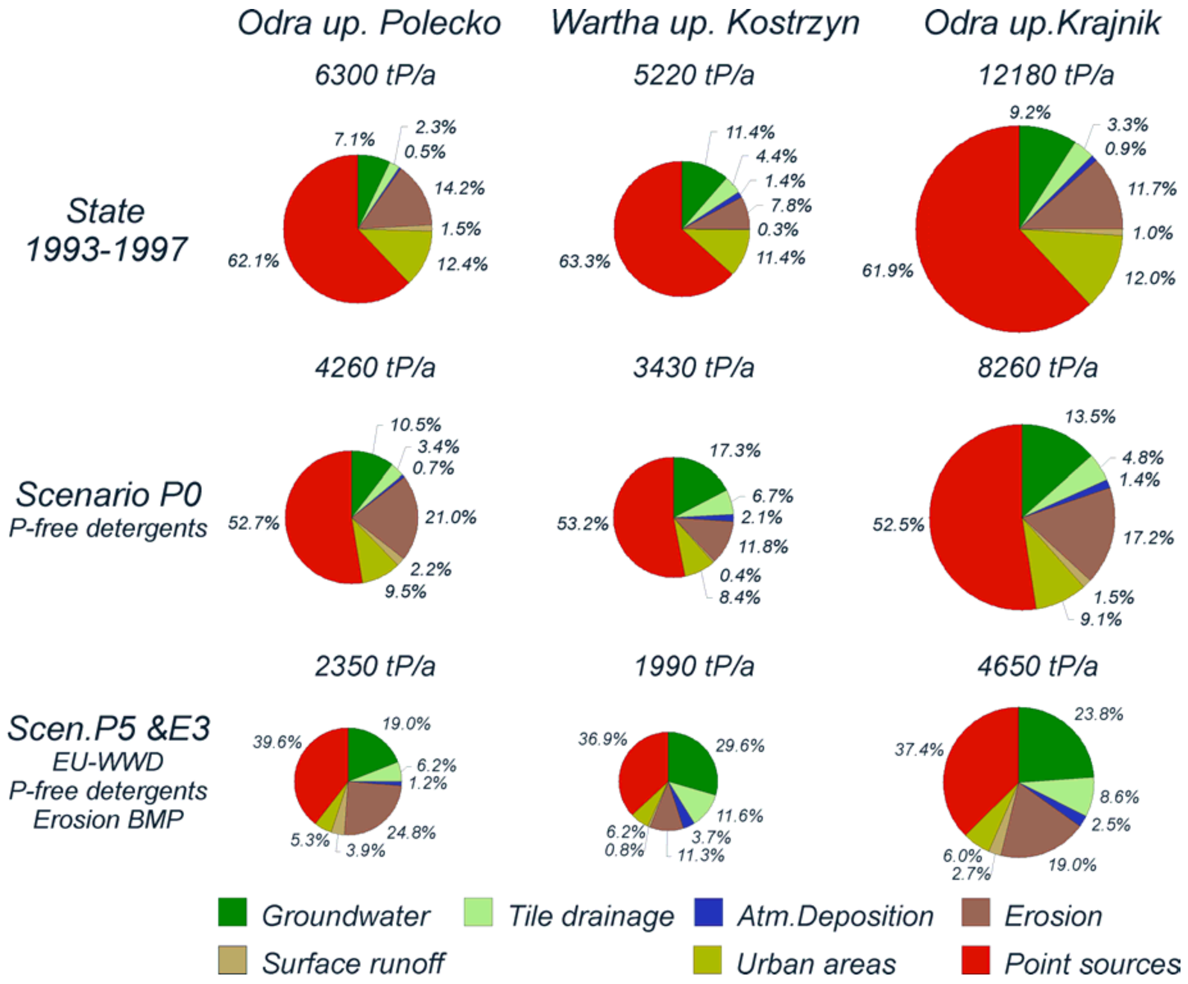

Figure 6.6: Possible changes of the P-emissions into the river system of the Odra and its main tributaries

Table 6.26: Point and diffuse P-inputs into the Odra basin summarized from the scenarios with the highest reduction.

	EGW$_P$ [tP/a]	**EDR$_P$ [tP/a]**	**EDEP$_P$ [tP/a]**	**EER$_P$ [tP/a]**	**ERO$_P$ [tP/a]**	**EURB$_P$ [tP/a]**	**ED$_P$ [tP/a]**	**EP$_P$ [tP/a]**	**ET$_P$ [tP/a]**
Odra - Polanka	13	6	0	50	6	2	76	14	91
Opawa	15	4	0	46	2	2	70	20	90
Ostravice	8	3	0	9	14	5	40	48	87
Odra - Chalupki	37	13	1	109	24	12	196	127	324
Odra - Raciborz	79	22	2	168	35	19	325	164	488
Klodnica	6	2	1	6	2	15	31	120	152
Odra - Groszowice	101	34	4	223	40	42	444	346	790
Mala Panew	15	6	1	3	2	3	30	32	62
Nysa Klodzka	42	9	2	81	14	6	153	30	183
Stobrawa	6	4	1	3	1	2	17	4	21
Odra - Wroclaw	167	55	9	315	57	59	662	471	1133
Olawa	7	6	0	23	1	4	41	3	44
Bystrzyca	11	6	1	31	2	6	58	86	144
Widawa	11	8	1	13	1	4	37	16	53
Kaczawa	24	7	1	40	5	5	81	37	119
Odra - Scinawa	249	93	13	459	68	88	971	775	1745
Barycz	91	27	6	42	2	13	180	29	209
Odra - Nowa Sol	363	123	20	520	71	107	1204	835	2039
Kwisa	16	5	0	13	5	1	39	4	43
Bobr	71	13	3	47	20	9	164	62	227
Odra - Polecko	447	145	29	582	93	126	1421	929	2350
Nysa Luzycka Z	20	11	0	41	11	8	90	34	124
Nysa Luzycka G	41	14	2	45	14	13	129	45	174
Odra - Kostrzyn	509	160	34	631	109	146	1589	989	2578
Grabia	24	3	0	2	0	2	31	15	47
Widawka	42	7	1	4	1	4	59	28	86
Warta - Sieradz	108	19	4	24	5	12	172	158	330
Ner	61	10	1	6	1	15	94	107	200
Prosna	32	28	3	36	1	11	110	43	153
Warta - Poznan	319	135	21	138	8	72	694	464	1158
Welna	23	19	4	14	0	5	66	11	76
Obra	34	8	4	5	1	4	56	6	62
Notec - Osiek	111	25	11	38	0	11	195	31	226
Gwda	41	13	11	8	2	7	82	32	114
Drawa	28	4	9	4	2	3	51	1	52
Notec - mouth	182	47	35	53	5	25	348	72	421
Warta - Kostrzyn	595	230	73	224	15	124	1262	733	1995
Mysla	4	3	3	3	0	2	15	7	22
Odra - Krajnik	1115	399	114	882	124	280	2914	1740	4654
Peonia	3	7	4	16	0	2	32	8	40
Ina	32	12	3	26	1	4	79	42	122
Odra - mouth	1172	425	131	946	126	309	3109	1791	4900
Peene	28	19	8	48	1	11	116	25	141
Zarow	9	2	1	6	0	1	19	0	20
Uecker	22	7	5	32	0	5	72	10	82
Odra Haff	62	30	16	86	2	19	215	36	251

Table 6.27: Reduction of point and diffuse P-inputs into the Odra basin summarized from the scenarios of the highest reduction and compared with the situation 1993-1997.

	EGW$_P$ **[%]**	**EDR$_P$** **[%]**	**EDEP$_P$** **[%]**	**EER$_P$** **[%]**	**ERO$_P$** **[%]**	**EURB$_P$** **[%]**	**ED$_P$** **[%]**	**EP$_P$** **[%]**	**ET$_P$** **[%]**
Odra - Polanka	0.0	0.0	0.0	32.6	0.0	78.7	29.1	68.8	41.0
Opawa	0.0	0.0	0.0	35.3	0.0	84.3	33.8	69.8	47.7
Ostravice	0.0	0.0	0.0	21.8	0.0	84.1	43.0	62.8	55.8
Odra - Chalupki	0.0	0.0	0.0	32.1	0.0	86.0	39.4	67.9	55.1
Odra - Raciborz	0.0	0.0	0.0	28.9	0.0	86.1	36.4	67.6	51.9
Klodnica	0.0	0.0	0.0	50.3	0.0	90.4	82.7	77.9	79.1
Odra - Groszowice	0.0	0.0	0.0	30.9	0.0	88.1	48.2	74.7	64.5
Mala Panew	0.0	0.0	0.0	50.3	0.0	87.2	44.1	66.6	58.5
Nysa Klodzka	0.0	0.0	0.0	33.4	0.0	88.1	35.1	75.4	48.9
Stobrawa	0.0	0.0	0.0	50.1	0.0	69.1	31.8	77.2	51.1
Odra - Wroclaw	0.0	0.0	0.0	32.4	0.0	86.9	44.9	74.6	62.9
Olawa	0.0	0.0	0.0	30.9	0.0	64.4	29.7	79.9	40.8
Bystrzyca	0.0	0.0	0.0	30.6	0.0	84.0	44.2	74.7	67.6
Widawa	0.0	0.0	0.0	42.1	0.0	57.4	29.1	68.5	48.8
Kaczawa	0.0	0.0	0.0	31.1	0.0	72.8	27.6	72.6	52.3
Odra - Scinawa	0.0	0.0	0.0	32.3	0.0	85.9	43.8	75.8	64.6
Barycz	0.0	0.0	0.0	47.1	0.0	55.9	23.0	76.4	41.5
Odra - Nowa Sol	0.0	0.0	0.0	33.7	0.0	84.7	41.6	76.3	63.5
Kwisa	0.0	0.0	0.0	30.1	0.0	88.4	23.5	77.5	37.7
Bobr	0.0	0.0	0.0	41.0	0.0	81.3	30.7	74.0	52.5
Odra - Polecko	0.0	0.0	0.0	34.9	0.0	83.9	40.5	76.2	62.7
Nysa Luzycka Z	0.0	0.0	0.0	29.0	0.0	84.1	38.8	65.0	49.2
Nysa Luzycka G	0.0	0.0	0.0	31.7	0.0	78.3	35.0	71.2	50.9
Odra - Kostrzyn	0.0	0.0	0.0	34.8	0.0	82.9	39.7	76.3	62.1
Grabia	0.0	0.0	0.0	47.6	0.0	62.1	13.8	45.0	27.4
Widawka	0.0	0.0	0.0	48.9	0.0	84.1	28.5	61.1	43.6
Warta - Sieradz	0.0	0.0	0.0	49.5	0.0	84.2	33.4	61.7	50.8
Ner	0.0	0.0	0.0	49.4	0.0	87.7	54.1	87.1	80.6
Prosna	0.0	0.0	0.0	40.6	0.0	74.0	33.3	73.6	53.3
Warta - Poznan	0.0	0.0	0.0	43.8	0.0	83.2	40.0	78.0	64.6
Welna	0.0	0.0	0.0	46.4	0.0	75.1	29.9	83.6	51.8
Obra	0.0	0.0	0.0	49.4	0.0	70.2	20.6	71.0	32.6
Notec - Osiek	0.0	0.0	0.0	41.7	0.0	66.3	19.6	72.3	36.0
Gwda	0.0	0.0	0.0	49.7	0.0	79.7	30.7	73.3	52.3
Drawa	0.0	0.0	0.0	51.0	0.0	65.8	16.7	94.9	29.4
Notec - mouth	0.0	0.0	0.0	44.4	0.0	71.5	23.4	76.0	44.4
Warta - Kostrzyn	0.0	0.0	0.0	44.7	0.0	79.2	34.1	77.8	61.8
Mysla	0.0	0.0	0.0	48.6	0.0	67.7	32.8	74.6	56.0
Odra - Krajnik	0.0	0.0	0.0	37.9	0.0	80.9	37.1	76.9	61.8
Peonia	0.0	0.0	0.0	30.9	0.0	51.4	23.6	77.5	49.1
Ina	0.0	0.0	0.0	30.1	0.0	53.8	17.1	81.8	63.1
Odra - mouth	0.0	0.0	0.0	37.8	0.0	79.9	36.7	77.4	61.9
Peene	0.0	0.0	0.0	34.7	0.0	26.0	20.1	9.3	18.4
Zarow	0.0	0.0	0.0	41.0	0.0	24.1	18.3	81.4	23.5
Uecker	0.0	0.0	0.0	30.7	0.0	13.4	17.3	34.7	19.9
Odra Haff	0.0	0.0	0.0	33.8	0.0	24.9	18.9	22.3	19.4

Table 6.28: Point and diffuse N-inputs into the Odra basin summarized from the scenarios with the highest reduction.

	EGW_N [tN/a]	**EDR_N [tN/a]**	**$EDEP_N$ [tN/a]**	**EER_N [tN/a]**	**ERO_N [tN/a]**	**$EURB_N$ [tN/a]**	**ED_N [tN/a]**	**EP_N [tN/a]**	**ET_N [tN/a]**
Odra - Polanka	1260	910	30	30	20	30	2280	90	2380
Opawa	1760	490	30	30	10	30	2350	130	2470
Ostravice	550	240	20	10	50	60	920	340	1260
Odra - Chalupki	3660	1690	90	70	100	150	5760	970	6730
Odra - Raciborz	5510	2500	150	110	150	240	8650	1310	9960
Klodnica	310	110	30	0	10	150	610	1080	1690
Odra - Groszowice	6460	3340	280	150	170	480	10880	2910	13790
Mala Panew	680	340	70	0	10	30	1120	260	1380
Nysa Klodzka	2670	790	110	50	50	70	3740	260	4010
Stobrawa	190	290	40	0	0	20	540	40	580
Odra - Wroclaw	10110	5050	550	210	230	670	16830	3980	20810
Olawa	120	360	20	10	0	50	560	30	590
Bystrzyca	450	400	40	20	10	70	990	740	1730
Widawa	190	500	30	10	0	50	780	160	940
Kaczawa	700	340	60	20	20	60	1200	300	1490
Odra - Scinawa	12320	7290	780	300	280	1020	21980	6700	28680
Barycz	700	2690	200	30	10	130	3760	250	4010
Odra - Nowa Sol	13220	10240	1030	340	290	1220	26340	7200	33550
Kwisa	760	250	20	10	20	10	1060	40	1100
Bobr	3340	710	130	30	80	110	4400	550	4950
Odra - Polecko	16960	11730	1320	380	380	1420	32190	8000	40190
Nysa Luzycka Z	1230	650	20	30	40	100	2060	360	2420
Nysa Luzycka G	2110	880	80	30	50	170	3310	530	3840
Odra - Kostrzyn	19960	12750	1490	410	440	1670	36710	8780	45490
Grabia	140	250	10	0	0	20	420	120	540
Widawka	460	550	50	0	10	40	1100	210	1310
Warta - Sieradz	1780	1630	150	20	20	130	3730	1320	5050
Ner	330	790	30	0	0	150	1320	1080	2400
Prosna	540	2290	90	20	0	110	3050	380	3430
Warta - Poznan	3370	9690	620	100	30	750	14560	4120	18690
Welna	120	620	100	10	0	50	900	80	980
Obra	190	520	100	0	0	40	860	50	910
Notec - Osiek	530	1080	260	30	0	110	2010	260	2270
Gwda	810	660	220	0	10	70	1780	270	2050
Drawa	730	230	190	0	10	30	1190	10	1200
Notec - mouth	2140	2430	760	40	20	250	5640	630	6280
Warta - Kostrzyn	6160	14740	1800	160	60	1280	24200	6550	30750
Mysla	100	240	60	0	0	20	420	50	470
Odra - Krajnik	26530	28160	3460	600	490	3080	62310	15540	77860
Peonia	20	340	90	10	0	20	480	70	550
Ina	440	550	70	20	0	40	1120	360	1480
Odra - mouth	27250	29670	3870	640	500	3340	65270	16330	81610
Peene	1000	2600	200	40	10	130	3980	400	4380
Zarow	90	230	20	10	0	20	370	10	370
Uecker	250	880	140	40	0	60	1370	130	1500
Odra Haff	1420	3830	400	80	10	220	5960	570	6530

Table 6.29: Reduction of point and diffuse N-inputs into the Odra basin summarized from the scenarios of highest reduction and compared with the situation 1993-97.

	EGW_N [%]	EDR_N [%]	$EDEP_N$ [%]	EER_N [%]	ERO_N [%]	$EURB_N$ [%]	ED_N [%]	EP_N [%]	ET_N [%]
Odra - Polanka	29.6	6.8	0.0	32.6	0.0	48.6	21.9	60.5	24.8
Opawa	27.3	6.8	0.0	35.3	0.0	60.5	24.4	61.5	27.9
Ostravice	7.5	6.8	0.0	21.8	0.0	64.4	15.4	49.5	28.4
Odra - Chalupki	25.4	6.8	0.0	32.1	0.0	66.8	22.9	54.9	30.1
Odra - Raciborz	22.1	5.6	0.0	29.0	0.0	65.2	20.3	53.3	27.1
Klodnica	17.7	1.9	0.0	50.3	0.0	75.0	45.9	61.8	57.3
Odra - Groszowice	21.9	5.2	0.0	31.0	0.0	69.5	22.5	59.1	34.8
Mala Panew	17.7	3.6	0.0	50.3	0.0	73.0	18.2	46.6	25.6
Nysa Klodzka	19.5	5.5	0.0	33.4	0.0	68.6	18.9	64.1	25.1
Stobrawa	6.5	5.5	0.0	50.1	0.0	50.1	9.1	62.2	17.3
Odra - Wroclaw	20.6	5.2	0.0	32.4	0.0	67.3	20.7	59.2	32.8
Olawa	27.9	3.8	0.0	30.9	0.0	32.8	13.7	62.9	18.7
Bystrzyca	27.3	4.9	0.0	30.6	0.0	59.7	23.5	54.2	40.6
Widawa	27.7	6.3	0.0	41.2	0.0	29.7	14.3	31.6	17.8
Kaczawa	21.7	1.1	0.0	31.1	0.0	45.9	17.6	44.5	24.8
Odra - Scinawa	21.3	4.7	0.0	32.3	0.0	65.0	20.7	59.9	35.4
Barycz	29.7	10.5	0.0	46.3	0.0	30.8	15.7	54.4	19.9
Odra - Nowa Sol	22.0	6.3	0.0	33.8	0.0	62.9	20.2	59.9	34.2
Kwisa	6.9	2.0	0.0	30.1	0.0	72.5	8.1	69.7	13.8
Bobr	11.9	2.2	0.0	40.4	0.0	59.1	12.7	56.1	21.3
Odra - Polecko	19.9	6.0	0.0	34.9	0.0	61.8	18.8	60.1	32.7
Nysa Luzycka Z	10.1	4.7	0.0	29.0	0.0	47.7	11.7	54.3	22.4
Nysa Luzycka G	10.1	4.5	0.0	31.7	0.0	39.6	10.8	57.1	22.4
Odra - Kostrzyn	18.5	5.9	0.0	34.8	0.0	59.2	17.8	60.4	31.9
Grabia	24.8	9.5	0.0	47.6	0.0	39.4	17.0	15.7	16.7
Widawka	21.6	8.3	0.0	48.9	0.0	66.6	19.0	64.7	32.9
Warta - Sieradz	25.3	7.1	0.0	49.5	0.0	69.0	21.6	57.4	35.7
Ner	23.1	12.0	0.0	49.4	0.0	68.6	29.5	73.0	59.1
Prosna	25.3	10.5	0.0	39.7	0.0	54.0	16.3	72.0	31.4
Warta - Poznan	22.5	11.1	0.0	43.2	0.0	63.4	19.6	65.8	38.1
Welna	21.1	9.8	0.0	45.6	0.0	51.3	15.4	71.9	27.4
Obra	23.1	6.7	0.0	49.4	0.0	46.7	13.7	54.3	17.9
Notec - Osiek	25.1	12.3	0.0	40.8	0.0	43.7	17.7	47.4	22.7
Gwda	23.6	5.2	0.0	49.7	0.0	58.2	18.0	64.5	30.2
Drawa	19.1	3.8	0.0	51.0	0.0	39.7	14.6	84.6	17.2
Notec - mouth	22.1	8.3	0.0	43.5	0.0	48.1	16.2	61.2	25.0
Warta - Kostrzyn	21.5	10.0	0.0	44.0	0.0	57.4	17.7	67.7	38.1
Mysla	13.8	5.4	0.0	48.6	0.0	42.5	10.0	57.2	19.9
Odra - Krajnik	19.1	8.1	0.0	37.9	0.0	57.5	17.6	63.7	34.3
Peonia	10.6	4.9	0.0	30.9	0.0	26.1	6.3	60.9	19.9
Ina	30.0	5.4	0.0	30.1	0.0	28.9	17.8	67.0	39.8
Odra - mouth	19.1	8.0	0.0	37.8	0.0	56.0	17.3	63.8	34.2
Peene	25.0	11.4	0.0	33.7	0.0	16.5	15.3	32.4	17.2
Zarow	25.2	13.9	0.0	40.1	0.0	14.6	17.0	56.7	18.4
Uecker	18.3	10.0	0.0	30.7	0.0	6.8	11.3	15.9	11.7
Odra Haff	23.6	11.2	0.0	33.0	0.0	13.7	14.3	28.9	15.8

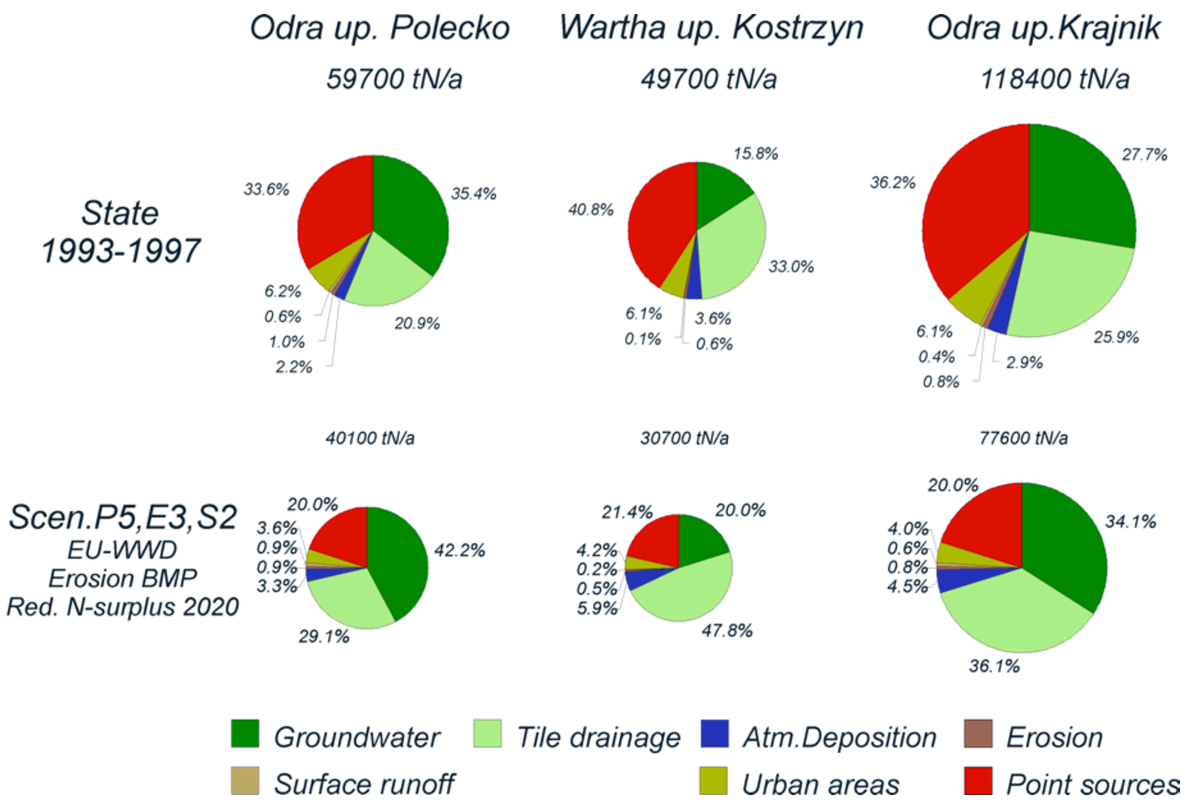

Figure 6.7: Possible changes of the N-emissions into the river system of the Odra and its main tributaries.

As shown in Figure 6.7 a further reduction of N-inputs into the river systems of Odra is only possible if N-inputs by tile drainage will be reduced, but this means that additionally to the proposed scenarios the area of tile drainage have to be reduced.

Acknowledgements

We would like to thank the German Environmental Agency for funding the project. Further it is important for us to thank all of the institutions which have supported the project by supplying data and helpful discussions in Czech Republic, Poland, and Germany. Our special thanks are related to the members of the Work Team Prof. Dr. Henryk Okruszko (Chairman), Prof. Dr. Jerzy Kowalski, Doc. Dr. Edmund Kaca, Doc. Dr. Janusz Zurek, Dr. Alicja Gruszecka, Dagmar Fischer, Prof. Dr. Ralph Meißner, Prof. Dr. Hans-Jürgen Voigt, Dr. René Schenk for the examination of the scientific outcome of this project within the last 5 years.

Without the technical and organizational support of the German Association for Water Resources and Land Improvement (DVWK) and the Polish Academy of Sciences (PAN) this international project would not be feasible. In this relation we have especially to thank Dr. Wolfgang Dirksen.

Dr. Bernd Mehlhorn and Dr. Volker Mohaupt from the German Environmental Agency we have to thank for the helpful critical discussions during the project.

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