5. Temporal and spatial trend of Berlin surface water quality

5.1 Temporal trends

The temporal change of nutrient loads is evaluated through an integration method, including monitoring data (1984-2003) to identify the current trends and analysing the emission and retention processes to recognize the specific natural background and utilization context. The water monitoring stations, water bodies of Berlin is shown in Figure 4.1.

5.1.1 Seasonal variations

Results

For the flowing water bodies in the Berlin area discharge is recorded since 1984, here used as monthly averages. All water courses show maximum discharge in March and minimum discharge in August. At the Upper Havel (1984-2003) average discharge in March totals 9.58 m^3/s (std=8.2, n=20), while average discharge in August reaches minimum values with 6.42 m^3/s (std=3.53, n=20). The discharges of the Spree at Müggelsee show the maximum in March of 9.8 m^3/s (std=2.64, n=18) and the minimum in August (μ=4.53 m^3/s, std=2.189, n=18).

The typical seasonal pattern of water temperature shows a maximum during summer and low values in winter (Figures 5.1, 5.2a). At the monitoring station Sophienwerder, the Spree (station 160) in the period 1984-2003 August water temperatures average 24 ^oC (std=1.67, n=20) and reach lowest values in January (μ=4.4 ^oC, std=1.65, n=17). For the same station seasonal pattern of dissolved oxygen shows maximum values in March (μ= 12.48 mg/l, std=1.33, n=20) and minimum value in June (μ=6.25 mg/l, std=1.95, n=20) (Figure 5.3b). Summarizing, for both parameter changes within a seasonal cycle are similar at all monitoring stations investigated. Water temperature in Teltowkanal has the highest monthly means and this value is always 3-5 ^oC higher than other water bodies.

Also the seasonal cycle of nitrate-N concentrations shows a similar pattern for most of the monitoring stations (Figure 5.3). Only for the monitoring station in the Teltowkanal distinct differences can be observed (Figure 5.4). In general, average monthly nitrate-N concentrations decrease after reaching in average maximum values in March and reach lowest values in July and August. Corresponding to this overall pattern, at the monitoring station 120 - Spreetunnel (Müggelspree) monthly average nitrate-N concentrations reach highest values in March (μ=1.44 mg/l, std=0.77, n=19) and lowest value in July (μ=0.267 mg/l, std =0.359, n=18). In contrast, at monitoring station 420 – Teltowkanal seasonal pattern of nitrate-N concentrations is almost reverse with average monthly maximum values in August (μ=4.73 mg/l, std=1.4, n=20) and minimum values in February (μ=2.17 mg/l, std=1.84, n= 20) and long-term annual average of 3.5 mg/l.

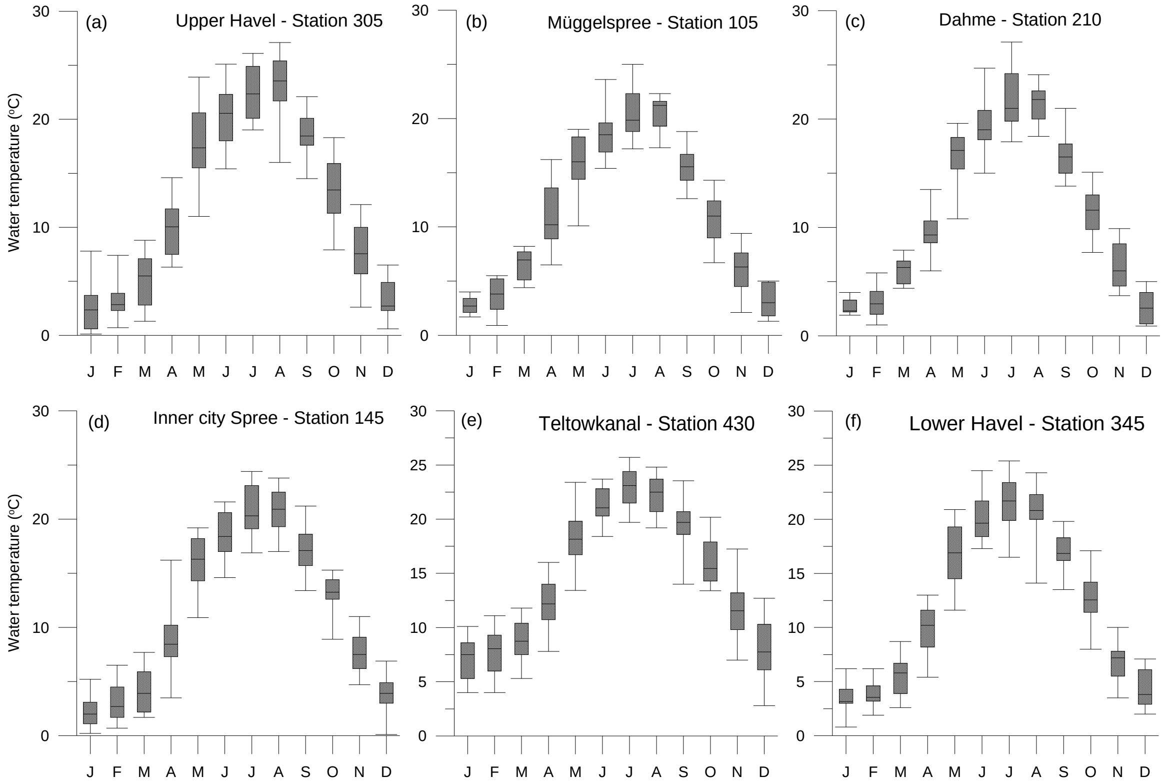

Figure 5.1: Seasonal variations of monthly average of water temperature at (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel
(Data base: Surface Quality Measurement Program, SENSTADTUM, 1994-2003).

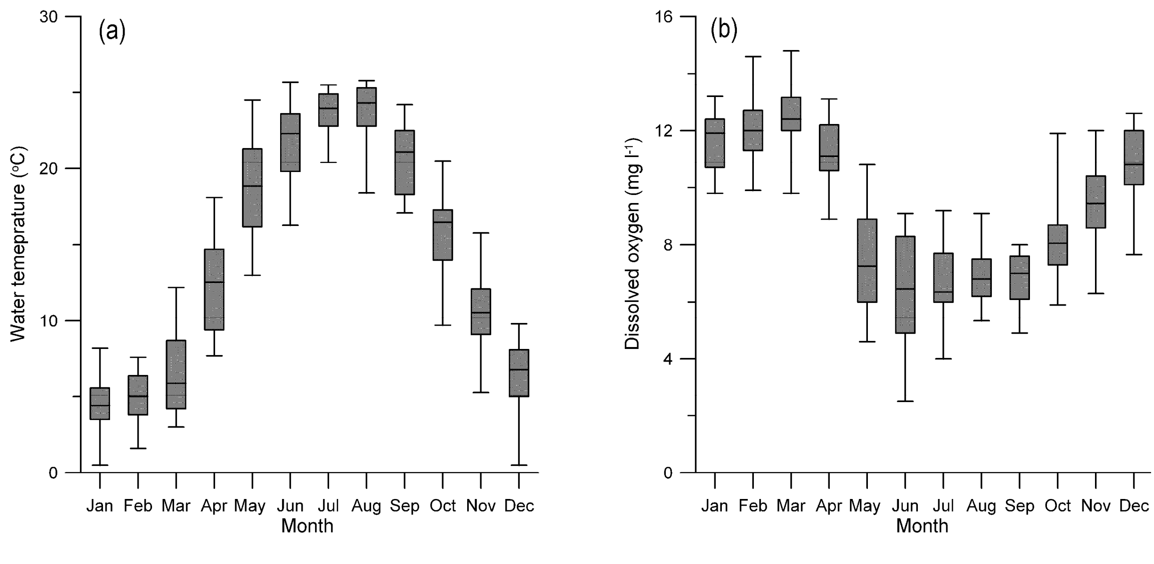

Figure 5.2: Seasonal variations of monthly average surface water quality parameters at monitoring station 160 - Sophienwerder, Spree for (a) Temperature and (b) Dissolved oxygen
(Data base: Surface Quality Measurement Program, SENSTADTUM, 1984-2000).

In the period 1993-1997 WWTPs discharged 3.69 m^3/s (std=1.33, n= 60; calculations based on monthly average values) of cleaned waste water with average nitrate-N concentrations of 10.54 mg/l NO_3-N (std=5, n=223) into the Teltowkanal. Concurrently, the monthly average inflow into the Teltowkanal at Grünau totaled 1.67 m^3/s (std=1.30, n=60). During this period, monthly nitrate-N concentrations of the Dahme - acting as the major natural inflow water of the Teltowkanal - averaged 0.66 mg/l NO_3-N (std=0.72, n=54).

Figure 5.5 shows the same patterns for seasonal variation of total phosphorus concentration in water bodies of Berlin, with the elevated values in summer and the lowest value in spring.

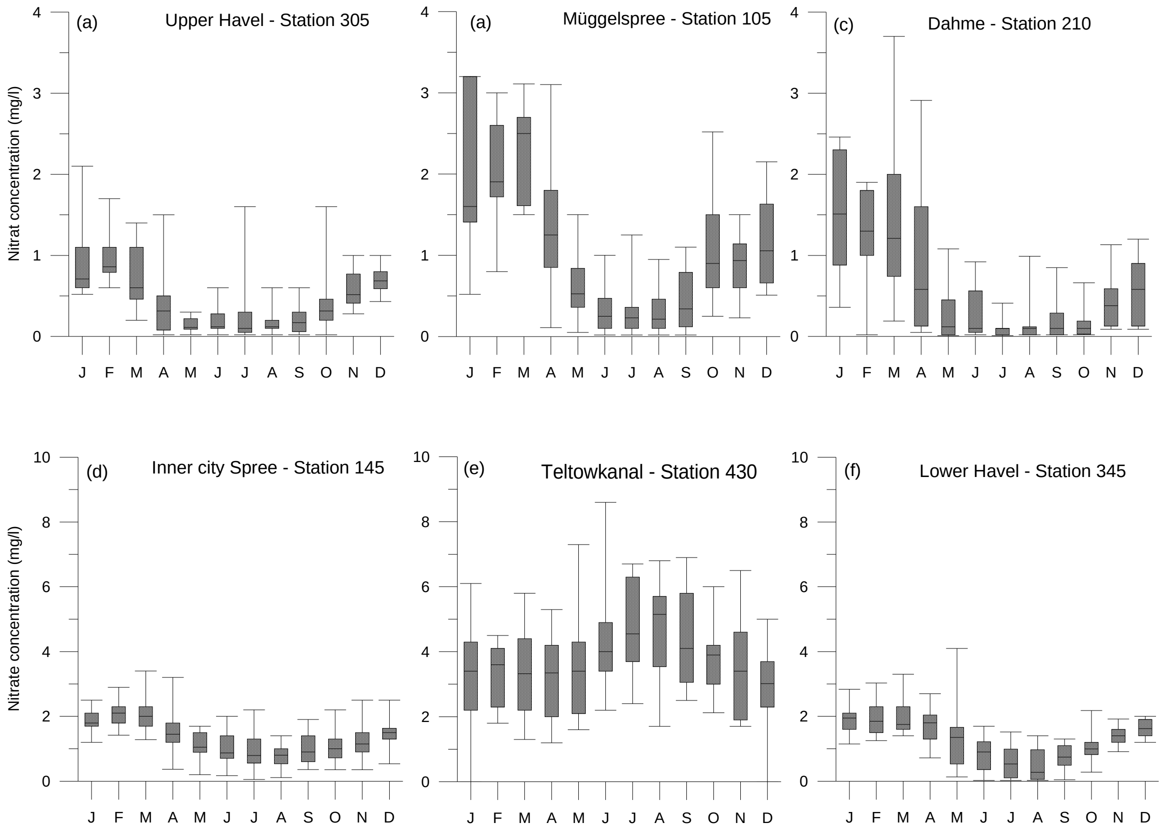

Figure 5.3: Seasonal variations of monthly average of nitrate concentrations at (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel
(Data base: Surface Quality Measurement Program, SenStadtUm, 1994-2003).

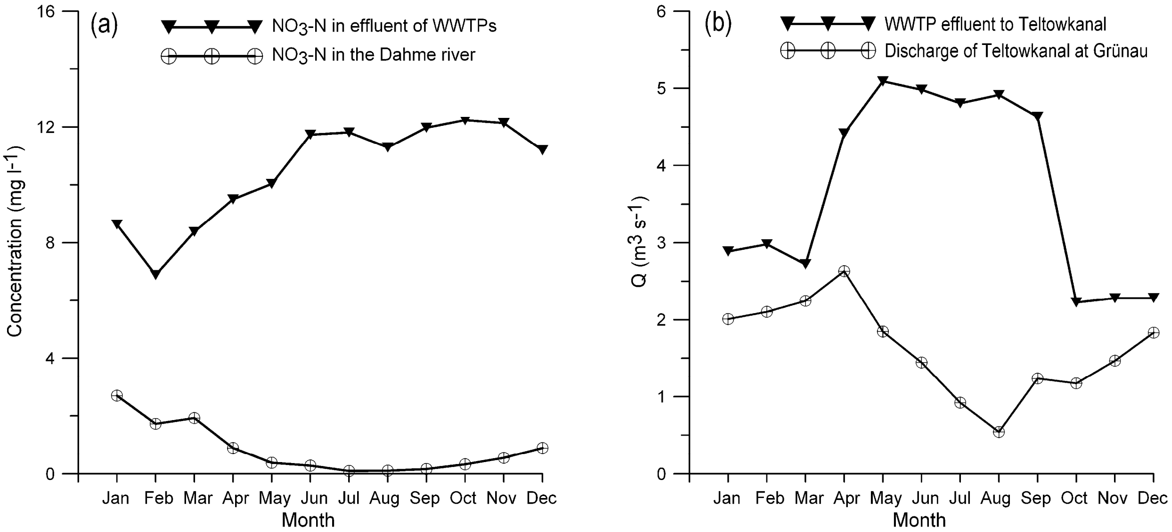

Figure 5.4: Seasonal variations of monthly average (a) Nitrate-N concentrations of WWTPs effluents, the Dahme; and (b) effluents of WWTPs purred into the Teltowkanal and inflow-discharge of the Teltowkanal at Grünau
(Data base: Surface Quality Measurement Program, SENSTADTUM, 1993-1997; BWB, 1993-1997).

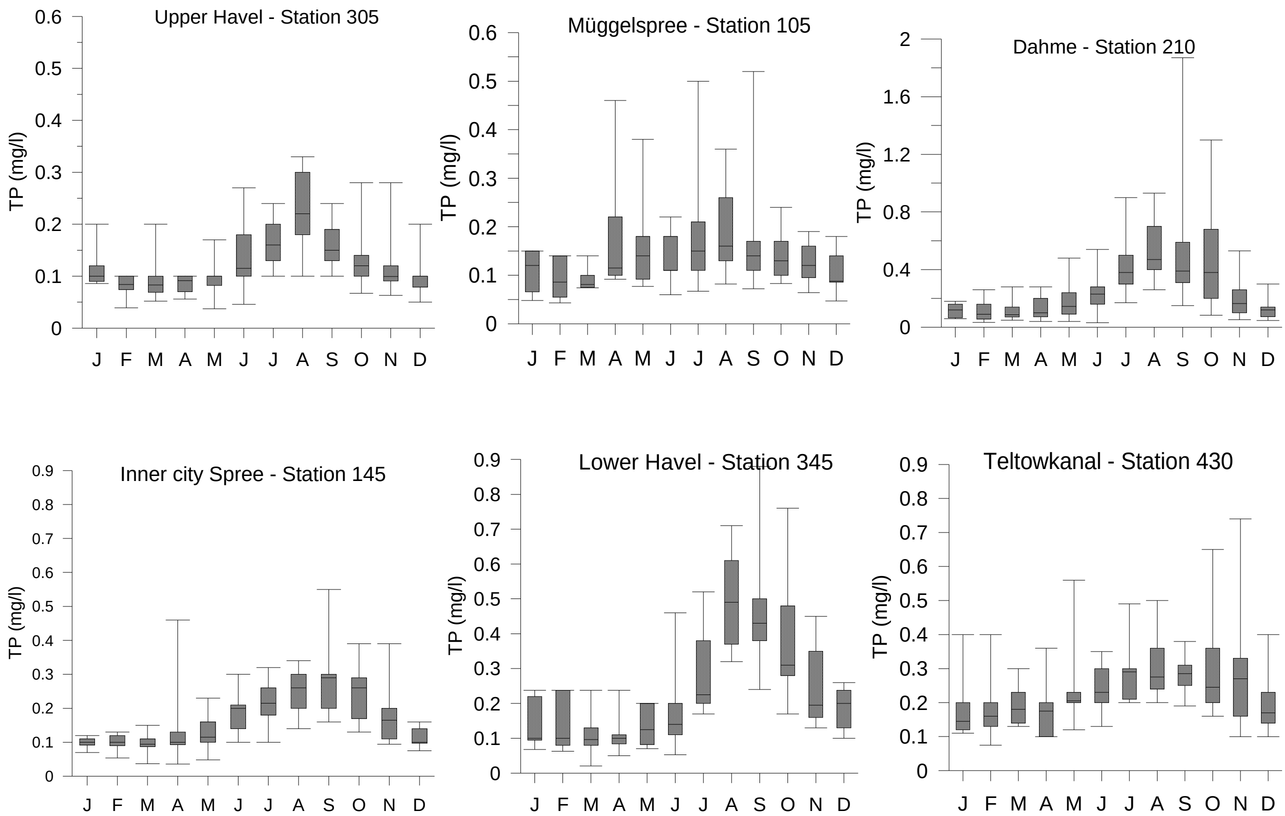

Figure 5.5: Seasonal variations of monthly average of total phosphorus concentration in (a) Upper Havel, (b) Müggelspree, (c) Dahme, (d) Inner city Spree, (e) Teltowkanal and (f) Lower Havel
(Data base: Surface Quality Measurement Program, SENSTADTUM, 1994-2003).

Discussion

The seasonal variations of the surface water parameters in Berlin are as well impacted by the natural cycle as by the - seasonally varying – human impact:

Discharge. Discharge volume of the Teltowkanal in the period of 1984-2003 is mostly determined by the effluents of Berlin WWTPs (Wassmannsdorf, Stahnsdorf, Ruhleben and Marienfelde in the past) (Figure 5.4). The Teltowkanal received very high nitrate-N emissions from the local WWTPs compared to the nitrate-N concentrations inflowing from the Dahme. In addition, the nitrogen transformation process is accelerated during summer time when high biogenic activity concurrently occurs. Accordingly, ammonium-N as provided from effluents of WWTPs along the Teltowkanal was converted into nitrate-N (WETZEL, 1983; HENZE, 1995) (Figures 5.3, 5.4). Summarizing, it becomes obvious that nitrate-N loading of the Teltowkanal is predominantly defined by the internal sub-catchment point sources: the effluents from WWTPs. The high level of nitrate-N concentrations in the Teltowkanal is also an indicator of inadequate dilution of effluents from WWTPs. Attributed to this effect the seasonal nitrate-N pattern of the Teltowkanal (Figure 5.4) is significantly diverging from the remaining Berlin water bodies.

Temperature. In the period of 1984-2003, the pattern of seasonal variation in water temperature coincides to the seasonal air temperature course with an altogether temperate/mesothemal climate in the Berlin region (Cfb according to the Köppen climate classification) (ALLAN, 1995). According to the high water temperatures during summer, dissolved oxygen concentrations occur lower. Solubility of oxygen is affected nonlinearly by temperature, and decreases considerably in warm water (WETZEL, 1983). The rate of biological stabilization is a time-temperature function with deoxygenation increasing as the temperature rises (HAMMER, 1986; ALLAN, 1995). Next to the natural dependency between seasonal primary production and bacteria activity, water temperature and oxygen, heat immissions from the thermoelectric plants along the Teltowkanal contribute further impact on the oxygen balance (Figure 5.1). Due to the artificially increased temperatures most chemical and biological processes are accelerated and cause shortage of dissolved oxygen concentrations especially in the slow flowing and broadening water bodies during summer (KEUP, 1967; HOUNSLOW, 1995; STUMM, 1996). In contrast, low water temperature during winter as well as increased flow velocity improves the water bodies' oxygen contents (HOUNSLOW, 1995; STUMM, 1996). Especially the inflowing water bodies have high dissolved oxygen concentrations due to turbulence in the flow process as it can be observed for the Dahme.

Nitrogen. The seasonality of nitrogen in water bodies is influenced by seasonal changes of both hydrological conditions and biogeochemical processes in the period of 1984-2004. In general, nitrogen export from the catchment in this region decreases remarkably in summer growing season, and this has been explained by high denitrification and plant nitrogen uptake and low water discharge mainly by baseflow which is characterized in the unconsolidated rock region by low N concentrations (OHTE et al., 2006). Watersheds have the capacity to transport parts of their NO^{3-} load through biomass accumulation and to retain nitrate in groundwater, riparian zones and surface waters. Due to the high mobility of nitrate in soil, it can be easily lost from soil during the storm events. Furthermore, as the flow rate increases there is less time for the degradation of nitrate (HILL et al., 1999; GOOLSBY et al., 1999). Higher water temperatures reduce the oxygen concentration in the water and increase the rate of biological activity. Nitrogen retention is mostly due to denitrification. This process is strongly dependent on temperature and therefore high denitrification rates occur during summer (Figure 5.3).

Sewage treatment plants discharge a high proportion of ammonium-N. Through the decomposition process (nitrification) ammonium-N is transformed to nitrite-N as an intermediate stage and finally to nitrate in the waters (Figures 5.3 and 5.4) (WETZEL, 1983; HAMMER, 1986; HOUNSLOW, 1995; HENZE, 1995). Due to the different treatment technologies in use the nutrient concentrations in effluents from WWTPs of Berlin vary locally (BWB, 2005).

Phosphorous. The increased total-P concentrations observed in summer were almost dominated by the orthophosphate component. The common forms of phosphorus in water are orthophosphate, polyphosphates and inorganic as well as organically bound phosphates. Polyphosphates gradually hydrolyze in water to the ortho-form and bacterial decomposition of organic compounds also releases orthophosphate. If the water at the sediment-water interface is oxygenated an oxidized microzone forms in the sediments. Below this point, sediments normally become reducing. The formation of an oxidized microzone effectively prevents sediment-bound P from migration into the water column. When the oxidized microzone is lost during formation of an anoxic hypolimnion, the release of phosphate and ferrous iron to the water column readily occurs (RIGLER, 1964). The high rates of regeneration and sediment release during summer for dissolved inorganic phosphorus, brings P back into the water, creating an internal source of nutrient and causing increased P-concentrations (Figure 5.5) (WETZEL, 1983; CONLEY, 2000)

5.1.2 Long-term trends

Results

The nutrient input- and output-loads of Berlin's water bodies were calculated on an annual base for six sub-catchments. In the period of 1966-1983, data on nutrient concentrations are available only for the water bodies in West Berlin in the form of mean summer values. Discharge data of water bodies in West Berlin in this period are available on monthly base. The mean annual values were estimated from the mean summer values by regression method (Table 4.1) (Gewässerkundlicher Jahresbericht des Landes Berlin, Abflußjahr 1966-1987). In the period of 1984-2003, monthly data on nutrient concentrations and discharge volumes are available for the water bodies of whole Berlin (SENSTADTUM, 2004). The TN load is build as the sum of ammonium-N, nitrite-N, nitrate-N and organic nitrogen loads; calculations of balances be on the hand for five-year-intervals. The total nitrogen and phosphorus loads of water bodies in Berlin in the period of 1984-2003 are shown in Table 5.1, 5.2 and Figures: 5.6-5.9 and in the period of 1966-2003 in Figures 5.10 and 5.11.

Accordingly, during the last 20 years the Inner City Spree, Lower Havel and Upper Havel show the same decreasing trend of TN input while the Müggelspree and the Dahme also here show a period of increasing TN input from 1984-1990 (Table 5.1; Figure 5.7). Contemplating, in the period 1984-2003 TN outputs of the Lower Havel and the Inner City Spree showed distinctly decreasing trends (Figure 5.9). In contrast, the three tributary water bodies Dahme, Müggelspree and Upper Havel showed a slightly increasing of TN output in 1981-1986 before also here values started to decrease continuously. For the Teltowkanal peak of TN output appears with a time-lag in the period 1991-1995.

Table 5.1: TN load development of Berlin's water bodies, 1984 – 2003

(Data base: Surface Quality Measurement Program, SENSTADTUM, 1984-2003).

Water bodies		1984-1985 (ton/a)	1986-1990 (ton/a)	1991-1995 (ton/a)	1996-2000 (ton/a)	2001-2003 (ton/a)
Dahme	Input		2626	1812	1202	1097
	Output		2533	1520	1111	1099
Müggelspree	Input	1647	2512	1237	654	594
	Output	1630	2014	1700	1079	781
Inner City Spree	Input	5213	4063	2648	1723	842
	Output	7930	5741	3421	3167	2127
Teltowkanal	Input	861	506	558	660	605
	Output	3114	2891	4505	1999	1255
Upper Havel	Input	812	830	758	576	491
	Output	1174	1861	1325	939	609
Lower Havel	Input	9204	7991	5567	3743	2744
	Output	7219	7020	5057	3007	2260
Berlin water bodies	Input	6426	4914	3598	2460	2217
	Output	9243	8400	8624	4438	3204

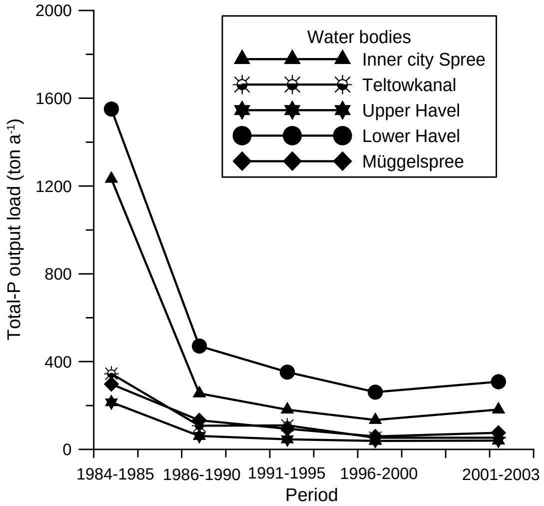

Figure 5.6: Development of TP output load of Berlin water bodies shown by five-year-averages from 1984-2003 *(Source: Surface Quality Measurement Program, SENSTADTUM, 1984-2003)*

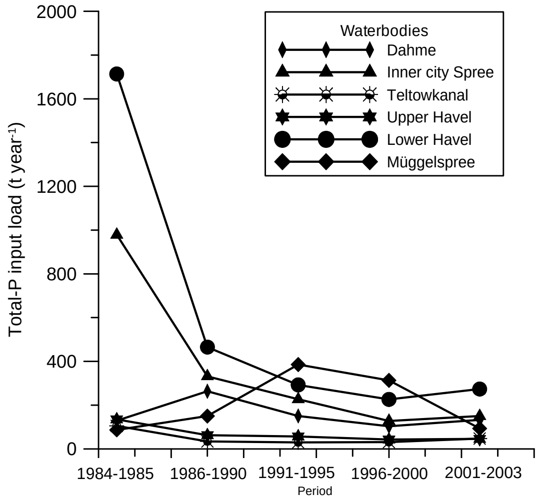

Figure 5.7: Development of TP input load and output load of Berlin water bodies shown by five-year-averages from 1984-2003 *(Source: Surface Quality Measurement Program, SENSTADTUM, 1984-2003)*

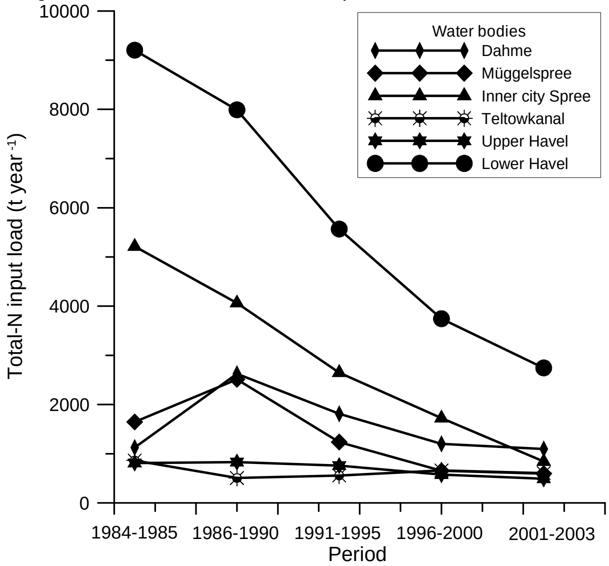

Figure 5.8: The development of TN input of Berlin water bodies in the period of 1984-2003 *(Source: SENSTADTUM, 1984-2003)*

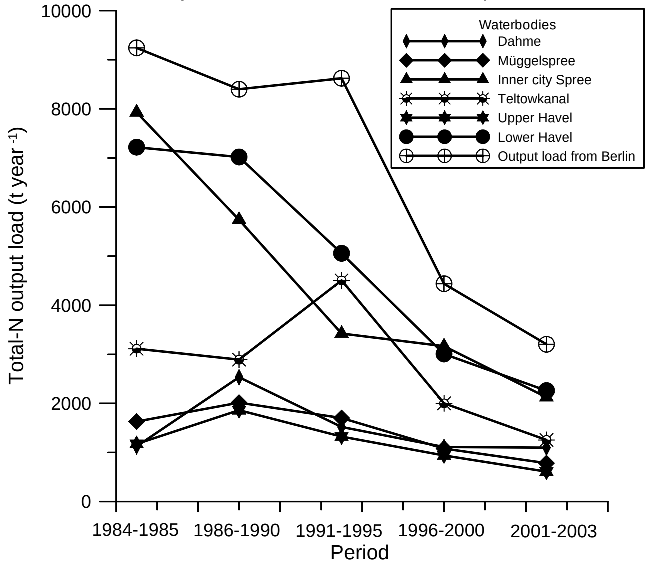

Figure 5.9: The development of TN output of Berlin water bodies in the period of 1984-2003 (*Source: SENSTADTUM, 1984-2003)*

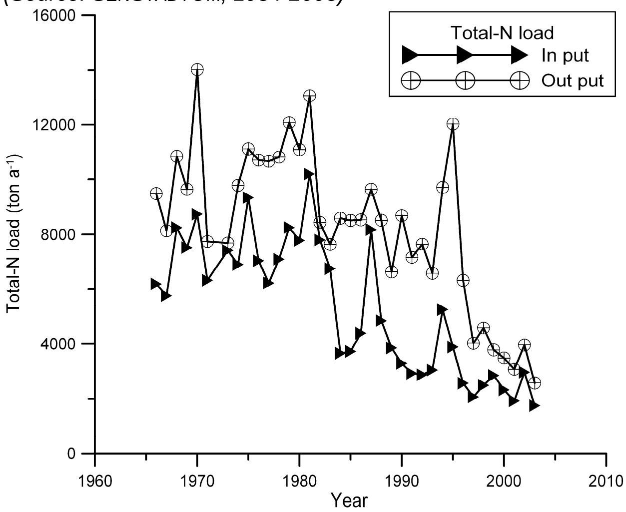

Figure 5.10: TN load of Berlin water bodies 1966–2003 *(Source: SENSTADTUM, 1966-1992, 1984-2003).* (Note: 1966-1983: input for West Berlin only)

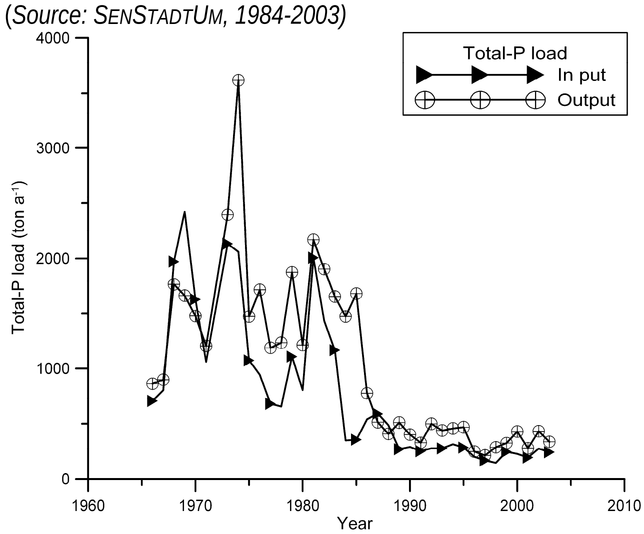

Figure 5.11: TP load of Berlin water bodies 1966–2003 *(Source: SENSTADTUM, 1966-1992, 1984-2003).* (Note: 1966-1983: input for West Berlin only)

Table 5.2: TP load development of Berlin's water bodies, 1984 – 2003

(Data base: Surface Quality Measurement Program, SENSTADTUM, 1984-2003)

Water bodies		1984-1985 (ton/a)	1986-1990 (ton/a)	1991-1995 (ton/a)	1996-2000 (ton/a)	2001-2003 (ton/a)
Dahme	Input		263	150	103	132
	Output		260	177	93	142
Müggelspree	Input	87	150	385	313	93
	Output	297	133	94	59	75
Inner city Spree	Input	979	331	226	127	150
	Output	1233	255	181	133	181
Teltowkanal	Input	86	23	8	13	26
	Output	345	108	109	53	53
Upper Havel	Input	135	62	56	42	45
	Output	215	61	46	39	39
Lower Havel	Input	1713	465	292	226	273
	Output	1550	471	352	260	308
Berlin water bodies	Input	1062	434	279	196	235
	Output	1774	521	437	299	348

Development of annual TN input and output loads of Berlin (on an annual base in the period of 1966-1983 for West Berlin and monthly base in the period of 1984-2003 for the whole Berlin) shows three development phases (Figure 5.10):

- 1966-1981: period of increasing TN load,
- 1982-1995: period of slightly decreasing TN loads,
- 1996-2003: period of distinctly decreasing TN loads.

TN output loads increased in the years 1966-1981 with a peak load of 14,017 tons TN in 1970. From 1982 to 1995, in water bodies of Berlin the TN load slightly decreased, with aggravating trend since 1996.

The Lower Havel and the Inner City Spree show a period of distinctly decreasing TP input from 1981 to 1990 with amounts reduced by 73% and 33% respectively. In the period 1981-2000 also the Teltowkanal and the Upper Havel showed the same decreasing trends of TP input, while from 1984-1990 in the Müggelspree as well as in the Dahme input of TP still increased (Figure 5.7). However, TP output loads of Berlin water bodies show allover distinctly decreasing trends for the period 1981-2000 (Figure 5.7).

The TP includes the loads of phosphorus in solution (reactive) and in particle form; calculations are available on an annual base (Table 5.2, Figure 5.11). For TP in- and output data from Berlin water bodies are available on an annual base in the period of 1966-1983 for West Berlin and monthly base in the period of 1984-2003 for the whole Berlin; load curves are assigned to stages:

- 1966-1974: period of high TP loads,
- 1975-1985: period of decreasing TP loads,
- 1986-2003: period of low TP loads.

In the period 1966-1974, the water bodies of West-Berlin hold high TP loads. Maximum TP input loads added up to 2,423 tons in 1969, while the maximum TP output load occurred in 1974. From 1975-1985 a distinctly decreasing trend of TP loads can be detected. The phase of low TP loads starts in 1986. Since this time, Berlin discharges an amount of TP lower than 500 tons per year into downstream areas. Distinct changes can be observed for the years 1985/1986 when the TP output load was reduced to 954 tons, corresponding to 46% of the TP output load in the year before.

Discussion

Since the 1980ies the nitrogen load of Berlin decreased continuously, but until today still remains on a high level. Increasing total-N load in Berlin until 1981 was due to various reasons: increasing emissions and limited treatment capacity and technology of WWTPs and a sewage farm system with the high-loaded trickling filter process (SEEGER, 1999). In the period from 1982 to 1995 a slight decrease of total-N load occurred as the result of building a new WWTP (Schönerlinde in 1985) and the renovation of treatment technologies at in-operation WWTPs (Ruhleben and Falkenberg in 1985, Schönerlinde in 1987) (KLOSE, 1985; BÄRTHEL, 2003; MOHAJERI, 2005).

However, until today the waste water treatment system of Berlin has the strongest impact on the nitrogen loads of Berlin water bodies among other emission sources. The transitional points in the course of nutrient development are the prints of the construction of new WWTPs as well as the closure of the sewage farms and improvement of waste water treatment technologies, the changes of drainage system and the legal and management system with the goal of pollution prevention at the emission sources.

Due to its high discharge volume the river Spree plays an important role to quality of waters running through Berlin. Correspondingly, it can act diluting for highly polluted waters of the Inner City areas. However, in most recent years the reduction of brown coal mining in the middle Spree drainage basin resulted in a decline of discharge of the river Spree (LUA BRANDENBURG, 1995; PUSCH, 2000; KÖHLER, 2002; SENSTADTUM, 1966-1992, 2001).

The period of very high total-P loads in Berlin water bodies from 1966-1974 was due the situation that the domestic and industrial waste water of Berlin increased faster than the treatment capacity of the WWTP system and the sewage farms (Figure 5.8). Until 1968 only four WWTPs were in operation (Waßmannsdorf, Stahnsdorf, Ruhleben and Falkenberg). However, their nutrient removal capacity was limited before they were upgraded in 1974. Next to this, the treatment capacity of sewage farms in Berlin was increasingly inefficient after long-time operation in overload situation (KLOSE, 1985; HENZE, 1995; BÄRTHEL, 2003; MOHAJERI, 2005; BWB, 2005)

In 1975 “The Detergents and Cleaners Act” was passed (BMU, 2001). In this context new WWTPs were established, such as the WWTP Marienfelde which started operation already in the run-up of this amendment in 1974.

Aftermath the total-P load of Berlin water bodies was reduced distinctly (Figure 5.11). The distinctly low total-P loadings since 1986 are predominantly formed by different developments:

a) The amendment of “The Detergent and Cleaners Acts” enforced in West-Berlin in 1986 and in the whole Berlin area after the reunion (LEYMANN, 1991),

b) The new WWTP Schönerlinde went in operation in 1985 and replaced the sewage farm system in the north of Berlin, including Blankenfelde, Hobrechsfelde and Buch (SENSTADTUM, 2001; BWB, 2005),

c) The technological upgrades of the existed WWTPs (Falkenberg in 1985, Ruhleben in 1985 and 1987, Münchehofe in 1987) (KLOSE, 1985; PETER, 1990; SENSTADTUM, 2001; BWB, 2005),

d) The installation of Phosphate Elimination Plant in Tegel in 1985 (HENZE, 2001).

5.2 Spatial trends

In order to characterize the surface water quality of Berlin, 14 physical and hydrochemical parameters including the most important indicators for eutrophication in the period of 1984-2003 have been considered (SENSTADTUM, 2004). On this data base the retention and transport of nutrients are designed and driving forces behind nutrient-related environmental issues are identified.

Results

Based on the surface water quality as surveyed in the years 1984-2003, Berlin surface waters can be divided by cluster analysis (Ward method) into the six sub-catchments Dahme, Müggelspree, Inner city Spree, Teltowkanal, Upper Havel and Lower Havel (Figures 5.12, 5.13).

- The cluster 1 (**Müggelspree**) has the lowest mean water temperature (µ=11.38 ^{o}C, std=6.986, n=645) and is characterized by altogether low nitrogen concentrations (ammonium-N: µ=0.185 mg/l NH_4-N, std=0.32, n=423, nitrite-N: µ=0.02 mg/l NO_2-N, std=0.022, n=695, nitrate-N: µ=0.81 mg/l NO_3-N, std=0.72, n=516) as well as low orthophosphate concentrations (µ=0.056 mg/l PO_4-P, std=0.064, n=520).
- In contrast, water quality in cluster 2 (**Inner City Spree**) shows increased concentrations of nitrite-N (µ=0.08 mg/l NO_2-N, std=0.274, n=719) and chlorophyll-a (µ=55.85 µg/l chlorophyll-a, std=41.09, n=750).
- Cluster 3 (**Teltowkanal**) has the highest nitrogen, phosphorus concentrations water temperature in compare to other areas. N concentrations in the Teltowkanal have quite high values (ammonium-N: µ=1.76 mg/l NH_4-N, std=2.33, n=603, nitrite-N: µ=0.23 mg/l NO_2-N, std=0.249, n=735, nitrate-N: µ=3.2 mg/l NO_3-N, std=2.4, n=718). The average orthophosphate is 0.161 mg/l PO_4-P (std=0.184, n=724). Water temperature values average around 14.9 ^{o}C (std=6.57, n=912).
- Waters in cluster 4 (**Upper Havel**) are characterized by the lowest orthophosphate concentrations and high electric conductivity (µ=825.96 µS cm^{-1}, std=148, n=589). Concentrations of dissolved oxygen are distinctly below average (µ=8.68 mg/l DO, std=2.369, n=787). The same pattern applies for orthophosphate concentrations which average µ=0.052 mg/l PO_4-P (std=0.049, n=540).
- The cluster 5 (**Lower Havel**) shows increased orthophosphate concentrations (µ=1.37 mg/l PO_4-P, std=0.707, n=548), just lower than the peak in the Teltowkanal and has quite high dissolved oxygen concentrations (µ=10.88 mg/l DO, std=2.51, n=588) and also has an elevated thermal regime (µ=12.88 ^{o}C, std=7.06, n=902).
- The cluster 6 (**Dahme**) shows the high dissolved oxygen concentrations (µ=11.9 mg/l DO, std=2.928, n=677). Next to this, also average chlorophyll-a values (µ=63.35 µg/l chlorophyll-a, std=93.07, n=572) and average pH-values (µ=8.35, std=0.442, n=713) peak.

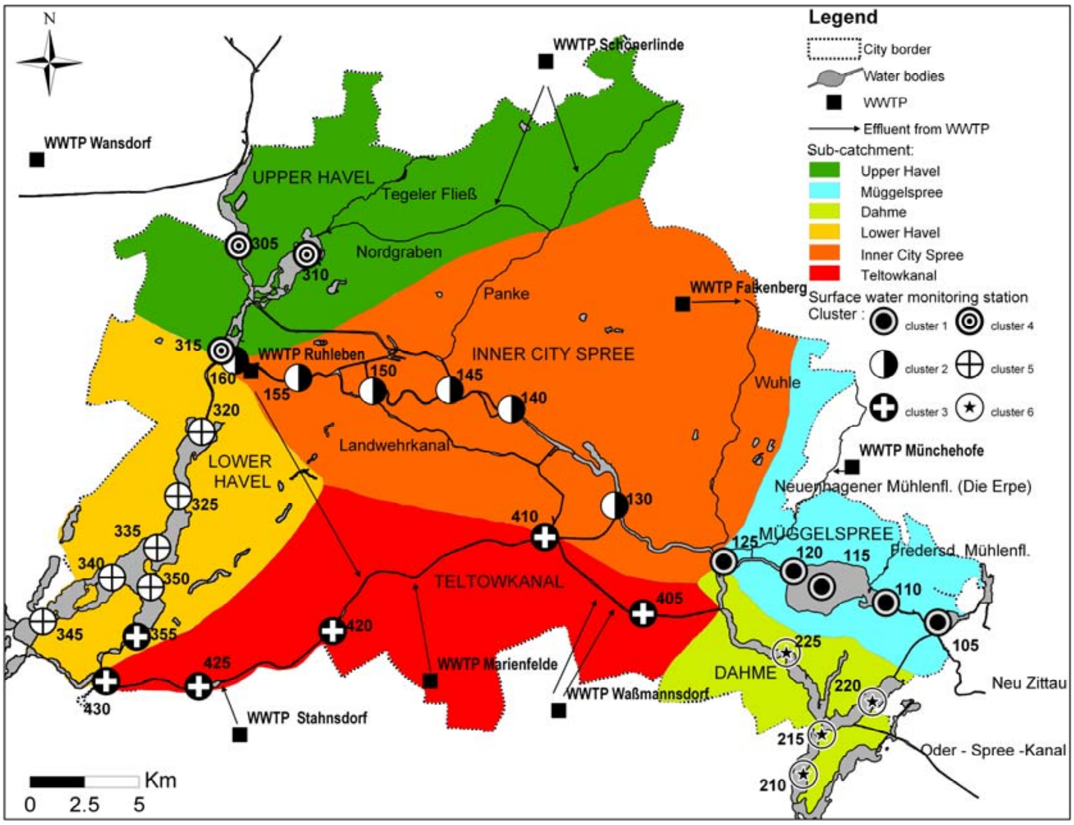

Figure 5.12: Spatial distribution of Berlin water bodies and subcatchments

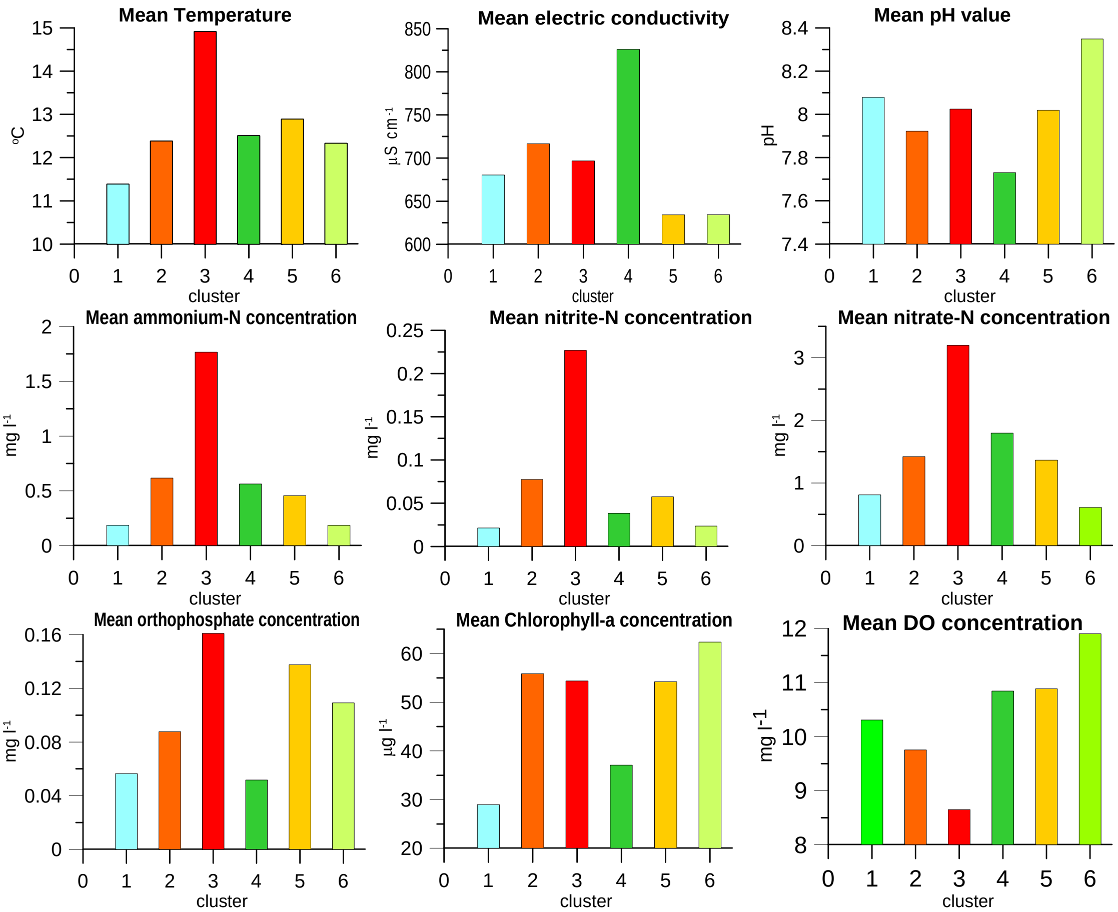

Figure 5.13: Mean value of temperature, electric conductivity, pH and concentrations of NH_4-N, NO_2-N, NO_3-N, PO_4-P, chlorophyll-a and dissolved oxygen in six different clusters of water bodies, 1984-2003 *(Data base: Surface Quality Measurement Program, SenStadtUm, 1984-2003)*

The ammonium-N concentration of all waste water treatment plants in Berlin averaged 6.22 mg/l (n=4524, std=9.08) in the time-period 1993-1999. Correspondingly, average ammonium-N concentrations of inflow water at the Müggelspree 0.186 mg/l NH_4-N (std=0.324, n=423), at the Dahme 0.187 mg/l NH_4-N (std=0.384, n= 450) and at the Upper Havel 0.562 mg/l NH_4-N (std=1.388, n= 451).

From 1995 to 1997, 247 million m^3 of waste water were purified in the treatment plant system each year and the treatment capacity allocated as Ruhleben: 34.7 %, Falkenberg: 14.5%, Schönerlinde: 13.9 %, Waßmansdorf: 13.2 %, Marienfelde: 9.4%, Müchehofe: 7.9% and Stahnsdorf: 6.2 %. During this period, the Teltowkanal received approx. 100 million m^3 of purified water each year, corresponding to 45.9% of the annually accumulating total amount of purified water (data base BWB, 1995-1999). Average annual ammonium-N concentrations have highest values in the effluent from the Marienfelde waste water treatment plant (μ=18.4 mg/l NH_4-N, n=540, std=11.9), while average annual ammonium-N concentrations of all waste water treatment plants in Berlin total 6.22 NH_4-N mg/l, n=45240, std=9.08). The outlet water of the Münchehofe and the Stahnsdorf waste water treatment plants reach highest nitrate-N concentrations (μ=17.2 mg/l NO_3-N, n=911, std=4.76 and μ=17.04 NO_3-N mg/l, n=724, std=6.2 respectively).

The highest values of the TP compounds are founded in the effluent of the Schönerlinde waste water treatment plant (μ=0.77 mg/l TP, n=724, std=0.306), while, in comparison, the annual average TP concentrations of all waste water treatment plants in Berlin total 0.60 mg/l TP (std=0.30, n=4875). In the period 1993-1999 orthophosphate concentrations had low annual average concentrations in the inflow water bodies of the Müggelspree (μ= 0.056 mg/l PO_4-P, std=0.064, n=520) and the Upper Havel (μ= 0.052 mg/l PO_4-P, std =0.049, n=540), while in the Dahme values were distinctly higher (μ= 0.109 mg/l PO_4-P, std=0.152, n=519). The corresponding orthophosphate concentrations of the WWTPs averaged 0.318 mg/l PO_4-P (std=0.196, n=2823).

Discussion

The spatial differentiation of Berlin water bodies is predominantly determined by the effluent of WWTPs. Next to this, overflows in the old city area, where still a combined drainage system is in use, are an important pollution source (SENSTADTUM, 2001). However, hydrochemical character of inflow waters also bias the overall water bodies' hydrochemical conditions, due to the different economic activities in upstream area. However, corresponding to different pollutants, stock flow paths, retention period, and decomposition rates, concentration of solutes surveyed need to be explained individually:

Temperature. High average water temperature of the Teltowkanal occurs relatively constant throughout the year and is the consequence of it acting as the cooling water source for the three power plants Rudow, Steglitz and Lichterfelde with high specific heat immissions. In the period of 1977–1989 the cooling water withdrawal of the seven Berlin thermoelectric power plants totaled around 1,122 million m^3 each year and the Teltowkanal received 47% of it (SENSTADTUM, 1988). The cooling water demand of Berlin in dry years even exceeds the total annual discharge of the river Spree (GROSCH et al., 2000).

Nitrogen. Total-N introduction into Berlin water bodies by WWTPs is considerably higher than its total input by inflowing waters. However, input of total-N was in the most recent years increased in comparison to the emission from WWTPs, caused by diffuse sources, especially overflows from the combined sewer system of the Inner City area. Whenever the removing capacity of WWTPs is improved, the role of diffuse emission of nitrogen increases and demands a stricter control, especially in the areas serviced by the combined sewage system (SENSTADTUM, 1993, 2001, 2004). However, in the Teltowkanal and Tegel lake the concentrations of nitrogen compounds (ammonium-N, nitrate-N) are altogether increased as both are receiving water bodies of the WWTPs (SENSTADTUM, 2004; BWB, 2005). In contrast, low average nitrogen concentrations in the Upper Havel, the Lower Havel and the Müggelspree are due to the removing capacity of these slack waters (KOZERSKI et al., 1999).

Phosphorous. In the Spree upper course, the phosphorous concentrations total below detection limit (BEHRENDT et al., 1999, 2000). In the downstream located the river Dahme high levels of average orthophosphate concentrations result from anthropogenic causes (KÖHLER et al, 2002). High average phosphorous concentrations in the Inner City Spree are due to the impacts from point sources (the effluents from WWTP Falkenberg and Münchehofe) as well as from diffusive sources (overflow water from the combined sewer system) (SENSTADTUM, 2001). The low average level of phosphorous concentration at the lake Tegel (Station 310 – Figure 5.13) indicates the impact of Phosphorus Elimination Plant. This plant was installed and operated in adjacent settlement Tegel since 1985. Therefore, the lake Tegel has quite different property in P concentration in comparison to the rest water bodies. In contrast, the high level of total-P in the Teltowkanal is the consequence of inflow of water from WWTPs.