8. Nutrient loads in Berlin surface water system and in the Havel catchment during the last 150 years

8.1 Nutrient emission, load and retention in Berlin surface water system

8.1.1 The total nutrient emissions into the water bodies of Berlin during the last 20 years

Results

Discharge. Based on the discharge data provided by the Senate Berlin, Jahrbuch für die Gewässerkunde Norddeutschlands and Deutsche Gewässerkundliche Jahrbuch, the total discharges into Berlin's surface water bodies in the period of 1983-2004 were estimated. The total discharge into Berlin's surface water bodies average 61 m^3/s between 1983 and 2003 with maximum of 100 m^3/s in 1987 and the lowest value of 42 m^3/a in 2000. Regarding discharge, the Spree is the dominant contributor to the total discharge to the water bodies of Berlin. On average, it contributed 40% of the total discharge in the period of 1983-2003, with a maximum contribution of 46% in 1989 and a minimum contribution of 34% in 1998. The Dahme contributed 19% to the total discharge with a maximum contribution of 27% in 1993 and a minimum contribution of 12% in 1998. The contribution of the river Upper Havel to the total discharge varied from 15% (1989) to 25% (2000) with an average of 21%. Discharge from Berlin's urban area (effluent of WWTPs, sewage farms, overflow water, surface runoff and direct precipitation on surface water) has contributed a stable portion (21%) and its contribution changed from a maximum of 26% in 2000 to minimum of 14% in 1987 (Table 8.1, Figure 8.1).

Nitrogen emissions. Based on monitoring data in Berlin surface waters as well as the Upper Havel at Hennigsdorf, the Spree at Neuzittau and Wernsdorf, the Dahme at Neue Mühle and Nottekanal, the total nutrient emissions into Berlin water bodies in the period of 1981-2003 were estimated (Tables 8.2, 8.3). The mean annual flow-weighted concentrations of TN in water of the rivers Spree, Havel and Dahme as well as in the discharge from Berlin in the period of 1983-2003 are presented in Figure 8.2.

Among inflow water, the Spree is the dominant source of nitrogen loads to the water bodies of Berlin in the period of 1983-2003: it contributes between 50 to 80% of the total inflow TN loads. The Upper Havel contributes between 15 to 30% of the total inflow TN load. The Dahme (including Nottekanal) has the lowest contribution to the inflow TN loads with 10 to 25%. A decreasing trend in inflow TN loads to Berlin can be recognized since 1992 with a strong decline in the TN load from the Spree. In the period of 1983-1991, the Spree contributed 62% to the inflow TN loads (Figure 8.3), while in the period of 1992-2003, its contribution declined to a level of 54%.

In general, TN input emissions from Berlin's city total 60% of the TN emissions to the water bodies of Berlin. TN emissions to the water bodies of Berlin varied at high stand in the period of 1983-1987. It reached the peak of 18000 t TN/a in 1987. In the period of 1989-2002, the TN emissions have an overall deceasing trend. The TN emissions in the period of 1988-1995 varied from 16000 to 8000 t TN/a. In the period of 1996-2002, the TN emissions fluctuated from 8000 to 5000 t TN/a.

Table 8.1: Total discharges into surface water bodies of Berlin in the period of 1983-2003

Year	Havel (Hennigsdorf)	Spree (Neuzittau +Werzdorf)	Dahme (Neue Mühle +Nottekanal)	Urban area of Berlin	Total discharge to water bodies
	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)	(m^3/s)
1983	15	28	16	14	72
1984	15	33	12	13	60
1985	12	28	12	13	52
1986	14	31	21	14	65
1987	17	43	25	14	85
1988	18	33	12	14	63
1989	8	24	8	13	39
1990	9	25	8	14	41
1991	9	26	9	12	44
1992	9	18	6	13	33
1993	12	21	17	13	49
1994	20	30	15	14	65
1995	18	25	13	12	57
1996	10	20	11	11	41
1997	8	17	9	11	34
1998	12	20	11	11	43
1999	12	18	8	10	39
2000	11	16	5	11	31
2001	12	16	8	12	36
2002	18	24	10	12	53
2003	9	18	10	10	38

(Source: Gewässerkundlicher Jahresbericht des Landes Berlin, Abflußjahr 1966-1987, SENSTADTUM, 2004; IGB Database)

Table 8.2: TN input and output loads of Berlin's surface water bodies, 1981-2003

	Period	1981-1985	1986-1990	1991-1995	1996-2000	2001-2003
From inflows: Havel, Spree and Dahme	t/a	5195	6095	3401	2157	2142
From point sources in Berlin	t/a	8011	7787	6184	4396	3559
From diffuse sources in Berlin	t/a	405	432	380	290	312
Total TN input	t/a	13611	14315	9965	6843	6013
Total TN output	t/a	6990	9933	9747	4962	4072

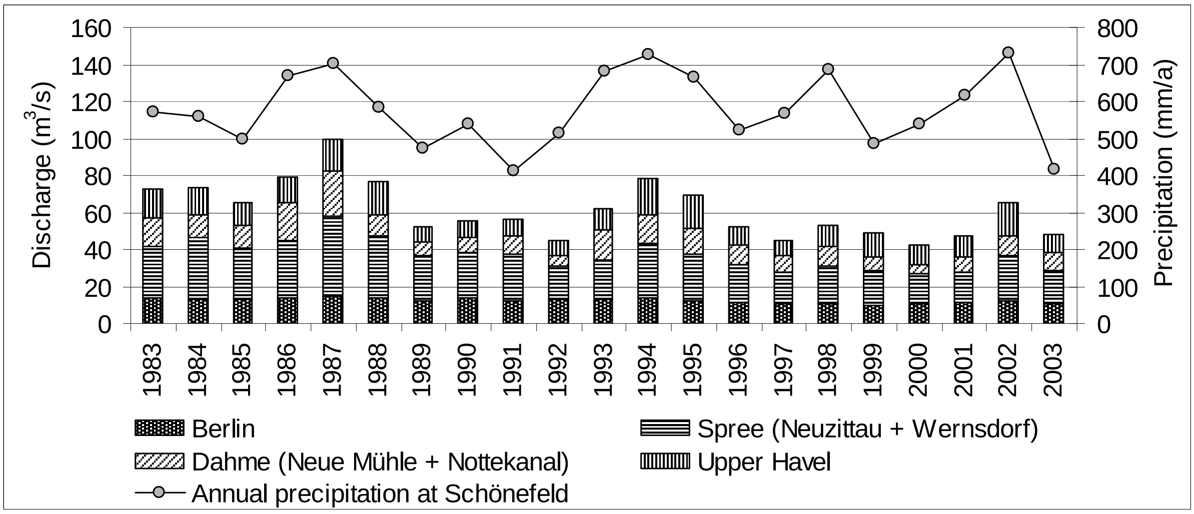

Figure 8.1: Total discharges into surface water bodies of Berlin in the period of 1983-2003

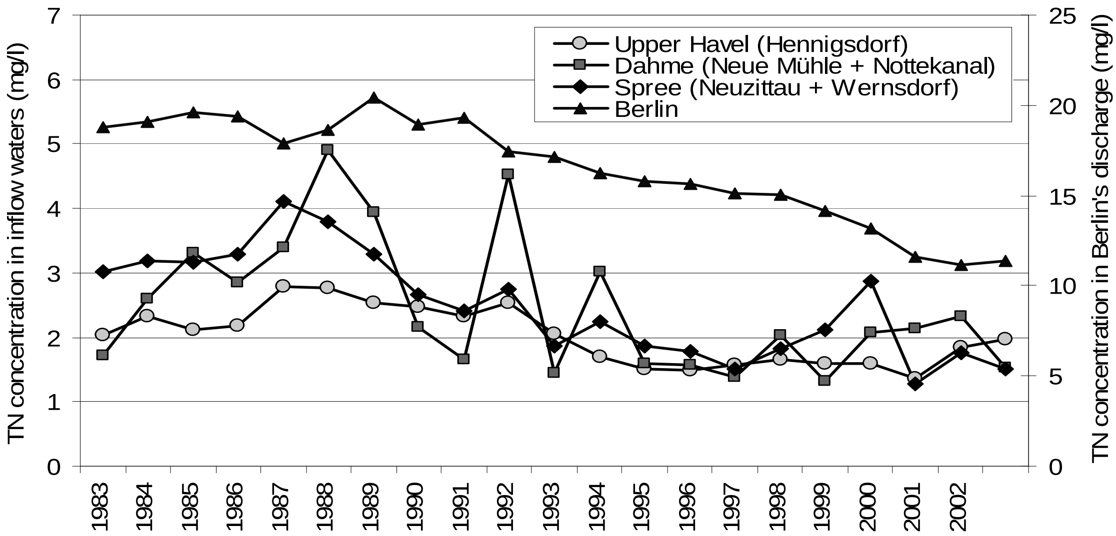

Figure 8.2: TN concentrations in inflow waters to Berlin in the period of 1983-2003

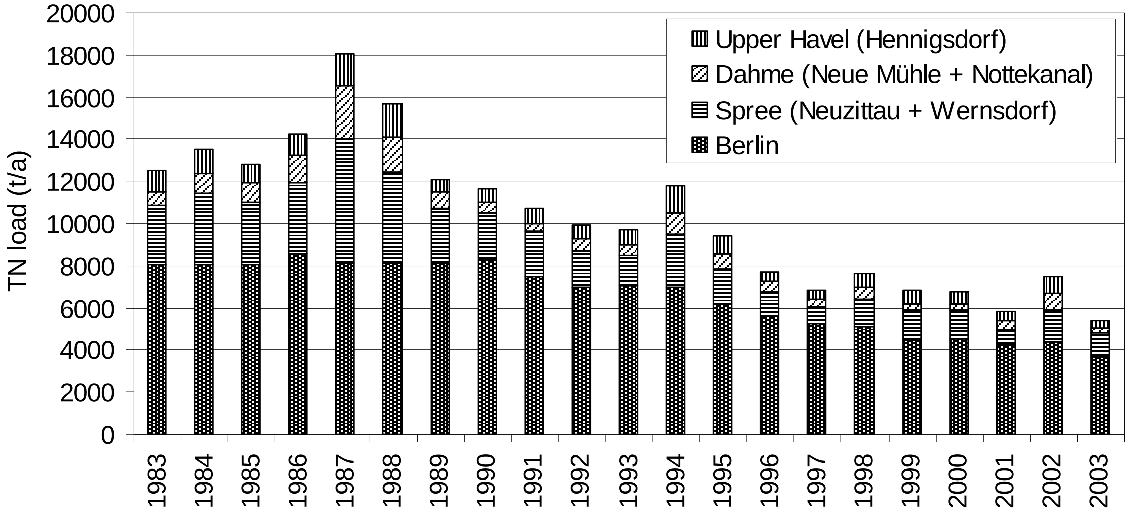

Figure 8.3: TN emissions into surface water bodies of Berlin in the period of 1983-2002

TP emissions. The total phosphorus emissions into surface water bodies of Berlin in the period of 1983-2002 are shown in Table 8.3 and Figure 8.5. The total TP emissions to Berlin's water bodies have three different periods of development:

- 1983-1984 is a period with very high TP emissions (3200 - 4500 t TP/a). During this phase, Berlin's city area contributed 80-90% of the total TP emissions to the water bodies of Berlin.
- 1985-1990 is a period of decreasing TP emissions from 1700 t TP/a in 1985 to 930 t TP/a in 1990. During this period, Berlin's city area contributed 70-80% of the total TP emissions to the water bodies of Berlin.
- 1991-2002 is a period of decreasing and low TP emissions: from 550 t TP/a in 1991 to 280 t TP/a in 2000. During this period, Berlin's city area contributed 40-60% of the total TP emissions to the water bodies of Berlin.

The total TP loads from inflow waters have a decreasing trend since 1987, when the TP load peaked at of 630 t TP/a. During the period of 1983-1991, the inflow TP loads stayed at a level of 240-620 t TP/a. Between 1992-2003, except for the year 1994, the TP loads from inflow waters were at a level of < 200 t TP/a.

Table 8.3: TP input and output loads of Berlin's surface water bodies, 1981-2003

Period		1981-1985	1986-1990	1991-1995	1996-2000	2001-2003
From inflows: Havel, Spree and Dahme	t/a	423	411	210	155	143
From point sources in Berlin	t/a	2705	856	179	115	104
From diffuse sources in Berlin	t/a	44	56	47	34	39
Total P input	t/a	3173	1323	435	304	286
Total P output	t/a	1648	483	362	238	143

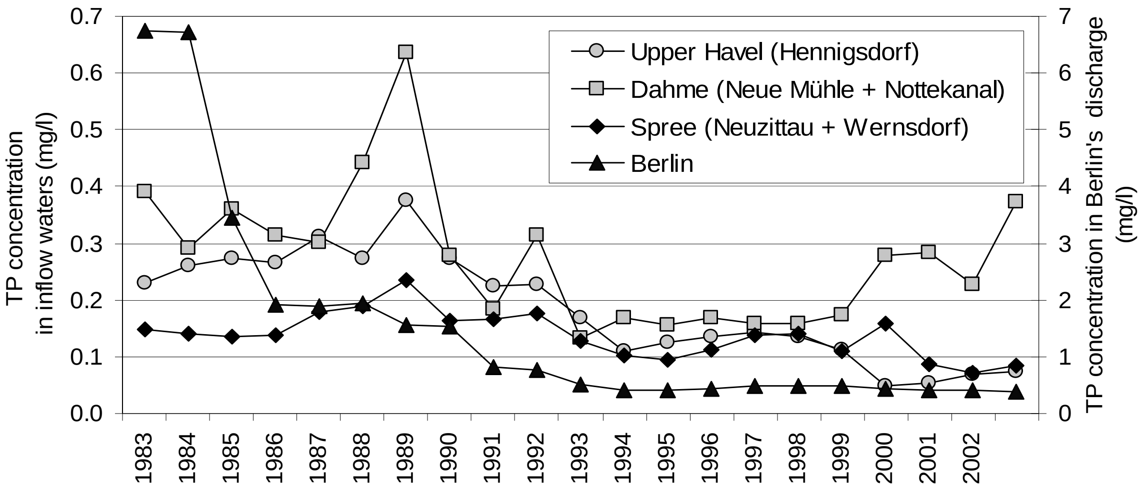

Figure 8.4: TP concentration in inflow waters and discharge from urban area of Berlin in the period of 1983-2003

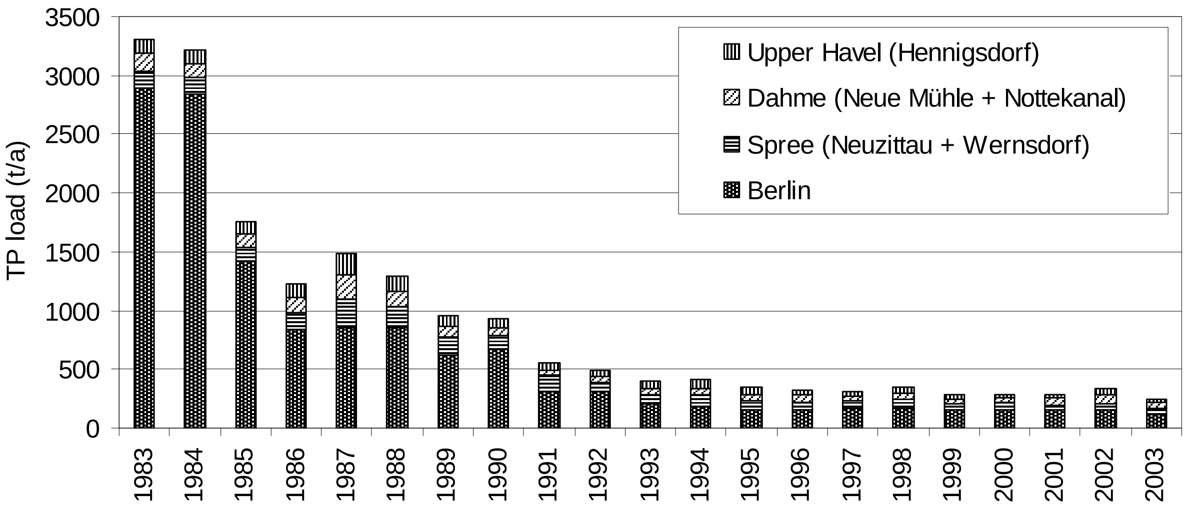

Figure 8.5: TP emissions into surface water bodies of Berlin in the period of 1983-2002

Discussion

Discharge. Total discharge to the water bodies of Berlin depends on the precipitation (Figure 8.1) and it is dominated by the discharge from the Spree. However, the discharge from the river Spree to Berlin has reduced since the mid 1980s due to the closure of brown-coal mining activities in the upstream area (LANDESUMWELTAMT BRANDENBURG, 1995; PUSCH, 2000; KÖHLER, 2002). Due to its high discharge the river Spree is important for the quality of all water running through Berlin. The discharge from Berlin's urban area is determined by the effluent of WWTPs. It has a decreasing trend since 1990s due to the reducing water consumption per inhabitant, especially in the eastern part of Berlin after reunification (BWB, 2005).

TN emissions. The total nutrient input (emissions) is the sum of the inflow loads from the upstream areas (the rivers Havel, Spree and Dahme) and emissions from point sources (Sewage farms and WWTPs) as well as diffuse sources of Berlin (overflow water from the combined sewer system, surface runoff from the separate sewer system and direct deposition from the atmosphere). The periods of high TN emission into the water bodies of Berlin have main causes of the high N surplus in agricultural lands, low nutrient removal capacities in WWTPs in upstream areas as well as the high nutrient deposition from the atmosphere (LANDESUMWELTAMT BRANDENBURG, 2003). Since 1990, the declining in total TN emissions originated mainly from the reduction of nutrient emissions from the city area of Berlin and resulted from improvements within the N-elimination capacities of WWTPs (SENSTADTUM, 2004; BWB, 2005). Since 1991, the successive closure of the brown coal open mines in the catchment of the Spree resulted in a decreasing water flux of the river

(STATISTIK DER KOHLENWIRTSCHAFT e.V., 2003). In addition, this declining trend trend was also observed (Figure 8.2) in the TN concentrations in the Spree water since 1987.

In general, TN emissions to the water bodies of Berlin reduced by 53% in the period of 1990-2003. In this period, TN emissions from the urban area of Berlin decreased by 53% while the TP inflow from the Upper Havel and Spree have reduced by 50%. The Dahme shows the modest reduction in TN loads (44%) for the same period. In order to get a better surface water quality of Berlin, more reductions in P emissions are required, not only inside the city area of Berlin but also in upstream areas. To reduce TN emissions to the water bodies of Berlin, elimination efforts should focus on the reduction of TN emissions from the city of Berlin, because at present, TN emissions form Berlin are still the major TN emission source (contributing up to 68% of total TN emissions).

TP emissions. TP emissions from the city area of Berlin are the dominant source for TP emissions to the water bodies of Berlin. The decreasing trend of P emissions to the water bodies of Berlin is the result of P elimination effort in WWTPs as well as of the decline in the specific emission per inhabitant, especially after reunification. This reduction is contributing to the reduction in P loads from upstream areas of Berlin within the subcatchment of the Upper Havel, Spree and Dahme. As these areas are new states of Federal Republic of Germany (FRG), a lot of improvements with focus on P and N elimination capacities were made for waste water collection and waste water treatment systems after reunification. This is an additional reason of the decreasing trend in TP concentrations in water of the Spree and Havel since 1991. The decrease of TP emissions is also the consequence of the decline in the discharge volume of the Spree. The Dahme has very high TP concentrations in comparison to the Spree and Havel (Figure 8.5). Therefore, despite of very low discharge volume, the Dahme is an important external source of TP emissions to water bodies of Berlin. TP emission from the city area of Berlin shows the fastest decreasing trend. TP emissions from the city area of Berlin decreased by 82% in the period between 1990 to 2003. TP loads from the Upper Havel and Spree to the water bodies of Berlin also were reduced by 62% in the same period. In comparison to the level in 1990, the Dahme has the modest reduction in TP load (23%). In order to get a better surface water quality of Berlin, further reductions in P emissions are required, not only within the city area of Berlin but also in the upstream areas. For Berlin’s area this reduction have to be focused on point as well as diffuse sources.

8.1.2 Nutrient loads and retention capacity of Berlin's water bodies

Results

Surface water bodies in Berlin are lowland flows, with typical widening water bodies. They received continuous and intensive nutrient emissions from the urban area over the last 150 years. The river system has a high potential of nutrient transformation, loss and retention due to low flow velocities and the existence of lakes. Therefore, in this study different retention estimation methods were applied to calculate the nutrient loads and to compare these with observed data.

The following nutrient retention estimations are used in this study:

- Empirical model with hydraulic load and specific runoff – equations eq .6.25 and eq. 6.27 (BEHRENDT & OPITZ, 1999);
- Phosphorus retention estimation by the method given by VOLLENWEIDER (1975) with a consideration of the residence time of water in lakes – equation 6.28;
- Nitrogen retention estimation by the method given by VENOHR (2006), taking into account the hydraulic load as well as water temperature – equation 6.30.

By detailed study of long-term behaviour of input and output loadings for an area containing shallow lakes, the retention time and the correction factor for retention processes could be estimated and used in other studies.

TN retention capacity of Berlin's water bodies. As shown in Figures 8.6 and 8.8, nitrogen retention capacities of Berlin's water bodies varied in the rage of 20-32% of the input loads in the period of 1983-2002. For nitrogen retention, the same results are received in estimations by methods of BEHRENDT & OPITZ (1999) and VENOHR (2006) in the period of 1983-2002 and have a good agreement with measured loads (Figure 7.9). The method that uses hydraulic load only (BEHRENDT & OPITZ, 1999) has better results for dissolved nitrogen (DIN) retention estimation compared to the method that uses both hydraulic load and water temperature (VENOHR, 2006) (Figure 8.10).

TP retention capacity of Berlin's water bodies. TP retention capacity of Berlin's waters varies in a range of 37-52% in the period of 1983-1988, then decreased to 20-23% in the period of 1989-2002 (Figures 8.7, 8.8). For phosphorus retention, BEHRENDT & OPITZ's method has a better agreement with measured data in the period of high phosphorus emissions. In contrast, for the period of low phosphorus emissions like in recent years, VOLLENWEIDER's method has a better agreement with the measured data (Figure 8.11). Figure 8.11 shows the over-estimated loads of phosphorus when the equations according to BEHRENDT & OPITZ (1999) and the VOLLENWEIDER (1975) method with original coefficients are applied. An adaptation of these equations was made for Berlin based on the existing measured output loads of phosphorus. Based on these data, the coefficients of the equation of BEHRENDT & OPITZ (1999) were calibrated.

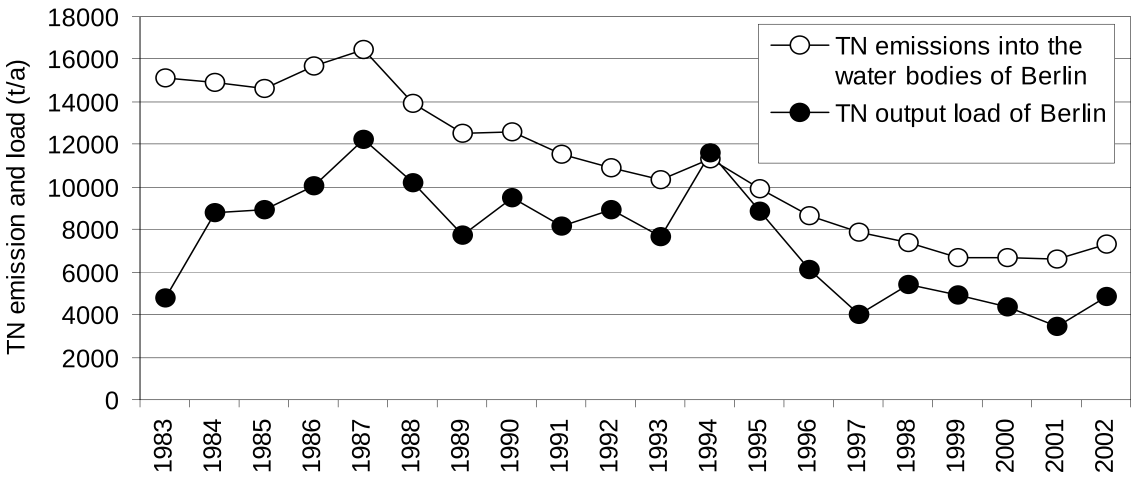

Figure 8.6: TN emissions and loads of Berlin's water bodies, 1983-2002

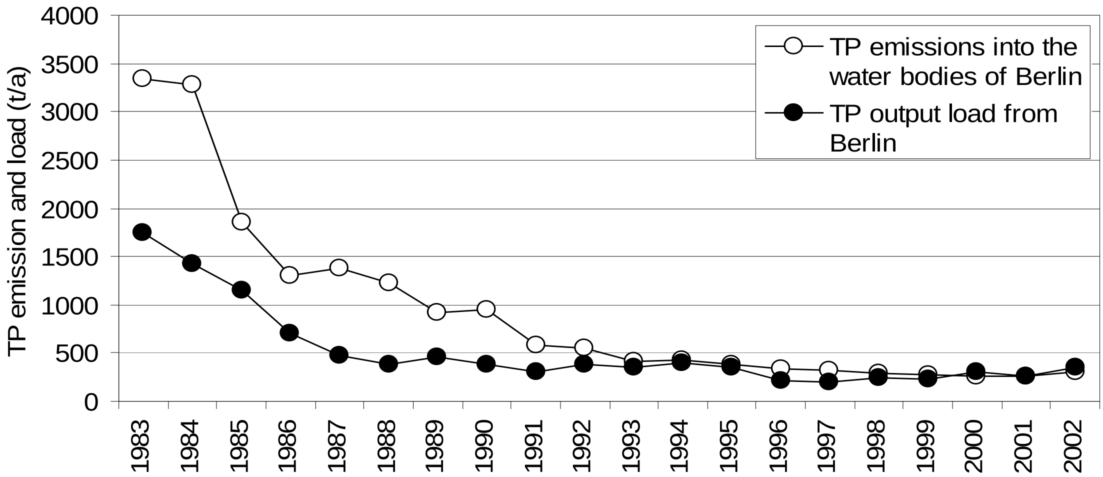

Figure 8.7: TP emissions and load of Berlin's water bodies, 1983-2002

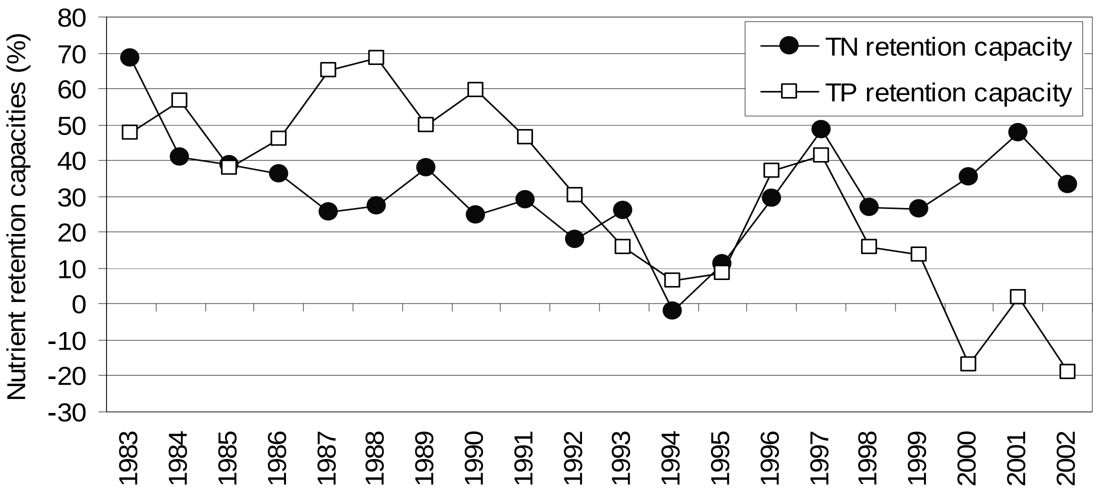

Figure 8.8: Nutrient retention capacities of Berlin's water bodies, 1983-2002

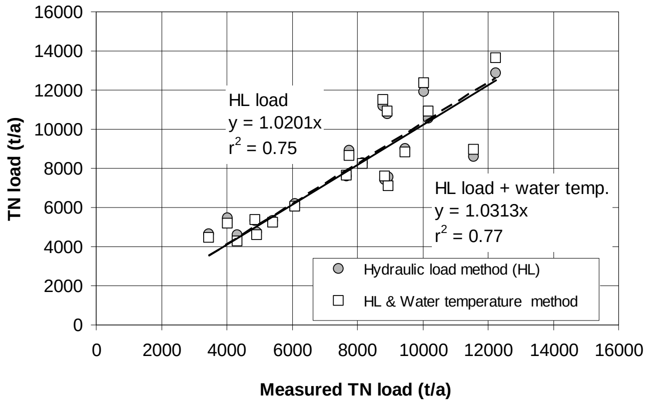

Figure 8.9: Estimated and measured TN loads into surface waters of Berlin by different approaches in the period of 1983-2002

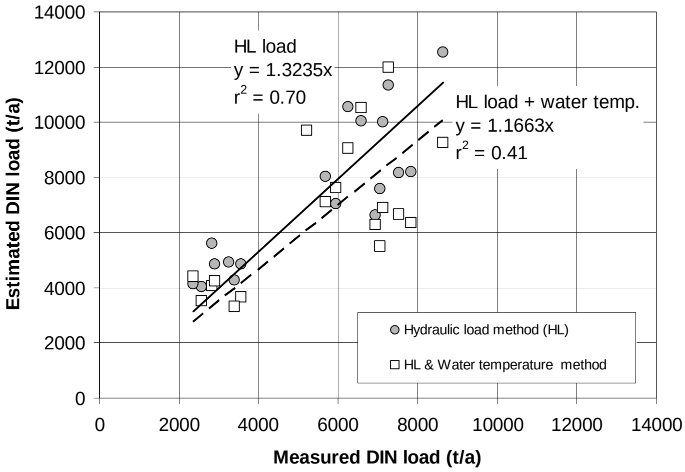

Figure 8.10: Comparison between estimated DIN loads to surface water bodies of Berlin with different approaches and measured loads in the period of 1983-2002

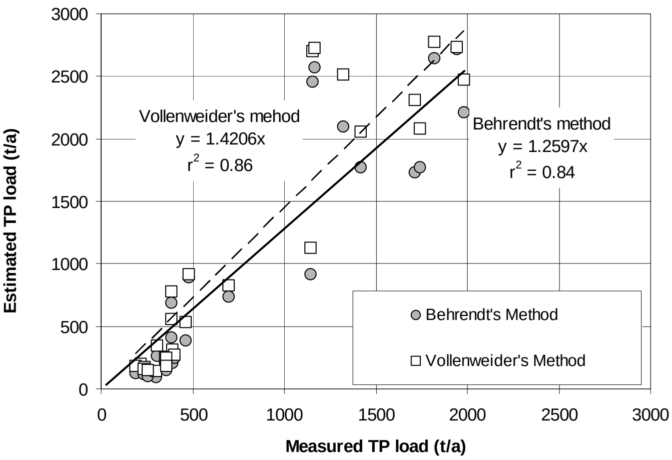

Figure 8.11: Comparison between estimated TP loads to surface water bodies of Berlin with different approaches and measured loads, 1976-2002

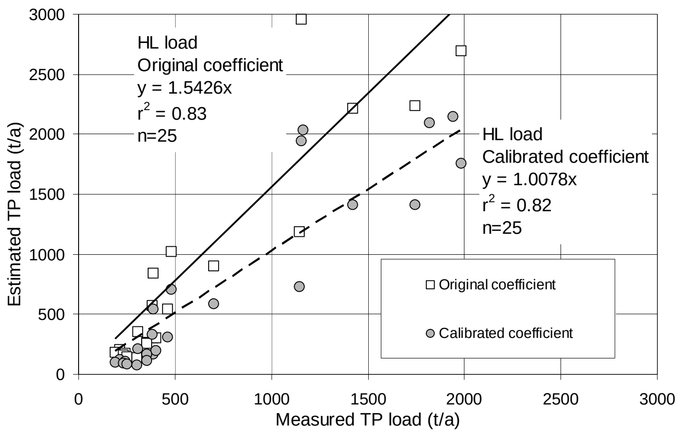

Figure 8.12: Comparison between estimated TP loads to surface water bodies of Berlin with original and calibrated coefficients and measured loads, 1978-2002

Discussion

Nitrogen retention. The dominant processes determining the temporary or definite nitrogen removal from the water bodies include mainly denitrification, biological uptake and sedimentation. The retention processes can occur in lakes, rivers and streams as well as in recharge areas under the root zone and in discharge areas near the water streams (WINDOLF et al., 1996; OLAH et al., 1998; 1999; SEITZINGER et al., 2002; RODE et al., 2005; VEHNOHR, 2006). Due to the low flow rates and high water temperatures, the denitrification processes and plant uptake are strengthened in the polymictic and highly eutrophic lakes of Berlin, increasing the nitrogen removal capacity of the water bodies (BEHRENDT, 2003). However, this potential is strongly dependent on external loadings or, in the case of Berlin, the anthropogenic pressures from urban areas. In general, nitrogen can be stored and then easily removed from sediment and absorbed environment (KRONVANG et al., 1999; BEHRENDT & OPITZ, 1999; SEITZINGER et al., 2002). Therefore, nitrogen retention capacity of the water bodies in Berlin can be restored and maintained at a stable ratio. The estimated TN and DIN loads with the original coefficients have a very good agreement with the measured load. Therefore the original coefficients for TN and DIN retention estimation can be applied for the water bodies of Berlin (Figures 8.9, 8.10, 8.11).

Phosphorus retention. In general, the P removal capacity of Berlin's water bodies is very limited in the period of 1989-2002, because, an internal phosphorus loading from the shallow lakes in Berlin seems to contribute to the phosphorus load and have to be considered in the mass balance by the reduced P-retention capacity (MOSS et al., 1996; WHITE et al., 2004; SCHAUSER et al., 2006). The water bodies of Berlin have a very high nutrient retention capacity due to the polymictic character of the lakes (e.g. Müggelsee, Tegelsee, Lower Havel) inside the lowland river system. Due to polymixis the lake sediments can release phosphorus during short stratification periods in summer and bring this P back to the mixed zone after the end of these phases. Therefore this internal loading can be considered as an additional source of nutrients that contributes to a decrease of the retention capacity (NURNBERG, 1984; SONDERGAARD et al., 2001, 2003; BEHRENDT, 2003). Because, the P-release rate from the lake sediment depends on the DO concentration, NO_3 concentration and also the accumulated amount of P in the sediment from previous periods, the P-release is delayed in relation to loading and in the case of Berlin is can be estimated of 10 years (BOSTRÖM, 1982; FISHER & WOOD, 2001; KLEEBERG et al., 2001; BEHRENDT, 2003; SCHAUSER et al., 2006). For Berlin shallow lakes with very low flow rate and a long loading history with a high loading rate, a rapid flushing rate in lakes can not be expected immediately after the decline of a external loading (1983-1985). The P retention capacity of Berlin water bodies is now no longer maintained as before. As a consequence of the longer residence time for P of the shallow lakes in comparison to other river networks (KOZERSKI et al., 1999; BEHRENDT, 2003; KÖHLER et al., 2005), now Berlin has also an internal emission source of P from its shallow lakes. This means that the total P emissions from Berlin's city area have a tendency to be discharged completely into downstream catchments (Figure 8.10).

8.2 The impacts of nutrient emissions from Berlin on the river Havel

Results

Based on the monitoring data in downstream of Berlin (Lower Havel and Teltwokanal), the Havel at Potsdam and Havelberg in the period of 1983-2003 and the equations 6.19, 6.20, nutrient loads downstream of Berlin and the Havel were calculated. In general, the dissolved inorganic nitrogen (DIN) loads and TN loads in the river Havel downstream of Berlin are higher than at Havelberg (shortly before the confluence with the Elbe) (Figures 8.13, 8.14). However, in the most recent years (since 1994), the differences between the two locations in term of TN and DIN loads were reduced.

Figure 8.15 shows TP loads of the Havel in Havelberg and downstream of Berlin that have the same trend over the period of 1983-2003. In contrast to TN and DIN loads, TP loads in Havelberg are higher than TP loads downstream of Berlin. The difference in the TP loads between the two locations increased in the period of 1992-1999 to 420 t/a from 290 t/a in previous time. For the subcatchments of the rivers Spree, Upper Havel and Dahme and total Havel catchment, based on the modelling results, the nutrient retention estimation methods (VOLLENWEIDER, 1975; BEHRENDT & OPITZ, 1999; VENOHR, 2006) and monitoring data, some adjustments have been made with the coefficients for a better agreement between estimated load and observed load (Figure 8.16).

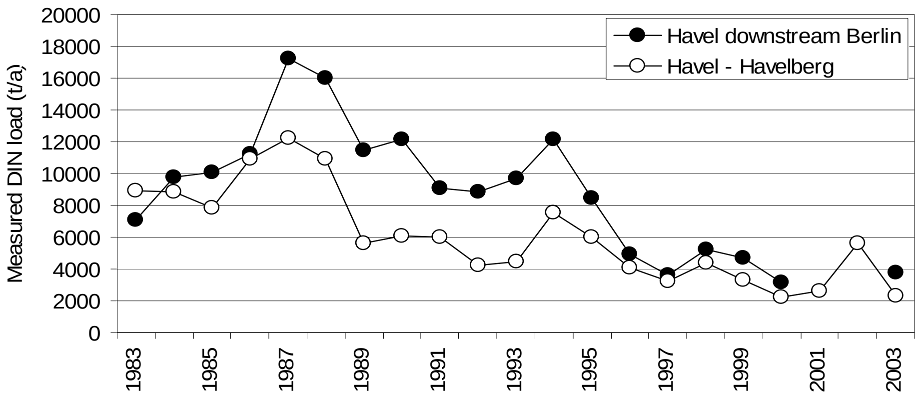

Figure 8.13: DIN loads of the river Havel at downstream of Berlin and at Havelberg

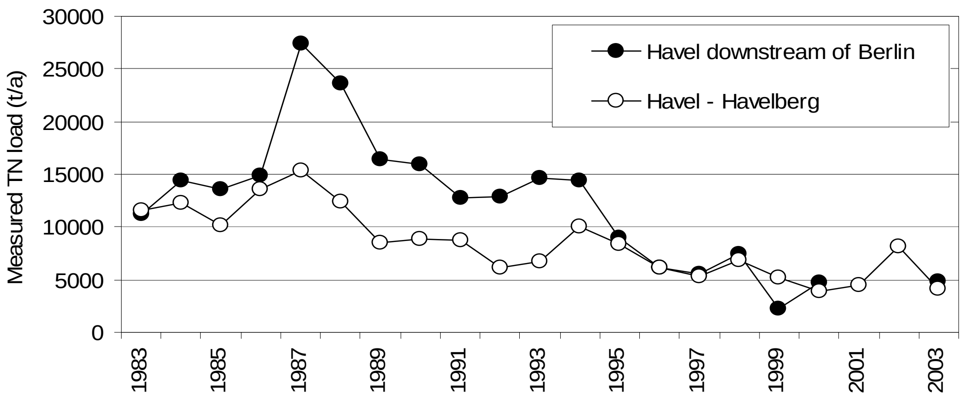

Figure 8.14: TN loads of the river Havel at downstream of Berlin and at Havelberg

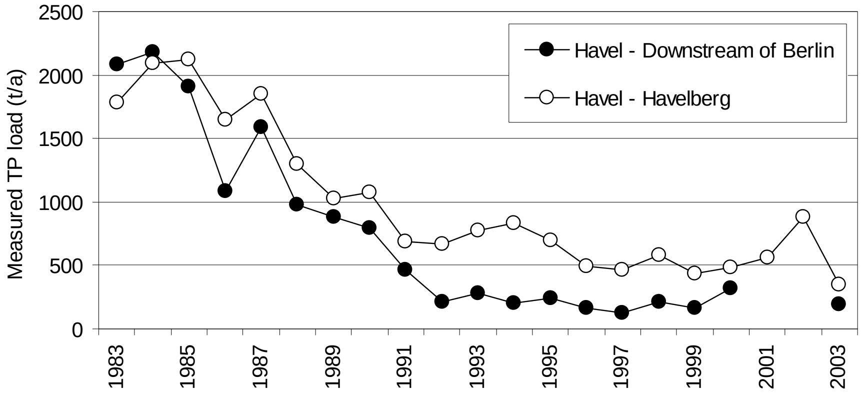

Figure 8.15: TP loads of the river Havel at downstream of Berlin and at Havelberg

Discussion

In the Havel catchment the area of Berlin contributes only 3.8 % of the total area but 61% of total population (Figure 2.5) (LANDESUMWELTAMT BRANDENBURG, 1995; BEHRENDT, 1999, 2004; BERLINER STATISTIK, 2006). TP emissions from Berlin's urban area have been clearly significant contributions to the total P emissions of the catchment Havel in the period of 1983-2003 (Figure 8.15).

Water bodies downstream of Berlin in the period of 1987-1994 have a very good TN retention capacities in case the high nitrogen emissions originate from upstream area. The high nitrogen retention capacities during this period are mainly the results of the reduction of dissolved inorganic nitrogen (Figures 8.13, 8.14) (KRONVANG, 1999; BEHRENDT & OPITZ, 1999; BEHRENDT et al., 2000). This means that in the water bodies dissolved inorganic nitrogen was converted into particulate forms and then buried in the sediment or was uptaken by plants and phytoplankton (KRONVANG, 1999; BEHRENDT & OPITZ, 1999; SEITZINGER, 2002; VERNOHR, 2006). Since 1994 as a result from nitrogen mitigation efforts, the nutrient emissions from the city of Berlin and upstream areas were reduced. Therefore, the differences between TN and DIN loads of the Havel at downstream Berlin and at Havelberg were also reduced.

In the period 1983-1991 high phosphorus loads characterized by Havel upstream of Potsdam and also for the water bodies downstream of Berlin. Since 1992, the deference between TP load at Havelberg and downstream of Berlin were increased. This might be due to the decreasing of retention capacities of water bodies after a period of high external loads or in this area could be some additional phosphorus emission sources (KOZERSKI et al., 1999; BEHRENDT, 2003; KÖHLER et al., 2002, 2005). In general, TP loads in downstream of Berlin and Havel at Havelberg have a the same development and close relationship.

In three upstream catchments the Upper Havel, Spree and Dahme, the estimated nitrogen and phosphorus loads (by MONERIS model) are in good agreement with the measured loads for the period of 1983-2004 (Figure 8.16).

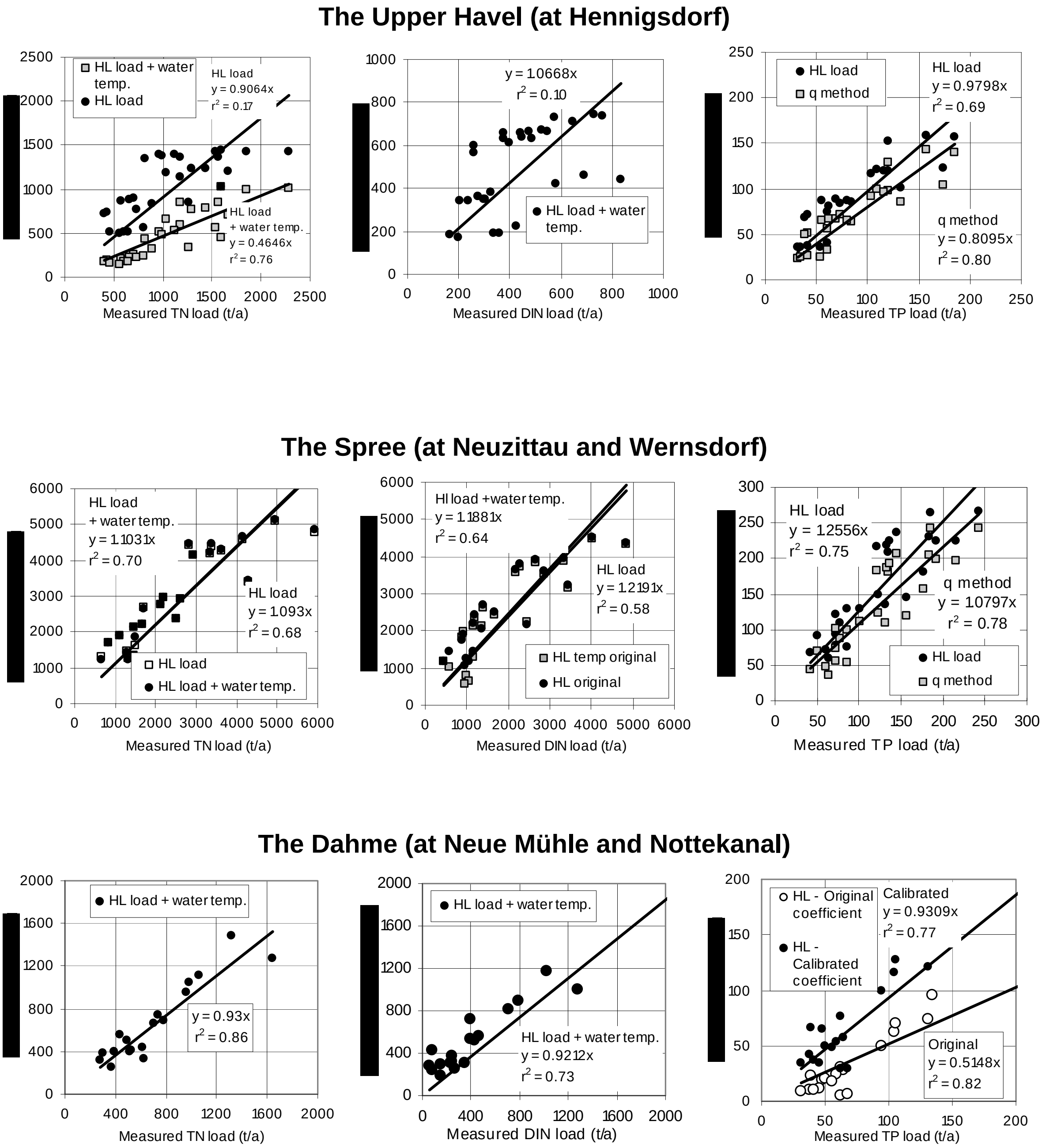

Figure 8.16: Comparison between estimated and observed nutrient loads in the Spree, Upper Havel and Dahme with original and calibrated coefficients, 1978-2002

8.3 Reconstruction of nutrient load developments of Berlin and subcatchments of the Havel over the last 150 years

Results

Table 8.4 and Table 8.5 show nutrient loads in the subcatchments of the Upper Havel, Spree, Dahme, and total Havel catchment at Havelberg as well as the city of Berlin since 1850. These data are modeled based on historical and statistical data on discharge, land use, urbanization, agriculture and industrial production, waste water collection and treatment system (see also Chapter 6). TN emissions upstream of Berlin has two difference period of increase: period of 1850-1944 with moderate TN emissions and period of 1945-1987 with high TN emissions and then decreased continuously (Figure 8.17). TP emissions upstream of Berlin increased continuously since 1850 but relative small up to the 1940ies but strong since the 1950ies. TP emissions got the maximum in the period of 1978-1982 and then decreased to the current level which is at the same level as before the Second World War (Figure 8.18).

Discussion

For the whole period of the past 150 years, nitrogen emissions from urban areas of Berlin play a dominant role in total nitrogen emissions to the surface water bodies of Berlin (Figures 8.17, 8.23). TN emissions from urban areas of Berlin reached their maximum contribution in the period 1901-1920 with an average of 88% of total emissions. Berlin itself contributed 66% of total nitrogen emissions into the water bodies of Berlin in the period of 1988-2000 in comparison to 73% in the period of 1850-1975. Nitrogen loads from upstream areas (Upper Havel, Spree and Dahme) increased their contribution since 1945 to a maximum value in 1980. The maximum contributions by inflow waters occurred in the period of 1978-1982 and mostly from the catchment Spree.

The reduction of TN loads of the total Havel catchment and its subcatchments in the most recent years has the following main reasons: a) After reunification (especially in the first ten years), waste water collection (sewer construction) and treatment facilities (WWTP upgrading) were improved (SENSTADTUM, 2001; LANDESUMWELTAMT BRANDENBURG, 2002; BWB, 2005; STATISTICHES LANDESAMT DES FREIST SCAHEN, 2006; STATISTICHES AMT MECKLENBURG-VORPOMMEN, 2007; STATISTISCHE LANDEAMT SACHEN-ANHALT, 2007).; b) The reduction of nitrogen emission from coal mining (groundwater withdrawal pumped to the Spree) as a result of a strong reduction in brown coal mining in the Lusatia area since 1990 (STATISTIK DER KOHLENWIRTSCHAFT e.V., 2003); c) The reduction of N surplus in agricultural area, as a result of reduction in agricultural activities due to economic changes (reduced application of mineral fertilizers as well as decreasing livestock numbers) (BEHRENDT et al., 2003; NITSCH & OSTERBURG, 2004).

Table 8.4: Estimated TN loads in Berlin surface water system and Havel catchment and subcatchments during the last 150 years *(Model result)*

Period	Upper Havel	Dahme	Spree	Berlin surface waters	Havelberg
	(t TN/a)	(t TN/a)	(t TN/a)	(t TN/a)	(t TN/a)
1850-1875	95	76	204	1114	904
1876-1900	139	90	228	2367	1261
1901-1920	203	109	324	4047	2123
1921-1945	307	160	608	5407	3177
1946-1952	414	199	818	5143	3985
1953-5357	569	226	1476	5943	6017
1958-1962	731	250	1772	6286	6467
1963-1967	902	302	2201	7339	8055
1968-1972	1119	373	2867	11565	9876
1973-1977	1432	612	3750	11941	11186
1978-1982	1775	1783	5135	13540	17522
1983-1987	1273	1402	3654	11625	10782
1988-1992	767	832	2053	8220	6561
1993-1997	656	690	1671	6790	6199
1998-2002	478	376	929	4320	3229

Table 8.5: Estimated TP loads in Berlin surface water system and Havel catchment and subcatchments over the last 150 years *(Model result)*

	Upper Havel	Dahme	Spree	Berlin surface waters	Havelberg
Period	(t TP/a)	(t TP/a)	(t TP/a)	(t TP/a)	(t TP/a)
1850-1875	20	10	15	99	209
1876-1900	31	23	25	93	346
1901-1920	45	28	30	120	719
1921-1945	67	42	77	270	1186
1946-1952	89	55	78	963	1377
1953-5357	90	60	91	1554	1148
1958-1962	95	61	100	1708	1218
1963-1967	97	67	114	1953	1406
1968-1972	103	74	127	2413	1534
1973-1977	134	109	136	2328	1534
1978-1982	194	211	165	2576	2088
1983-1987	123	179	176	1397	2043
1988-1992	71	112	114	496	1071
1993-1997	74	80	66	232	497
1998-2002	34	61	31	161	273

The reduction of TP emissions in the most recent decades originates from the improving in waste water collection and treatment facilities (Table 7.8), the reduction of P deposition, the lower specific P emission per inhabitant (Figure 7.1, 7.3, 7.7) and a reduction of P surplus in agricultural areas (SENSTADTUM, 2001; BEHRENDT et al., 2003; BWB, 2005). Phosphorus emission from Berlin is a dominant source in total P emissions to surface water bodies of Berlin in the period of 1921-1992 (Figure 8.18). The increasing trend is driven mostly by the decreasing of P retention capacity of sewage farms (Table 7.7), and over use of P-content detergents (DANOWSKI, 1990; SENSTADTUM, 1992; BÄRTHEL, 2003). The decreasing trend results from the improving of phosphorus elimination capacity in WWTPs (SENSTADTUM, 2001; BÄRTHEL, 2003), the closure of sewage farms (SENSTADTUM, 1992) as well as the decreasing trend in the specific phosphorus emission per inhabitant (BEHRENDT, 1994, 1998). In the time of 1946-1987, Berlin contributed more than 80% of the total P emissions to its surface water system. Berlin itself contributed 59% of total emissions into water bodies of Berlin in the period of 1988-2000 in comparison to 64% in the period of 1850-1975. In general, the transformation of the hydrochemical conditions of surface water bodies of Berlin are determined by the internal pressures of the city.

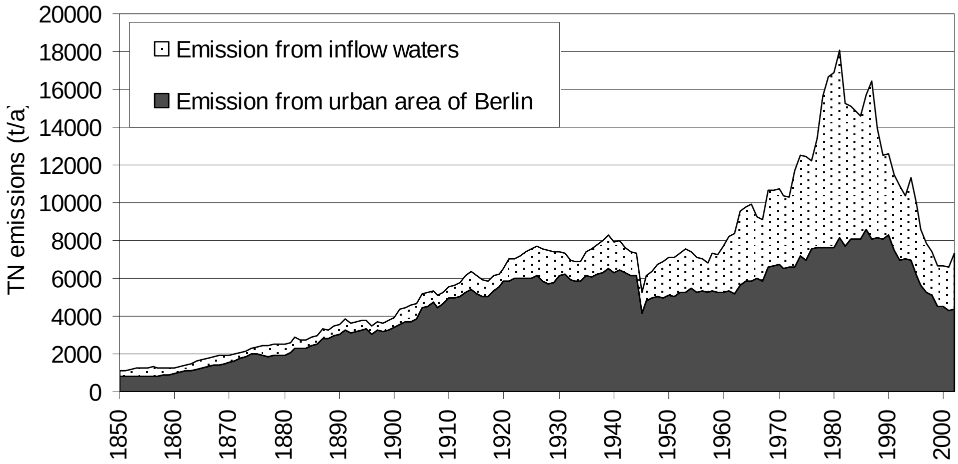

Figure 8.17: TN emissions into the water bodies of Berlin from urban area and inflow waters during the last 150 years *(Model result)*

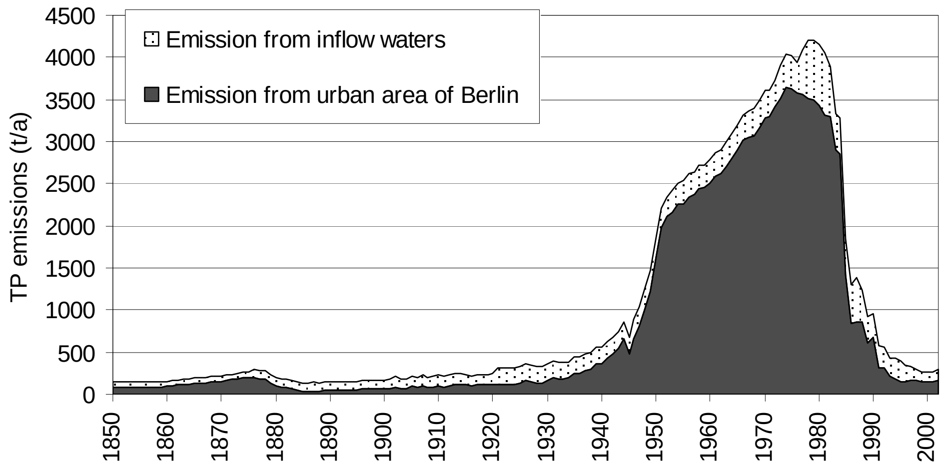

Figure 8.18: TP emissions into the water bodies of Berlin from urban area and inflow waters over the last 150 years *(Model result)*

8.4 Validation of the model results

In order to verify the applicability and plausibility of the model, the results of the study are also compared with other studies. Few studies on nutrient loadings in the whole Berlin area in the period of 1992-1994 and 1995-1997 and for the western part of Berlin in the period of 1983-1985 and 1986-1989 exist (BÖTTCHER et al., 1990; RIPL & KOPPELMAYER,1990; BEHRENDT & OPITZ, 2001).

The estimated phosphorus concentrations in precipitation and drains of Berlin in this study are in the range of previously published data in former studies (BEHRENDT, 1994). The results of this study on nutrient concentrations in influent and effluent of sewage farm were in good agreement with the measured result both for total nitrogen and phosphorus (Table 8.5).

The model results were in good agreement with the result of BEHRENDT and OPITZ (1996, 2000) study for the period of 1995-1997. For the period of 1992-1994, a considerable deviation can be observed between the model result and the BEHRENDT and OPITZ study. In this study, the nutrient loads from upstream area of small inflow waters (like the river Erpe, Fredersdorfer Fließ, and Neuenhagener Mühlenfließ) were not included. This might be due to the difference between estimated inflow loads in this study and in studies of BEHRENDT and OPITZ (Table 8.6).

Comparison with the second nutrient data from sediment analyses

For the time between 1850 and 1965, monitoring data are not available. In order to evaluate the human impacts on the nutrient status of the water bodies of the Berlin-Bradenburg region as well as the rivers Havel and Spree studies by HOELZMANN (1998), BEHRENDT et al. (2001) and SCHÖNFELDER (2001, 2002, 2005) are taken into account. In these studies, the lowland river sediments were used as archives for the paleolimnic reconstruction. Littoral diatom assemblages were encoded to secondary nitrogen and phosphorus concentrations (SCHÖNFELDER et al., 2001, 2002, 2005).

PO_4-P concentrations in sediment of the lake Quenzsee – downstream of Berlin have been continiously reconstructed back to 1945 (HOELZMANN, 1998). The estimated TP concentrations in the outflow water of Berlin are in good agreement with the development of PO_4-P concentrations in sediment of the lake Quenzsee, downstream of Berlin (Figure 8.22). This confirmes the strongly impacts of P emissions from Berlin's urban area on downstream of the Havel as discussed above. The delay of the two curves in the decreasing phrase (in the period of 1985-1995) can be observed. This is the consequence of the large amount of P stored in the sediments which needs more time for reduction.

Figure 8.19, 8.20 and 8.21 show the reconstructed profile of diatom inferred TN, TP concentrations, the ratio of TN/TP concentrations in the sediment of the lake Jungfernsee over the last 400 years and the results of this study (BEHRENDT et al., 2001; SCHÖNFELDER, 2002, 2005). In general, the results of both methods show an increasing trend in nitrogen concentrations over the last 150 years. However, a strong deviation can be observed in the 1850ies and for TP in the late second half of the 20th century. For phosphorus concentrations in water a better agreement in the magnitude and development trend can be recognized between both studies in the period of 1940-1965. However, due to the limitation of the encoding process as well as the dating resolution and the limited number of data points, some variations should be taken into account in the comparison processes. The contradicting trends in N and P concentrations in water in two studies can be pointed out to the period of 1850-1865. However, in this period nutrient emission from Berlin could not be decreased a) population of Berlin increased continuously from 508,000 inhabitants in 1850 to 741,000 inhabitants in 1865 (Figures 2.12, 2.13). b) at the beginning of the Industrial Revolution, the urbanization processes are accelerated, as a result, more areas are converted into impervious surface; and a larger portion of rainfall is realized as surface runoff and discharged into surface water bodies. c) Since 1856, more and more people are to be connected to the central water supply (Figure 2.15) (GERICKE, 1956). Therefore, the total waste water volume increased rapidly. d) In this time, all household and industrial/commercial waste water discharged directly to surface water bodies via open gutter system (BÄRTHEL, 2003; MOHAJERI, 2005),

A strong difference can be observed comparing the TN/TP ratio as reconstructed in this study and the TN/TP ratio as given by SCHÖNFELDER (2001) (Figure 8.21). Due to the differences in development of N and P emissions, the TN/TP ratio could not be more or less constant over the last 150 years as described by SCHÖNFELDER (2002). The water bodies of Berlin have very high TN/TP ratios in the period of 1885-1925 with a mean value of 25.5. The reason for this situation is the strong P retention capacity of the sewage farm systems of Berlin during this time (Table 7.7) (NASCH, 1916; MOHAJERI, 2003). Such a high TN/TP ratio reflects the beginning of a P limitation in the water bodies. In order to reach this ratio again a further reduction of the TP load of Berlin is necessary. To reach a TN/TP ratio of 25-26 the P load must be reduced from the level of 357 t/a in 2002 to the level of about 200 t/a or an average TP concentration in surface water at the level of 0.10 mg/l.

The present level for nitrogen load is about 4-4.5 times higher than the level in the mid 19th Century (Figures 8.23). Phosphorus load is 3 times higher (period of 1998-2002). Therefore, in order to get the “good status” required by the The Water Framework Directive - WFD, total phosphorus emissions from urban area of Berlin must be continously reduced to the level of 0.1 mg/l (REHFELD-KLEIN and BEHRENDT, 1999; EUROPEAN PARLIAMENT, 2000; SENSTADTUM, 2001). Therefore the phosphorus loads into Berlin’s water bodies should be reduced to the level of 160 t TP/a in comparision to the current load of 270 t TP/a (period of 1998-2002). This goal can be reached by application of new technologies in waste water treament plants as well as new efforts in nutrient mitigation.

Table 8.6: Comparison of measured and estimated nutrient concentrations in influent and effluent of sewage farms of Berlin

Period	1888				1885-1895		1896-1905	
	WEIGMAN	Study result	WEIGMAN	Study result	NASCH	Study result	NASCH	Study result
	Inflow	Inflow	Outflow	Outflow	Inflow	Inflow	Inflow	Inflow
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Total Nitrogen	87.3	83.3	31.6	33.2	106	83.1	85	91
Phosphoric acid-anhydride	18.5		trace		26.8		19.4	
Total P		11.2		0.2		11		12.3

(Source: NASCH, 1916; MOHAJERI, 2003)

Table 8.7: Comparison of estimated nutrient loads for Berlin water bodies and previous study results

Emission sources	Period	The study result	Previous studies	Author(s) and year
		TN load (t/a)	TN load (t/a)	
Total inflow load	1992-1994	3509	4140	BEHRENDT & OPITZ (2001)
Total inflow load	1995-1997	2317	2630	BEHRENDT & OPITZ (2001)
WWTPs	1992-1994	6219	7180	BEHRENDT & OPITZ (2001)
WWTPs	1995-1997	5024	4810	BEHRENDT & OPITZ (2001)
Sewer system	1992-1994	400	230	BEHRENDT & OPITZ (2001)
Sewer system	1995-1997	230	230	BEHRENDT & OPITZ (2001)
Out flow	1992-1994	9399	8650	BEHRENDT & OPITZ (2001)
Out flow	1995-1997	5070	4950	BEHRENDT & OPITZ (2001)
Out flow	1986-1990	9933	11900	RIPL & KOPPELMAYER (1990)
Emission sources	Period	TP load (t/a)	TP load (t/a)	
Total inflow load	1992-1994	205	265	BEHRENDT & OPITZ (2001)
Total inflow load	1995-1997	171	188	BEHRENDT & OPITZ (2001)
WWTPs	1992-1994	172	132	BEHRENDT & OPITZ (2001)
WWTPs	1995-1997	111	109	BEHRENDT & OPITZ (2001)
Sewer system	1992-1994	51	38	BEHRENDT & OPITZ (2001)
Sewer system	1995-1997	37	38	BEHRENDT & OPITZ (2001)
Out flow	1992-1994	381	440	BEHRENDT & OPITZ (2001)
Out flow	1995-1997	255	283	BEHRENDT & OPITZ (2001)
Out flow	1983-1985	1437	1543 (PO_4-P)	BÖTTCHER et al. (1990)
Out flow	1986-1988	522	407 (PO_4-P)	BÖTTCHER et al. (1990)
Out flow	1986-1990	619	670	RIPL & KOPPELMAYER (1990)

(Source: BÖTTCHER et al. 1990; BEHRENDT & OPITZ, 2001)

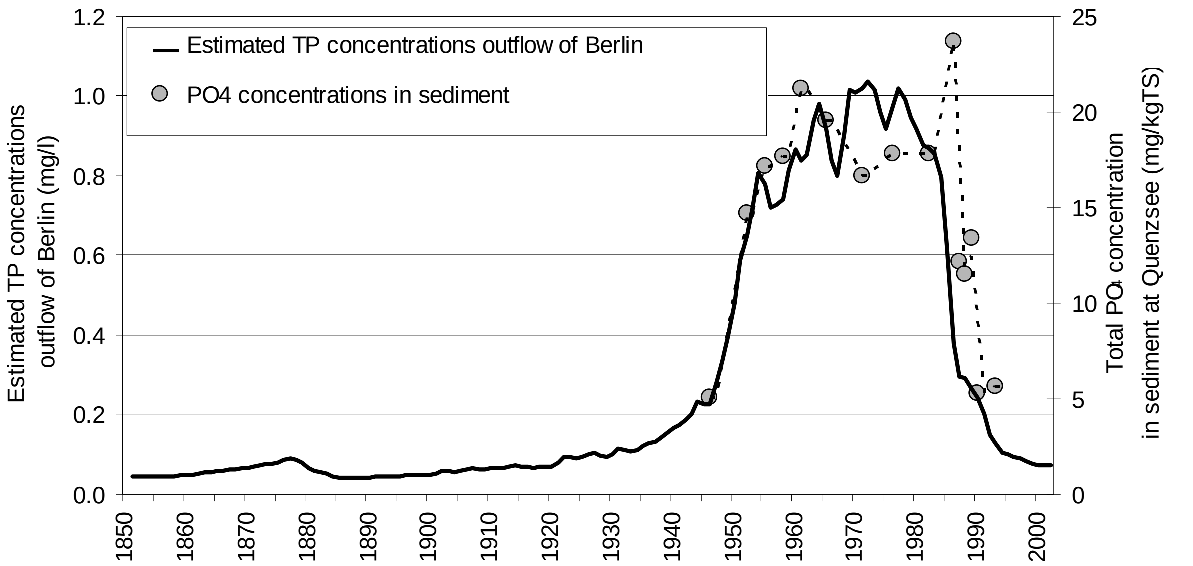

Figure 8.19: Comparison between the long-term developments of phosphorus status in water reconstructed by results of this study and PO_4 concentrations in sediment of Quenzsee (HOELZMANN, 1998)

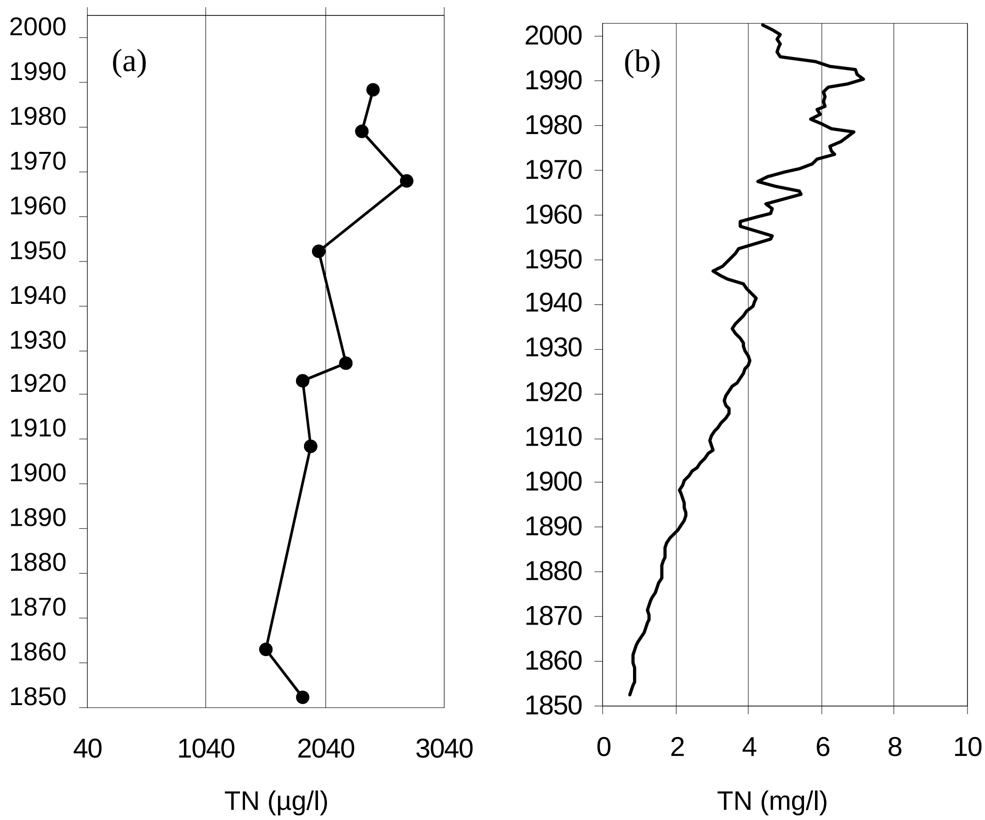

Figure 8.20: Comparison between the long-term nitrogen status in water reconstructed by (a) diatom inferred concentration method (SCHÖNFELDER et al., 2001) and (b) the results of this study

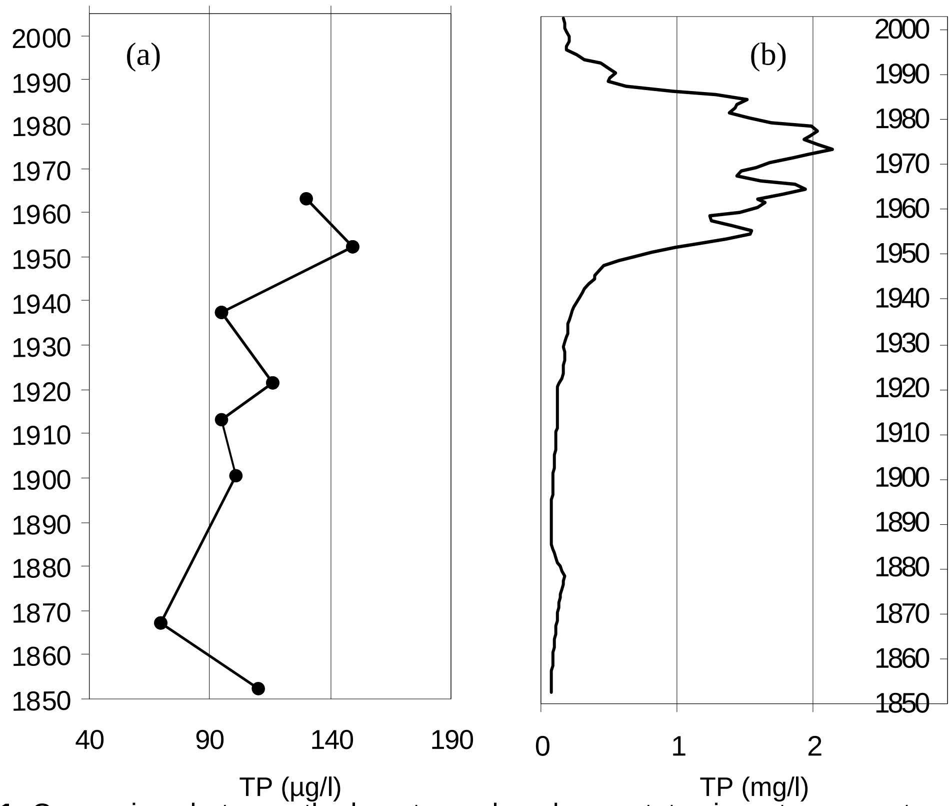

Figure 8.21: Comparison between the long-term phosphorus status in water reconstructed by (a) diatom inferred concentration method (SCHÖNFELDER et al., 2001) and (b) the results of this study

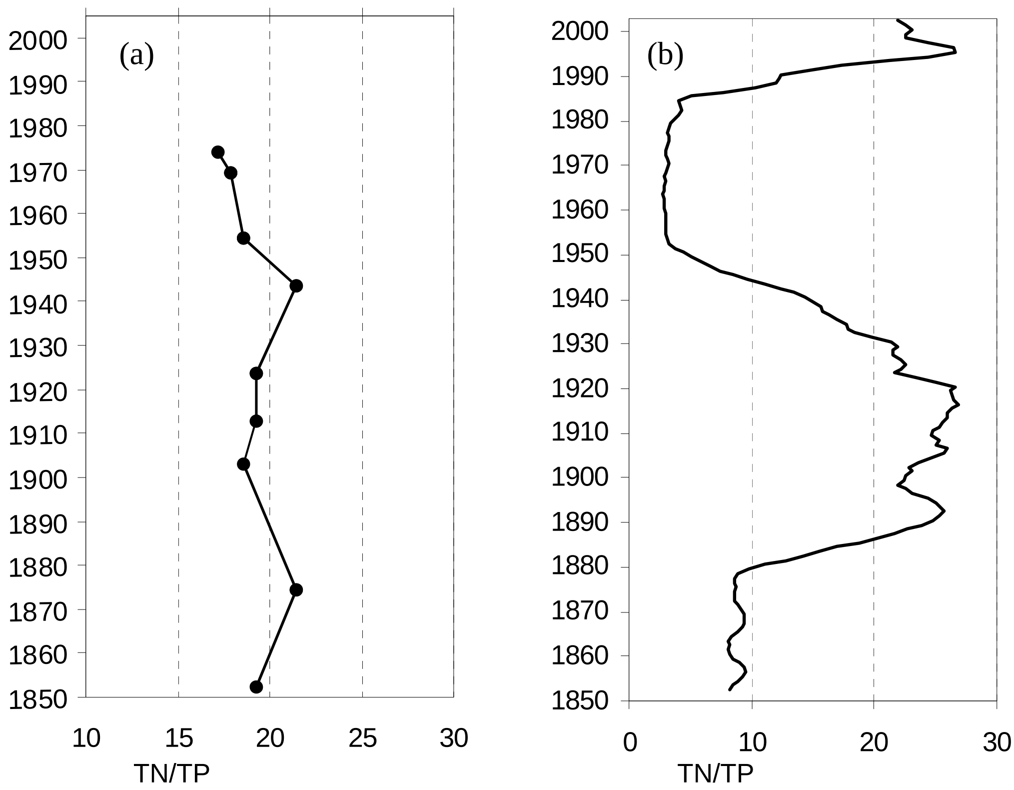

Figure 8.22: Comparison between the long-term developments of TN/TP status in water reconstructed by results of this study and diatom inferred concentration method (SCHÖNFELDER et al., 2001).

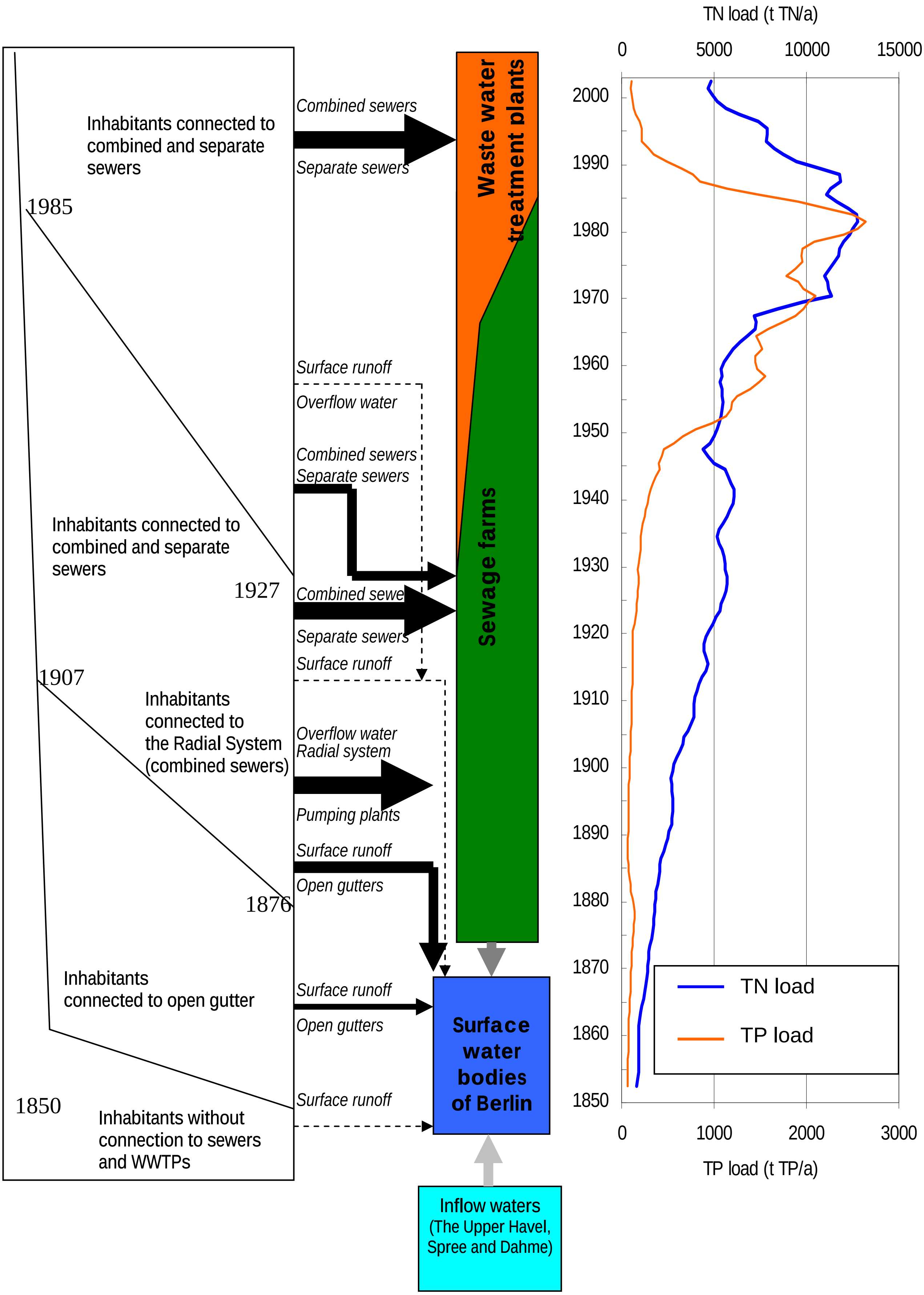

Figure 8.23: The conceptual model for nutrient load developments into the surface water bodies of Berlin during the last 150 years