03.11 Traffic-related Air Pollution – NO_2 and PM10 (Edition 2005)

Overview

Starting Position

In the past, reduction of industrial and domestic fuel emissions was at the center of air monitoring planning. In these areas sizeable reductions of air borne pollutant emissions could be achieved through broad scale successful redevelopment programs and closures. Enhancements could also be achieved in the area of transportation. Notwithstanding these facts - not only in Berlin - transportation is the largest single source of both current and future air pollutants, and determines the course of action for air monitoring strategies.

Historical development conditions caused the physical layout of Berlin-Brandenburg to be organized in a travel-efficient way. No other region of Germany approaches such favourable conditions. Markedly characteristic of Berlin are the substantial multiple central structures and high utilization of limited space in the inner city, as well as in the centers of the outer city, with intensive large and small scale multiple uses resulting in less suburbanization than in other large cities. Only 20% of the population lives in the surrounding area. However, large sections of the peripheries of the city lay within the administrative borders of Berlin as a result of the implementation of the amalgamated community of "Greater Berlin" in 1920.

Since 1990, the city, with its tight interconnectedness with Brandenburg, has experienced considerable changes to its topography: the dispersion of population, businesses, and new jobs; and the establishment of important locations for shopping and leisure activities, especially evolving in the eastern part of the city and in the neighboring surrounding area. The dynamics of change continues, but at a reduced rate.

Since reunification, the city of Berlin has been confronted with a considerable increase in traffic. The number of registered motor vehicles in Berlin alone has increased by 45% since 1989, swelling to 1,534,530 (according to the state office for citizens and civic order (LABO), on December 31st, 2004 all "registered motor vehicles" includes 1,263,203 operative motor vehicles without trailers, inoperative motor vehicles, and trailers).
The future will bring a further increase in traffic, especially by pollution intensive freight transporters.

The increase in traffic is caused by, among other things: the continuing expansion of the common living and commercial areas of Berlin-Brandenburg; the intensification of international economic interdependence; and, especially in Berlin, the expanded strengthening of the interdependence with Eastern Europe.

The Contribution of Motor Vehicle Traffic to Air Pollutant Concentrations: Origins and Trends

For some years now, in important problem areas, Berlin's motor vehicle traffic has caused not only substantial noise emissions (see map 07.02, Street Traffic Noise (2005 Edition)), sondern auch der Luftverschmutzung, but air pollution as well, especially since other groups that originally contributed to air pollution have been substantially reduced. Table 1 shows the combined emissions of all of Berlin's sources of major pollutants since 1989.

Since the fall of the Berlin Wall in 1989, many industrial enterprises have been redeveloped or closed, and the use of coal for fuel for the furnaces to heat Berlin's residences has been replaced with heating oil, natural gas, or community heating. In 1989 domestic heating and industry were significant sources of sulphur dioxide and fine particulate pollutants, but these have been reduced substantially. As well, between 2000 and 2002 the total emissions of nitrogen oxides have declined almost 25%, while fine particulates have declined over 10%.

Table 1: Emissions in Berlin according to emitting groups						
	Data in tonnes per year (t/a)					
	1989	1994	2000	2002	Trend 2005	Trend 2010
Sulphur dioxide	**70801**	**17590**	**8868**	**7158**	**6674**	**6462**
emittent approved facilities	60470	10870	5683	4433	4100	3967
Domestic fuel	8526	4890	2500	2400	2323	2268
Small trade	75	70	60	60	50	40
Traffic (only motor vehicles)	1440	1400	400	55	14	15
Traffic (other)	140	140	75	75	68	60
Other sources	150	220	150	135	120	113
Nitrogen oxide	**69971**	**42417**	**26109**	**22141**	**19768**	**17536**
emittent approved facilities	41757	16172	8331	6499	6012	5817
Domestic fuel	2704	3120	2860	2860	2657	2594
Small trade	1200	700	190	185	160	125
Traffic (only motor vehicles)	21410	19025	12400	10455	8876	7015
Traffic (other)	1400	1300	1128	1128	1100	1072
Other sources	1500	2100	1200	1014	963	913
Carbon monoxide	**293705**	**203948**	**101828**	**69133**	**48236**	**39126**
emittent approved facilities	32443	3888	2028	1581	1462	1415
Domestic fuel	68712	41560	8000	8000	7432	7256
Small trade	1500	800	200	193	168	135
Traffic (only motor vehicles)	182050	144200	76500	44259	24829	16730
Traffic (other)	4000	3500	3100	3100	2945	2790
Other sources	5000	10000	12000	12000	11400	10800
Particulate matter (PM10)	**18180**	**8804**	**4728**	**4199**	**4041**	**3939**
emittent approved facilities	9563	3161	960	650	601	514
Domestic fuel	2693	1148	131	132	98	85
Small trade	250	220	160	153	149	145
Traffic (only motor vehicles,exhaust)	2336	1135	667	394	311	238
Friction and air movement from motor vehicle traffic	1200	1150	997	1050	1113	1239
Traffic (other)	238	190	124	130	121	112
Other sources	1900	1800	1690	1690	1648	1606
Organic Gases	**103351**	**73703**	**32814**	**24251**	**20043**	**17691**
emittent approved facilities	11801	3473	2554	1966	1887	1863
Domestic fuel	5250	2340	550	550	511	499
Small trade	15500	15000	6500	6484	5511	4539
Traffic (only motor vehicles)	49800	33890	12500	5661	3057	2208
Traffic (other)	3000	2000	1710	1710	1590	1471
Other sources and Households	18000	17000	9000	7880	7486	7112

Tab. 1: Emissions in Berlin According to Emitting Groups 1989 to 2010 (Trend)

In addition, fine particulate emissions from motor vehicle exhaust between 1989 and 2002 have decreased by more than 80 %. This rings true with the readings of measured diesel soot in street ravines - the main component of motor vehicle exhaust emissions: the measured soot concentration on the Frankfurter Allee, in the Berlin district of Friedrichshain, at monitoring station 174 of the Berlin air quality observation network BLUME has fallen by almost 40 % within the last 6 years. However, since fine particulates from friction and air movement caused by street traffic have barely decreased during this time, after other sources, street traffic is the main source of particulate matter in Berlin. Street traffic causes 34 % of the fine particulate emissions in Berlin, while other sources cause 40 %.

By the beginning of the 1990s, street traffic replaced industrial plants as the main source of nitrogen oxides in Berlin. As of 2002 street traffic produces 47 % of the nitrogen oxides in Berlin, whereas industrial plants account for 29 % of the total emissions.

Noticeably high in comparison are the pressures from motor vehicle traffic in the inner city center, where over one million people live in an area of 100 square kilometres. Especially here, if current trends for use of and competition for space continue, motor vehicle traffic will increase. If current conditions continue, especially freight transport will encounter increased bottlenecks in the streets.

In order to influence these partially incompatible but health-relevant developments for the city, Berlin has developed two planning strategies that compliment each other:

- the City Traffic Development Plan; and
- the Clean Air Preservation and Action Plan Berlin 2005 -2010.

With the City Development Traffic Plan, the Berlin Senate (with a resolution from July 8, 2003) has presented an action plan which combines the possible and necessary steps to further develop the Berlin traffic system for the coming years with a long term strategic orientation. The essence of the action plan forms a catalogue of measures that were previously analyzed in detail and balanced according to their effectiveness, acceptance and financability. The investigations of the Clean Air Preservation Plan Berlin are based on this long term action plan in regard to the future development of traffic in Berlin and the surrounding area.

"Health and Safety", one of the central strategies of the City Traffic Development Plan, already considers a number of important strategies to limit the increase of motor vehicle traffic resulting in the reduction of air and noise pollution in the main traffic network.
The implementation of the measures of the City Traffic Development Plan is expected to be completed by 2015.

In August 2005, the Berlin Senate adopted the EU mandated, standardized Clean Air Preservation Plan.
Pursuant to the European-wide standards, the Clean Air Preservation Plan data must disclose details:

- of pollution measurements;
- of the causes of high pollution levels;
- of the frequency and level of measurements that exceed the limits;
- of pollution emissions and the breakdown of causative factors (e.g. industry, commercial activity, home heating, traffic);
- of the measures and a timetable for implementation; and
- forecast, with an achievable goal.

The Clean Air Preservation Plan at hand discloses information about the legal framework, information about the prevailing situation, and describes the causes of air pollution. The measures take into account future atmospheric changes until 2010. The focal point is the presentation of a broad range of potential measures and their evaluation. Based on the effectiveness of these measures a strategy for the Berlin Clean Air Preservation Plan will be developed. The Clean Air Preservation Plan documents that Berlin, as do many other large German and European cities, is challenged to meet the new EU limits.
The important results came from the "made in Berlin" measures which reduced fine particulates from the urban background and other sources by about half. Urban background pollution is mostly caused by street traffic (16% of the total pollution of PM10). The rest (11%) is made up of approximate equal parts from Berlin residential heating, industry / power plants, construction, and other sources within the city.

The results of the measurements from last year and those carried out with the year 2002 calculation model lead, among other things, to the following conclusions:

- The multi-year trend of fine particulate and nitrogen dioxide pollution barely declines. The high PM10 results in 2002 and 2003, as well as the decline in 2004 are predominately weather related.
- At all measuring stations located close to traffic, the 24 hour limits for fine particulates and the annual limits for nitrogen oxide were exceeded. The calculations for 2002 widely show excesses in all main street traffic networks, especially in the city center.

Effects

Nitrogen oxides are acidifiers. They are harmful to human health, cause damage to plants, buildings, and monuments, and significantly contribute to the excessive formation of ground level ozone and various noxious oxidants during summer heat waves.

Nitrogen oxide, and especially nitrogen dioxide lead to irritation of the mucus membranes of the air passages in people and animals and can increase the risk of infection (see Kühling 1986). As well, cell mutations have been observed (BMUNR 1987). Various epidemiological studies have shown a correlation between the deterioration of the lungs' respiratory tract symptoms, and increased nitrogen dioxide (see Nowak et al. 1994).

Diesel soot is a major component of fine particulate matter (PM10) in motor vehicle exhaust. It is a carrier for polycyclic aromatic hydrocarbons (PAK), a cancer risk, and, on their own, are also possible causes of lung and bladder cancer (see Kalker 1993). Moreover, ultra fine particles such as diesel soot which are smaller than 0,1 µm, are suspected to increase the risk of cardiovascular disease.

Legal Regulations and Limits

Air pollution from motor vehicle traffic could only be evaluated by emission control authorities starting in 1985, after the European community, in the "Guideline Advice of 7 March, 1985, About Air Quality Standards for Nitrogen Dioxide" (Guideline 85/203/EWG), specified limits and goals for this pollutant. In addition, it prescribed measurements of concentrations of nitrogen dioxide in street ravines and at focal traffic points.
In 1996, due to a multiplicity of new findings regarding this, as well as other air pollutants, "Guideline 96/62/EG About the Evaluation and Control of Air Quality" (the so-called "Framework Guideline") was written and brought into force.
In this guideline the Commission is called upon to submit, within a specified time period, so-called "Sub Guidelines" specifying limits and details for measurement and evaluation of a given list of components.

In the meantime, three Sub Guidelines have come into force:

- on July 19, 1999, Guideline 99/30/EG, with a limit for sulphur dioxide, fine particulate matter (PM10), nitrogen dioxide and lead;
- on December 13, 2000,Guideline 2000/69/EG, with a limit for benzene and carbon monoxide;
- on February 9, 2002, Guideline 2002/3/EG, for comparing ozone at ground level to the data and elevation of measurements exceeding the limits; and
- on December 15, 2004, Guideline 2004/107/EC, with limits for arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons.

Two years were allocated to enact the first two Sub Guidelines into law. The first Sub Guideline was enacted in September 2002 in the Seventh Amendment of the State Emissions Protection Act (BImSchG), well beyond the allotted two years. The new Ozone Guideline was, in the meanwhile, enacted into German law in the new 33rd Ordinance of the BImSchG.

The essence of the air quality Guidelines is the emission limits , which "must be achieved within a certain time frame and are not to be exceeded thereafter". The pollution concentrations, and the time in which the limits must be met, are stipulated in the Sub Guidelines, i.e. in the 22nd Federal E Protection Law.
Table 2 shows the stipulated limits for the two air pollutants which are the largest potential problem for Berlin: PM10 and nitrogen dioxide.

Table 2: European Union wide emission limits and deadlines for PM10 and nitrogen dioxide			
Substance	**Medium over**	**Limit Values**	**Observance Period**
PM10	24h	50 µg/m³ 35 Excesses/Year	1.1.2005
	1 Year	40 µg/m³	1.1.2005
NO2	1h	200 µg/m³ 18 Excesses/Year	1.1.2010
	1 Year	40 µg/m³	1.1.2010

Tab. 2: European Union wide emission limits and deadlines for PM10 and nitrogen dioxide stipulated in the 22nd BlmSchV

According to Paragraph 1 of the 22nd BlmSchV, Berlin is a conurbation in which the air quality must be evaluated annually and, if necessary, steps must be taken to comply with the limits. The complete city was designated as a planning area for the possible establishment of a plan to preserve air quality. Exceeding the limits occurs everywhere in the city, especially on main traffic streets. Therefore it is not sensible to limit the planning area to parts of the city , or to divide the city into distinct planning areas.

Problems In Applying Guideline 99/33/EG and 22. BImSchV, For Example, PM10 Pollution in the City

In the proximity of high pollution emissions, such as on street ravines, high concentrations of emissions are evident. Unlike in most industrial areas, there are many people on traffic filled streets, whether they be residents, customers or workers, who face an increased exposure to pollution. In order to meet the EU Guidelines for emissions at the locations of highest concentrations, quantification of damaging pollutants must be as accurate as possible. In addition, in Berlin the said measurements are supplemented with model measurements for all traffic congested streets in which limits could potentially be exceeded.
However, even on a traffic congested street ravine, pollution, whether from other sources or transported from a distance, plays an important role. Therefore, for the planning of measures to improve air quality in Berlin, a model system was used. The model applies to:

- street ravines
- city wide background pollution, and
- regional background pollution,

and calculates the effect of pollution from the surrounding area as well as the effect of all emitters within the city, even on traffic congested street ravines.

From the said investigations of the origin of particulate matter in Berlin, a simplified diagram shown in figure 1 was developed to show the spatial distribution of PM10 concentrations in Berlin and the surrounding area.

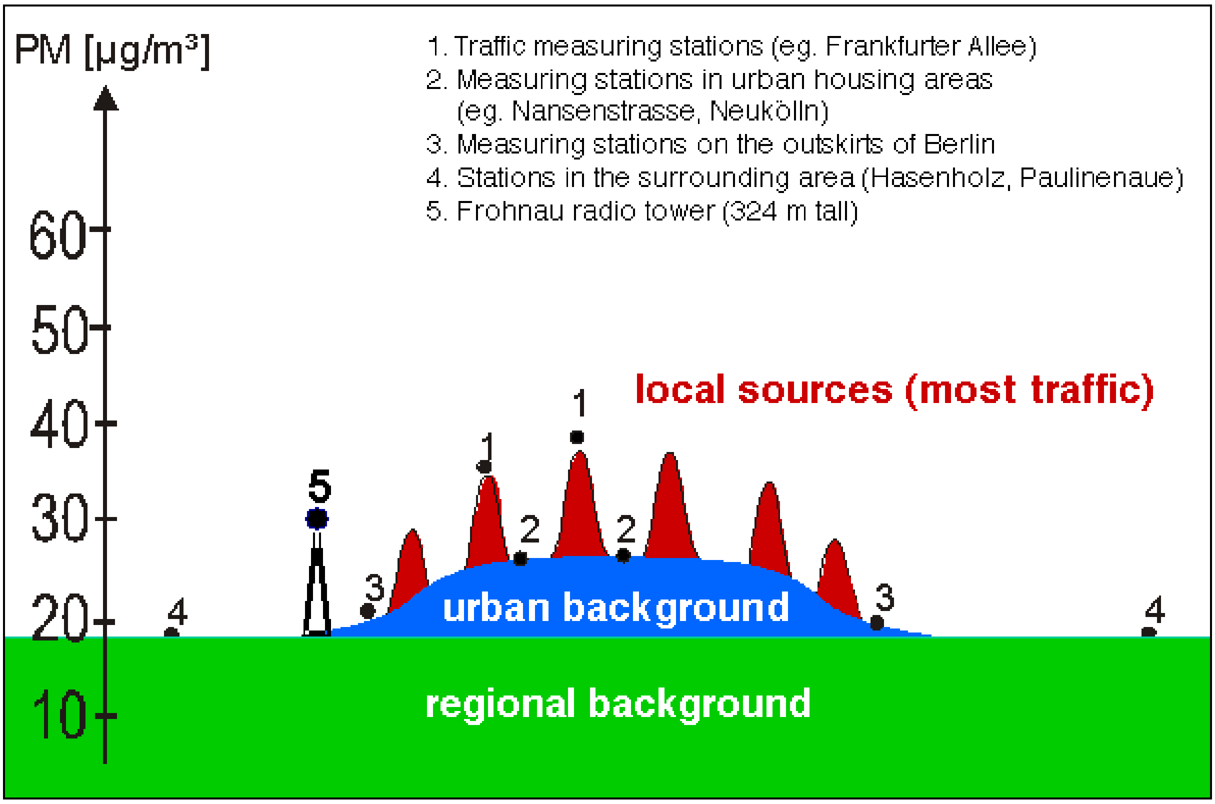

Fig. 1: Diagram showing the concentration of fine particulate (PM10) pollution in Berlin and the surrounding area (SenStadt 2005b)

In 2002, widely distributed baseline measures (green space) exists that almost amounts to 20 µg/m³ on the basis of measurements at several rural stations in Brandenburg. The portion described as regional background pollution is, outside of the city, relatively evenly distributed, as the widely distributed model results show. Added to that, the "made in Berlin" sources of pollution cause part of the PM10 pollution. It can be divided into:

- that portion contributed by the overloading of all of B's sources of e (t, power plants, industry, residential heating), (blue area). Together with the regional background, this corresponds with the fine particulate concentrations which are measured in residential areas of the city far away from t and industry; and
- an additional contribution, i.e. local emitters in the immediate area of the source, such as motor vehicle traffic in the Frankfurter Allee (red points).

In summary, in Berlin, barely half of the PM10 pollution measured at stations near traffic in the inner city comes from the regional background and the remaining, "made in Berlin" portion, is fine particulate pollution equally divided between contributions from local traffic and the pollution sources in the remainder of the city. Only this portion can be influenced by local measures in Berlin.

Statistical Base

Motor Vehicle Traffic Emissions Registry

The Motor Vehicle Traffic Emissions Registry was revived in 2004 because, according to previous experience, this group of polluters is a significant contributor to fine particulate and nitrogen oxide pollution. Traffic counters have been installed in many locations on the main traffic arteries of Berlin since 2001. This data shows the actual traffic patterns in Berlin and is used to design traffic flow. This information is evaluated in the **Office of Traffic Management (VMZ)** and is used to inform the populace (especially drivers) of traffic conditions and provide routing recommendations to avoid traffic jams through radio broadcasts, the internet, and centrally located sign boards.

Investigation of Traffic Patterns

Since 2002, data from approximately 400 traffic counters at approximately 300 locations on the main street networks of Berlin has been provided by the VMZ. Many of these counters are able to differentiate between passenger cars and trucks. On the basis of this automatically collected data from 2002, exhaust emissions were determined as follows:

processing of counter data from different sources available to the Office of Traffic Management for Berlin for 2002;

integration of available data with a quality weighted summary of all entry data and completion through location related diurnal variation lines;

spatial projection of the location referenced data on the complete arterial street network of Berlin, with results of mid-day traffic counts (DTV) and truck participation;

investigation of those parts of the main arterial street network used by the Berlin Public Transit Authority (BVG) busses according to route data from 2002; and

calculation of emissions with new emission factors from the UBA manual for emission factors, with consideration for the type and function of streets with the help of the IMMISem/air program.

Investigation of Emissions

Exhaust and friction emissions from moving traffic, evaporation emissions from standing traffic, and evaporation emissions from petrol stations contribute to the pollution emissions from motor vehicle traffic. Figure 2 shows an overview of the collection system. Emissions at petrol stations are assigned to "small business".

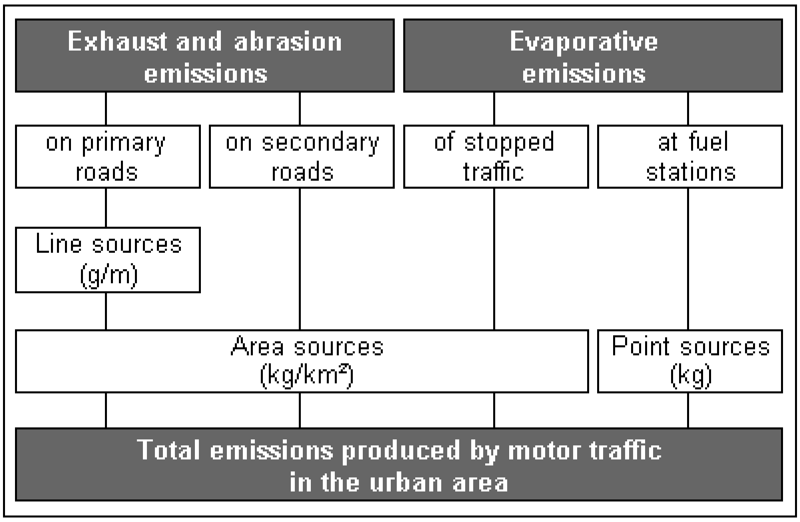

Fig. 2: Collection systems of the Traffic Emission Registry 2002

With help from emission models the pollution and CO2-emissions for line sources (main traffic streets) and surface sources (side street networks and evaporation emissions) are calculated.

The exhaust and friction emissions appear as line sources on main traffic and side streets. However, they are only calculated for the main traffic street network as line sources because the aforementioned DTV traffic counts are only available for those streets. Afterwards, the emissions from the line sources are assigned to the framework as surface sources. The emissions from the side street network are, however, derived from assumptions of traffic volume and put directly into the truck framework.

Emission Models for Main Traffic Streets (Line Sources) and Side Street Networks (Surface Sources)

Exhaust emissions from motor vehicle traffic depend on factors which can be summarized into traffic-specific and motor vehicle-specific characteristics.

Traffic-specific characteristics are described by traffic density, i.e. the number of vehicles moving on a prescribed section of a street (source), and their driving style (driving mode). Driving style is organized according to different street types (city center street, side street, main traffic artery with or without traffic control lights, freeway), and function (shopping street, residential street, or access street).

The motor vehicle-specific characteristics, generally expressed by exhaust emissions, are determined by:

- the kind of engine (four-stroke, two-stroke or diesel);
- the carburation (carburetor or fuel injection).
- the type of the fuel (two-stroke mixture, gasoline, diesel);
- the possible type of existing cleaning systems (regulated and unregulated catalytic converter, recycling of exhaust gases); and, as well,
- other factors regarding the technical condition of the engine.

Emissions also depend on the driving style (driving mode) and therefore are listed for different driving styles. Cold weather starts, which lead to increased emissions during the warm-up phase of the engine, together with evaporation emissions are considered as vehicle specific points. Here you can find all relevant emissions factors of all emitted substances for each vehicle group (passenger automobiles, light trucks, motorized two wheeled vehicles, busses and heavy trucks), and currently at least five reduction steps (80s ECE cycles, Euro I, Euro II, Euro III, Euro IV, Euro V), and for each street type.

Evaluation of Emissions From Friction and Air Movement Caused by Street Traffic

With today's knowledge, one assumes that a large part of traffic related PM10-emissions do not originate from vehicle exhaust, but rather from the stirring up of particles lying on the street surface and from tire and brake friction.

Investigations have resulted in the modified EPA formula which is the basis for the calculation of e with IMMISem/air. This formula was developed through measurements on the Schildhornstraße and the Frankfurter Allee and is based on the finding that approximately 50% of the measured added fine particulate in street ravines in not attributable to motor vehicle exhaust but, rather, is caused by motor vehicle related friction (braking and street / tire friction) and air movement.

Figure 3 shows individual output sizes for the calculation of exhaust and friction emissions from traffic, such as driving style, "stop and go" add-ons, cold weather starts etc., as well as the outcomes.

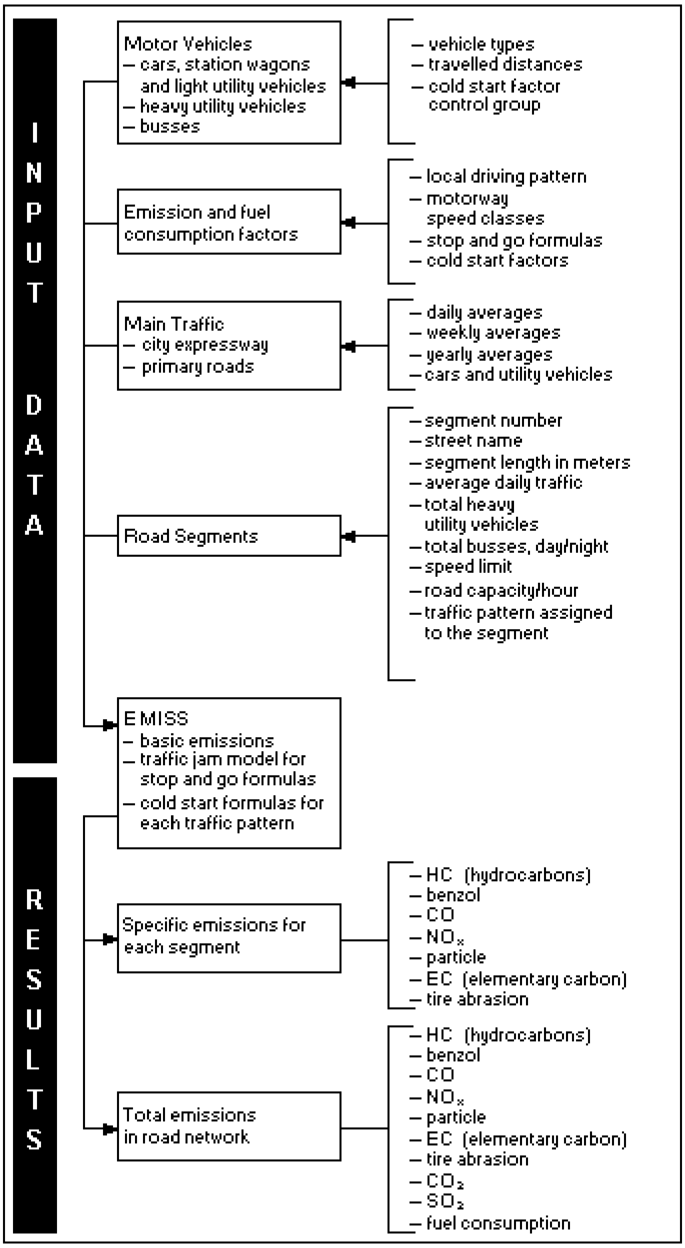

Fig. 3: Emission model for the calculation of quantities of emitted pollutants on main traffic streets (Liwicki, Garben 1993)

Emissions from motorized two wheeled vehicles cannot be shown due to missing traffic counts on main traffic networks. Their contribution to the total is determined on the basis of average traffic load in Germany and available emission data.

For areas with distinct orography, the street sections should be arranged in longitudinal categories. However, this is not necessary in Berlin.

Emission Model Side Street Networks (Surface Sources)

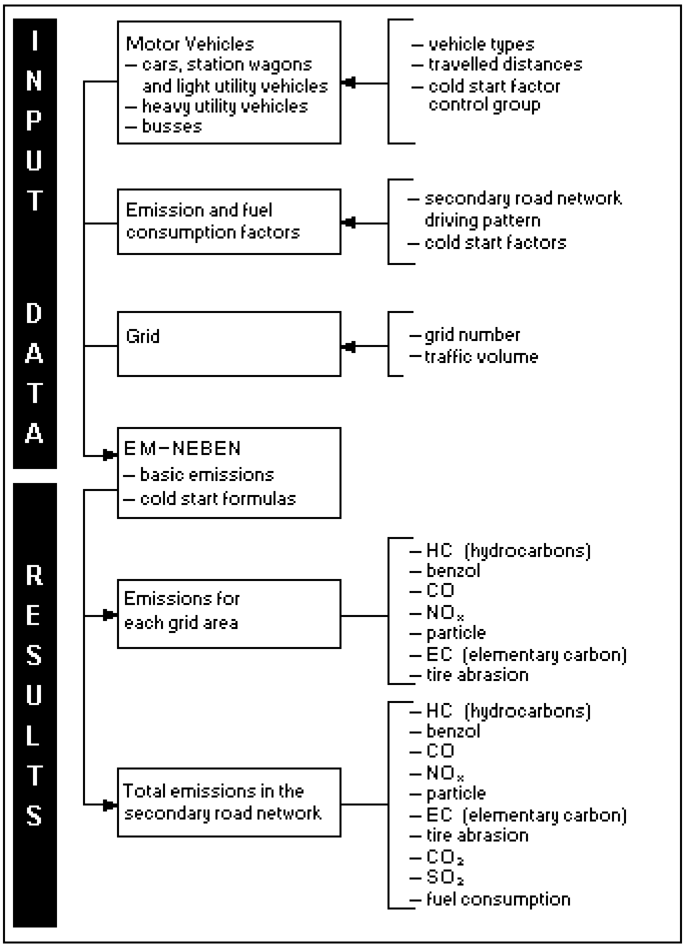

Fig. 4: EM-NEBEN - Emission model for the side street networks (Surface Sources) (Liwicki, Garben 1993)

The 2002 traffic pollution on side streets was calculated with the help of the traffic routing program VISUM which is based on the relationship between starting and end points. The resulting total driving performance and the proportion of heavy commercial vehicles was assigned to traffic cells in the city. The emissions from exhaust, air movement, and friction in side streets was determined with the emission module from IMMIS$^{em/air}$.

In side street networks, emissions are not calculated for specified sections of streets, but rather as grids for each square kilometre. The driving performance for the grids is determined on the basis of:

- the general use of the area, divided into
  - residential outskirts;
  - commercial and industry; and
  - inner city and sub centers
- the number of residents and jobs is differentiated according to
  - trade and service jobs and
  - manufacturing,
- resulting in source / goal matrixes of motor vehicle traffic.

Further inputs for determination of total emissions of each pollution component for each area corresponds to those for the calculation in the main traffic street network.

Exhaust and Friction Emissions in the City

Table 3 divides the results of motor vehicle traffic in the city of Berlin for 2002 as follows:

a. vehicle use (millions of vehicle kilometres per year);

b. fuel use (tonnes);

c. exhaust and friction emisions from motor vehicle traffic (tonnes per year);

d. according to vehicle type.

Table 3: Traffic volume (million vehicle km per year), fuel consumption (tonnes) and exhaust and friction emissions (tonnes per year) arranged by motor vehicles type in the city of Berlin - reference year 2002

	Total	Cars and station wagons	Heavy commercial transport	Light commercial transport	Transit bus	Motorized tho wheelers
Main streets						
Mileage	10.638,7	9.180,6	510,6	784,2	56,3	107,0
Fuel consumption	739.089,7	535.745,7	120.607,7	59.925,6	17.587,9	6.362,0
Hydrocarbons	2.897,0	2.389,9	235,3	130,2	38,1	103,5
Benzene	145,7	132,1	2,1	6,0	0,3	5,2
Carbon dioxide	2.346.609,8	1.657.794,9	415.317,6	174.252,2	88.758,1	10.487,0
Carbon monoxide	31.433,4	27.766,6	699,6	1.517,9	269,0	1.180,2
Nitrogen oxide	8.767,0	4.132,6	3.220,5	517,2	883,0	13,8
Exhaust particles	327,0	90,4	154,8	48,4	31,9	1,6
Particulate matter (PM10) from tire friction, air movement, etc.	925,0	472,9	331,1	63,3	55,2	2,5
Elemental carbon (exhaust and tire friction)	142,1	48,1	63,6	18,4	11,5	0,6
Sulphur dioxide	44,0	15,6	18,8	5,4	4,0	0,1
Side streets						
Mileage	2.073,0	1.848,4	63,6	144,4	7,8	10,1
Fuel consumption	196.682,6	147.294,9	20.507,1	15.071,8	3.330,5	651,4
Hydrocarbons (also from tank respiration)	2.764,3	2.511,5	97,3	133,0	10,5	12,0
Benzene	56,0	53,2	0,4	2,4	0,0	0,2
Carbon dioxide	587.494,9	470.930,3	58.037,6	49.619,4	89.075,6	556,3
Carbon monoxide	12.825,6	12.082,3	100,0	616,6	27,1	53,2
Nitrogen oxide	1.687,9	945,9	505,7	134,4	101,8	0,9
Exhaust particles	67,1	23,4	25,8	14,1	3,9	0,1
Particulate matter (PM10) from tire friction, air movement, etc.	125,0	77,6	33,0	10,4	3,9	0,1
Elemental carbon (exhaust and tire friction)	34,6	14,6	11,9	6,4	1,7	0,0
Sulphur dioxide	10,8	5,3	3,2	1,8	0,5	0,0
Entire City						
Mileage	12.711,7	11.029,0	574,2	928,6	64,1	117,1
Fuel consumption	935.772,3	683.040,6	141.114,8	74.997,4	20.918,4	7.013,4
Hydrocarbons	5.661,3	4.901,4	332,6	263,2	48,6	115,5
Benzene	201,7	185,3	2,5	8,4	0,3	5,4
Carbon dioxide	2.934.104,7	2.128.725,2	473.355,2	223.871,6	177.833,7	11.043,3
Carbon monoxide	44.259,0	39.848,9	799,6	2.134,5	296,1	1.233,4
Nitrogen oxide	10.454,9	5.078,5	3.726,2	651,6	984,8	14,7
Exhaust particles	394,1	113,8	180,6	62,5	35,8	1,7
Particulate matter (PM10) from tire friction, air movement, etc.	1.050,0	550,5	364,1	73,7	59,1	2,6
Elemental carbon (exhaust and tire friction)	176,7	62,7	75,5	24,8	13,2	0,6
Sulphur dioxide	54,8	20,9	22,0	7,2	1,0	0,1

Tab. 3: Traffic volume (million vehicle km per year), fuel consumption (tonnes) and exhaust and friction emissions (tonnes per year) arranged by motor vehicle type in the city of Berlin - reference year 2002

The new method of measuring emissions for this KATASTER is also a suitable basis for extended calculations to determine the extent of pollution in streets. The far reaching reorganization of calculation methods allows for only very limited comparisons with previous emissions increases because they are based on a much simpler method of calculation.

Emissions - Results of Stationary Measurements

Street measuring stations are operated to collect pollution caused by motor vehicle traffic with the existing automatic BLUME air measurement street measuring station system. Some changes have

taken place in the Berlin air quality measuring system in the past years in order to meet the EU Guidelines and the previously issued amendment of BlmSchG and the 22nd BlmSchV from 2002.
The measurement of these components could be correspondingly reduced because the concentration of sulphur dioxide and carbon monoxide still amounts to a fraction of the limits. At the same time, more attention is being directed towards the regulation of particulate matter (PM10) and nitrogen dioxide, particularly in the proximity of traffic.

Measurement of the Impact of Emissions in Urban Areas

In 2005, at 16 measuring containers (5 on the outskirts of the city, 5 in the inner city background, and 6 at road locations) and at 35 RUBIS measuring locations, air pollution measurements were conducted. Starting in 2005, the RUBIS measurements (small measurement locations with active and passive collectors of nitrogen dioxide, benzene and soot weekly averages) were collected biweekly. The location of the measuring stations is shown in figure 5. The concrete addresses can be taken from the monthly air pollution control reports of the Senate Department of Urban Development (only in german).

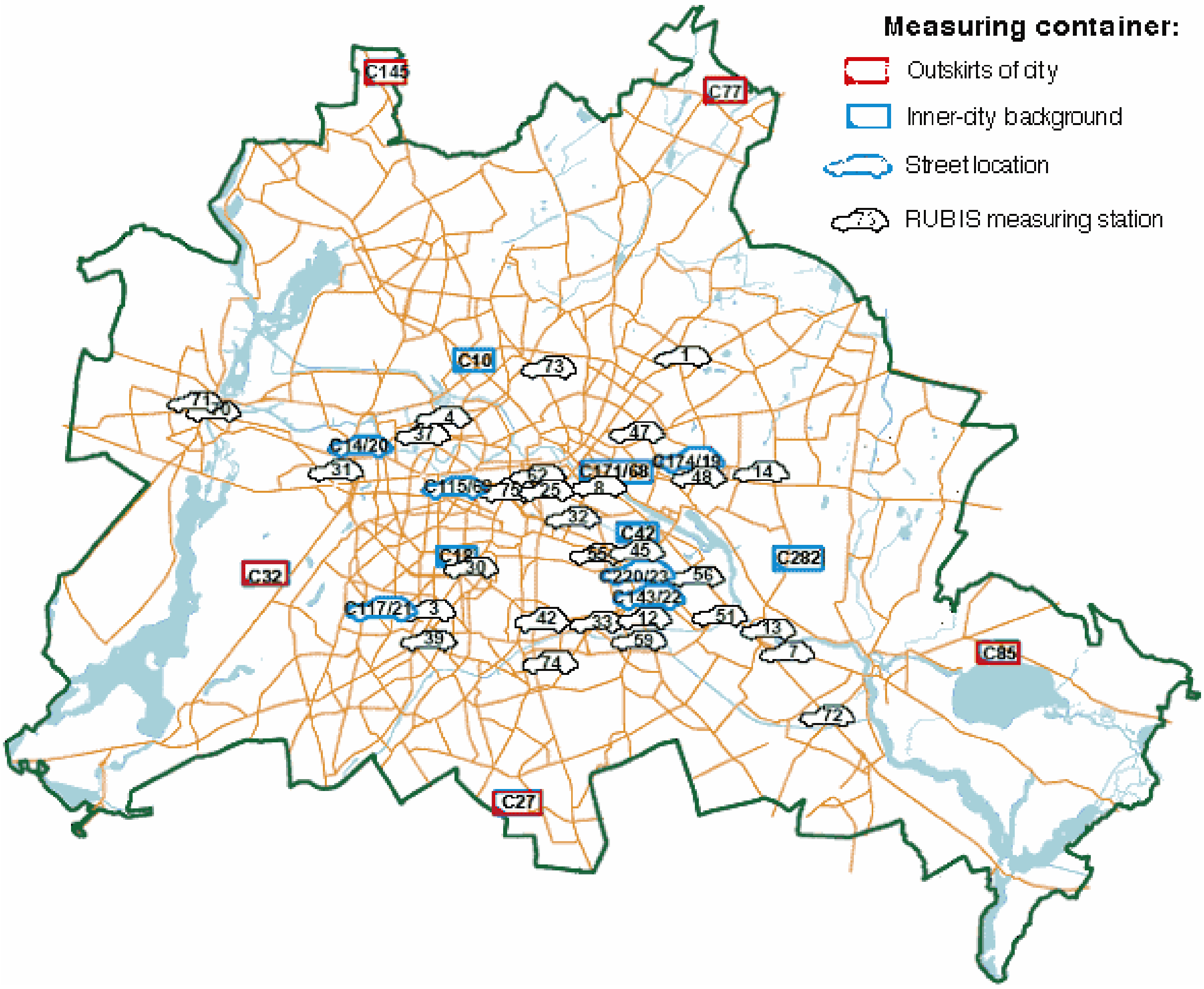

Fig. 5: Location of the active and passive collection devices for the collection of weekly samples of benzene, PM10 and nitrogen dioxide, as well as the automatic container measuring locations

The elevation of the measured concentration levels is not totally dependent on the number of motor vehicles and the resulting emissions, but also on the air movement conditions that, on the one hand are controlled by meteorological parameters (e.g. the wind), and, on the other hand, by the style and extent of building construction. As there is a high emission impact registered in streets where buildings are constructed on both sides (street ravines), such as in the Silberstein Street in Neu Koeln, or the Schildhorn Street in Steglitz, while on the city freeway, which carries a noticeably higher traffic volume, lower pollution concentrations are found. Figure 6 shows typical pollution distribution in a road ravine. Such distribution develops if the wind blows (over roofs) from the measuring location in the direction of the road, resulting in a turbulence that is formed in the street ravine. This blows the motor vehicle emissions to the side of the road where the measuring station is located.

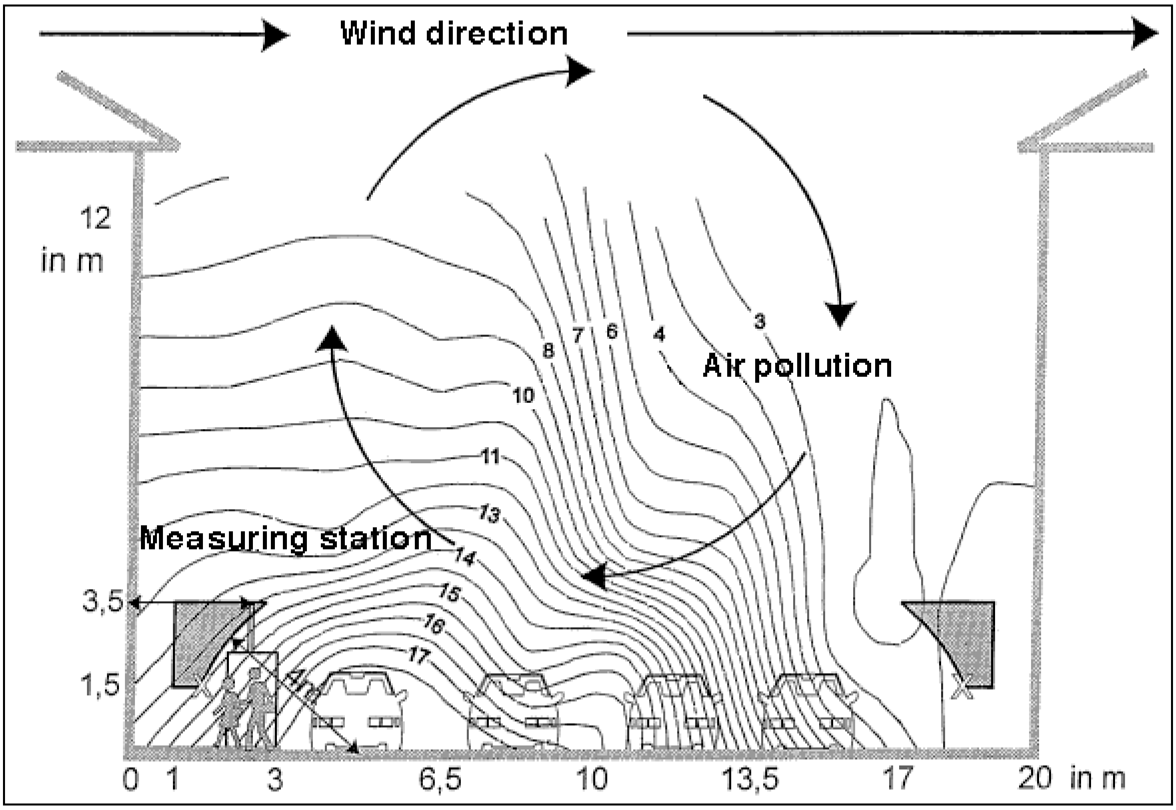

Fig. 6: Pollution distribution in a street ravine with measuring range according to the 23. BImSchV and points considered for calculation with the IMMIS$^{em/air}$ street ravine model

Long Term Trend for Nitrogen Dioxide Concentrations in the City

Until 2005, the results of measurements taken on major streets showed a long term trend (see firgure 7):

- At all three station categories shown, the NO_2 pollution hardly changed during the past ten years. The results at busy streets (red curve) still clearly lay above the European Union limit of 40 µg/m³. The expectation of reduced nitrogen oxide emissions due to improvements to exhaust technology for vehicles has not lead to a decrease of these emissions.
- By contrast, the results for nitrogen monoxide (NO) from traffic near measuring locations have - as shown by the pink curve - decreased by nearly 40 % during the past 5 years. Nitrogen oxide emissions are decreasing as well, but with only a 30 % reduction between 2000 and 2005.
- The obvious discrepancy between the development of NO_2 pollution which is relevant to air pollution and NO_x emissions from street traffic is not a phenomenon that is limited to Berlin, as it is also observed in many European conurbations.

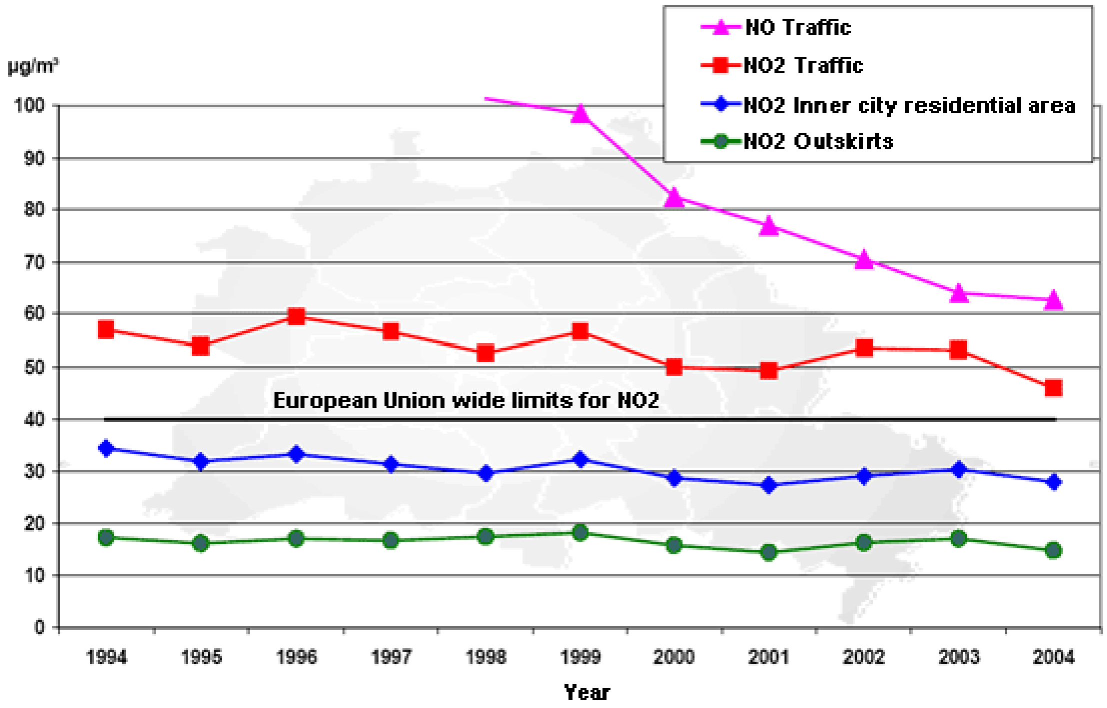

Fig. 7: Long term trend of nitrogen dioxide and nitrogen monoxide data in Berlin

Long Term Trend of the PM10 Concentrations in the City

Figure 8 shows the development of PM10 and soot concentrations in Berlin and the surrounding area over the past years, when the convervsion of measurements from total particulate to fine particulate matter (PM10) took place.

The red curve shows pollution at three measuring locations near traffic, while the blue and dark-green lines show the concentrations at three measuring locations in populated areas of the inner city and five measuring locations on the outskirts of the city. The measured soot levels at eight traffic measuring locations are shown by the black curve. In order to compare data from urban areas, data from up to four rural stations in Brandenburg was added.

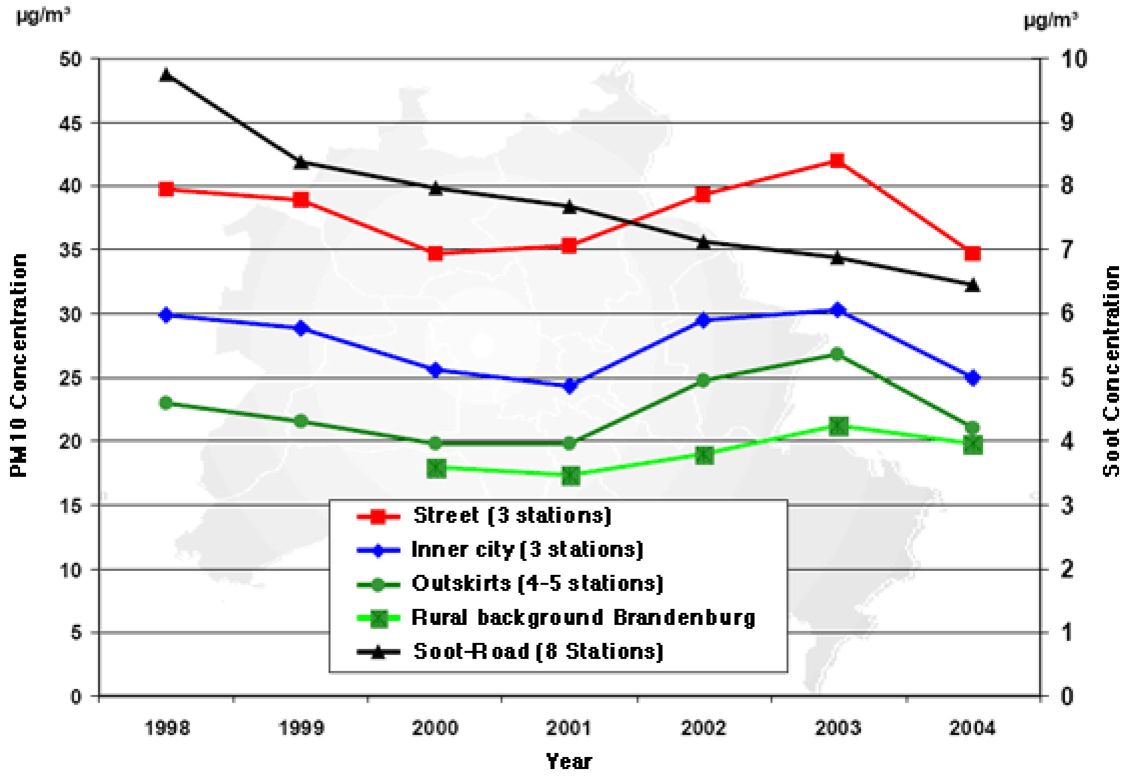

Fig. 8: Long term trend of PM10 and soot concentrations in Berlin

Comparison of the curves, reveals the following noteworthy points:

- The PM10 concentration in the rural environment of Brandenburg equals about half of the PM10 pollution on the main streets the city center of Berlin.
- The steady decrease in particulate levels that continued until the end of the 90s has not continued during the past few years.
- In contrast, during the past six years, soot pollution on main traffic streets has decreased by nearly 40 % - a result, amongst other things, of the technical improvement of vehicle exhaust systems, such as the bus fleet of the Berlin Transit Authority, the BVG.
- The annual variation of PM10 levels is similar at all stations. In particular, the clear resurgence of PM10 levels in 2002 and 2003 is a phenomenon that appears at the same time throughout the city, as well as at stations located on the outskirts of the city. Therefore, to find the cause, one should not concentrate primarily on Berlin's PM10 emissions, but, rather, the cause is attributable to unfavourable weather conditions and large scale transport of fine particulates.

Methodology

Model Input

The results of street measurements show that the concentration levels set forth in Guideline 99/33/EG and the 22nd BImSchV are exceeded at a large number of main traffic streets, especially soot levels. As technical measurements on all streets in the city are not possible for cost reasons alone, the pollution emissions from all of the main street networks in Berlin were established using emission and extension calculations. Thereby the streets where, most likely, legal limits are exceeded, and those where limits are met, are determined.

To achieve this, the said measurements are supplemented with model calculations in all traffic filled streets in which limits are potentially exceeded. However, even in a traffic filled street ravine, the background pollution produced by other sources in the city and by the long distance transport of pollution plays an important role. Therefore, to plan the improvement of air quality in Berlin, a system of models was developed that can calculate both the large scale influence of distant sources as well as the contribution of all emitters in the city, even in traffic filled street ravines. For such an estimation of all main streets (**Screening**), the aptly designed modular program system IMMIS■■■ is suitable.

IMMIS■■■ is a Screening program system for the evaluation of pollution caused by street traffic. It was developed specifically for applications of traffic related evaluations. With the help of this program - provided the necessary input data is known - a rapid computation of the emission load is possible for both individual streets and comprehensive street systems.

Herewith pollution on both sides of the street is calculated for each point at an elevation of 1.5 m and a distance of 1.5 m from the edge of the building (see figure 6). The average of the calculated emissions at these two points is regarded as a characteristic estimation of the emission pollutants in this section.

Pollution from traffic in street ravines was modelled with the $IMMIS^{cpb}$ IMMIScpb program. It facilitates the calculation of hourly levels of pollutants produced by local traffic, as arbitrary points (receptors) are located in street ravines with differing building heights and differing spaces between buildings which allow the passage of wind on the basis of easily accessible meteorological data. The emission levels for each section of street are additional and necessary input data. The emissions were calculated with the $IMMIS^{em}$ program from actual data. The pre existing pollution from the city is made up of: the additional pollution measured by the street ravine model; pollution caused by local street traffic; and the urban background calculated with the $IMMIS^{net}$ program.

Evaluation Based on an Index

The map derived from these works shows the spatial distribution of traffic caused pollution for NO_2 and PM10. For both substances a collective evaluation was conducted. The resulting index weighs the calculated concentrations of both pollutants according to their readings from about 7000 street sections of the main traffic network for 2002 and it adds the quotients. An index of 1.00 results when both components reach 50% of the limit. All sections that show a reading exceeding 2.00 require special attention in the future (compare effects on human health).

Data Display

The results capture detailed information regarding selected sections. (With the appropriate button, mark one or more of the colored count sections with the right mouse button and confirm with the left. If you press the "actual data display" button the selected data will appear on the right side.) Beside the key number of the section, the following parameters are represented:

- name of the municipality where the section lays;
- street name;
- average daily traffic volume (DTV) for automobiles, trucks and two-wheeled vehicles;
- number of BVG busses per day;
- emission data for 2002 related to the following substances:
    - benzene;
    - soot;
    - carbon Monoxide;
    - carbon Dioxide;
    - nitrogen Oxide;
    - particles (total); and
    - particles (exhaust);
- the calculated e for 2002 related to the following substances:
    - the annual average amount of NO_2;
    - the 24 hour amount of PM10; and
    - the annual average amount of PM10;

- the trend calculations of emissions for 2005 and 2010, in each case related to the following substances:
    - the annual average amount of NO_2;
    - the 24 hour amount of PM10; and
    - the annual average amount of PM10.

Map Description

Index of Air Pollution for PM10 and NO_2 in 2002

Measurements of the concentration of pollutants are only representative for a limited area around the measuring location. Extensive calculation models were applied to the distribution of pollution in the city, together with the information garnered from the BLUME measuring locations to attain a complete picture. The calculation models are fully explained in the chapter Methodology in relation to street ravine weather conditions, together with traffic and emission data from 2002 which served as a base.

The urban background pollution from PM10 is illustrated in figure 9. Clearly there is a noticeable rise in the data from the outskirts of the city to the city center within the S-Train ring (large dog head).
The concentration between 25 and 32 µg/m³, calculated in the city center, represents pollution in residential areas with less traffic and at greater distances from industrial plants.

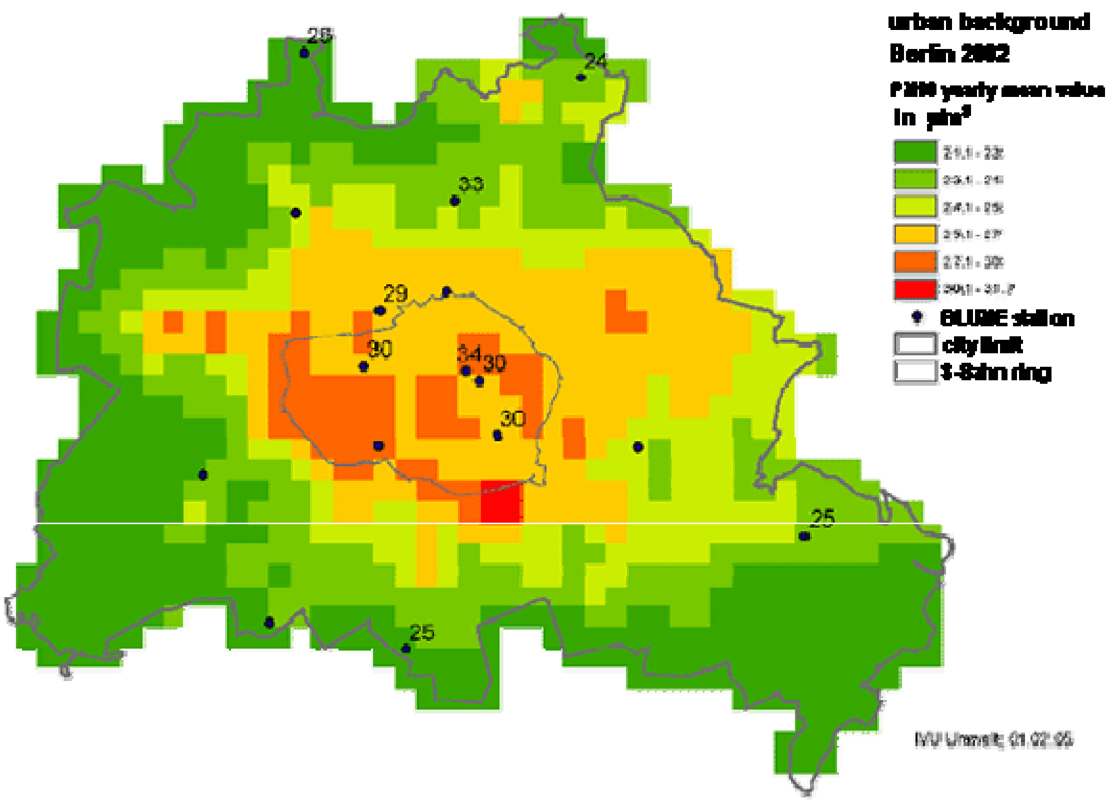

Fig. 9: PM10 pollution (annual average) calculated with IMMIS^net and measured at BLUME measuring locations in the urban background of Berlin for the base year 2002 (SenStadt 2005b)

Based on the pollution distribution the calculations of PM10 and NO2 pollution emissions in the main street transit network was pursued as shown on the map. The calculation is completed through an extensive data display for each evaluated street section. It results from the overlay of the respective concentration in the urban background and the calculated additional pollution from local transit in respective sections of the main traffic streets. All red coloured street sections show excesses of the 24 hour limits for PM10 and / or the annual averages for NO2 from 2002 (compare table 2).
These sections are therefore classified as "very highly polluted" and require special attention to minimize near-surface air pollution in the future. The sections are distributed throughout the whole of

the city, concentrated, however, in a ring formation around the city center, in the large arterial streets heading south and east, and the important connecting streets in the city such as the streets Bismarckstr./Kaiserdamm in Charlottenburg, the Tempelhofer Damm, including the southern extension, and the Frankfurter Allee or the Adlergestell in Köpenick. The overall length of the street sections adds up to approximately 281 km (= 23 % of the main arterial street system), where more than 125,000 people live (see table 4).

Those most affected live within the area of the so-called "large dog head" and along the arterial streets. The high pollution levels on the city freeway, which are clearly shown on the map, affect very few residents because the gap between the freeway and the houses is relatively large and the open space on the freeway allows the air to mix well.
The map also shows that a further quarter of all sections also exceed the index limit of 1.76 - 2.00. As well, this approximate 335 kilometre long section of the main street network can, at least in some parts, pose a problem in the future as usually also exceeds at least one parameter of the relevant limits.

Table 4: Section lengths of the air pollution index and affected residents in the main arterial street networks of Berlin 2002

Index of air pollution through PM10 and NO2	Analysis of Main Street Network			
	km street length	%	% accumulated	Affected Residents
<=1,50 slightly polluted	350,8	28,2%	28,2%	36.615
1,51 - 1,75 moderately polluted	278,6	22,4%	50,5%	65.788
1,76 - 2,00 increasingly polluted	335,0	26,9%	77,4%	117.449
> 2,00 very high polluted	281,0	22,6%	100,0%	125.031
Sum	**1.245,4**	**100,0%**		**344.883**

Tab. 4: Section lengths of the air pollution index and affected residents in the main arterial street network of Berlin 2002

The method applied to calculate the number of residents affected by limit excesses is taken from noise mapping (see also map 07.02 traffic noise (edition 2005)). The number of inhabitants whose residences front on the street is calculated. The number of citizens affected by limit excesses represents a rather conservative estimate, because pollutants spread everywhere and therefore increased concentrations can also be found outside of highly polluted street ravines.

Computed Trends for the Substances PM10 and Nitrogen Dioxide (NO_2) for 2005 and 2010

In regard to long term compliance with air quality limits, the calculation of trend scenarios has significant value. They allow for the future development of large scale and local air pollution estimates and evaluation of whether the adopted measures must be strengthened in order to achieve a decline in air pollution. The emission readings for 2002, which form a basis for the calculation of air pollution indexes establish baselines. The resulting trend scenario takes into account both the 2005 and 2010 trend lines for e decreases in Europe and Germany, as well as in Berlin. They also show the progress achieved in the reduction of emissions from factories, power plants, and motor vehicles, as well as, for example, emissions of fine particulate matter from agricultural activity as a result of European regulations.
Due to the gradual replacement of older vehicles that have high pollution emissions, exhaust emissions (including nitrogen oxides and particles) from motor vehicle traffic will see a 30 % reduction by 2010. However, as traffic volume will increase, tire and brake friction, combined with the stirring up of street dust will increase the amount of fine particulate.

Compared to 2002 readings, 2010 total results for Berlin will see at least a 20 % reduction of NO_x emissions and an approximate 6 % reduction of PM10.

It can be predicted that, even in 2010, the 24 hour limits for PM10 on about 200 kilometres of main street networks will be exceeded, affecting approximately 80,000 residents (see table 5)). Thus, additional measures in Berlin on national and European scales must be taken to further reduce both components.

The concentrations in main traffic streets will be reduced by 2010 by 22 % on average due to the measures resulting from trend scenarios which have been introduced to date. Hence the number of streets with limit excesses, and the number of impacted residents are clearly reduced. In addition, Berlin's specific measures are needed to relieve the remaining 59 kilometres of streets where 17,700 people live.

Table 5: Calculation for 2002 and trend calculation for 2005 and 2010 from limit excesses on affected section lengths and residents in arterial street networks						
Accounted Substances PM10 and NO2	Calculation of exceeded limit values for 2002		Trend calculation of exceeded limit values for			
			2005		2010	
	km street length	Affected residents	km street length	Affected residents	km street length	Affected residents
NO2 [Annual mean in µg/m3]	211	92.000	170	70.000	59	17.500
PM10 [24hour limit in µg/m3]	450	192.000	344	146.000	199	80.000
PM10 [Annual mean in µg/m3]	17	5.700	15	4.000	9	2.300

Tab. 5: Calculation for 2002 and trend calculations for 2005 and 2010 from limit excesses on affected section lengths and residents in arterial street networks.

Summarised, it can be concluded that

- on the action side, in Berlin for 2007, the prescribed limits for pollution output from industrial plants have already been achieved and are, in part, below limits;
- the measures already implemented or introduced will lead to a 7 to 10 % reduction of fine particulate pollution and a 22% reduction of nitrogen dioxide emissions in the city's residential areas; and
- these decreases will suffice to meet the annual average fine particulate limit in years with adverse weather conditions. As well, by 2010 they will more than halve the length of street sections and affected citizens where the 24 hour limit for fine particulates and the annual limit for nitrogen dioxide are exceeded.

The additional possible measures and their effect on air quality is described in detail in the air monitoring and action plan for Berlin 2005-2010, passed by the Berliner Senate in August 2005.

Literature

[1] **BMUNR (Bundesminister für Umwelt, Naturschutz und Reaktorsicherheit) (Hrsg.) 1987:**
Auswirkungen der Luftverunreinigung auf die menschliche Gesundheit. Bericht für die Umweltministerkonferenz, Bonn.

[2] **IVU Umwelt GmbH 2005:**
Programmsystem **IMMIS**■■■
Internet:
http://www.immis.de/

[3] **Kalker, U. 1993:**
Gesundheitliche Bewertung der verkehrsbedingten Schadstoffe Stickoxide, Benzol und Dieselruß-Partikel, in: Forum Städte-Hygiene 44, Frankfurt.

[4] **Kühling, W. 1986:**
Planungsrichtwerte für die Luftqualität, in: Schriftenreihe Landes- und Stadtentwicklungsforschung des Landes Nordrhein-Westfalen. Materialien, Band 4.045, Hrsg.:

Institut für Landes- und Stadtentwicklungsforschung des Landes Nordrhein-Westfalen im Auftrag des Ministers für Umwelt, Raumordnung und Landwirtschaft des Landes NRW, Dortmund.

[5] **Liwicki, M., Garben, M. 1993:**
Emissionskataster Straßenverkehr Berlin 1993, Gutachten im Auftrag der Senatsverwaltung für Stadtentwicklung und Umweltschutz, Berlin, not published.

[6] **Nowak, D., Jörres, R., Magnussen, H. 1994:**
Luftverschmutzung - Asthma - Atemswegsallergien. Zwischenergebnisse deutsch-deutscher epidemologischer Studien, in: Deutsches Ärzteblatt 91, Heft 1/2, Köln.

[7] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2005a:**
Luftgüte-Meßnetz (BLUME), Download detaillierter Monats- und Jahresberichte, Berlin.
Internet:
http://www.stadtentwicklung.berlin.de/umwelt/luftqualitaet/de/messnetz/monat.shtml

[8] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2003:**
mobil2010, Stadtentwicklungsplan Verkehr, Entwurfsstand Juli 2003, Berlin.
Internet:
http://www.stadtentwicklung.berlin.de/planen/stadtentwicklungsplanung/de/verkehr/download.shtml

[9] **SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2005b:**
Luftreinhalte- und Aktionsplan 2005-2010, Berlin.
Internet:
http://www.stadtentwicklung.berlin.de/umwelt/luftqualitaet/de/luftreinhalteplan/doku_lrp_2005_2010.shtml

Laws and Ordinances

[10] **Allgemeine Verwaltungsvorschrift über straßenverkehrsrechtliche Maßnahmen bei Überschreiten von Konzentrationswerten nach der 23. BImSchV (VwV-StV-ImSch) Bundesanzeiger Nr. 243, S. 13393 vom 31. Dezember 1996.**

[11] **23. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Festlegung von Konzentrationswerten - 23. BImSchV), BGBl I Nr. 66, S. 1962 vom 20. Dezember 1996.**

[12] **Richtlinie des Rates vom 7. März 1985 über Luftqualitätsnormen für Stickstoffdioxid (Richtlinie 85/203/EWG), Amtsblatt der Europäischen Gemeinschaften L 87/1.**

[13] **Richtlinie 96/62/EG über die Beurteilung und die Kontrolle der Luftqualität. Amtsblatt der EG v. 21.11.96 Nr. L 296 S. 55.**

[14] **Richtlinie 99/33/EG über die Grenzwerte für Schwefeldioxid, Stickstoffdioxid und Stickoxide, Partikel und Blei in der Luft. Amtsblatt der EG vom 29.6.99, Nr. L 163 Seite 41.**

[15] **Richtlinie 2000/69/EG über Grenzwerte für Benzol und Kohlenmonoxid in der Luft. Amtsblatt der EG vom 13.12.2000, Nr. L 313 Seite 12.**

[16] **Richtlinie 2002/3/EG über den Ozongehalt der Luft. Amtsblatt der EG vom 9.3.2002 Nr. L 67 Seite 14.**

[17] **Richtlinie 2004/107/EC über Grenzwerte für Arsen, Kadmium, Quecksilber, Nickel und polyzyklische aromatische Kohlenwasserstoffe. Amtsblatt der EG vom 26.01.2005 Nr. L 23 Seite 3.**

[18] **Siebtes Gesetz zur Änderung des BImschG. BGBl. Jahrgang 2002, Teil I, Nr. 66, S. 3622 ff, vom 17. September 2002.**

[19] **33. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes vom 13. Juli 2004. BGBl. I Nr. 36 2004, Seite 1612 ff.**

[20] **22. Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes vom 11. September 2002. BGBl. I 2002, Seite 3626 ff.**
Internet:
http://bundesrecht.juris.de/bundesrecht/bimschv_22_2002/index.html

Maps

[21] SenStadt (Senatsverwaltung für Stadtentwicklung Berlin) (Hrsg.) 2005c:

Umweltatlas Berlin, aktualisierte und erweiterte Ausgabe 2005, Karte 07.02 Straßenverkehrslärm, 1 : 50 000, Berlin.
Internet:
http://www.stadtentwicklung.berlin.de/umwelt/umweltatlas/din_702.htm