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Dissertation to obtain Degree

Dr. rer. nat.

**Long-term development of nutrient loads
in Berlin surface water system and their causes
during the last 150 years**

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Date of defence: 23.01.2008

Acknowledgement

This research is supported by Vietnamese Ministry of Education and Training, the Institute of Geography/Freie Universität Berlin, Senate Department for Urban Development of Berlin and Leibniz-Institute of Freshwater Ecology and Inland Fisheries in Berlin.

I would like to express my sincere and deepest gratitude to my supervisor Prof. Dr. Brigitta Schütt for her admirable supervision, constructive advises, continuous encouragement throughout the entire work of this Ph.D. thesis and also for her provision of an office and all necessary conditions for my study at the Freie Universität Berlin. I wish to express my sincere gratitude to Prof. Dr. Asaf Pekdeger, my second supervisor for giving me comments and criticism on my thesis. I would like to give special thanks to Dr. Horst Behrendt at the IGB, for helping me with the application of MONERIS, for giving fruitful discussions and scientific revision of my thesis.

I would like to express my great thanks to Dr. Steffen Möller, Dr. Philipp Hoelzmann and all colleagues from Physical Geography, Institute of Geography, Department of Earth Sciences, Freie Universität Berlin who have helped me during this study and gave comments on my thesis.

Finally, my heartfelt thanks to my family for their love, inspiration and encouragement me to accomplish this work.

Contents

Abstract	<i>xv</i>
Zusammenfassung	<i>xvii</i>
1. Introduction	1
2. Study site	3
2.1 Geographical, geological and climate conditions	3
2.1.1 Geographical and geological conditions	3
2.1.2 Climate	4
2.2 The surface water system	4
2.2.1 The water bodies of Berlin	4
2.2.2 The river Havel	6
2.2.3 The river Spree	9
2.2.4 The river Dahme	9
2.3 Development of the population and urban infrastructure of Berlin in the last 150 years	11
2.3.1 Urban and impervious area development	11
2.3.2 Population development	13
2.4 The development of water supply, waste water collection and treatment system	15
2.4.1 The development of water supply	15
2.4.2 The development of waste water collection system	18
2.4.3 The development of waste water treatment system	27
2.5 The development of legal, policies and standards on waste water collection and treatment of Berlin in the last 150 years	32
3. Biogeochemistry of nutrients and nutrient emission modelling	35
3.1 Biogeochemistry of nutrients	35
3.1.1 Biogeochemistry of nitrogen	35
3.1.2 Biogeochemistry of phosphorus	39
3.2 Nutrient emission modelling	43
3.2.1 Major trends of nutrient emission modelling	43
3.2.2 Source of emissions, pathways and riverine budgets of nutrients in models	46
3.2.3 MONERIS model and its applications	47

4. Database development	49
4.1 Spatial input data	49
4.2 Data for reconstruction of urban development, waster water collection and treatment of Berlin	50
4.2.1 Data on population and urban development	50
4.2.2 Data on waste water collection and treatment	50
4.3 Monitoring data for surface waters	51
4.3.1 Monitoring data for the water bodies of Berlin	51
4.3.2 Monitoring data for upstream and downstream surface waters	55
4.4 Data on climate and hydrology	57
4.4.1 Discharge data	57
4.4.2 Precipitation and climate data	58
4.4.3 Data on nutrient deposition	59
4.5 Data for calculating point source emissions	59
4.5.1 Data on sewage farms	59
4.5.2 Data on WWTPs	59
5. Temporal and spatial trend of Berlin surface water quality	63
5.1 Temporal trends	63
5.1.1 Seasonal variations	63
5.1.2 Long-term trends	69
5.2 Spatial trends	75
6. Model design	79
6.1 Modelling approach	79
6.2 Estimate nutrient emissions and loads by modelling	80
6.2.1 Nutrient emissions from point sources	81
6.2.2 Nutrient emissions from diffuse sources	83
6.3 Quantification of nutrient loads by monitoring data	91
6.4 Nutrient retention in the water bodies	92
6.5 Reconstruction of the urban development of Berlin and secondary data method	94
6.5.1 Reconstruction of the development of impervious area in the Greater Berlin	94
6.5.2 Reconstruction of the sewerage development	96
6.5.3 The development of collected waste water volume	101

7. Development of nutrient emissions from Berlin's urban area to surface waters during the last 150 years	105
7.1 The development of the specific nutrient emissions	105
7.2 Nutrient emissions from diffuse sources	112
7.2.1 Nutrient emissions from different diffuse pathways	112
7.2.2 Development of nitrogen emissions from diffuse sources	118
7.3 Nutrient emissions from point sources	122
7.3.1 Nutrient emissions from sewage farms	122
7.3.2 Nutrient emissions from waste water treatment plants	128
7.4 Total nutrient emissions from urban area of Berlin	132
8. Nutrient loads in Berlin surface water system and in the Havel catchment during the last 150 years	135
8.1 Nutrient emission, load and retention in Berlin surface water system	135
8.1.1 The total nutrient emissions into the water bodies of Berlin during the last 20 years	135
8.1.2 Nutrient loads and retention capacity of Berlin's water bodies	141
8.2 The impacts of nutrient emissions from Berlin on downstream of the river Havel	145
8.3 Reconstruction of nutrient load developments of Berlin and subcatchments of the Havel over the last 150 years	148
8.4 Validation of the model results	151
9. Conclusions	157
10. References	159
11. Appendices	173

Figures

Figure 2.1:	Berlin Geological Scheme	3
Figure 2.2:	Annual air temperature and precipitation in Berlin over the last 150 years	4
Figure 2.3:	The surface water system of Berlin	5
Figure 2.4:	The Havel catchment and subcatchments	7
Figure 2.5:	Population density within administrative boundaries of the Havel catchment	8
Figure 2.6:	The Havel's discharge at Hennigsdorf and Havelberg in the period of 1953-2003	10
Figure 2.7:	The Spree's discharge at Neuzittau and Sophienwerder in the period of 1953-2003	10
Figure 2.8:	The Dahme's discharge at Neue Mühle in the period of 1953-2003	10
Figure 2.9:	The Old Berlin city and the Greater Berlin in 1920	11
Figure 2.10:	The development of the impervious area in the Greater Berlin, 1850-2003	12
Figure 2.11:	Contribution of the Old Berlin city and the extension parts to the total impervious area of the Greater Berlin	12
Figure 2.12:	Population development of the Greater Berlin (entire city) over the last 150 years	13
Figure 2.13:	Development of population density in Berlin over the last 150 years	14
Figure 2.14:	Contribution of the Old Berlin city and the extension parts to the total population of the Greater Berlin in the period of 1850-1920	14
Figure 2.15:	Development of water supply volume in Berlin, 1857-1950	15
Figure 2.16:	Backyard with toilet and pump from near surface groundwater in a Berlin's house, 1850s	18
Figure 2.17:	The CRELLE Plan for Berlin drainage system in 1842 with 11 drainage zones and 11 introduction points within the inner city	20
Figure 2.18:	The WIEBE Plan for Berlin drainage system in 1861 with only one drainage zone and a single introduction point into the Spree out side the city	20
Figure 2.19:	The HOBRECHT Plan for Berlin waste water collection and treatment in 1871 with 12 drainage zones (radial systems), pressure pipes and the sewage farms without any introduction into Spree river	20
Figure 2.20:	Waste water collection and treatment system of Berlin	21
Figure 2.21:	Collected waste water of the Greater Berlin in the period of 1875-1920	23
Figure 2.22:	The waste water collection system of the Greater Berlin in 1927	23
Figure 2.23:	Development of connected houseblocks to the sewer system of the Greater Berlin, 1925-1938	23
Figure 2.24:	Drainage system in one radial system in the Old Berlin city	24
Figure 2.25:	The combined sewer system in Berlin	25
Figure 2.26:	The separate sewer system in Berlin	26
Figure 2.27:	Location of Berlin sewage farms – the first waste water treatment facilities implemented in the late 19 th century	27
Figure 2.28:	Schematic illustration of types of sewage farms	28
Figure 2.29:	Waste water treatment capacity of Berlin sewage farms 1876 – 1985	29
Figure 2.30:	Treatment capacity development of the Berlin's WWTPs	30
Figure 3.1:	The nitrogen cycle	36
Figure 3.2:	The phosphorus cycle	40

Figure 4.1:	Surface water monitoring stations of Berlin	53
Figure 4.2:	Monitoring stations for surface water quality in upstream and downstream areas of Berlin	56
Figure 4.3:	Hydrogeological map of the Havel catchment	60
Figure 4.4:	Connection degree to sewer system in the Havel catchment area in 1989	61
Figure 4.5:	Existing waste water treatment plants in Havel catchment	62
Figure 5.1:	Seasonal variations of monthly average of water temperature at (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel	64
Figure 5.2:	Seasonal variations of monthly average surface water quality parameters at monitoring station 160 - Sophienwerder, Spree for (a) Temperature and (b) Dissolved oxygen	64
Figure 5.3:	Seasonal variations of monthly average of nitrate concentrations at (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel	65
Figure 5.4:	Seasonal variations of monthly average (a) Nitrate-N concentrations of WWTPs effluents, the Dahme; and (b) effluents of WWTPs purged into the Teltowkanal and inflow-discharge of the Teltowkanal at Grünau	66
Figure 5.5:	Seasonal variations of monthly average of total phosphorus concentration in (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel	66
Figure 5.6:	Development of TP output load of Berlin water bodies shown by five-year-averages from 1984-2003	70
Figure 5.7:	Development of TP input load and output load of Berlin water bodies shown by five-year-averages from 1984-2003	70
Figure 5.8:	The development of TN input of Berlin water bodies in the period of 1984-2003	70
Figure 5.9:	The development of TN output of Berlin water bodies in the period of 1984-2003	70
Figure 5.10:	TN load of Berlin water bodies 1966–2003	70
Figure 5.11:	TP load of Berlin water bodies 1966–2003	70
Figure 5.12:	Spatial distribution of Berlin water bodies and subcatchments	75
Figure 5.13:	Mean value of temperature, electric conductivity, pH and concentrations of NH ₄ -N, NO ₂ -N, NO ₃ -N, PO ₄ -P, chlorophyll-a and dissolved oxygen in six different clusters of water bodies, 1984-2003	75
Figure 6.1:	Overall approaches for nutrient loading calculation for Berlin	79
Figure 6.2:	Pathways and processes in MONERIS	80
Figure 6.3:	Sources and pathways of nitrogen and phosphorus discharges and losses in urban areas	83
Figure 6.4:	Nutrient emissions from households and impervious areas connected to the gutter system without treatment	88
Figure 6.5:	Relationship between the impervious area and population of the Old Berlin city, 1875-1920	95
Figure 6.6:	Sewer connections in the Old Berlin city, 1875-1920	96
Figure 6.7:	Area connected to sewers in Greater Berlin city, 1875-1920	99
Figure 6.8:	Population connected to sewers in Greater Berlin, 1875-1920	99
Figure 6.9:	Estimated waste water volume and statistical data on collected waste water volume of the Old Berlin city	102
Figure 6.10:	Estimated waste water volume and measured data in the Old Berlin city in the period of 1876-1920	104

Figure 7.1:	The development of the specific P emission per inhabitant over the last 150 years	105
Figure 7.2:	Development of P – content in the popular detergents in Germany in the period of 1961-1986	105
Figure 7.3:	The long-term development of the area specific nitrogen emission in Berlin	107
Figure 7.4:	Estimated NO _x emission in Germany in the period of 1990-2030	107
Figure 7.5:	Relationship between the area specific nitrogen depositions (NO _x + NH _y) and the total carbon dioxide emission of Germany in the period of 1850-2000	108
Figure 7.6:	Relationship between the nitrogen depositions (NO _x + NH _y) in EMEP database and estimated area specific nitrogen deposition in the period of 1985-1997	108
Figure 7.7:	The long-term development of the area specific phosphorus deposition in Berlin	109
Figure 7.8:	The development of direct nutrient depositions into Berlin's water bodies over the last 150 years	112
Figure 7.9:	Surface runoff from separate sewer system into water bodies of Berlin over the last 150 years	113
Figure 7.10:	Nutrient emissions via surface runoff from separate sewers of Berlin over the last 150 years	113
Figure 7.11:	Overflow water volume direct discharged into the receiving water bodies of Berlin in the period of 1875-2000	114
Figure 7.12:	Nutrient emissions from combined sewer overflow of Berlin in the period of 1875-2000	115
Figure 7.13:	Non-point source discharges development in Berlin, 1876-2000	118
Figure 7.14:	TN concentrations in individual non-point sources in Berlin over the last 150 year	119
Figure 7.15:	TN emissions from different non-point sources in Berlin over the last 150 years	119
Figure 7.16:	TP concentrations in different non-point sources in Berlin over the last 150 years	120
Figure 7.17:	TP emission via different non-point sources in Berlin over the last 150 years	120
Figure 7.18:	Nitrogen emission from sewage farms and purified waste water volume for the period 1876 to 1985	123
Figure 7.19:	Phosphorus emissions from sewage farms and purified waste water volume, period of 1876-1985	123
Figure 7.20:	TN emissions from WWTPs in Berlin over the last 150 years	130
Figure 7.21:	TP emissions from WWTPs in Berlin over the last 150 years	130
Figure 7.22:	Total discharges to Berlin's surface water bodies via different sources over the last 150 years	133
Figure 7.23:	Nitrogen emissions to Berlin's surface water bodies via different pathways and their contributions over the last 150 years	133
Figure 7.24:	Phosphorus emissions to Berlin's surface water bodies via different pathways and their contributions over the last 150 years	133
Figure 8.1:	Total discharges into surface water bodies of Berlin in the period of 1983-2002	137
Figure 8.2:	TN concentrations in inflow waters to Berlin in the period of 1983-2003	137
Figure 8.3:	TN emissions into surface water bodies of Berlin in the period of 1983-2002	137
Figure 8.4:	TP concentration in inflow waters and discharge from urban area of Berlin in the period of 1983-2003.	138
Figure 8.5:	TP emissions into surface water bodies of Berlin in the period of 1983-2002	139
Figure 8.6:	TN emissions and loads of Berlin's water bodies, 1983-2002	142
Figure 8.7:	TP emissions and load of Berlin's water bodies, 1983-2002	142
Figure 8.8:	Nutrient retention capacities of Berlin's water bodies, 1983-2002	142

Figure 8.9: Estimated and measured TN loads into surface waters of Berlin by different approaches in the period of 1983-2002	143
Figure 8.10: Comparison between estimated DIN loads to surface water bodies of Berlin with different approaches and measured loads in the period of 1983-2002	143
Figure 8.11: Comparison between estimated TP loads to surface water bodies of Berlin with different approaches and measured loads, 1976-2002	143
Figure 8.12: Comparison between estimated TP loads to surface water bodies of Berlin with original and calibrated coefficients and measured loads, 1978-2002	143
Figure 8.13: DIN loads of the river Havel at downstream of Berlin and at Havelberg	145
Figure 8.14: TN loads of the river Havel at downstream of Berlin and at Havelberg	145
Figure 8.15: TP loads of the river Havel at downstream of Berlin and at Havelberg	146
Figure 8.16: Comparison between estimated and observed nutrient loads in the Spree, Upper Havel and Dahme with original and calibrated coefficients, 1978-2002	147
Figure 8.17: TN emissions into the water bodies of Berlin from urban area and inflow waters during the last 150 years	150
Figure 8.18: TP emissions into the water bodies of Berlin from urban area and inflow waters during the last 150 years	150
Figure 8.19: Comparison between the long-term developments of phosphorus status in water reconstructed by results of this study and PO ₄ concentrations in sediment of Quenzsee	154
Figure 8.20: Comparison between the long-term nitrogen status in water reconstructed by (a) diatom inferred concentration method and (b) the results of this study	154
Figure 8.21: Comparison between the long-term phosphorus status in water reconstructed by (a) diatom inferred concentration method and (b) the results of this study	155
Figure 8.22: Comparison between the long-term developments of TN/TP status in water reconstructed by results of this study and diatom inferred concentration method	155
Figure 8.23: The conceptual model for nutrient load developments into the surface water bodies of Berlin during the last 150 year	156

Tables

Table 2.1: The water bodies of Berlin	5
Table 2.2: Land use in the Havel catchment	6
Table 2.3: The development of Berlin's water sector, 1852- 2002	16
Table 2.4: Water quality in the central supply system and wells of Berlin in 1856	17
Table 2.5: Water use development in Berlin in the period of 1986-2000	17
Table 2.6: Sewer construction in German cities	19
Table 2.7: Nitrogen removal performance for various types of treatment plants	31
Table 3.1: Emissions of nitrogen compounds and related human activities	38
Table 4.1: Relationship between the mean annual and summer nutrient concentrations in surface water of Berlin, 1984-2003	52
Table 4.2: Berlin surface water monitoring stations	54
Table 4.3: Monitoring data on upstream and downstream of Berlin	55
Table 4.4: Water level and discharge at main gauges of the Havel, Spree and Dahme	57
Table 4.5: Relationship of discharges at different stations in the Havel catchment	58
Table 5.1: TN load development of Berlin's water bodies, 1984 – 2003	69
Table 5.2: TP load development of Berlin's water bodies, 1984 – 2003	71
Table 6.1: Comparison of measured phosphorus concentrations in the precipitation of urban areas and in separate sewers	84
Table 6.2: Parameters used for nutrient load calculation in combined sewer system	86
Table 6.3: Population, urban area and impervious area of the Old Berlin city, 1875-1919	94
Table 7.1: The development of the specific P emission per inhabitant in different parts of Berlin for the period 1945 to 2000	106
Table 7.2: Development of specific N emission per inhabitant in Germany, 1880-1990	106
Table 7.3: Development of specific P emission per inhabitant in Germany, 1890-1990	106
Table 7.4: The area specific nutrient emissions in Berlin in the period of 1750-2000	109
Table 7.5: Direct nutrient depositions into water bodies of Berlin in the period of 1850-2000	112
Table 7.6: Storm overflow quantities of the pumping plants in Berlin	114
Table 7.7: Estimated removal capacity of sewage farms, 1876-1985	122
Table 7.8: Technological developments of WWTPs of Berlin	128
Table 8.1: Total discharges into surface water bodies of Berlin in the period of 1983-2003	136
Table 8.2: TN input and output loads of Berlin's surface water bodies, 1981-2003	136
Table 8.3: TP input and output loads of Berlin's surface water bodies, 1981-2003	138
Table 8.4: Estimated TN loads in Berlin surface water system and Havel catchment and subcatchments during the last 150 years	149
Table 8.5: Estimated TP loads in Berlin surface water system and Havel catchment and subcatchments over the last 150 years	149
Table 8.6: Comparison of measured and estimated nutrient concentrations in influent and effluent of sewage farms of Berlin	153
Table 8.7: Comparison of estimated nutrient loads for Berlin water bodies and previous study results	153

Abbreviations used in the text

a.s.l.	above sea level
BMU	German Federal Ministry for the Environment Nature Conservation and Nuclear Safety
BOD	Biochemical Oxygen Demand
BWB	Berlin Water Company
Chla	chlorophyll-a
CIDAC	Carbon Dioxide Information Analysis Center, USA
COD	Chemical oxygen demand
DIN	Dissolved inorganic nitrogen
DO	Dissolved oxygen
DWD	German Weather Services (Deutscher Wetterdienst)
EC	European Commission
EEC	European Economic Community
EMEP	Co-operative programme for monitoring and evaluation of the long-range transmission of air-pollution in Europe
EU	European Union
FRG	Federal Republic of Germany
GDR	German Democratic Republic
IBG	Institut für Gewässerökologie u. Binnenfischei Berlin (IGB)
IIASA	International Institute for Applied Systems Analysis
IPCC	The Intergovernmental Panel on Climate Change
MONERIS	MOdelling Nutrient Emissions in Rlver Systems
N	Nitrogen
N ₂	Nitrogen gas
N ₂ O	Nitrous oxide
NH ₃	Ammonia
NH ₄	Ammonium
NO ₂	Nitrite
NO ₃	Nitrate
NO _x	nitric oxides
Nr	reactive nitrogen species
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
P	Phosphorus
PO ₄	Phosphate
Ppb	Parts per billion
SRP	Soluble reactive phosphorus
TN	Total nitrogen
TP	Total phosphorus
TSS	Total Suspended Solids
USA	United States of America
WC	Water closet
WFD	The Water Framework Directive
WHG	Federal Water Act (Wasserhaushaltsgesetz)
WWTP	waste water treatment plant

Abbreviations used in Formulas

A_{GB}	total area of the Greater Berlin.
A_{IMP_S}	impervious area connected to separate sewer system and the total surface water area
A_{IMP_C}	impervious urban area connected to the combined sewer system
a_{IMP}	share of precipitation realized as surface runoff from paved urban area
A_{IMP_N}	paved areas not connected to sewers
$A_{IMP-old}$	Impervious area in the Old Berlin city
a_{IND}	the percentage of the industrial and commercial areas within the total urban area
a_P	area specific phosphorus emission from animal excrements and traffic wastes
A_{SEW-C}	total area connected to combined sewers of the Greater Berlin
A_{SEW}	total sewered area of the Greater Berlin,
A_{SW}	area of surface waters within the river catchment
A_{URB}	urban area
$C_{COM_{N,P}}$	nutrient concentration in commercial waste water
$C_{C_{N,P}}$	nutrient concentration in the combined sewer system during overflow
$C_{D_{N,P}}$	nutrient concentrations in runoff water
C_{IN}	nutrient concentration in waste water discharged into sewage farms
$C_{IND_{N,P}}$	nutrient concentration in industrial and commercial waste water
$C_{WWTP_{out}}$	nutrient concentration in effluent of WWTP.
$D_{N,P}$	area specific nutrient emissions
$ED_{N,P}$	nutrient input via diffuse sources
$EIN_{N,P}$	inhabitant specific nutrient output
$EIN_{D_{N,P}}$	inhabitant specific output of dissolved nutrients
E_{OE}	nutrient emissions from overflow water
$EP_{N,P}$	nutrient input via point source [t/a]
E_{runoff}	nutrient emissions from surface runoff on impervious area connected to the separate drainage system
E_{SF}	nutrient emissions from sewage farms
$ES_{IMP_{N,P}}$	specific nutrient emissions from impermeable urban area
$ET_{N,P}$	total nutrient input
$EUN_{N,P}$	nutrient input via people and impervious urban areas not connected to sewers
$EUOS_{N,P}$	nutrient input via paved urban areas and people connected only to sewers
$E_{WWTP_{out}}$	nutrient emissions from WWTP
HL	hydraulic load
$H_{SEW-ext}$	number of houseblocks connected to the sewer system in extension parts
$H_{SEW-ext}$	number of houseblocks connected to the sewer system in the extension part
IN_N	people not connected to sewers

IN_{SO}	people connected only to sewers
$L_{N,P}$	nutrient load
$L_{SF_{in}}$	nutrient input load into sewage farms
L_y	annual nutrient load via inflow river
N_{DEP}	area specific nitrogen deposition
P_{DEP}	area specific phosphorus deposition
P_{ext}	population in the extension parts
P_{OB}	population of the Old Berlin city
P_{SEW}	population connected to the sewer system
P_{SEW_c}	population connected to the combined sewer system
P_{SEW}	total population connected to the sewer system of the Greater Berlin
P_{SEW_c}	population connected to the combined sewer system
P_y	annual precipitation
$Q_{COM_{N,P}}$	runoff from commercial areas connected to the sewer system
Q_{flow}	mean annual river flow
Q_{IMP_c}	total water runoff from combined sewer system
q_{inh}	daily waste water output per inhabitant
Q_{IND_c}	runoff from commercial areas connected to the combined sewer system
Q_O	discharge of combined sewer overflow
q_R	rainfall runoff
Q_{SF}	total input waste water to sewage farms
Q_t	total waste water volume of the year
q_{URB_c}	surface runoff from urban area with combined sewer system
Q_{WWTP}	influent discharge of WWTP
$Q_{WW_{URB}}$	total collected waste water in Berlin
$Q_{WWTP_{in}}$	total influent of WWTPs
Q_y	mean annual river flow
RE	discharge rate of combined sewer overflows
RL_N	load weighted nitrogen retention
$R_{N,P}$	loss or retention of nutrients
$R_{S_{N,P}}$	nutrient retention in soil
R_{SF}	nutrient removal capacity of sewage farm
R_{WWTP}	nutrient removal capacity of WWTP
τ	residence time of water
V_{Lake}	total water volume of surface water bodies
V_S	volume of the specific storage of waste water in the combined sewer system
V_{SEW}	total collected waste water volume of the Greater Berlin per year
W_{TR}	proportion of dissolved human nutrient output transported to waste water treatment plants or other activities
Z_{RD}	number of days with storm water overflows

Abstract

Based on a comprehensive database, the spatial and temporal trends of surface water quality of Berlin and the surroundings catchments of Spree, Dahme and Havel were detected. The transitional points in the course of nutrient development are due to the changes in water supply and drainage system, the sewage farms, the establishment of waste water treatment plants and their technological improvements, the legal and management system. The changes in nutrient removal capacity of sewage farms, technological improvements in waste water treatment plants and the nutrient-related legal requirements are the major driving forces for nutrient emission mitigation in Berlin. Due to intensive anthropogenic impacts, some surface water bodies in Berlin particularly in the Teltowkanal have quite different seasonal variations compared to the natural water bodies. The spatial differentiation of Berlin water bodies is predominantly determined by the inside factors (effluent of waste water treatment plants, overflow water, heat emission from power plants) and inflow waters. Overflow from combined sewer system is the dominant diffuse source in the inner city area. The upstream water quality also contributes to the differentiation in quality of Berlin waters.

This study analyses nutrient emissions by point and diffuses sources and their loads were estimated for the city of Berlin and also for the subcatchment of Upper Havel, Spree and Dahme and the whole Havel catchment over the last 150 years by modelling approaches.

It was found that the present level of nitrogen load is about 4-4.5 times higher than the level in the mid 19th century. Phosphorus load is 3 times higher. In order to reach a “good status” required by the The Water Framework Directive (WFD) corresponds to the phosphorus concentration of 0.1 mg/l, total phosphorus emissions from Berlin must be further reduced. This goal can be reached by the application of new technologies in waste water treatment plants as well as new efforts in nutrient mitigation. At present, the runoff from urban area increases the discharge in Berlin’s rivers by one third. But the nitrogen load of these waters doubles the nitrogen load of the sources in the upstream catchments.

Because the surface waters downstream of Berlin possess a high retention capacity for nitrogen and phosphorus is for the freshwater systems the limiting factor it can be concluded that the further reduction of the P load by 40% is the urgent task.

Specific nutrient emission per inhabitant of Berlin depends on the living standards, particularly on the application of P-containing detergents and automatic wash machines or dish washers. The atmospheric nutrient deposition in Berlin is strongly affected not only from the local source, but also the regional and global sources.

The diffuse sources play more and more an important role in nutrient emissions to surface water bodies. The riverine lakes of the lowland river system in Berlin have a high nutrient retention capacity. However, after along time of overloading, their nutrient retention capacities have been degraded, especially for phosphorus. It is shown that these lakes contribute for a transition period by internal loading to the reduced retention in the last decade.

The nutrient loads are being altered due to changes in population growth and distribution, the development of waste water collection (combined and separate sewers) and treatment system (sewage farms and waste water treatment plants), the use of chemicals (P-detergents) and relevant legislation.

Zusammenfassung

Basierend auf einer umfassenden Basis von thematischen Karten, Statistiken und hydrochemischen Beobachtungsdaten werden Hauptmerkmale der Qualität Berliner Gewässer und der Einzugsgebiete ihrer Zuflüsse, Spree, Dahme und Havel, analysiert. Im Focus stehen dabei die räumliche und zeitliche Entwicklung der Nährstoffkonzentrationen und -frachten.

Der zeitliche Verlauf der Nährstoffkonzentrationen wird hauptsächlich durch Änderungen des Wasserdargebots und des Abwassersystems, der Bewirtschaftung von Rieselfeldern, der Einführung von Kläranlagen und deren technologischen Verbesserungen sowie von gesetzlichen Grundlagen bestimmt.

Änderungen in der Aufnahmefähigkeit von Rieselfeldern, technischer Fortschritt in Klärwerken und nährstoffbezogene gesetzliche Anforderungen sind die wichtigsten Ursachen für die Veränderungen der Nährstoffflüsse in den Berliner Gewässern. Die Unterschiede im Grad der anthropogenen Belastungen der Gewässer spiegeln sich deutlich in den jahreszeitlichen Variationen der verschiedenen Berliner Gewässern (insbesondere dem Teltowkanal) wieder. Die räumlichen Unterschiede in der Qualität der Berliner Gewässer wird hauptsächlich von internen Faktoren (Kläranlagen, Überlaufwässer, Aufheizung durch Kraftwerke) aber auch durch die zufließenden Gewässern gesteuert. Der Überlauf des Mischwassersystems stellt dabei die dominierende diffuse Eintragsquelle im innerstädtischen Bereich dar.

Die Untersuchung der Langzeitveränderungen der Nährstoffemissionen aus punktuellen und diffusen Quellen und der Nährstofffrachten in den Flüssen wurde separat für den innerstädtischen Bereich von Berlin und für die Teileinzugsgebiete der Oberen Havel (Pegel Hennigsdorf), der Spree (Pegel Neuzittau und Wernsdorf), der Dahme (Pegel Neue Mühle und Notttekanal) und das Haveleinzugsgebiet unterhalb von Berlin durchgeführt, so daß neben den Veränderungen in den Teilgebieten auch die im gesamten Havelsystem analysiert werden konnten. Als Zeitraum der Analyse der Langzeitveränderungen wurden die zurückliegenden 150 Jahre gewählt, so daß ein Überblick zu den Veränderungen der Nährstoffbelastungen von der vorindustriellen Periode um die Mitte des 19. Jahrhunderts bis zur Gegenwart gegeben werden kann.

Es konnte nachgewiesen werden, dass die derzeitige Stickstofffracht etwa 4-4,5-mal höher ist als in der Mitte des 19. Jahrhunderts. Die gegenwärtige Phosphorfracht liegt dagegen nur 3-mal über denen um 1850. Geht man davon aus, dass um 1850 die Belastungen und die Inanspruchnahme der Berliner Gewässer noch weitgehend einem guten Zustand entsprach und berücksichtigt man darüber hinaus, dass der ökologische Zustand der Binnengewässer

vor allem durch die Phosphorbelastung bestimmt wird, so kann man aus den Ergebnissen der Langzeitanalysen ableiten, dass zur Erreichung eines guten Zustandes die Phosphorbelastung noch um ca. 40% gesenkt werden muß. Dieses Ziel kann sowohl durch die Anwendung neuer Technologien in der Abwasseraufbereitung sowie in Anstrengungen zur Verringerung der Nährstoffemissionen erreicht werden. Gegenwärtig liegt der Anteil der Belastungen aus dem innerstädtischen Einzugsgebiet an der Gesamtfracht der Nährstoffe bei ca. einem Drittel, d.h. Maßnahmen zur Reduzierung der Phosphorbelastung müssen sich nicht nur auf Berlin sondern auch auf die Senkung der Frachten in den Zuläufen konzentrieren

Die spezifische Pro-Kopf-Emission von Nährstoffen in Berlin hängt vor allem vom Lebensstandard und für Phosphor insbesondere vom Einsatz phosphorhaltiger Waschmittel für Waschmaschinen oder Geschirrspüler, ab.

Die atmosphärische Deposition von Stickstoff wird nicht nur von lokalen, sondern auch regionalen und globalen Quellen gesteuert.

Diffuse Quellen spielen eine immer entscheidendere Rolle für die Nährstoffemissionen in Oberflächenwasserkörper.

Die Flusseen der Berliner Region dagegen verfügen über ein hohes Rückhaltevermögen für Nährstoffe. Allerdings ist nach langjähriger Überfrachtung ihr Rückhaltevermögen, insbesondere für Phosphor, herabgesetzt. Es wird dargelegt, dass die Remobilisierung der Nährstoffe aus diesen Seen in der letzten Dekade zu einer Verminderung der Retentionsleistung dieser Gewässer führt.

Die Nährstofffrachten wiesen in der Vergangenheit Veränderungen auf, die auf Bevölkerungswachstum und veränderte regionale Bevölkerungsverteilung, auf die Entwicklung von Abwassersammel- (Misch- und Trennsystemen) und -aufbereitungssystemen (Rieselfelder und Kläranlagen), auf die Anwendung von Chemikalien (phosphorhaltige Reinigungsmittel) sowie auf die Entwicklung gesetzlicher Richtlinien zurückgeführt werden können.

Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Die Stellen der Arbeit, die anderen Werken wörtlich oder inhaltlich entnommen sind, wurden durch entsprechende Angaben der Quellen kenntlich gemacht.

Diese Arbeit hat in gleicher oder ähnlicher Form noch keiner Prüfungsbehörde vorgelegen.

Berlin, 21 December 2007.

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