**SPATIAL REPRESENTATIVENESS OF AIR QUALITY SAMPLES AT HOT SPOTS**

*V. Diegmann[1], F. Pfäfflin[1], Y. Breitenbach[1], M. Lutz[2], A. Rauterberg-Wulff[2], W. Reichenbächer[2] and R. Kohlen[3]*

[1]IVU Umwelt GmbH, Emmy-Noether-Str. 2, 79110 Freiburg, Germany
[2]Senate Departement for Urban Development and the Environment, 10707 Berlin, Germany
[3]VMZ Berlin Betreibergesellschaft mbH, Tempelhofer Damm 1-7, 12101 Berlin, Germany

**Abstract**: Exceedances of the air quality limit values for $NO_2$ and PM2.5/PM10 in Europe are mostly measured in the vicinity of roads. In general, the concentration distribution at hot spot locations in urban areas is very inhomogeneous due to the complex building situation. The EU air quality directive specifies details for the siting of air quality sampling points at traffic-oriented sites. Based on microscale model calculations, this paper discusses the possibility of assessing the spatial representativeness of the air pollution for specific hot spot examples and provides some hints on the applicability of HBEFA in hot spot analysis.

***Key words:*** *road traffic, concentrations, hot spot, spatial representativeness, EU air quality directive, HBEFA, LOS, microscale, model,* $NO_2$, $NO_X$

## INTRODUCTION

The highest concentrations of $NO_2$ and PM2.5/PM10 in Europe are measured in the vicinity of roads (e. g. Mol et al., 2011; EEA, 2012). At these hot spots, exceedances of the air quality limit values are observed. The hot spots are usually characterized by a high building-density resulting in poor ventilation, by a large share in heavy vehicles and high traffic volumes, often in conjunction with a low traffic quality. The EU air quality directive 2008/50/EC specifies details for the siting of air quality sampling points in hot spots. Sampling points at traffic-oriented sites should be representative of the air quality for a street segment no less than 100 m length and more than 25 m distant from junctions. It is, however, not specified how the representativeness of 100 m is to be assessed and how the segment of 100 m is to be defined exactly.

In general, the pollution concentration distribution at hot spot locations in urban areas is very inhomogeneous due to the complex building situation. A sampling site being representative for a street segment of 100 m length in the sense that concentrations are constant along this segment is not definable in most cases. Therefore, the assessment of spatial representativeness has to be based on the concentration distribution in the hot spot area, which is usually not known.

This paper discusses the possibility of assessing the spatial representativeness of hot spot air quality sampling points by means of modelling. Emission modelling based on HBEFA 3.1 (INFRAS, 2010) and microscale modelling was employed to calculate in detail the complex air flow conditions and the resulting concentration distribution at two hot spot areas in Berlin, Germany. Criteria are described to define an assessment area and an approach is presented to assess the spatial representativeness from the modelling results. In addition, some hints on the applicability of HBEFA in hot spot analysis are provided.

## MODELLING

Modelling was carried out for two hot spot areas in Berlin, Germany, namely the air quality sampling sites Silbersteinstraße (Figure 1) and Frankfurter Allee (Figure 2). While the sampling point Silbersteinstraße is on a narrow sidewalk at a busy traffic spot close to a complex intersection, the sampling point Frankfurter Allee is located just beyond the kerbside between the carriageway and a wide sidewalk including a separate cycle track in a typical, relatively homogeneous street canyon.

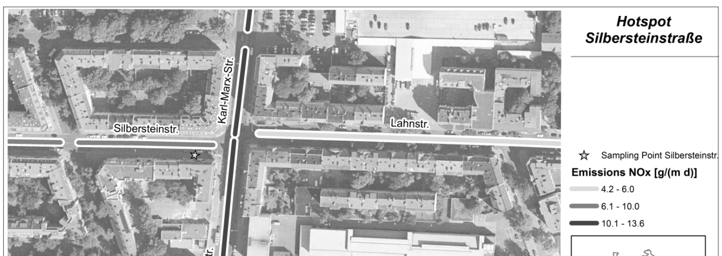

Figure 1: Hot spot area Silbersteinstraße

The calculation of vehicle emissions was done with IMMIS$^{em}$ (IVU Umwelt, 2011) based on HBEFA 3.1 (INFRAS, 2010). Vehicle emissions were assumed to be homogeneous throughout each considered street segment (Figure 1 and Figure 2). Information on mean daily traffic volumes and fractions of vehicle types (cars, vans, lorries and buses) was available for each street segment. Traffic situations were assigned depending on the respective road category. For each road section, traffic volumes were distributed among the different quality levels of traffic flow (level of service, LOS) according to HBEFA, inter alia, by assessing the individual traffic capacity of each street segment. The calculated vehicle emissions were distributed over the respective street segments for use as input data for the dispersion modelling.

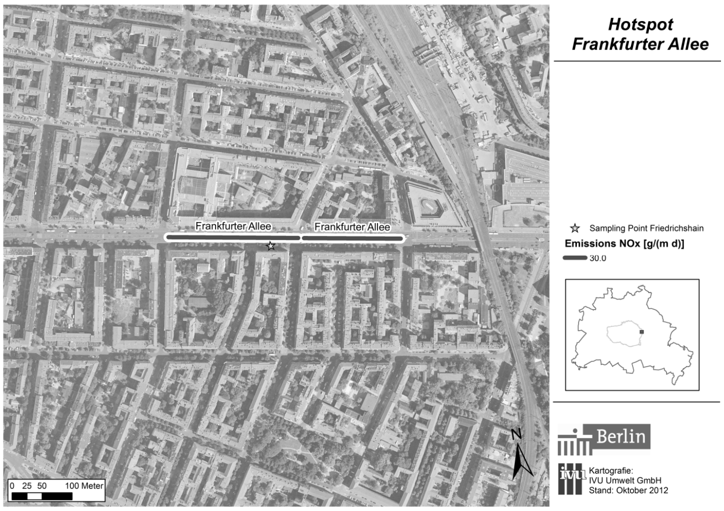


Figure 2: Hot spot area Frankfurter Allee

Dispersion modelling was carried out with the three-dimensional microscale model MISKAM (Eichhorn, J. 2011). MISKAM consists of a prognostic, non-hydrostatic wind field model and a Eulerian dispersion model. Buildings are considered in the form of rectangular block structures. The investigation area for the sampling site Silbersteinstraße has a size of 380 m x 300 m with a horizontal resolution of 1 m. It contains the location of the air quality monitoring station and the adjacent street sections, including the intersection with Karl-Marx-Straße. The size of the investigation area Frankfurter Allee is 240 m x 200 m, horizontal resolution is 1 m as well. Both investigation areas are the centre part of a much larger modelling area to avoid boundary effects within the investigation area.

MISKAM modelling was performed based on the IMMIS$^{em}$ emission data described above and on the meteorological data measured at the Berlin air quality monitoring station Grunewald. Base year was 2008 for Frankfurter Allee and 2009 for Silbersteinstraße. The annual mean wind velocity was in the order of 2.5 m/s in both years. While westerly and south easterly winds prevailed in 2008, north easterly to south easterly winds dominated in 2009.

Figure 3 shows the modelling results of the additional $NO_X$ pollution generated by traffic for the surroundings of the sampling point Silbersteinstraße. Results were evaluated for the modelling level 3 - 5 m above ground which corresponds to the sampling height of 3.5 m at the monitoring site. The example shows a strong variation of $NO_X$ concentrations along this part of Silbersteinstraße due to the intersection with the heavily-trafficked Karl-Marx-Straße. The mean daily traffic of Karl-Marx-Straße amounts to 30000 vehicles per day north and 24000 vehicles south of this intersection, being twice as much as the traffic volume in Silbersteinstraße. Emissions from the intersection are transported along Silbersteinstraße, leading to higher concentrations close to the intersection and a strong gradient along Silbersteinstraße, where the sampling point is located. Due to the strong spatial decrease in concentrations, it is difficult to define a representative sampling site in Silbersteinstraße.

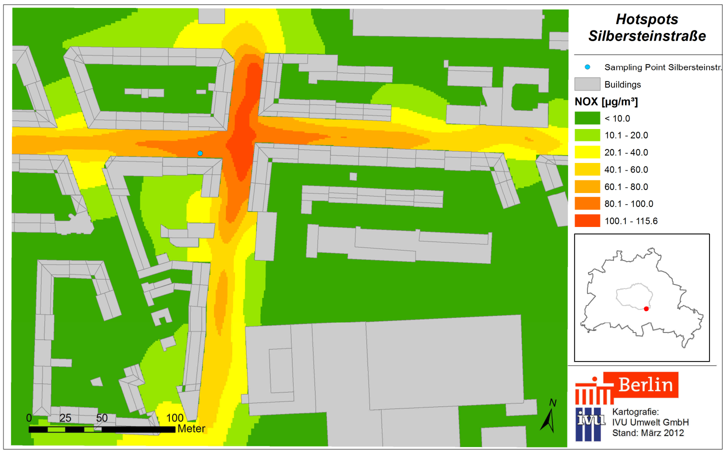


Figure 3: Distribution of the additional $NO_X$ pollution from traffic at hot spot location Silbersteinstraße

Figure 4 gives the additional $NO_X$ pollutant load from traffic for the surroundings of the sampling point "Friedrichshain" in the Frankfurter Allee. The $NO_X$ concentration along Frankfurter Allee varies less than in the Silbersteinstraße. In this type of street sections, air quality samples are expected to be more representative than in the first example.

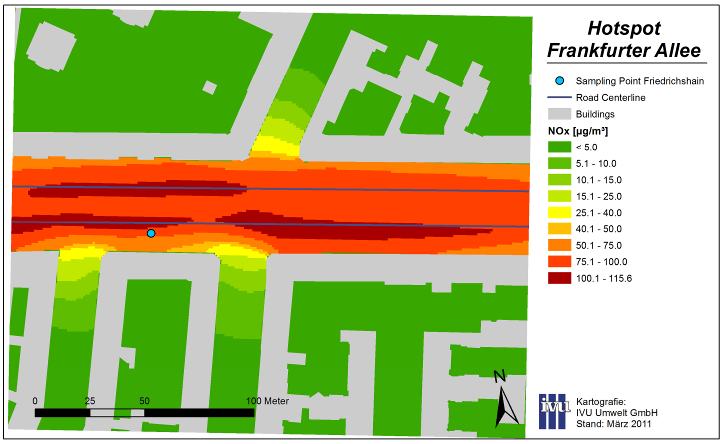


Figure 4: Distribution of the additional NOX pollution from traffic at hot spot location Frankfurter Allee

**DISCUSSION OF SPATIAL REPRESENTATIVENESS**

The EU air quality directive 2008/50/EC specifies that sampling points at traffic-oriented sites should be representative of air quality for a street segment no less than 100 m length. Modelling results for both hot spots considered in this paper show spatially varying concentrations around the sampling sites. So, it seems almost impossible to define sampling sites for Silbersteinstraße and Frankfurter Allee which can be considered as representative in the sense that concentrations are constant along a street segment of at least 100 m length.

In a first approach to analyse the representativeness of the sampling location, an assessment area of 100 m length around the sampling site was evaluated based on the modelling results. The mean concentration of all grid cells within the assessment area was calculated and compared to the concentration value of the grid cell where the sampling point is located.

The assessment area was defined in terms of the grid cells of the modelling grid, meeting the criteria given above and the following additional criteria:

(1) no evaluation on the carriageway of roads as stipulated by EU air quality directive 2008/50/EC

(2) at least two grid cells between buildings and assessment area (Guideline VDI 3783 Part 9 for prognostic microscale wind field modelling).

Figure 5 and Figure 6 show the resulting assessment area for Silbersteinstraße and Frankfurter Allee, respectively.

However, there is no specification in the EU air quality directive given for the transverse direction except that the distance between sampling point and kerbside must not exceed 10 m. I. e., there is no statement as to the transverse extent of the assessment area. Thus, the assessment area width around the sampling point Frankfurter Allee has been varied from the maximum width of 7 m (Figure 6), which covers almost the whole sidewalk, to 1 m (close to the kerbside) to investigate its influence on the evaluation results.

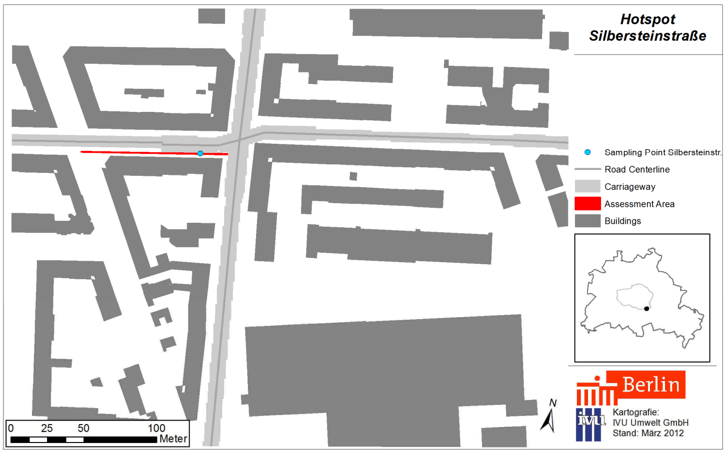


Figure 5: Location of assessment area for spatial representativeness at hot spot location Silbersteinstraße

Table 1 shows the results based on total concentration. The total concentration level was calculated from the additional pollutant load from traffic given in Figure 3 and Figure 4, respectively, and the background concentration level which amounts to 35.2 µg/m³ for Silbersteinstraße and to 37.1 µg/m³ for Frankfurter Allee. As we have a strong $NO_X$ gradient from the edge of the carriageway towards the buildings in Frankfurter Allee, absolute and relative differences and standard deviation from the mean concentration in the assessment area are larger in most cases than for the Silbersteinstraße with its complex intersection. Only the smallest assessment area width of 1 m, which is equal to the transverse extent of the assessment area at Silbersteinstraße, shows significantly smaller differences and standard deviation than the evaluation for Silbersteinstraße.

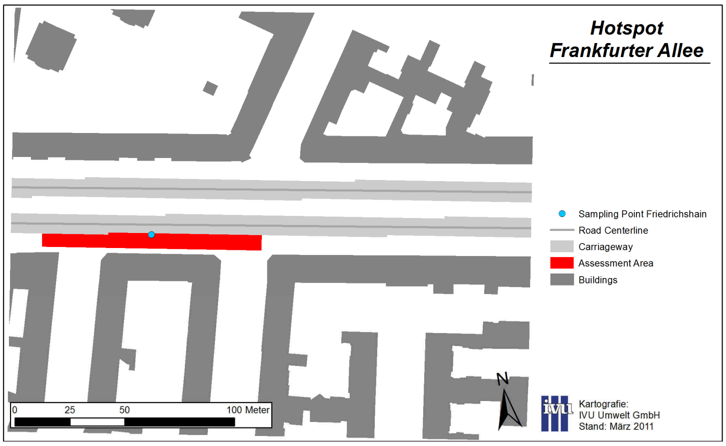

Figure 6: Location of assessment area for spatial representativeness at hot spot location Frankfurter Allee

Table 1: Comparison of $NO_X$ modelled total concentration level at sampling point with modelled mean total concentration level of assessment area

| | width of assess-ment area [m] | modelled total concentration at sampling point [µg/m³] | modelled mean total concentra-tion of assess-ment area [µg/m³] | absolute difference [µg/m³] | relative difference [%] | standard deviation from modelled mean concentration [µg/m³] |
|---|---|---|---|---|---|---|
| Silbersteinstraße | 1 | 123.2 | 109.3 | 13.9 | 11.3 | 12.5 |
| Frankfurter Allee | 7 | 128.4 | 102.7 | 25.7 | 20.0 | 13.1 |
| Frankfurter Allee | 5 | 128.4 | 108.2 | 20.2 | 15.7 | 10.6 |
| Frankfurter Allee | 3 | 128.4 | 114.6 | 13.8 | 10.7 | 7.6 |
| Frankfurter Allee | 1 | 128.4 | 120.2 | 8.2 | 6.4 | 5.6 |

## INHOMOGENOUS EMISSIONS

In the examples given above, vehicle emissions were assumed to be constant within each street segment. However, considering street sections within the scale of some 100 m, the traffic flow is expected to be rather inhomogeneous. For instance, junctions with traffic signals may interfere with the traffic flow in the street section considered. In the first few meters near to the stop line one has to expect a larger percentage of stop-and-go traffic than in the last few meters far away from the stop line. Additionally, the area of disruption induced by a traffic-signal system is depending on some specific traffic parameters like the circle time of the traffic lights. Hence, it has to be assumed that the spatial distribution of vehicle emissions along a street section is very inhomogeneous as well. Taking into account these inhomogeneities in the microscale model will increase the concentration variation in the assessment area and thus strengthen the need for an approach to assess the spatial representativeness of sampling points.

An idea to describe the inhomogeneous traffic state along a given street segment is to classify the percentage of traffic volume by the level of service (LOS) classes. At discrete time steps of the day (e. g. each 5 min), the considered street segment is spatially divided into parts where the traffic flow corresponds to LOS 4 (stop+go), LOS 3 (saturated), LOS 2 (heavy) and LOS 1 (free), respectively. This information is summed up over the considered time period, e. g. 3 hours, to get a LOS distribution along the considered street segment, dependent on the distance to the stop line. Figure 7 shows an example for this partition of traffic volume along the Frankfurter Allee with a segment

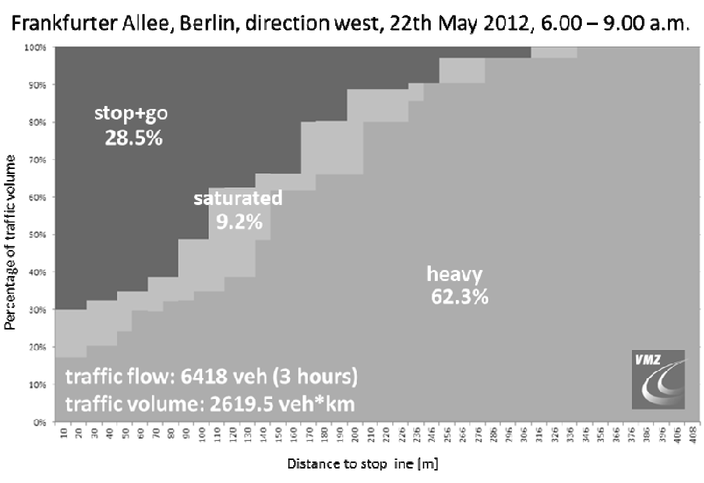

Figure 7: Partitioned traffic volumes by LOS for Frankfurter Allee

length of 408 meter as a result of the measured travel time. Data source for the results in Figure 7 is the traffic situation module of the Berlin Traffic Information Centre (TIC Berlin), which was introduced in August 2012.

In this example, the input data for the emission calculation based on HBEFA for the total segment would be a traffic volume of 6418 vehicles per hour with 0% LOS 1, 62.3% LOS 2, 9.2% LOS 3 and 28.5% LOS 4. It is also possible to estimate spatially varied emissions along the segment based on Figure 7, using the LOS distribution dependent on the distance to the stop line. The advantages of this idea of LOS-partitioned traffic volumes are (1) the better accuracy, (2) the independence from the segment length and (3) the independence from the position of a traffic measurement point.

## CONCLUSIONS

This paper presents a first approach to assess the representativeness of traffic-oriented sampling sites as defined by the EU air quality directive 2008/50/EC. As the concentration distribution at hot spot locations in urban areas is very inhomogeneous due to the complex building situation, it seems almost impossible to define a sampling site, which can be considered as representative in the sense that concentrations are constant along a street segment of at least 100 m length.

The approach outlined here is based on microscale modelling results for two hot spot areas. An assessment area is defined in terms of the grid cells of the modelling grid, using criteria given in the EU air quality directive 2008/50/EC and in the guideline VDI 3783 Part 9. As the EU directive does not explicitly specify the transverse extent of the assessment area, the influence of different transverse extents on the representativeness has been analysed. To evaluate the representativeness of the sampling point for the assessment area, the mean concentration of all grid cells within the assessment area is calculated and compared with the concentration value of the grid cell where the sampling point is located.

Evaluation results of the given approach are strongly dependent on the exact location and definition of the assessment area, in the cases presented in this paper namely on the transverse extent of the assessment area. Only when comparing the assessment areas with the width of 1 m for Frankfurter Allee and Silbersteinstraße, the results indicate, as expected, that the sampling point Frankfurter Allee may be sufficiently representative while the sampling point Silbersteinstraße may not.

Due to the fact that the evaluation results strongly depend on the location and definition of the assessment area, it is necessary to exactly determine the area for which the sampling site should be representative, before the method of evaluation of the representativeness can be discussed.

Furthermore, the spatial distribution of vehicle emissions within a street section is assumed to be very inhomogeneous, which in turn increases the variation of the modelled concentrations. It is therefore recommended to consider the inhomogeneous traffic emissions when assessing the representativeness of traffic-oriented sampling sites.

## ACKNOWLEDGEMENTS

This work was funded by the Senate Department for Urban Development and Environment, Berlin and the German Federal Environment Agency, Dessau.

## REFERENCES

2008/50/EC Directive of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (2008), Official Journal of the European Union, L 152, 11.06.2008.

EEA, 2012: Air quality in Europe -2012 report. EEA report No 4/20012, ISBN 978-92-9213-328-3, Copenhagen.

Eichhorn, J., 2011: MISKAM-Handbuch zu Version 6.1, giese-eichhorn umweltmeteorologische software.

Mol, W. J. A., P. R. van Hooydonk, F. A. A. M. de Leeuw, 2011: The state of the air quality in 2009 and the European exchange of monitoring information in 2010. ETC/ACM Technical paper 2011/1.

INFRAS, 2010: Handbook emission factors for road transport 3.1

IVU Umwelt, 2011: IMMISem/luft/lärm - User's guide Version 5.3. IVU Umwelt GmbH, Freiburg.

VDI 3783 Part 9, 2005: Environmental meteorology - Prognostic microscale wind field models - Evaluation for flow around buildings and obstacles, Beuth Verlag, Berlin.