02.01 Quality of Surface Waters (Edition 1993)

Nutrient Loads in Surface Waters: Overview

Waters

Berlin lies between the two large water systems of the Elbe and Oder rivers. The most important **natural** watercourses in the Berlin area are the Spree and Havel rivers. Other natural watercourses are the Dahme, Straussberger Mühlenfliess, Fredersdorfer Fliess, Neuenhagener Mühlenfliess, Wuhle, Panke and Tegeler Fliess.

There are many **man-made** running waters - the canals. The most important canals in Berlin are the Teltowkanal (canal), the Landwehr canal, the Berlin-Spandau shipping canal, and the Hohenzollern canal.

The **Spree river** is especially important for the quality of waters flowing through Berlin. Berlin canals are fed primarily by water from the Spree river; its quality is decisive. The Spree river has much larger flow amounts than the Oberhavel (Upper Havel) river. Spree river water qualities are decisive for qualities of the Havel river below their point of confluence. Water qualities of the 'urban' Spree (flow within the city) are marked by the many small influxes of other waters.

The Spree river takes only a modest lower position in the ranks of German rivers. The Oder river has a long-term average outflow at Hohensaaten-Finow of 543 m^3/s. The Elbe river long-term average outflow at Barby is 558 m^3/s. The Spree and Havel together (converging at the Unterhavel) have an outflow 10 times smaller.

Discharges / Cooling Water

High loads in the Spree and Havel rivers become clear in a comparison of annual outflow and the sum of **inflows** it contains. The yearly sum of inflows in the Berlin area amounts to 400 million m^3 (without rainwater in the separate sewer system). The mean annual outflow sum of the Spree and Oberhavel is estimated at 1.73 billion m^3. Thus $^1/_4$ of flow is composed of inflow water. About $^3/_4$ of this inflow water comes from large public sewage treatment plants.

Cooling water withdrawals by thermoelectric power plants and industry are much greater than inflow volumes. Water withdrawals from surface waters in West Berlin alone average a total of about 1.3 billion m^3 annually. The cooling water demand in dry years is greater than the total water content of the Spree itself.

This situation can intensify in view of increasing industrial development in the growing Berlin metropolitan area, for a long-term drop in flow amounts of the Spree is to be reckoned with. The influx of mine drainage water from brown coal surface mines in the middle Spree area has raised water availability in the lower Spree considerably, compared to natural amounts. Increasing reduction of brown coal mining will lead to lower amounts of outflow for the Spree.

Eutrophication

The main problem for waters in and around Berlin is the increasing accumulation of **plant nutrients**, especially nitrogen and phosphorus compounds. Low available amounts of nutrients in unimpacted waters normally limit plant growth. The biogenic exchange of substances in waters with low nutrient inflow will, by means of the self-regulating food-chain, lead to a balanced distribution among all participants in the exchange of substances: **the producers, consumers and decomposers**. Algae are among the most important producers in waters. They are able to build organic substances from the inorganic nutrient salts, which then serve consumers (including zooplankton and fish) as a nutrient base. The microbial decomposition of dead algae, water plants and fish is accomplished by decomposers (bacteria).

In addition to previously existing (mainly low) pollution, public and industrial waste waters bring excessively high nutrient inputs of phosphorus and nitrogen into waters. The nutrient overload **(eutrophication)** enables phytoplankton to reproduce at a rate so high that animal plankton organisms are often unable to cope with this development. The normally self-regulating material cycle is disturbed. A mass breeding of algae (algal bloom) results. Algal blooms occur mainly in warm summer months and affect waters negatively. Massive amounts of algae affect light conditions, the oxygen supply (oversaturation or saturation deficit), the pH value, and thus the exchange of inorganic nitrogen.

High dissolved oxygen content is required for quick microbial decomposition of masses of dead algae. Oxygen contents in stratified lakes lessen with depth, causing most of the algae masses sink to the bottom. A considerably slower, mainly anaerobic, bacterial decomposition takes place here. This is linked to the formation of foul sludge.

The river lake (lake-like broadenings) areas of the Spree and Havel rivers have all the conditions that promote heavy algae growth and its negative consequences: large water surfaces with good light penetration and shallow water depths, extremely low flow speed and thereby long fallow periods, favorable water temperatures from the influence of power plants, and a continual supply of nutrients from discharges of large sewage treatment plants.

Statistical Base

The most important Berlin running and still waters were analyzed by a **Quality Measurement Program** of the Berlin Department of Urban Development and Environmental Protection, Department IV. One-hundred and fifty sites were tested; once a month in West Berlin, and about every 14 days in East Berlin. Measuring sites in areas surrounding Berlin were represented by data from the Water Quality Measuring Network of the Environmental Agency of the state of Brandenburg. Tests were usually made every 14 days. Samples were taken from the center of the body of water at a depth of about 50 cm and analyzed by various institutes. The range to which samples were investigated at various sites differs. The tests included chemical-physical, biological, bacteriological, and radiological parameters.

The maps use measuring data from 1991. The Map “Quality of Surface Waters” used results from 94 sampling sites in 99 measurement sections. The “Chlorophyll a in Surface Waters” used results from 59 sampling sites.

Methodology

Environmental Atlas - Methodology

The parameters observed the **“Environmental Atlas - Methodology”** and are to characterize local and regional surface waters quality. Characterization of waters by the “LAWA Method” (Länderarbeitsgemeinschaft Wasser 1991) proceeds on the basis of a variety of parameters and is summarized for a total evaluation. For this work, however, 5 of the parameters most important for **eutrophication** of Berlin waters were considered, separately evaluated and presented. They are orthophosphoric-phosphorus, ammonium-nitrogen, the oxygen saturation index, oxygen minimum, and Titer for Escherichia coli. A clear and differentiated presentation of the relatively small investigation area of Berlin can thus be made.

Following the example of water quality maps of the Federal Republic of Germany, **classifications** were made into 4 quality classes with 3 intermediary levels. Class limits for the 2 oxygen parameters followed water quality mapping classes chosen for use by the LAWA. Concentrations of orthophosphoric-phosphorus and ammonium-nitrogen nutrients are categorized into quality classes so that load levels of the various parameters can be compared. Phosphorus amounts are the limiting factor for algae growth. The eutrophication threshold for dumping up running waters is generally given as 0.01 - 0.03 mg/l. The value 0.01 mg/l is thus the upper limit of quality class 2, “moderately polluted”. The classification for ammonium-nitrogen was taken from the Rhine River report of 1978, in which ammonium-nitrogen was classified into 7 categories (IWAR 1978).

Bacteriological parameters of Escherichi coli (E. coli) are observed here in the presentation of water quality for many waters in Berlin used for swimming and water recreation.

Only the most important running waters in Berlin and some running water sections in the state of Brandenburg directly bordering Berlin are included in the appended map. Waters were divided into 99 sections, each usually with a measuring point in the middle of the section. The study results of these measuring sites are considered representative for the entire section.

Values appearing in the summer half-year (1 May to 31 October) were used in order to measure the time-span of biological activity particularly critical for polluted waters. Parameters observed for orthophosphoric-phosphorus, ammonium-nitrogen, and the oxygen-saturation index were mean values of the summer half-year. The most unfavorable single value in this time span is given for oxygen levels and E. coli Titer.

Measuring results are evaluated and depicted in differentiated colors, according to a 7-step scale from "practically unpolluted" to "extremely polluted", similar to earlier presentations of other outflow years in the Environmental Atlas.

Orthophosphate-Phosphorus (PO_4-P)

Phosphates exist in water in various forms, but phosphates can only be taken up and used by plants to build up their own physical biomass in the form of dissolved orthophosphoric ions.

The majority of phosphates in Berlin waters come from domestic effluents, particularly from feces. The use of cleaning agents containing phosphates also contributes to phosphate loads.

A large portion of Berlin sewage waters is dephosphorized in sewage treatment plants today by biological phosphate elimination or by chemical phosphate removers.

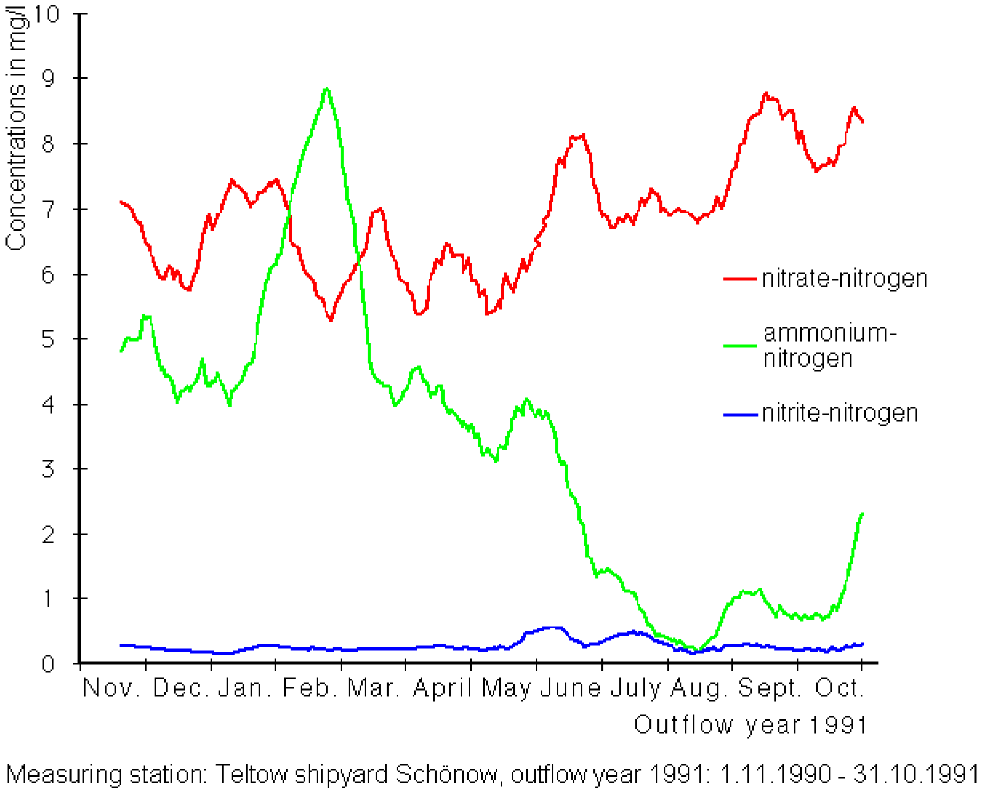

Fig. 1: Concentration of Ammonium-Nitrogen, Nitrate-Nitrogen and Nitrite-Nitrogen in the Teltow Canal for the Outflow Year 1991 (floating medien over 20 days)

Ammonium-Nitrogen (NH_4-N)

Nitrogen compounds also highly influence nutrient amounts in water. Nitrogen is present in water in elementary form as well as inorganic and organic compounds.

Organically-bound nitrogen is present in waters as proteins originating from dead organisms. Plants can use the nitrogen needed to build up their own proteins usually only in the form of nitrates and ammonium ions. Nitrogen compounds in water must first be transformed. This is done by micro-organisms that decompose protein substances in water. Other micro-organisms transform the resulting ammonium under aerobic conditions (in the presence of oxygen) first to nitrites and then to nitrates.

During the spring to autumn period of high biogenic activity, the substance transformation process proceeds faster, so that parallel to low ammonium amounts, higher nitrate amounts exist in the waters. Nitrite is only a transitional product in this transformation, so nitrite amounts in waters usually remain low. Figure 1 shows amounts of ammonium, nitrites and nitrates at the Teltow shipyard Schönow measuring station. The depicted substance transformation process in waters at this measuring station were substantially influenced by the discharge pipelines of the sewage treatment plant. Low ammonium loads in summer at this sampling station, behind the Ruhleben sewage treatment plant, are mainly due to the better clarification performance of this treatment plant in summer. The fact that ammonium levels in summer drop more strongly than nitrate levels rise is explainable by the binding conversion (fixing) of nitrates by algae.

The greatest portion of nitrogen compounds in Berlin waters originate from domestic effluents. Sewage treatment plants have particularly negative effects on the oxygen economy of water. They discharge a high proportion of ammonium-nitrogen and the decomposition process to nitrate takes place in the waters themselves. The transformation of 1 mg/l of ammonium-nitrogen to nitrate-nitrogen requires about 4.4 mg/l oxygen.

Oxygen Saturation Index

Levels of dissolved oxygen in waters are primarily influenced by water temperature. Increasing water temperature reduces the capacity of water to take up and hold oxygen.

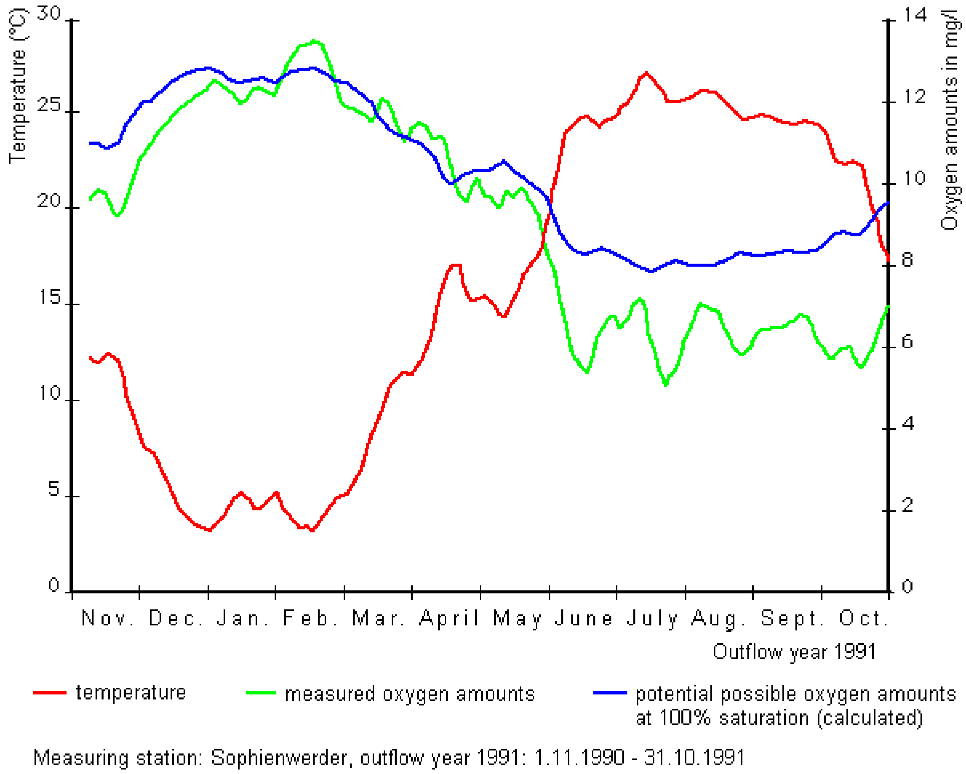

Fig. 2: Water Temperature and Oxygen Levels in the Spree for the Outflow Year 1991 (floating medien over 10 days)

Besides high temperatures in summer, the warming of waters by cooling water discharges leads to a further impact on the oxygen economy. All chemical and biological processes are accelerated; oxygen demand increases while the capability for absorption of oxygen drops. Increasingly critical oxygen levels are then shown precisely in slowly-flowing waters that form large surface areas, lake-like broadenings of running waters.

The oxygen saturation index indicates what percent of physically possible oxygen saturation has been reached at the time of sampling. Unimpacted waters usually have no large swings in the oxygen saturation index and oxygen amounts correspond roughly to those theoretically possible (oxygen saturation index about 100%). Since most decomposition processes in waters use up oxygen, but strong algae growth produces oxygen by photosynthesis, considerable swings can appear in nutrient-rich waters. Indices for impacted waters are not only low oxygen saturation indices, but also strong biogenic oxygen inputs and the oxygen oversaturation connected with it.

Figure 2 shows the course of water temperatures and measured oxygen amounts as exemplified at the measuring station Sophienwerder on the Spree for the outflow year 1991. Temperature-related possible oxygen amounts at 100% saturation are shown in order to make oversaturation and saturation deficit visible. While measured oxygen amounts in winter and spring basically match those to be expected in view of the temperatures, water in summer is not saturated. This is due to the predominance of oxygen-consuming decomposition processes in summer.

Oxygen Minimum

Oxygen needed for the respiration of all organisms is given into water through the air or through photosynthesis by water plants. Oxygen amounts of impacted, slowly-flowing waters are subject not only to climatic changes (wind speed, temperature, light penetration, etc.) but also to annual and daily variations due to excess algae growth. Additional oxygen by the assimilation capabilities of algae can only be produced in the upper layers of water. The penetration depth of sunlight into a body of water is a critical factor.

Individual types of fish each require certain environmental conditions for their survival. One such condition is a **minimum amount** of dissolved oxygen in waters.

Highly critical oxygen conditions can always occur in waters with large rain water or mixed rainwater and sewage system discharges after heavy rainfalls. Organic substances transported by inflows are decomposed by bacteria with considerable oxygen demand. More oxygen in waters may be used than can be reaerated from the air or from biogenic production. Oxygen amounts below a certain limit (about 4 mg/l for carp) are critical for fish. Any further drop in oxygen amounts will cause fish to die.

The complex and quickly occurring changes in the oxygen balance in waters with high levels of nutrients and intensive phytoplankton development can be only incompletely registered by measurements every month or every 14 days. The tense situation of oxygen conditions in Berlin waters is reflected in the fluctuations of oxygen amounts, which vary considerably depending on the time of day, at continually measured monitoring points.

Escherichia coli

Tests for Escherichia coli (E. coli) are made to determine bacteriological qualities of waters - particularly their suitability for swimming and water recreation. E. coli itself does not usually cause disease. Its presence, however, gives an indication of the pollution of a body of water from animal and human feces. If large amounts of E. coli are present, the water is heavily impacted with fecal effluents. That means the probability that disease bacteria are present increases with increasing amounts of E. coli. The measurement scale is Coli-Titer, the minimum amount of water in which E. coli can be detected.

EU bathing water guidelines for surface waters suitable for swimming give an E. coli Titer of 10^{-1} ml as barely tolerable.

Chlorophyll a

Chlorophyll a amounts in waters are also presented separately. This depiction is in keeping with the Environmental Atlas standard because one of the main problems in Berlin waters is high nutrient impacts.

Chlorophyll a is the blue-green portion of chlorophyll (leaf-green). The determination of chlorophyll a levels in waters gives an indication of algae density. Chlorophyll a levels are not valid as an absolute measure for phytoplankton biomass, but indeed this pigment amount, in common with other biomass and bioactivity parameters, gives information about amounts present and the potential metabolic capabilities of phytoplankton in waters.

The pigment exploitation of the diatomic algae, which appear in spring and late autumn, is somewhat higher by the same wavelength in tests than that of blue-green algae, which form primarily in summer. The comparison of chlorophyll a values with counts determined by census of algae biomasses is thus recommended at special measuring points.

The development of phytoplankton composition varies according to the time of year and depends on various factors, including temperature, light penetration, zooplankton development, and level and type of nutrients. While diatomic algae (Bacillariophyceae) develop primarily in spring, blue-green algae (Cyanophyceae) dominate the phytoplankton make-up in high-summer (cf. Fig. 3). Precisely the higher temperatures and intense light penetration in high-summer facilitate algae growth. If excess loads of nutrients are present at the same time, massive algal bloom can occur.

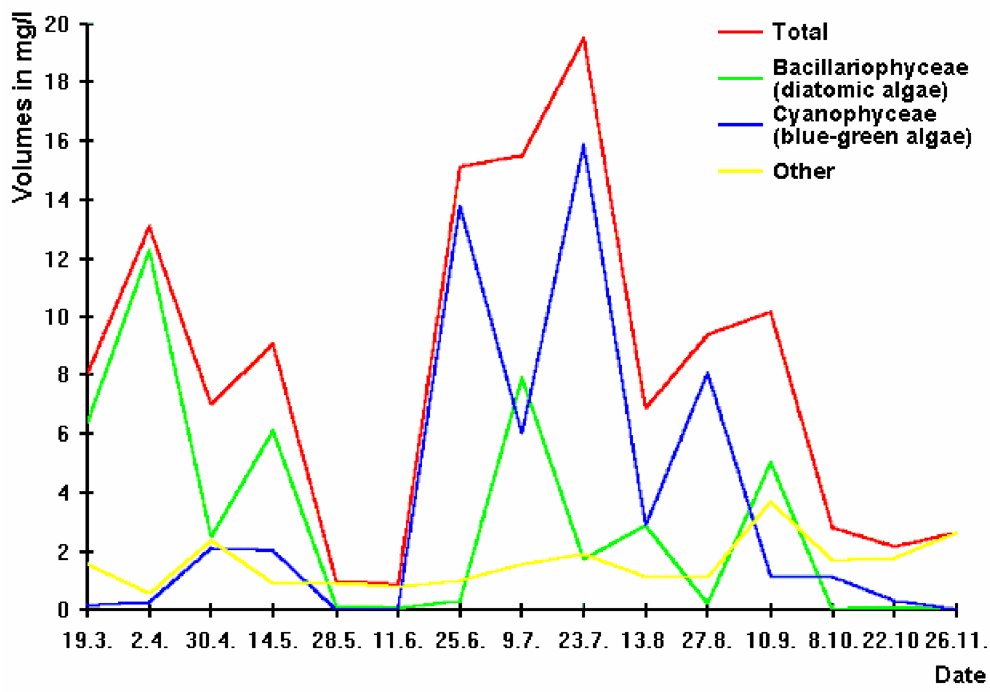

Fig. 3: Phytoplankton Development in Müggelsee (lake middle) 1991

The phytoplankton minimum principally occurs in May and June and depends on many factors, such as weather, composition of algae types, and especially zooplankton structures. If the spring algae community is dominated by edible types (diatomic algae), then a mass development of zooplankton can occur which are capable of filtering great amounts of algae biomass. A high water transparency can be reached (cf. Fig. 4). This "clear water stage" is observed more frequently in the Spree, the Upper Havel and somewhat in the Lower Havel, but not in the Dahme, where thready, hardly edible blue-green algae appear as early as spring.

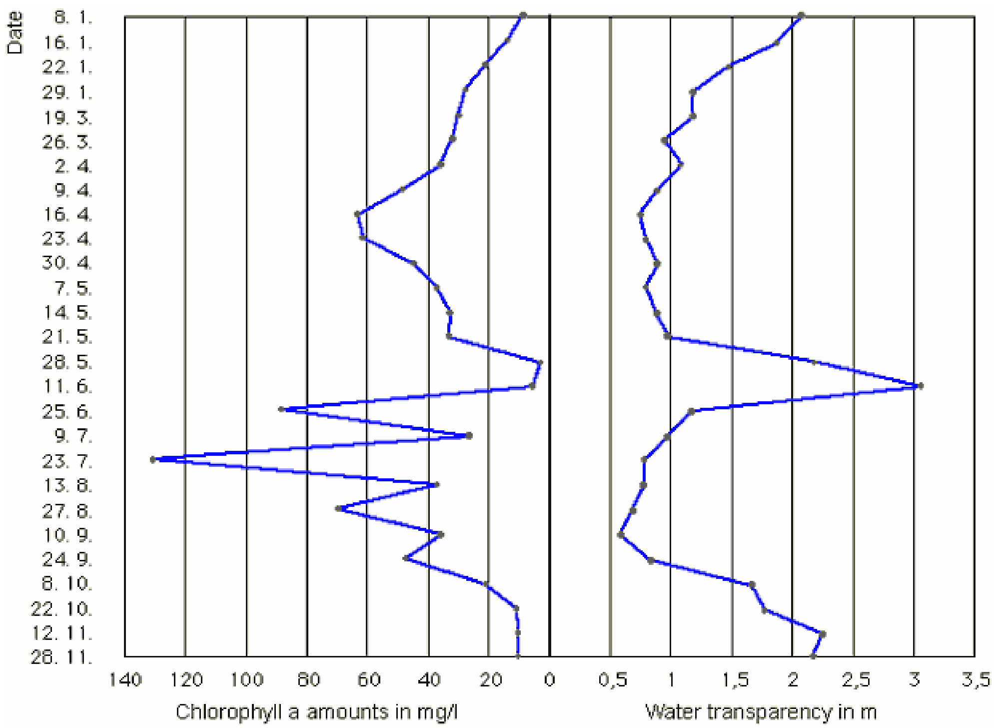

Fig. 4 Chlorophyll a Amounts and Water Transparency in Grosse Müggelsee (lake middle) 1991

The measured values for April to September 1991 are represented in the maps. The maximum and minimum values of this period for single water sections are displayed beside the mean values. The strips depicting the average value of the months April to June and July to September reflect the development of phytoplankton in spring and high-summer. Algae development also influences the turbidity of water, so the 6th strip depicts the water transparency with the average value of the summer half-year, April to September.

Measurement values are ordered in a 7-stage evaluation scale. The value of 30 µg chlorophyll a per liter is considered as the restoration goal for Berlin waters. This value is used as the upper value of quality class 1 and 2. Quality classes 1 to 3 follow a linear graduation of measurement values. The linear graduation in quality classes 3 and 4 was not used because a of greater imprecision of measurement process at higher measuring values.

Map Description

The accumulation of plant nutrients, especially nitrogen and phosphorus compounds, continues to be very high in Berlin waters. Linked to this excess are considerable fluctuations of oxygen amounts, caused by heightened growth or decomposition of algae.

Nutrient concentration is generally strongly dependent on water outflows. Water quality is thus fundamentally better in years of heavy precipitation than in years of low precipitation. High outflows have only a certain “diluting effect” in large cities, however, for here the entry of nutrients and pollutants rise with amounts of precipitation.

1991 is characterized by very low outflow amounts (average value in summer at Sophienwerder measuring point = 15.17 m^3/s).

Influence of Sewage Treatment Plants

Berlin's main body of water, the **Spree**, reaches the urban area relatively unpolluted. The urban Spree, its small tributaries, and the canals in Berlin are heavily to excessively polluted by industry, large sewage treatment plants and rain water inflows.

Waters directly impacted by sewage treatment plant discharges are extraordinarily heavily polluted. Particularly high levels are found in waters whose outflows are low compared to the inflow amounts, such as the rivers Neuenhagener Mühlenfliess, Wuhle, Nordgraben and Panke, and the Teltow canal. A good half of the waters influenced by sewage treatment plant outflows enter the Spree. The urban Spree and the canals dependent upon it also show high impact values.

Pollution from sewage farm discharges has only a subordinate to no significance at all for waters, because most sewage farms have been discontinued. Only a few sewage farms remained in operation after the Schönerlinde sewage treatment plant took up operations and the Ruhleben treatment plant was enlarged.

The **Teltow canal** is the receiving body of water for the sewage treatment plant discharges of Wassmannsdorf, Marienfelde, Ruhleben and Stahnsdorf. The phosphate reduction measures at the treatment plants led indeed to reduced phosphate impact, but nutrient levels in the Teltow canal remain excessive, nevertheless. The high E. coli values prove a relatively high impact of fecal water.

Water quality of the **Havel** below the mouth of the Spree is influenced by the considerably larger outflow amounts of the Spree. Water quality protection measures undertaken in Berlin (East and West) since the middle of the 80's include the construction of simultaneous precipitation facilities in sewage treatment plants; the operation of phosphate elimination facilities at the influx of Nordgraben into Tegeler See (*see* = lake); and the diversion of discharges from the sewage treatment plant Ruhleben from the Spree into the Teltow canal. These measures successfully reduced the previously excessive phosphate loads of the urban Spree and the Berlin Lower Havel. An improvement of about one value class was reached in phosphate impacts compared to the comparable outflow year of 1976 presented in the first edition of the Environmental Atlas. A further reduction is necessary, however, for the phytoplankton mass developments have not noticeably diminished. The lake-like areas of the Lower Havel used as water recreational areas are the most heavily affected of all Berlin waters by the intensive development of phytoplanktons. Measured to the eutrophication threshold of 0.01 mg/l PO_4-P, the eutrophication level of the Lower Havel is still too high.

Tab. 1: Development of Orthophosphate-Phosphorus and Ammonium-Nitrogen Concentrations at Measuring Sites with High Nutrient Loads						
Measuring Site	Orthophosphate-Phosphorus			Ammonium-Nitrogen		
	mg/l			mg/l		
	1991	1989	1986	1991	1989	1986
Neuenhagener Fliess, Friedrichshagener Str.	0.24	0.71	1.34	26.77	18.96	26.24
Neuenhagener Fliess, Heidemühle	0.14	0.20	–	31.26	19.67	–
Nordgraben, mouth of Tegel harbor	0.26	–	0.09	17.33	–	15
Nordgraben, Uhlandstr.	0.12	0.56	0.30	19.14	28.05	23.2
Panke, Bürgerpark	0.18	0.56	–	9.46	24.08	–
Prinz-Friedrich-Leopold-Canal, Hubertus Bridge	0.19	0.28	0.58	4.38	3.57	3.29
Teltow Canal, 50 m below Wrede Bridge (Rudow-East harbor)	0.29	0.68	0.38	4.59	3.27	1.38
Teltow Canal, Eugen-Kleine-Bridge (above Schilfluchgraben)	0.15	0.17	0.61	4.33	4.12	2.7
Teltow Canal, Nathan Bridge, Kohlhasen Bridge	0.18	0.27	0.54	4.25	3.8	3.24
Teltow Canal, below Steglitz harbor	0.15	0.20	0.42	4.98	4.73	3.97
Wuhle, Heese-Heer-Str.	0.31	–	0.27	25.73	–	28.66
Wuhle, Lindenstr.	0.34	0.63	0.64	22.35	15.63	27.73

– no measuring value available

Average value for summer half-year (April – September) 1986, 1989 and 1991. The outflow amount for all three years is comparably low.

Tab. 1: Development of Orthophosphate-Phosphorus and Ammonium-Nitrogen Concentrations at Measuring Sites with High Nutrient Loads

No significant improvement of ammonium impacts is recognizable for the outflow year 1991 compared to 1980, or in comparison to outflow years 1986 or 1989. The NH_4-N concentrations depicted in Table 1 have maintained a continually high level for years.

Nutrient impacts of these water sections allow a clear recognition that most nutrient inputs come from the sewage treatment plants in and around Berlin, for almost all sections are located below sewage treatment plant discharge points.

The amount of discharge inflows into Berlin waters will rise because of the high amounts of sewage water to be expected in the future and the increasing amounts of discharge from sewage treatment plants in the growing Berlin metropolitan area. The disparity between natural water supplies and nutrient-rich inflow water will increase in coming years because outflow amounts of the Spree will lower as inflows of water from brown coal mining are decreased.

Tab. 2: Receiving Waters for Sewage Plant Discharges	
Sewage Plant	Receiving Waters
Wassmannsdorf	Teltow Canal » Havel
Marienfelde	Teltow Canal » Havel
Ruhleben	Teltow Canal » Havel
Stahnsdorf	Teltow Canal (partial)
Münchehofe	Neuenhagener Fliess » Spree
Falkenberg	Wuhle » Spree
Schönerlinde	Nordgraben » Tegeler See and Panke » Spree
Königswusterhausen	Notte Canal » Dahme » Spree

Tab. 2: Receiving Waters for Sewage Plant Discharges

Nutrient impacts in Berlin waters are still too high. A perceptible reduction in coming years is conceivable only with: 1) rigorous application of the most modern sewage treatment plant technology (phosphate precipitation, nitrogen elimination, discharge filtration) in all sewage treatment plants in the greater Berlin area; 2) with the implementation of comprehensive restoration and extension works in sewer systems and; 3) with a stemming of inflows from the rainwater and the mixed sewage treatment systems into waters.

Pollutant Impacts in Sediments and Eels: Overview

Industrial development has enormously increased discharges of pollutants into waters. Besides their presence in water, there is a continual accumulation of pollutants in water bottom soils, such as **heavy metals and chlorinated hydrocarbons**.

Deposition in Sediments

Sediments form a natural buffer and filter system in the material cycles of waters. Waters are subject to strong variations of current, substance input and transport, and sedimentation. Diverse inputs of the Berlin metropolitan area, including domestic and industrial waste waters, and rainwater, flow through the urban waterways primarily into the Lower Havel. The lake-like enlarged areas of the Lower Havel, with their low flow velocity, offer ideal conditions for the settling out (sedimentation) of pollutants floating in the water onto the water bottom.

Sediment analysis is increasingly important in evaluating qualities of the total ecosystem of a body of water, in addition to the water sample analysis practiced for years.

In comparison to water testing, sediment testing reflects the **long-term** quality situation independent of current inputs. Sediment tests are a better basis for fundamental comparisons with other flowing waters. In water testing it is not possible to clearly divide between true suspension substances and temporary suspension substances stirred-up from the sediments. Sediment testing is not, or only minimally, affected by other influences.

The suspension and precipitate (non-floating) mineral and organic substances in waters are capable of adhering pollutant particles (adsorption). The sediments, both suspended and precipitate substances stored on the water bottom, form a **reservoir** for many pollutants and trace substances of low solubility and low degree of degradability.

(Pollutant) Substances are conserved in sediments over longer periods of time according to their chemical persistence and the physical-chemical and biochemical characteristics of the substrata. Analysis of sediment samples from different depths give a chronological record of inputs in waters. This can also allow conclusions to be drawn regarding sources of contamination.

Even after sedimentation, portions of fixed substances can be **remobilized** and reenter the material cycle of waters. Causes for this include desorption, liberation after mineralization by organic material, whirling up, weathering, and the physical and physiological activity of benthonic (water bottom) organisms.

Heavy Metals

Heavy metals can enter waters naturally in erosion and wash-out processes. By discharge from the effluent inflows mentioned above, amounts of heavy metals in waters are steadily increased. They are present in waters in dissolved form only at low levels, since heavy metal compounds are of low solubility. Mineral suspension and precipitation substances are able to store heavy metal ions on their outer surface. They can also be bound in water organisms. Heavy metals can be taken up by higher organisms through the food chain, or sink to the bottom as sediment, depending on the flow velocity of waters.

Some heavy metals are necessary for life in tiny amounts, such as the trace elements copper, zinc, manganese. But in higher concentrations they damage humans, animals and plants just like the highly-toxic heavy metals such as lead and cadmium.

The heavy metals most often present at high measured values in Berlin waters will now be discussed.

Copper is a semi-precious metal and often used in the electrical industry. The toxic effects of copper compounds are applied as algaecides and fungicides. Copper is toxic even in low amounts for all water organisms, such as bacteria, algae, fish prey and fish. Copper can have negative effects on the population and self-cleansing of waters. Copper is significant as the most important trace element for human metabolism. But high concentrations damage health, although usually only temporarily and not chronically.

Zinc, like copper, is an element important for human life. Zinc is often used in the manufacture and surface treatment of pipes and tin-cans. Like copper, high zinc concentrations have toxic effects on water organisms. Zinc accumulates particularly in mollusks such as snails and mussels.

Lead, next to cadmium and mercury, is one of the most toxic heavy metals. It is not essential for human metabolism. Lead compounds are used in the manufacture of paints, anticorrosion additives and batteries. Waterpipes of lead are sometimes found in old buildings. The largest lead emitter is still automobile traffic, in spite of reduced use of leaded gasoline. The continual ingestion of lead can lead to severe damage of the nervous system and the deactivation of various enzymes.

Cadmium is employed in battery production, as a stabilizer in PVC production, as pigment in plastics and lacquers, and in galvanizing. The toxic effects of cadmium at extremely low levels are recognized. Cadmium accumulates especially in the liver, kidneys, spleen and thyroid glands, and can lead to severe damage of these organs.

Pesticides, PCB and their Absorption by Eels

Chlorinated Hydrocarbons - CHC (=CKW) have bonded chlorine onto the shells of their carbon atoms. In the group of halogenated hydrocarbons, CHCs find the most frequent manufacture, application and dispersal.

Chlorinated hydrocarbons are numerous and have diverse compounds. Many organic chlorine compounds are very persistent, such as DDT and polychlorinated biphenyls, PCB.

Many compounds of chlorinated hydrocarbons are water-soluble. Others, such as DDT and PCB are fat-soluble and accumulate in fatty tissues of organisms. Various pesticides and PCB have the characteristic of being stored adsorptively on suspended matter or in plant organisms, especially with declining water solubility. Waters with weak currents suspended substances to sink. These substances are deposited with their pollutants in the **sediment.** Sediment organisms are an important nutrient basis for fish. Fish inhabiting the bottom (benthonic fish) are especially likely to take-up high contaminant concentrations in their fatty tissues. **Eels** become very fat, eat bottom organisms and bury themselves in sediment. This behavior leads to the intake of pesticides and PCB not only through nutrients but through the skin as well, and to their storage in body fat.

DDT, dichlorine diphenyl trichlorethane is a highly stable chlorinated hydrocarbon of extremely low degradability. DDT is one of the most well-known pesticides and was previously used world-wide. The fat-solubility and extreme-persistence of DDT have led to its storage in the body fats of almost all organisms. The global use of DDT has had an impact on the entire environment. The use of DDT has been made illegal by almost all countries. DDT is mutagenic (DNA damaging) and is suspected of being carcinogenic.

Lindane is mainly used as a contact and nutrient poison for pest control of ground insects and on harvested seed crops. Lindane is not evaporative at temperatures up to 30^o C and has a low chronically toxicity -but is acutely toxic. Poisoning symptoms in humans are nausea, headache, vomiting, cramping, breathing difficulties. It can damage the liver and kidneys. Lindane also possesses a high toxicity for fish, but it is relatively quickly excreted by the body and degraded.

PCBs, polychlorinated biphenyls. These chlorinated hydrocarbons are among the most stable chemical compounds and of low degradability. Their good isolation characteristics and low combustibility led to their use in condensers and high-tension transformers. Other uses of PCBs are in lubrication, impregnation, and flame-retardant materials. The main causes of PCB inputs into Berlin waters are automobile traffic, rainwater contaminated by automobiles, as well as automobile and scrap disposal.

PCB in high concentrations causes liver, spleen and kidney damage. Severe poisonings cause organ damage and cancer.

Some PCB manufacturers, handlers and applications have been subject to legal restrictions on its manufacture and use since 1989 (PCB-, PCT-, VC-Verbotsverordnung of 18 July 1989).

High values have been verified in Berlin waters and sediments. Tests conducted in the 80's on fish found CHCs such as PCB and the pesticides DDT and Lindane in concentrations extremely disturbing for foodstuffs.

High amounts of CHCs led to a marketing ban forbidding the sale of fish from Berlin waters after the Pollution Maximum Amount Regulations (SHmV of 23 March 1988) took effect. Fish caught after the issuance of this prohibition were disposed of as hazardous waste. The association of commercial fisheries, in commission of the Berlin Office of Fisheries, conducted a fishing program to effect a reduction of pollutant impacts in Berlin fish stocks by means of a specific influencing of the age structures of fish stocks. The intensive fishing of older fish was aimed at achieving a stock of younger fish, low in fat and thus low in lipophillic (fat-loving) CHCs like PCB, DDT and Lindane, etc. As a result of sharper permit procedures for potential polluters, and 'rejuvenated' fish stocks, the prohibition against marketing of fish was lifted in May, 1992.

Statistical Base

Pollution tests of Berlin waters sediments are not part of the routine measurement program of the Berlin Environmental Department. The measuring results evaluated here are based on **special investigations** regarding impacts of heavy metals or chlorinated hydrocarbons.

The **heavy metal** contamination of water sediments was investigated by Pachur and Ahrens from the Institute for Geographic Sciences of the Free University of Berlin. This research project of the Federal Ministry for Research and Technology and the Berlin Environmental Department was conducted in 1990 and 1991. A further sediment study was conducted by the Fechter Engineering Office in commission of the Berlin Department of Urban Development and Environmental Protection..

The heavy metal concentrations in Berlin water sediments depicted in these maps give information for the water sections of

- the **Spree** and the **Dahme**, based on Fechter's analysis data on 37 mud claw samples taken in 1991. They give information on heavy metal impacts in the upper sediment layer, 0 to a maximum depth of 40 cm.
- the **Havel waters** and the **Teltow canal**, based on analysis data determined by Pachur and Ahrens in 48 frozen-core bore samples performed in 1991.

The **frozen-core bore method** employed by Pachur and Ahrens enables a depth-appropriate removal of up to 4 meters of sediment. The frozen-core bore samples are divided by hot-wire into single sections of 5 or 10 cm length. The division of individual bore cores into sections of a few centimeters enhances the detection of **horizon-specific** geo-accumulations of heavy metals, as well as the allocation of their **chronological** deposition (cesium determination). One thousand eight hundred individual samples of 6 eco-toxilogical heavy metals (copper, zinc, lead, cadmium, chromium and nickel) were analyzed by atomic emissions spectrometer (ICP-AES) measurements.

Recent sediments were divided into 9 zones for chronological definition. The zones before 1880 show heavy metal concentrations that - with the exception of inputs at local points - lie within the range of natural **impacts** (geochemical background) uninfluenced by civilization. The zones from 1900 to 1990 were defined in view of increasing anthropogenic influences as **accumulation zones** and their heavy metal concentrations were used for evaluation of sediment contaminations (average value of accumulation zones). The zone from 1880 to 1900 can be characterized as a transitional zone. It can be disregarded because of its low levels and is not included here in average value calculations. The accumulation depth in sediments of the individual measuring points ranges from 25 cm (Havel, Höhe Quastenhorn) to 235 cm (Stössensee) (see = lake).

Tests for **DDT, Lindane and PCB** concentrations in **sediments**, as well as **DDT and PCB** impacts in **eels** were conducted in commission of the Berlin Office of Fisheries from 1989 to 1992. Sediment samples were taken by mud claw.

Methodology

Sampling and Analysis

The **heavy metals** copper, zinc, lead, cadmium, nickel and chromium were determined in **sediment samples.** Average values of the single tests are depicted in each water section. There were 1 to 10 measuring sites in each water section.

The quality of water sections was evaluated according to data derived by calculating average values from individual bore sample measurement values, and a further condensation for the average values of all bore-samples measurements in water sections. Samples taken by the frozen-core bore method were weighted for average values on the basis of the respective thickness of the accumulation zone.

Samples in the water sections of the Spree and Dahme were taken by mud-claw. Because sediments in these flowing water sections are considerably less thick than those of Havel waters, it can be assumed that the sampled 40 cm of sediments correspond to the accumulation horizon and that measured values are relatively comparable, in spite of the different sampling processes.

Values determined for **DDT, Lindane and PCB** in sediments are based on data from 1989, 1990, or 1991. An average value was taken when long-term measurements of water sections were available.

The depiction of **DDT and PCB** impacts in **eels** was derived from measurements made from 1989 to 1992. The most current year of sampling in individual water sections was used as a reference.

The PCB concentrations listed are based on values determined as **PCB_6.** In order to quantify the total PCB concentrations, six PCBs (IUPAC Nos. 28, 52, 101, 138, 153 and 180) of the 209 known PCBs were used as a standard substance, PCB_6. The total PCB amount corresponds, according to the experience of the Federal States' Working Group for Waste (LAGA), five times the PCB_6 amount. This formula is also used here as **total PCBs.**

A total of 461 sediment samples and 578 eel samples were evaluated in order to categorize 65 measured sections into quality classes. The only quality sections depicted are those for which 3 individual measurement values per water section were available. The number of individual tests per section was between 3 and 21 sediment samples and between 3 and 69 eel samples. The only exception is the measurement site section of the Teltow canal/Dahme tributary. Here only one measurement value was used as a basis for evaluation. The depicted DDT and PCB impacts of sediments in this water section match the results of earlier investigations.

The results of the heavy metal, pesticide and PCB measurements were also divided into 7 quality classes; as the chemical-physical and biological parameters had been.

Assessment

General impact criteria for the **evaluation** of **heavy metals** in sediments are not available up to now. The evaluation made here employs the “argillaceous rock standard” - supplemented by measurements made in the Berlin area of the original geological material - as reference standard for the geo-accumulation index (Igeo-Klasseneinteilung according to Müller 1979).

This index is a scale for the size of current loads in relation to heavy metal concentration in the original geologic material. The evaluation of anthropogeneous heavy metal inputs proceeds from a geochemical **“background level”** which should take into consideration the natural heavy metal concentrations in sediments. A range of values was given for geochemical backgrounds of individual heavy metals in the Berlin area (Pachur and Ahrens 1991), since the large range of individual results made the fixation of an exactly defined value more difficult.

The **“argillaceous rock standard"**, as order of magnitude for natural impact levels, fixed the following as background values in mg/kg dry substance (ds): copper, 45; zinc, 95; lead, 20; cadmium, 0.3; nickel, 68; and chromium, 90. These values are within the determined range for original impacts in the Berlin area, except for chromium and nickel. Chromium was assigned a background impact of 45 mg/kg because of conditions in the Berlin area, and nickel was assigned 20 mg/kg.

The geo-accumulation index employed for the evaluation of heavy metal impacts in sediments is based on these background values. In order to avoid overly evaluating natural ranges and the very low anthropogenic inputs, background concentrations were multiplied by a factor of 1.5, to define the upper limit of the lowest impact class. The doubling of this value form the upper limit of the next higher class, and so forth. It is an exponential evaluation.

The evaluation of **PCB** in **sediments** is based on statements of the Office of Fisheries. High PCB impacts in fish were found in investigations of the Office of Fisheries beginning at sediment values of 450 μg/kg dry substance. This value was then set as the upper limit of class 2 to 3. Because limit and index values for **DDT** and **Lindane** were not available, the classification from the Environmental Atlas of 1985 was used. This means - departing from the method used for other substances - that the class category does not allow any conclusions about the absolute impact degree of sediments. The DDT and Lindane values here are to be interpreted **relative** to each other.

The classification of contaminant loads of **PCB** in **eels** is oriented to the regulation regarding the highest permissible amounts of pollutants in foodstuffs (SHmV of 23 March 1988). No highest permissible foodstuff level for total-PCBs in eels is given. A total-PCB-value of 7.0 mg/kg fresh weight (fw) was assigned on the basis of highest tested values for single examples of the PCB group. This value connects to the high end of quality class 2-3. The **DDT** classification is based on the Plant Pesticide Maximum Level Regulation (PHmV of 16 October 1989). Under the present classification, the maximum allowable limit of DDT (3.5 mg/kg fw) for eels prescribed therein is the same as the higher value for quality class 2-3.

Map Description

Heavy Metals in Sediments

The **sediments** of the entire flow distance of the lower Havel, Wannsee and Lesser Wannseekette (lake chain) are primarily to be viewed as heavily impacted with **heavy metals.**

Almost all waters running through Berlin flow into the Havel. The extremely low flow velocity of the Havel lake-like areas facilitates the sedimentation of transported suspended and precipitate matter. Lower Havel sediments have high impact values in the quality class 3-4 and 4 for the heavy metals cadmium, zinc, lead and copper. Relatively low concentrations were detected of chromium, quality class 2 and 2-3. Nickel contents of Lower Havel sediments were insignificant, in the range of quality class 1-2.

The Lesser Wannsee lake chain shows the influence of Teltow canal water inflows. The Teltow canal has been flowing over the Prinz-Friedrich-Leopold canal since 1905. Increasing zinc concentrations since this time can be detected.

The upstream Havel shows a lower heavy metal contamination in sediments than the Lower Havel. Pollution here can be traced back to the industrial centers of Oranienburg and Hennigsdorf, located north of Berlin.

The extremely different contaminations of the Teltow canal section from the Dahme tributary to Rudow, in West Berlin, are caused by land-fill barriers in the former border area between East and West Berlin. A sedimentation of suspended and precipitate matter occurred here primarily in the eastern section. The generally high values of heavy metals here, particularly cadmium, were caused by effluents from VEB Berlin Chemie.

Measurements of Spree sediments in East Berlin show lower heavy metal impacts, in quality class 1 to 2-3. The Spree here has not yet entered the highly settled areas of Berlin, and it has a lower sedimentation rate. These factors explain the differences in quality compared to sediments of the Lower Havel.

Table 3 gives the highest, middle and lowest values of heavy metal impacts in sediment samples taken from the Havel waters and the Teltow canal by the frozen-core bore method. Extremely high heavy metal levels were determined at a few measurement bore sites, values which exceed by several times the limit values for mud of the Sewage Sludge Regulations (AbfKlärV of 15 April 1992).

Location of Bore Sites	No. of Bore Sites	Depth 1) (m)	Copper			Zinc			Lead			Cadmium			Nickel			Chromium		
			(mg/kg dry substance)																	
			Max.2)	Ø 3)	Min.4)	Max.	Ø	Min.	Max.	Ø	Min.	Max.	Ø	Min.	Max.	Ø	Min.	Max.	Ø	Min.
Upper Havel Nieder-neuendorfer See	1	0 – 120		495			1100			290			**12.0**			180			190	
Upper Havel Konradshöhe and Tegelort	2	0 – 110	475	420	385	1510	1009	695	410	278	195	**16.0**	**12.9**	**11.0**	150	117	97	130	99	80
Upper Havel Pioneer Island and Krienicke	2	0 – 135	580	468	420	1110	1012	970	375	298	265	7.0	6.7	6.0	89	82	67	145	117	50
Tegeler See Reiherwerder	1	0 – 35		150			655			80			4,0			41			45	
Lower Havel (cross-section) Weinmeistergrund-Jürgen Lanke	10	0 – 200	**2470**	**1940**	**920**	**2940**	**2540**	1640	**1010**	840	420	**19.5**	**15.0**	8.0	65	56	36	360	295	170
Lower Havel (cross-section) kl. Badewiese-Grunewaldturm	6	0 – 180	**2730**	**1786**	390	**2850**	2041	575	875	655	245	**18.0**	**13.0**	2.5	70	49	16	290	282	77
Unterhavel (cross-section) Havelkasino-Gr. Steinlanke	4	0 – 220	**2100**	**1780**	**1360**	2440	2320	1980	**915**	780	620	**17.0**	**13.5**	**10.5**	60	56	52	300	210	125
Unterhavel (cross-section) west- & east. outflow Höhe Kälberwerder	8	0 – 150	**1360**	**962**	61	**2500**	1863	220	**930**	645	39	**12.5**	9.3	< 2.0	56	44	< 10	325	176	< 20
Greater Wannsee (long-section)	3	0 – 120	**1120**	**980**	485	**3540**	2490	2060	825	700	480	**14.0**	**11.0**	**10.0**	71	60	53	250	210	90
Lesser Wannsee Lake Chain to Teltow Canal (long-section)	7	0 – 235	750	670	295	**9930**	**8010**	2410	455	395	215	**32.0**	**26.0**	8.5	64	53	39	130	93	63
Teltow Canal, decommissioned sections, tributaries Dahme-Rudow	3	0 – 200	255	232	200	1420	1257	395	340	276	100	**63.0**	**32.5**	2.5	110	76	<15	215	139	69
Teltow Canal, Rudow	1	0 – 44		40			165			230			< 2.0			< 20			< 20	
Rummelsburger See 5)	3	0 – 153	**2330**	**1770**	**1030**	**3210**	**2840**	2130	685	605	515	**25.0**	**23.0**	**18.0**	78	61	40	475	340	285
Limits for Sewage Sludge 6) (AbfKlärV of 15 April 92)			**800**			**2500**			**900**			**10.0**			**200**			**900**		

Compiled from Pachur and Ahrens 1991

1) statements refer to the bore site with the highest accumulation depth – 2) highest average value for accumulation zones of all bore sites in measuring station section
3) mean average value for accumulation zones of all bore sites in measuring station section - 4) lowest average value for accumulation zones of all bore sites in measuring station section – 5) not depicted in this map - not representative for this segment of the Spree – 6) limit values exceeded are printed bold

Tab. 3: Maximum, Minimum and Mean Values of Average Heavy Metal Amounts in Accumulation Zones in the Havel Waters and Teltow Canal Area

Pesticides and PCBs in Sediments

The **PCB** composition permits certain conclusions to be drawn regarding the age of inputs. Repeated readings of low chlorinated (and thus more easily degradable) PCB are new pollutions. Old PCB contaminations (PCB 138, 153, 180) were determined in almost all tested water sections. Examination results of urban Spree sediments indicate considerable new PCB impacts (PCB 28, 52). All larger rainwater inflows show somewhat high new PCB impacts, and PCB inflows from old contaminated sites. The Lower Havel shows some highly concentrated PCB deposits, in the Greater Wannsee lake area for example, corresponding to the sedimentation behavior of transported suspended and precipitate matter described above.

Sediments of the Upper Havel, the Dahme and the Spree at the beginning of its urban segment show only low to moderate PCB concentrations of quality class 2.

PCB sediment impacts in the Teltow canal area differ greatly, from quality class 1-2 to quality class 4. Conspicuous here are the high PCB values in the Tempelhof and Mariendorf harbor areas, below the outflow of the Lichterfelde-Lankwitz rainwater collection canal, and below the sewage treatment plant discharges from Wassmannsdorf, Mariendorf and Ruhleben.

Impacts of **DDT** in sediments are considerably smaller, on the whole, compared with PCB. The main areas of contamination are the Teltow canal and a few sections of the Lower Havel. High impacts in the upstream Teltow canal and the Neukölln ship canal can be traced back to the influence of discharges and sewage water inflows from the premises of VEB Berlin Chemie.

Lindane shows only low concentrations in Berlin water sediments. Measuring results in almost all measuring sections are evaluated as quality class 1-2.

PCB, DDT and Lindane measurement results are based on tests of the upper sediment layer. Further tests regarding the vertical range of CHCs show the presence of older inputs in deeper sediment layers. PCB measurement values in particular indicate that migration (transport within the ground) is taking place. Current knowledge of migration behavior indicates that potential long-term pollution of groundwater or of bank-filtered drinking water cannot be ruled out.

Pesticides and PCBs in Eels

The degree of **PCB** contamination of fish depends primarily on impacts in individual waters as well as the species-specific tendency of fat deposition. The fat fish species **eel** in Berlin waters is particularly affected. Almost a quarter of eels sampled by the Berlin Office of Fisheries in 1989-90 have levels exceeding the highest values set by laws for foodstuffs.

The relationship between PCB contaminated water sediments and high PCB amounts in eels is clear in the Lower Havel area and the downstream area of the Teltow canal. Eels have high PCB levels paralleling high PCB levels in sediments.

Eels in the Grunewaldsee and Hundekehlesee (lakes), on the other hand, are heavily contaminated with PCB even though PCB amounts in sediments are low. This area was recently dredged. It can be supposed that the tested eels were older and that their contamination was based on sediment pollutions that existed before dredging.

The fatty fish eel is also affected the most by **DDT** contamination of water sediments. Effects of DDT contaminated sediments are reflected in higher levels in eels.

High DDT amounts in eels from the Greater Grunewald lake chain indicate the persisting effects of DDT inputs about 40 years ago. These waters were treated with DDT to reduce mosquito populations.

The reduction determined in PCB and DDT contamination in fish species native to Berlin waters led to the lifting of the marketing ban prohibiting the sale of fish in 1992. The reduction of pollutants in fish was achieved by the 'rejuvenation' of fish stocks, by eliminating older fish. In the middle and long term, however, only a very slow reduction of pollution in benthonic fish species is to be expected, especially in regard to PCB, for the implemented measures did not remove the causes of fish pollution. Reduction of pollution can only be achieved to the degree that lower pollution inputs result in less contaminated sediments.

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