ENVIORNMENTAL IMPACT ASSESSMENT OF AIR QUALITY IN STREET CANYONS RELATED TO COUNCIL DIRECTIVES 1999/30/EC AND 2000/69/EC

C. Mensink, A. Colles, L. Janssen and J. Cornelis
VITO, Centre for Remote Sensing and Atmospheric Processes, Mol, BELGIUM

INTRODUCTION
Air quality models are recognised as valuable tools for ambient air quality assessment and management as required by Council directive 96/62/EC. On one hand, measurements can be complemented or replaced by models as assessment technique, depending on the difference between limit value and representative actual levels. On the other hand, air quality models may help to develop the action plans required for zones where concentrations of pollutants in ambient air exceed limit values.

Information on the limit values and on the expected quality of the model results is provided in the so-called daughter directives. Accuracy for modelling is defined as the maximum deviation of the measured and calculated concentration levels, over the period considered by the limit value, without taking into account the timing of the events. Council directive 1999/30/EC is related to limit values for SO\(_2\), NO\(_2\), NO\(_x\), PM\(_{10}\) and lead in ambient air. Council directive 2000/69/EC is related to limit values for benzene and CO in ambient air. A guideline for the accuracy to be obtained is provided depending on the pollutant considered. An overview of these quality objectives is given in Table 1.

The assessment locations are to be sited at locations where the highest concentrations occur to which the population is likely to be exposed. At traffic oriented sites the assessment point should be representative of the air quality in a surrounding area of at least 200 m\(^2\). At urban background sites this should be several square kilometres. This implies that an air quality model should focus not only on the urban background, but also on calculating representative values at street level.

For the assessment of air quality in cities, VIT\(O\) introduced an integrated model system, known as AURORA (Air quality modelling in Urban Regions using an Optimal Resolution Approach). This urban air quality management system has been designed for urban and regional policy support and reflects the state-of-the-art in air quality modelling, using fast and advanced numerical techniques. More details of this model are given in section 2.

In section 3 we discuss the application of AURORA to 11 selected streets in the City of Antwerp in order to evaluate the concentration levels of NO\(_2\), SO\(_2\), PM\(_{10}\), CO and benzene. In section 4 the results are analysed and compared with measurements of an urban monitoring station.

THE AURORA MODEL
The integrated model system AURORA (Mensink et al., 2001a) consists of various modules that have been designed and tested, resulting in an urban air quality management tool that can provide reliable answers to policy makers and traffic planners. The model system is implemented in the city of Antwerp and is applied in various EU 5th framework projects (BUGS, DECADE,…).
**Table 1. Quality objectives for air quality modelling as provided by the Council directives**

<table>
<thead>
<tr>
<th>Averaging period</th>
<th>SO$_2$ &amp; NO$_2$</th>
<th>PM$_{10}$</th>
<th>Benzene</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>hourly</td>
<td>50% - 60%</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8-hourly</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50%</td>
</tr>
<tr>
<td>daily</td>
<td>50%</td>
<td>N.A.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>yearly</td>
<td>30%</td>
<td>50%</td>
<td>50%</td>
<td>-</td>
</tr>
</tbody>
</table>

The model input consists of terrain data (digital elevation model, land use, road networks) that are integrated in a GIS system. Meteorological input data are provided, with a resolution up to a few hundred meters, by a separate meteorological model (ARPS). The emission input data are resulting from a detailed inventory and acquisition of existing emission data in combination with emission modelling (Mensink et al., 2000). In this way the emissions are described as a function of space, time and temperature.

The physical and chemical processes are modelled in a modular way following the state-of-the-art in urban air quality modelling and involving large-scale computations. Every module was tested and validated individually before integration in AURORA. The most important parts of the model system are the modules for physical transport phenomena (advection, diffusion, deposition, etc.) and the modelling of photochemical processes and chemical reactions. These modules include some advanced and improved numerical solvers. Concentrations at the street level are estimated by means of the Street box module (Mensink and Lewyckyj, 2001b), using the 3D spatial configuration of the considered street and the related traffic information.

**MODEL APPLICATION**

The Street box model (Mensink and Lewyckyj, 2001b) has been applied to compute concentrations of the pollutants SO$_2$, NO$_2$, PM$_{10}$, benzene and CO in 11 selected streets in the City of Antwerp for the year 1998. For the five pollutants considered, the hourly emissions inside the streets are obtained from the results of the urban traffic emission module (Mensink et al., 2000). This model computes hourly emissions coming from passenger cars, light duty vehicles, heavy duty vehicles and busses in the Antwerp area, in function of road type, vehicle type, fuel type, traffic volume, vehicle age, trip length distribution and the actual ambient temperature. Cold start emissions and evaporation losses are included in the model. The emission calculations are based on an urban traffic flow model, actually used by the Antwerp City authorities for traffic management purposes. The urban traffic flow model contains a network with 1963 road segments and was implemented in a GIS environment. For each segment of the network the number of vehicles is predicted. The emission factors used in the model are derived from the COPERT-II methodology (Ahlvik et al., 1997) and are presently being adapted to the COPERT-III methodology.

The hourly meteorological values for wind speed and wind direction were obtained from two meteorological towers located in the city. Wind speed at roof level was calculated from a wind profile described by a power law, with the exponent derived from the wind speed measured at heights of 30 m and 153 m respectively. The averaged regional background concentrations needed for the Street box model were computed by means of the Operational Priority Substances (OPS) model (van Jaarsveld, 1990). This model has been applied to obtain concentrations on a 1x1 km$^2$ grid covering the Flemish region in which Antwerp is located. OPS is a Lagrangian...
trajectory model for long-term simulations, ranging from a few days to several years. The model computes concentrations, dry and wet depositions for primary and secondary components. It uses a climatological database with statistical values for 18 meteorological parameters. The climatological database is constructed by a meteorological pre-processor using hourly observations of wind direction and wind speed (measured at two heights), global radiation, temperature, precipitation intensity and precipitation amount. Other input data are related to the receptor characteristics (roughness length) and the emission sources (co-ordinates, dimensions, source strength). The model has been implemented and validated for the Flemish region.

The monitoring station is located in one of the streets (Plantin en Moretuslei) included in this study. It is part of the telemetric network for the monitoring of air quality in the Flemish region. The network is operated by the Flemish Environmental Agency (VMM, 1999a). Averages and percentiles for NOx, SO2 O3, NMVOC and PM10 are reported on a yearly base (VMM, 1999b).

RESULTS AND DISCUSSION
For the street “Plantin Moretuslei” in Antwerp the model results for SO2, NO2, PM10 and benzene are compared with measured values in Figure 1. The error bars show the accuracy levels given in Table 1. The first two bars in Figure 1 show the measured and computed P99,726 for hourly averaged values of SO2. This corresponds to 24 exceedances per year for the hourly values. The next two bars show the P99,178 values for daily averages (3 exceedance days per year). The measured and modelled hourly averaged NO2 concentrations are compared as P99,795 value (18 exceedances per year) and as yearly average. Note that in Figure 1 the P99,795 values are divided by 10 for scaling purposes. Next in Figure 1 are the P90,41 for daily averaged PM10 concentrations (35 exceedances per year, 2005), the yearly averaged PM10 concentrations and the P98,08 for daily averaged values (7 exceedances per year, 2010). Finally the last two bars show the yearly averaged benzene (BZN) concentrations as measured and modelled in the street “Plantin Moretuslei”. The figure shows that for all pollutants, the modelled percentiles and averages fall within the accuracy bounds provided by the guideline.

For the same pollutants and percentiles, the modelled values as averaged over the 10 other selected streets in Antwerp are compared with the measured value in the street “Plantin Moretuslei”. This is shown in Figure 2. Now the error bars show the standard deviation for the modelled results. In Figure 2 we see that the calculated SO2 concentrations are hardly varying from one street to the other. This indicates that the hourly SO2 concentrations are almost completely determined by the background concentration and that the contribution from traffic sources within the street is very limited. The measured values are lower than the calculated values for SO2 (see Figure 1), indicating that the calculated background concentrations are overestimated.

The results for NO2 give a completely different picture. The calculated hourly concentrations show much more variation between the individual streets. It is clear that here the concentrations are dominated by the contributions from traffic. Since the P99,795 is a very high percentile it is very sensitive to particular circumstances. Despite this, the accuracy bounds are not exceeded.

The calculated PM10 concentrations in the 10 streets show little variation from street to street. Also in this case, the background contribution seems to be relatively high. Despite the fact that the maximum deviation between measured and calculated results is only 18% for the P90 and 17% for the P98, the model is not correctly representing the PM10 situation within the streets. The small differences (< 4%) in the calculated results for P90 and P98 indicate a very high contribution from background concentrations. But the difference between the measured P90 and P98 is much larger (44%), which demonstrates that there is much more (daily) variation within
the street than the model predicts. Thus in the model results the contribution from the street itself is underestimated.

![Figure 1. Comparison of measured and modelled limit values for the street “Plantin Moretuslei” in Antwerp, with the error bars indicating the required accuracy levels.](image1)

![Figure 2. Comparison of the modelled limit values averaged over 10 selected streets in Antwerp and the measured limit values for the street “Plantin Moretuslei” in Antwerp, with the error bars indicating the standard deviation for the 10 streets.](image2)

The calculated yearly averages for benzene are ranging from 1.79 to 3.63 µg/m³. This large variation indicates that here the concentrations are dominated by the traffic contribution as well. The measured value of 2.6 µg/m³ fits within this range, with a maximum deviation of 40%. Measurements for CO are not available within the Flemish region. In Brussels the measured CO concentrations varied in 1998 between 0.6 and 2.7 mg/m³. The calculated values for the 10 streets in Antwerp varied between 1.3 and 2.4 mg/m³.
CONCLUSIONS
The AURORA model was applied to 11 selected streets in the City of Antwerp in order to make an assessment against the air quality limit values as provided by the Council directives. Comparisons with an urban measurement station in one of the 11 streets show agreements that are within the uncertainty range given by the guidelines in the EU directives. An analysis of the measured and modelled concentrations and percentiles allows an evaluation of the contribution from traffic for each of the pollutants considered. The model shows that traffic contributions are relatively important for NO\textsubscript{x}, benzene and CO and less important for SO\textsubscript{2} and PM\textsubscript{10}, where background concentrations are predominant. The result for PM\textsubscript{10} is not confirmed by the measured higher percentiles. The (emission) model seems to underestimates the daily variations in PM\textsubscript{10} caused by traffic.

REFERENCES