03.01 Sulfur Dioxide - Emissions and Pollution (Edition 1997)

Overview

Effect of Sulfur Dioxide

Sulfur dioxide (SO_2) is a colorless gas which has a pungent odor in high concentrations. It is produced through the combustion of fossil fuels such as coal and oil. It is also a byproduct of ore smelting and used in many other industrial processes.

Once released into the atmosphere, it is transformed into sulfur trioxide and later sulfuric acid and sulfate particles at a rate of one percent per hour.

Sulfur dioxide impairs human health. Due to its high solubility, it acts directly upon the mucous membranes of eyes, and of upper respiratory tract (c.f. Kühling 1986). In heavy concentrations or intense inhalation, it can effect the lower respiratory tract (c.f. BMUNR 1987). Asthmatics are at considerably higher risk than healthy persons (c.f. Nowak et al. 1994).

The effects of SO_2 on plants are very complex. Direct damage to the leaves and needles occurs in the gaseous and aqueous forms. Indirect damage is done by sulfate inputs into the soil. These lead to a nutrient shortage and acid stress. There are multiple effects of SO_2 on the forest. The consequences are well known, esp. the changes in the abiotic and biotic soil conditions. This leads to bodies of water acidification, for example. Moreover, SO_2 causes damage to materials and buildings.

Limits

The gas can be measured effectively using a variety of methods. For years, it has been considered a prime component of air pollution from fuel combustion exhausts. Limits for sulfur dioxide air pollution load were set very early on. Attempts have been made to reduce the SO_2 concentration in the air.

Already the 1964 Technical Instructions for Air (*TA-Luft*) contained pollution limits for long-term sulfur dioxide pollution load (yearly average) of 400 µg/m^3 and a short-term pollution load level (97.5 %-summation of all half-hour values in one year) of 750 µg/m^3.

In Germany, the currently valid pollution limits are those contained in the 1986 *TA-Luft* and the limits prescribed in EC Guideline 80/779/EEC of 1980, last amended by EC Guideline 89/427/EEC. These, as well as the Regulation 22 for implementation of the Federal Air Pollution Control Law were adopted as national law in 1993 (c.f. Tab. 1).

Pollution limits which take into account the vulnerability of ecosystems must be maintained if the long-term capacity of the natural balance is to be guaranteed.

Limits (critical levels, critical loads), compliance with which should avoid any changes in the structure and function of ecosystems, were set by UN-ECE in 1988. The Federal Republic of Germany was among the first to sign as well as one of the co-initiators of the agreement. It has ratified the resolutions pertaining to new strategies in the European clean air regime.

The EC Guideline, resp. the applicable Regulation 22 BImSchV require, that the sulfur dioxide content of the air must not exceed the 98 % value of 250 µg/m^3, resp. 350 µg/m^3 on more than three consecutive days (c.f. Tab. 1). Until 1991, this level had been exceeded nearly every year under low exchange weather conditions. However, since 1991 it has no longer been exceeded. In addition, these regulations contain special limits for the sulfur dioxide concentration in winter. These limits have been maintained constantly in previous years.

Tab. 1: Limits, Standard Values and Recommendations for Pollution of Sulfur Dioxide and Floating Dust in the Air		
TA-Luft Pollution Limits (1986)	140 µg/m³	as yearly average (MW_1)
	400 µg/m³	as 98 % value of cumulative frequency for all measured half-hour values in a given year (MW_2)
EC Guideline 89/427/EWG resp. 22 BImSchV	80 µg/m³	as median of daily average measured during the year, if at the same time, more than 150 µg/m³ floating dust was measured
	120 µg/m³	as median of daily average measured during the year, if at the same time, less than or equal to 150 µg/m³ floating dust was measured
	250 µg/m³	as 98 % value for all daily averages, if at the same time, more than 350 µg/m³ floating dust was measured
	350 µg/m³	as 98 % value for all daily averages, if less than or equal to 350 µg/m³ floating dust was measured
Maximum Pollution Limit of VDI (Health Safety) – Guideline 2310, Bl. 11 1)	300 µg/m³	as average over 24 hours
	1,000 µg/m³	as average overr an half-hour
Maximum Pollution Limit of VDI (Protection of Vegetation) – Guideline 2310, Bl. 2 1)		as average over a vegetation period (7 months):
	50 µg/m³	for very sensitive plants
	80 µg/m³	for sensitive plants
	120 µg/m³	for less sensitive plants
		as 97.5 % value for half-hour average over the vegetation period (7 months):
	250 µg/m³	for very sensitive plants
	400 µg/m³	for sensitive plants
	600 µg/m³	for less sensitive plants
WHO Air Quality Guidelines (Health Safety) 2)	500 µg/m³	as average over ten minutes
	350 µg/m³	as average over an half-hour
	125 µg/m³	as average over 24 hours
	50 µg/m³	as annual average
WHO Air Quality Guidelines (Protection of Vegetation) 2)	100 µg/m³	as average over 24 hours
	30 µg/m³	as yearly average value
ECE Standards 1988 (Protection of Vegetation) 3)	70 µg/m³	as average over 24 hours
	20 - 30 µg/m³	as yearly average value

1) "Maximum pollution values", serve as the basis for defining the pollution limits the purpose of which is to avoid even under conditions of long-term exposure, damage to human health, esp. for children, the aged and sick and to protect animals, plants, and property. The "maximum pollution values" are pure affect-related, scientific-based values derived from practical experience with medical or physical science indications. The do not take into account technical feasibility.

2) The Air Quality Guidelines of the WHO were developed on the basis of toxicological and environmental findings. They are only recommendations for setting statutory norms.

3) The values are based on the measures adopted by the UN-ECE-member states under the Geneva Air Purity Agreement of 1979 for the reduction of transborder air pollution in Europe (SO_2 and NO_x Protocol of 1985 and 1988) (c.f. Köble et al. 1992).

Tab. 1: Limits, Standard Values and Recommendations for Pollution of Sulfur Dioxide and Floating Dust in the Air

When pollution limits have been exceeded, such as those of *TA-Luft* or the 22 BImSchV measures may be taken against the facilities identified as the polluters. If the specific polluter cannot be identified then the responsible agency must create an air purity plan which will specify the new, stricter standards for permissible emissions to be applied when approving any future facilities. Accordingly, air purity plans were drawn up in 1981, 1986, and 1994 in which the respective air pollution levels and the measures to reduce them are presented (c.f. SenStadtUm 1994).

Polluter and Quantity of Sulfur Dioxide Emissions

In Berlin, the **sulfur dioxide emissions** come primarily from burning of coal and oil for heat and electricity generation. Sulfur dioxide is discharged into the atmosphere as a component of the exhaust gases. It is produced with proportions of up to 3.0 % of sulfur contained in fuel. Because of its combustible qualities, it is possible to derive exactly the sulfur dioxide emissions from the sulfur content of the fuel.

The first data on sulfur dioxide emissions were calculated for 1892 on the basis of the fuel consumption statistics. At that time the discharge level already lay at 43,700 tons per annum (t/a). The emissions increased continuously, with interruptions due to the wars, reaching 80,000 t/a in West Berlin alone by 1970. The SO_2 emissions have sunk since 1970 (c.f. Map 03.01, SenStadtUm 1985).

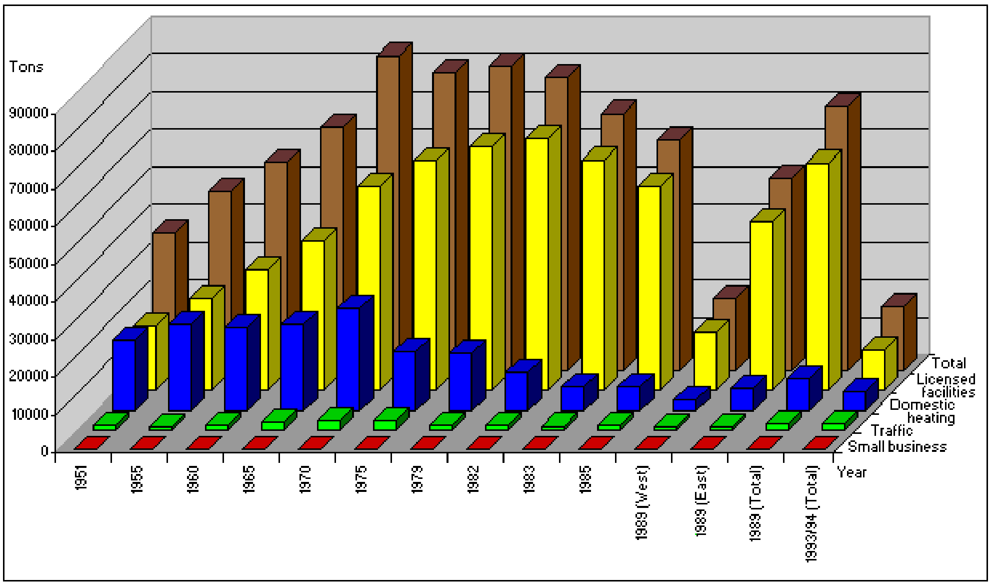

Fig. 1: Sulfur Dioxide Emissions from Individual Polluter Groups in Berlin 1951-1989 (for 1951-1985 West Berlin only, for 1989 West and East Berlin) (tons per year)

Figure 1 shows a heavy decline in emissions in the western part of the city. When both halves of the city are compared in 1989, the very high emission level in the eastern part can be seen. Since then, the emissions, which have continued to decrease significantly, are no longer measured separately for each half of the city. The greater part of the 17,200 t total emissions in 1994 (63 % of which was from licensed facilities, 10,900 t) comes from power, heating power and heating plants. Second place, with 4,900 t was domestic heating with 29 %, followed by motor vehicle traffic (1,400 t) at a little more than 8 %.

The variously high emission quantities in both halves of the city are due to the great difference in the types of fuel used. Until 1989, licensed facilities as well as domestic heating in the eastern part of the city relied primarily on lignite although gas was also used. In contrast to the western part of the city, there was no limit on the sulfur content of fuels. That meant that significant quantities of lignite, from the Leipzig/Bornaer region, with very high sulfur content (up to 3.0 %) were used. In contrast, the lignite burned in the western part was subject to the lignite regulation of 15.01.1981 limiting sulfur content to 1 %. At this time, only lignite from Lower Lusatia (Niederlausitz) or the Rhineland with a sulfur content of about 0.6 % was burned with an additional reduction to 0.3 % through ash retention. Moreover, mainly light heating oil with a sulfur content of less than 0.3 % was burned for domestic heating. Since 1988 numerous heat generating stations have already been using flue gas desulfurization plants (c.f. Tab. 2).

Tab. 2: Commissioning of Desulfurization and Denitrification Plants in Berlin Heating Power Plants (HKW) and Power Plants (KW) (as of August 1996)

Power Plant	Block	Flue Gas Desulfurization	Denitrification (DeNOx)	Comments
HKW Lichterfelde	1	1983	February 1992	
	2	not required	not required	(1a)
	3	1983	December 1991	
KW Oberhavel	1	June 1988	February 1992	
	2	May 1988	February 1992	
HKW Reuter	1	May 1988	February 1994	
	2	June 1988	February 1994	
	C	August 1988	February 1994	
HKW Rudow	1	January 1989	February 1994	
	2	November 1988	December 1993	
HKW Charlottenburg	1	June 1989	March 1994	
	2	July 1989	March 1994	
	3	May 1989	March 1994	
HKW Reuter West	D	June 1988	January 1989	
	E	March 1989	January 1989	
HKW Wilmersdorf		not required	not required	gas turbine
HKW Steglitz		not required	not required	gas turbine
HKW Moabit		not required	not required	fluidized-bed process
HKW Rummelsburg/ Klingenberg	1	none	none	(1b)
	2	none	none	(1b)
	3	none	none	(1b)
	4	none	none	(1b)
	5	June 1990	none	electrofilter
	6	June 1990	none	electrofilter
HKW Mitte		none	none	(1b) (2)
HKW Lichtenberg		none	none	(1b) (3)

(1a) Natural gas operation
(1b) Natural gas and other fuels
(2) 1996 completion of gas und steam turbine facility
(3) Modification of furnace to comply with 13 BImSchV

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After reunification, the application of the brown coal (lignite) regulation was extended to the eastern part of the city. In addition, the closing of a number of factories also led to dramatic emission decreases. In 1996, the conversion of gas supply to natural gas was completed for the whole city. This meant that an increasing number of households could be converted from coal and oil heating to gas heating which produces no sulfur dioxide emissions.

Development of Sulfur Dioxide Pollutions

In 1968 and 1969, the Institute for Water, Soil, and Air Hygiene at the Federal Health Agency began continuous **measurements of sulfur dioxide concentration** at three monitoring sites in Berlin. In 1975, the former Department of Health and Environmental Protection began operation of the Berlin Air Quality Monitoring Network (BLUME). Sulfur dioxide pollution were measured throughout the western part of the city at 31 monitoring stations distributed along a 4 x 4 km grid.

Figures 2 shows a summary of the yearly average values from each available station since 1970.

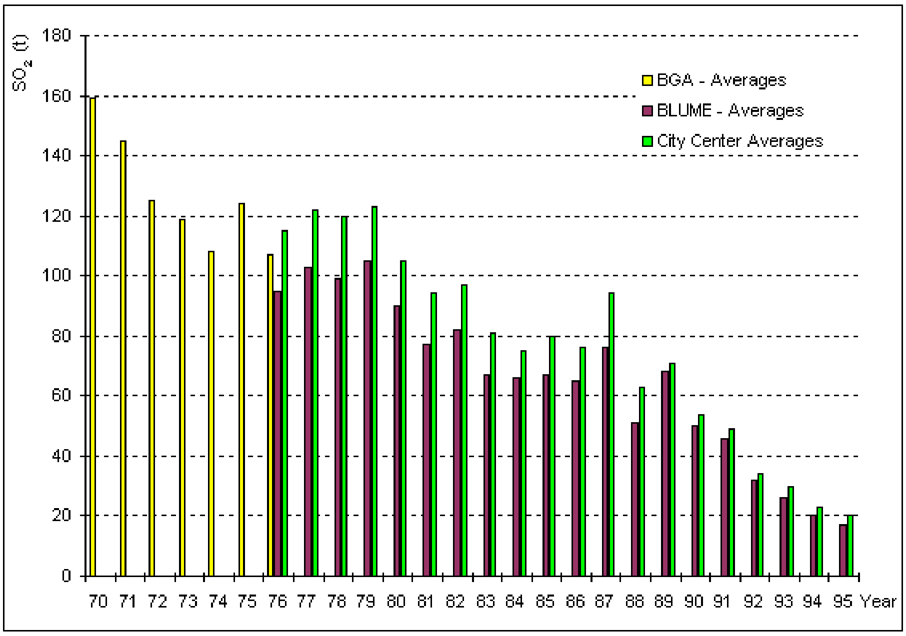

Fig. 2: Trends in the Yearly Average Values for Sulfur Dioxide 1970 -1995

BGA- Averages = Averages from three Federal Health Agency monitoring stations in Steglitz, Jungfernheide and Dahlem.
BLUME- Averages = Averages from 6 BLUME-monitoring stations in the western city center.
City Center Average = Average of the monitoring stations in the city center.

Altogether, the sulfur dioxide concentration in Berlin declined more than 85 % between 1970 and 1995. This decline could be observed in several stages. There has been a very great decline between 1970 and 1974, from 1979 to 1983 and again since 1989. However, two stagnation phases could be observed between 1974 and 1979 and again between 1983 and 1989 (c.f. Fig. 2).

Each phase of pollution decline has its specific origin. In the beginning of the 70s, heating plants were increasingly converted from coal-burning to light heating oil. At the end of the decade, the sulfur content of light heating oil and lignite was reduced. In recent years, the introduction of flue gas desulfurization plants in power stations pursuant to the *Grossfeuerungsanlagenverordnung* (central furnace facility regulation) and the introduction of the lignite regulation to the eastern part of Berlin made its impact (c.f. Tab. 2). This enabled a further reduction in sulfur dioxide discharges. Finally, the collapse of the GDR and the resulting decommissioning of numerous factories led to a further significant reduction in emissions.

In addition, the continuing extension of district and gas heating as well as intensified efforts at insulation and energy conservation, e.g. through technically-improved heating facilities, has had an pollution-reducing effect. Development has not come to an end. With the heavy reductions in sulfur dioxide concentrations in the air, this pollutant will lose its function as a leading indicator for the degree of air pollution.

Effects of Long-term Pollution Load on the Forest Ecosystem

The filter effect created by the surface structure of forests leads to a high pollutant impact and accumulation. Multiple effects on forest ecosystems are caused by the pollutant gas sulfur dioxide and its solid by-product sulfate. The intense international forest damage research which has been done since the beginning of the 80s has yielded completely new knowledge in the field. This has resulted in a very critical approach to the definition of pollution limits.

Direct damage impact from previously high SO_2 concentrations were particularly noticeable in Berlin (c.f. Map 03.07, SenStadtUmTech 1996a) through reduction in lichen growth and through **needle damage**. A special method was developed during the long-term investigations of the monitoring program in order to measure and access the macroscopically recognizable needle damage (c.f. Meyer and Kalhoff 1996). The damage profiles were summarized as damage types of which damage type 3 (needles with clearly distinguishable ribbon and spot-shaped chloroses and necroses) can certainly be attributed to SO_2 damage. Figure 3 shows the development of this kind of damage since 1986: parallel to the decreasing SO_2 load, the incidence of type 3 needle damage also declined. The positive correlation with the average SO_2 concentration from 1986-94 confirms the connection. The decline in this type of needle damage in Berlin coincides with the findings of Korsch and Jäger (1993) which also show a significant reduction in needle necroses in the Bitterfeld region within recent years.

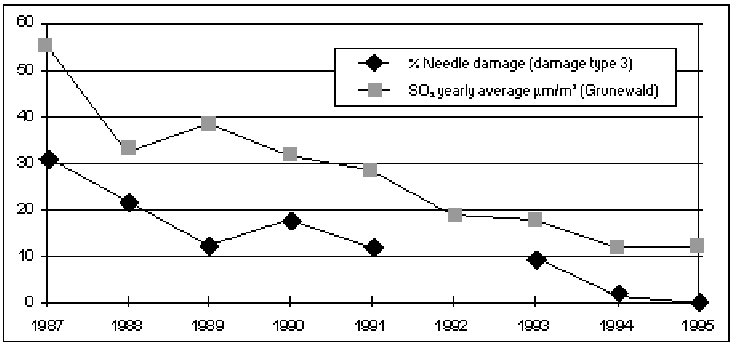

Fig. 3: Temporal Development of Needle Damage Type 3 in Three Test Areas in the Forests of the Western Part of Berlin and the Average SO_2 Concentration in Grunewald. The Average of all Test Trees with a Particular Damage Type is Shown (following Meyer and Kalhoff 1996). For 1992 there are no Needle Damage Data Available.

Despite these low concentrations of SO_2 in 1995, there continues to be **acid load of the Berlin forests** which has been caused about 75 % by SO_2. The acid inputs have been reduced as a result of the extensive pollution reduction measures taken, but not to the same extent as the reduction of SO_2 concentrations. This is due to the fact that the calcium inputs, which serve as an atmospheric buffer against acids, have been reduced (c.f. Fig. 4). In addition, the nitrogen oxide pollutions, which contribute to a third of all acid formation have scarcely declined (c.f. Map 03.03, SenStadtUmTech 1997). The result has been a slight increase in acid precipitation from 1991 to 1994.

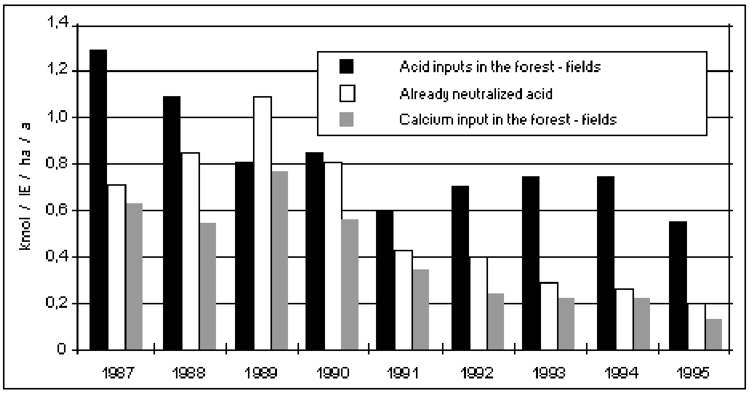

Fig. 4: Temporal Development of Acid Inputs, Atmospherically Buffered Acids and Calcium Inputs in kmol Ion Equivalents (IE) per Hectare and Year in Fields within Grunewald (following Fischer 1996)

These current acid input measurements still lie above the **level of tolerable acid inputs** for the Berlin forests, as defined by UN ECE “Critical Loads" for **sustainable maintenance of the natural balance** (c.f. Fig. 5).The value calculated shows what the forest soil's long-term acid neutralization capacity is. The acid neutralization capacity is determined by the ability of the soil, through erosion, to replenish basic cations (Ca, Mg, K). The same function is performed by the basic cations in dust which can also provide relief. This relief is reduced through the significant decline in calcium inputs as already mentioned.

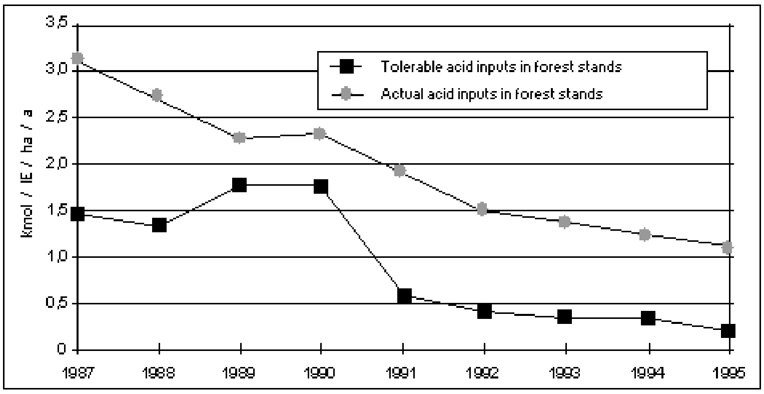

Fig. 5: Development of Actual along with Tolerable Acid Inputs According to the UN ECE Concept of Tolerable Inputs (Critical Loads) in Ion Equivalents pro Hectare and Year from 1987 to 1995 (Example Grunewald). Actual Acid Inputs: Calculated Input Values in the Forest Stand.

There has been a decline in the **pH value of rainwater** (1984 - 94 from 4.7 to 3.9) (c.f. Pelz 1995) caused by the reduction in the atmospheric acid buffer (c.f. Fig. 6). The high acid level in rain and fog is also problematic for the forests. This can lead to increased acid damage to needle surfaces (premature aging of the wax layer) and higher erosion of nutrients.

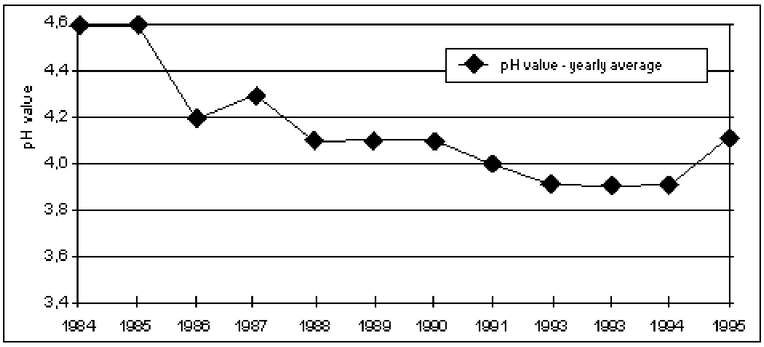

Fig. 6: Temporal Development of the pH Value in Precipitation in Berlin-Dahlem 1984 - 1995 (Pelz 1995, Pelz 1996)

The long-term acid inputs in the **forest soil** can be identified in the **soil solution**, which is a **sensitive indicator** of the soil-chemical condition. The soil solution from the forest long-term observation areas in Grunewald exhibit a high sulfate (SO_4) concentration. With 85 % of the total anions, there is also a decisive effect on the ion-levels in the soil solution (c.f. Schlenther et al. 1995). This makes the high SO_4-inputs of the past an important factor for the composition of the soil. Due to the continuing buffering of the sulfate-induced acidifications, increasing amounts of aluminum ions are released. These are toxic for roots. Only the pollution-effected calcium reserves in the soil prevent root damage. However, current acid inputs cause the gradual deterioration of these reserves. The "Critical Loads" concept which aims at long term soil quality, does not take this deteriorating reserve into account and therefore treats the current acid inputs from the standpoint of sustainability of the forest soil as intolerable.

Statistical Base

Emissions

An **emission data base** for the primary polluter groups is maintained by the Department of Urban Development, Environmental Protection and Technology in order to provide a differentiated evaluation and elimination of the sources of sulfur dioxide loads.

In order to create the **emission data base industry 1994**, data is taken from the emissions declarations of the large individual polluters such as power, heating power, and heating plants and industrial plants. The operators are required by regulations pursuant to the Federal Air Pollution Control Law to file such declarations with the air pollution control agencies every two years.

The **emission data base domestic heating 1994** has been developed statistically in order to cover the numerous small domestic heating plants found in the metropolitan area. The total heating requirements and proportions of different heating types has been assessed for all residential buildings. This includes the number of coal oven heaters, oil furnaces, gas apartment heaters, electrical and district heating. The emission level for each housing block has been determined using factors for each different heating type. Heating needs which are satisfied by means of electric heating or district heating were not counted if the heat was produced by facilities requiring a license. For gas heating, the emission factors are significantly lower than for coal and oil heating. Hence this type of furnace contributes very little to the sulfur dioxide load.

The **emission data base traffic 1993** for the share of sulfur dioxide emissions produced by motor vehicles is based on the count of traffic as performed by the traffic administration as well as data on the number of motor vehicles and the average performance of each vehicle. The emissions are calculated with the help of factors set for each class of motor vehicle. Diesel-powered vehicles are the only ones which cause significant sulfur dioxide emissions.

All estimates and calculations have been compared to the energy balance in which the total fuel consumption for Berlin is recorded.

Calculated Pollution

The **pollution calculations** were performed separately for large single polluters and the polluter groups domestic heating and traffic with the aid of a computer-supported meteorological dispersion model (c.f. Fath et al. 1991).

The **dispersion calculations** for domestic heating and traffic emissions were measured from a reference grid of 1 x 1 km. These were assigned particular emission levels. The large single polluters were assessed from the smokestack site and elevation.

For the calculations, it is assumed that the pollutant particles contained in the trails of smoke are transported with the wind and expand vertically in the average transport direction vertically and horizontally following a normal distribution. At that altitude they can only be dispersed so far until a temperature inversion prevents further expansion. Wind direction, wind speed, turbulent dispersion capacity of the atmosphere and a variable inversion altitude are all taken into account. In addition the fact that the heating needs and so thus also the pollutant emissions rise greatly in the winter with decreasing temperature.

Since the model calculations assume an unhindered expansion of the pollutants and because the assignment of domestic heating and traffic emissions as a whole follow grid areas of 1 x 1 km, the calculation results represent measurement sites ordered at a greater distance from pollutant sources, particularly streets. The pollutant concentration is calculated for about 100 points, which are distributed over the entire urban area.

Measured Pollution

In 1995, the **pollution measurements** in Berlin included continuous sulfur dioxide measurements taken at 36 BLUME stations. 20 stations lay in the western part and 16 stations in the eastern part of the city. Automatic measurement instruments are in service at all stations, joined by telephone leased lines to a central computer to which the values are transmitted in 3-minutes intervals. All measurement instruments work using the UV-fluorescence method.

Since the beginning of intensive measurement in 1975, it was ascertained that the pollution limits of the *TA-Luft* and limits of the EC Guideline for sulfur dioxide and floating dust were regularly exceeded, the measurement stations to 1989 in the western part of the city were ordered in a regular 4 x 4 km-grid, which covered the built-up urban area up to the city outskirts. After the great change in the GDR, the five existing stations in the eastern part of the city were replaced stations with six new stations which could also measure floating dust (c.f. Map 03.04, SenStadtUm 1994c). Further monitoring stations were removed from the western to the eastern part of Berlin since the higher concentrations of sulfur dioxide and floating dust were measured in the East and the pollution levels were exceeded primarily in the city center stations in the West after the reunification. The shift was completed in 1993.

At four stations measurements are taken under direct influence of road traffic. A station (14, Charlottenburg) lies in direct proximity to the city expressway, the second station (74, Friedrichshain) in the heavily traveled crossing Frankfurter Allee/Warschauer Strasse and two further stations on equally heavily traveled streets with closed-in construction surrounding the street lanes (117, Steglitz and 174, Friedrichshain) (traffic corridors). According to the general regulations of the Federal Air Pollution Control Law for the measurement and evaluation of the pollution loads the stations are prescribed at a distance of more than 20 m from pollutant sources. A measuring device on the broadcasting tower in Frohnau on the northern edge of the city was installed at approx. 300 m above the ground in order to measure the national sulfur dioxide load in the air (c.f. Maps 03.01.8 and 03.01.9).

By 1996 the concentration in the eastern part of the city had so declined that the limits have not been exceeded in the entire city area. Since there was no further reason to expect pollution limits to exceed those of the regulation pertaining to the reduction of damaging environmental impact during low-exchange weather conditions (Smog Regulation 1990), this regulation was repealed at the end of 1995. As a consequence, the number of measuring stations has been gradually reduced since 1994.

Methodology

The data from the **calculated 1 x 1 km-emissions** of sulfur dioxide are presented both as color grid as well as absolute value. The division into altogether eleven emission classes can now provide in equal gradations, in accordance with the 1994 edition of the Environmental Atlas. Since the sulfur dioxide emissions have greatly decreased as consequence of the environmental protection measures (until 1989 only in reference to West Berlin). Thus the necessity of a particular emission value for this category of pollutant has been obviated.

At the wide area depiction of the **measured pollution** 1995 for sulfur dioxide, the limits IW_1 and IW_2 of the *TA-Luft* 1986 were selected as class values for the delimitation of the highest class. They were compared to the reference values I_1 (yearly average) and I_2 (98 % value).

The interpolations of the isolines were performed manually. In addition the respective values from the BLUME-measurement stations are presented, distinguished according to type of station.

Map Description

Emission and Calculated Pollution

In the three Maps 03.01.1, 03.01.2 and 03.01.3, the emissions are presented for the primary polluter groups traffic 1993 as well as industry and domestic heating 1994 resp. in 1 x 1 kilometer-grid areas for the year 1989. The Maps 03.01.4, 03.01.5 and 03.01.6 depict respectively the calculated yearly average values from 1993 resp. 1994 for the named prime polluter groups for the sulfur dioxide load in Berlin air.

Industry 1994

The Map 03.01.1 of the **industry emissions** shows a very irregular picture. In 1994, 10,900 t/a sulfur dioxide were discharged by the facilities requiring a license. In the map, the locations of the power, heating power and heating plants can be clearly seen. Thereby the heating power plant Reuter in Ruhleben reaches the maximum with 1,700 t/a. The heating power plant Klingenberg, which emitted 22,800 t in 1989, has been shown in the map with only 680 t/a. In the other grid areas, the emission level has exhibited drastic reductions.

Although in the greater part of the city power and heating plants occur as isolated maxima, there is a concentration of industrial sites in the East and Southeast where emissions between 100 and 500 t/a are reached. So the industrial and small business areas in Treptow and Lichtenberg as well as in Köpenick, Weissensee and Pankow are clearly recognizable in the map.

In comparison to the depiction from the years 1985 and 1994, the emission quantities of the polluter group industry have clearly declined (c.f. Maps 03.01.1 and 03.01.8, SenStadtUm 1985 and 1994).

Since the height of industry chimneys, in accordance with the instructions specified in *TA-Luft*, must increase proportionately to the level of pollutant emissions, the pollutants of these plants are distributed at a higher altitude and more evenly over the whole urban area and surrounding countryside. Therefore increased concentrations in the vicinity of the plants are, as a rule, neither measured as Map 03.01.8 shows nor calculated, as the Map 03.01.4 documents.

The map of calculated **pollution** for the polluter group industry (Map 03.01.4) shows a pollution field which has been balanced accordingly. Two maxima have been calculated with values up to 8 µg/m^3 in Charlottenburg/Wedding and values up to 7 µg/m^3 in Neukölln/Treptow.

Domestic Heating 1994

The sulfur dioxide emissions from the **domestic heating** lay 1994 with 4,900 t. In the Map 03.01.2 the increasing emission density in direction inner city is easily recognizable. While sulfur dioxide emissions up to 5 t/km^2/a has been measured at the city's edge, Kreuzberg recorded up to 40 t/km^2/a and in the most densely populated boroughs of Prenzlauer Berg and Friedrichshain with a higher density of construction and the largest share of coal oven heating emissions of 66 t/km^2/a were reached (c.f. Maps 08.01 and 08.02, SenStadtUmTech 1996b and 1996c).

The amount of sulfur dioxide emissions from domestic heating has decreased very significantly in the last twenty years. This can be seen by comparing the above figures with those of the Environmental Atlases from 1985 and 1994. These show the emission from 1974 and 1983 for the western part of Berlin and 1989 for the combined sectors of Berlin on separate maps. Although selected emission levels in the western part had reached more than 200 t/km^2/a in 1974, by 1983, the emission levels had already declined to a maximum of 75 t/km^2/a. In 1989, a maximum of 50 t/km^2/a in the West and of up to 200 t/km^2/a in the East had been recorded.

The results of the **dispersion calculation in the area of domestic heating** (Map 03.01.5) show essentially the same structures as in the emission field. The maximum pollutions lie at 11 µg/m^3 in the most densely populated area (Prenzlauer Berg).

Also on this map the difference from the corresponding 1985 Environmental Atlas map is clearly noticeable. In 1974, the most heavily burdened area in the northern Schöneberg the calculated pollution for domestic heating at the were determined at values of more than 80 µg/m^3. This had been reduced by 1983 to barely under 50 µg/m^3; 1995 the values fell to 6 µg/m^3.

Traffic 1993

The **emissions in the area of traffic** are comparatively slight. Due to the substantial decline in other polluter groups which does not apply to traffic emissions, the relative portion has increased four-fold. It lay with 1,400 t/a in 1993 at approximately 8 % of total sulfur dioxide emissions. In the Map 03.01.3 it can be seen that the city expressway in the west of Berlin forms a line of higher emissions with quantities of up to 10 t/km^2 and year. These values are of comparable proportion to the emissions from domestic heating and the smaller industrial plants in this area.

In the measurements from near traffic measurement sites (Map 03.01.8) the emissions caused by the motor vehicle traffic are more prevalent than in the map of **calculated pollution for traffic** (Map 03.01.6), because the dispersion calculations have not been presented according to points, but according to area and median values in 1 x 1 km-grids, while the measured values reflect the single values as such in the map.

The pollutant load of the city air is caused not only through emissions in the urban area and in the directly surrounding countryside. Rather there is a **national pollution load level**, which is caused by a multitude of pollutant sources in Europe. After the German reunification, the Federal Environmental Agency extended its measurement network, with whose help of this background levels is determined, to the new federal states. In the Berlin vicinity are the stations Kyritz, Neuglobsow and Angermünde from the northwest to the northeast of the city as well as Wiesenburg and Lindenberg southwest and southeast of the city. In 1994, yearly average values for the sulfur dioxide concentration were available which could be used as background values for Berlin (c.f. Federal Environmental Agency 1996).

The values lie between 7 and 18 µg/m^3. The higher values are southward and the lower values were measured north of Berlin. They correspond with the value of 15 µg/m^3 which was determined at 300 m elevation at the radio tower Frohnau. On the basis of these measurements, Berlin has been assigned a value of 12 µg/m^3, given the concentration's vertical distribution.

Total Calculated Pollution 1993/94

The Map 03.01.7 reflects the sum of calculated pollution for the three main polluter groups industry, domestic heating and traffic and of course as **yearly average values** for the year 1993 resp. 1994. It exhibits a flat maximum of up to 18 µg/m^3 which extends from Prenzlauer Berg through Friedrichshain to the northern edge of Neukölln. At the edges of the city the concentration levels decline. The decline is more noticeable toward the West than in the East. The asymmetry is due to the predominance of the westwind which tends to drag the emissions more often to the East.

The causes of sulfur dioxide load are considered as sufficient exactly defined, if the concentration sums calculated for the polluter groups and the national background load conform with the measurement results achieved.

Given the national background pollution load of about 12 µg/m³ and a further reduction by 1995, the map shows the sum of calculated pollution (Map 03.01.7) only slightly higher values as those for comparable sites of the air quality monitoring network. The differences between the maxima lie in the margin of error between measurement and calculation.

As the trend presented in Figure 2 shows, the load has declined in the period of 1989 to 1995 on average over the urban area around about 60 %. In 1994 the range of the inner city maximum measurements of 21 µg/m³ were taken, still only about a third as high as 1989 values.

Tab. 3: Sulfur Dioxide Pollutions in Central Berlin according to Polluter Group		
	Concentration µg/m³	Share %
Measurement 1994 total	22	
Calculation 1994 total	27	100
Industry, licensed facilities	4	15
Domestic heating	8	30
Traffic	3	10
National background	12	45

Tab. 3: Sulfur Dioxide Pollution in Central Berlin according to Polluter Group

Measured Pollution 1995

The map shows the **yearly average values** (Map 03.01.8) in the entire municipal area to have only minimal concentration variances with as a whole very low values. The highest pollution loads were registered at the monitoring stations near streets, between 25 and 34 µg/m³. This is where the sulfur content of diesel fuel is particularly noticeable. In residential areas not directly effected by motor vehicle traffic, the concentrations at the urban perimeters lay between 11 and 15 µg/m³ and in the city center at approximately 20 µg/m³. If these values are compared with those from 1976-1980, when values up to 150 µg/m³ had been measured (c.f. SenStadtUm 1985), then this means that there is no longer an identifiably significant long-term sulfur dioxide pollution load from furnaces in the Berlin air.

In the map showing the **98 % values** (Map 03.01.9), a smoke plume-like structure extending over the city center from the southeast to the northwest can more easily be recognized than on the map showing the yearly average values. The maximum no longer lies over the eastern half of the city as in 1991 (c.f. SenStadtUm 1994a). Rather it has now shifted to the West as can be seen in the yearly average value map. The highest value lies at only 92 µg/m³, following 600 µg/m³ for the period 1976 until 1980 and approximately 300 µg/m³ in 1991. It is worth mentioning that the second highest 98 % value was measured at the city's edge on the broadcasting tower Frohnau in 300 m altitude at 103 µg/m³ and that the 14 µg/m³ is also a relatively high yearly average value. This is no doubt due to the fact that smoke plumes continue to be noticeable at this altitude because they originate from major polluters. They contribute to the formation of smoke plume-like distribution structure for the 98 % value. However they make no substantial contribution toward the increase in the total pollutant loads.

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