

ANNEX A Validation of the heaven DSS dispersion model

Validation of the HEAVEN DSS dispersion model



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Summary

This report is part of the evaluation procedures of the HEAVEN project. It deals with the validation of the calculations of the highway dispersion model in the Decision Support System (DSS). The predicted ambient air concentrations are compared to real-time measured concentrations and tested against predefined criteria.

The DSS features a public web site where modelled concentrations are shown in the form of a map. The concentrations are stored in a log file. The logged concentrations calculated at receptor points at 38 and 250 m from the centre of the road were compared with the measured values at similar distances for benzene, NO₂ and PM₁₀.

The results of the comparison between the log file of the dispersion model and the measured values in the first three weeks of July 2002 are shown in table 1.

The evaluation criteria are based on the average differences between measured and calculated concentrations. The average differences meet the predefined criteria and the model performs up to expectations. The general performance of the DSS is similar to the performance of the model under selected verification conditions.

It appears that the DSS is sensitive to the choice of erroneous background concentrations, especially in the case of benzene. This rarely happens but the problem will be remedied in a future version of the software.

A test of the model under winter conditions is planned for 2003.

1. Introduction

This report is part of the evaluation procedures of the HEAVEN project. It deals with the validation of the calculations of the high way dispersion model in the Decision Support System (DSS). The predicted ambient air concentrations are compared to real-time measured concentrations and tested against predefined criteria. A full description of the layout of the measuring sites and the development of the dispersion models for implementation in the DSS is reported in TNO report 2002/377 ¹.

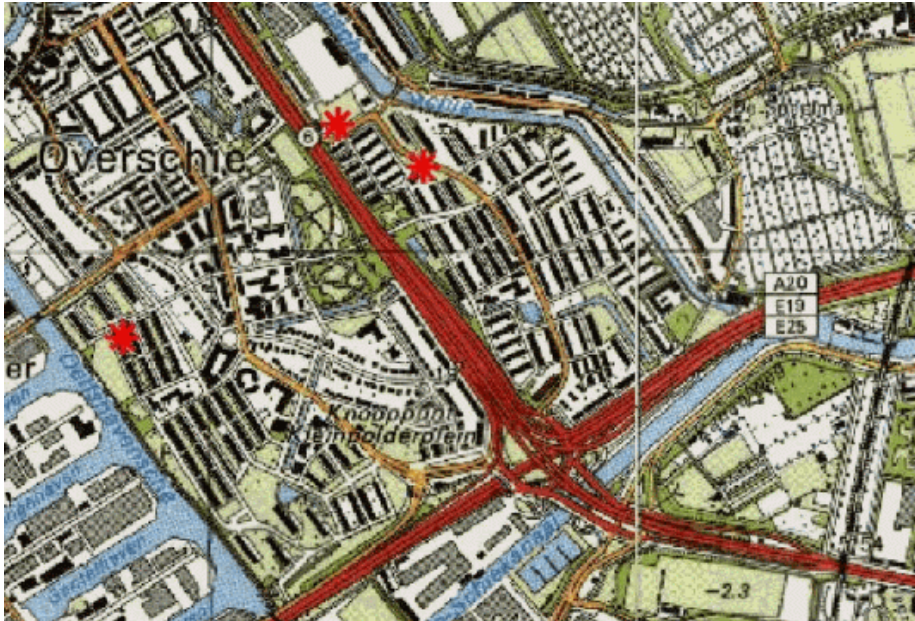
On July 5th the public version of the Rotterdam DSS was opened in the form of a web site. The web site provides hourly updates of modelled concentrations. The concentration log files for the month of July were compared to measurements at two distances from the national highway A13. A period of 19 days was studied for the independent evaluation of the "predicted" results as generated by the dispersion model in the DSS. The results of these validation measurements are similar to the results of the verification measurements during model development so no further research was done in summer. As measurements along the A13 will continue an additional validation will be done during winter months but this then would take place after the HEAVEN project has been completed.

Verification of the street canyon model with actual measurements has taken place at the time of model development and fine tuning at the Pleinweg. As the measurements at the Pleinweg were not continued after the model development and verification period, the street canyon model is not validated by a period of independent measurements

¹ H. Spoelstra, J. Hollander, H. Verhagen, J. Wesseling, S. Teeuwisse. 2002. *HEAVEN-project. Report on the TNO measuring and modelling results in 2000 and 2001 for use of the development of a new atmospheric dispersion model.* TNO-report R2002/377.

2. Validation methodology

The map shows the position of the three highway monitoring sites. The two sites east of the highway are used for model validation. Site E1 one is located at 40-50 m and E2 at 210 m from the central axis of highway. Concentrations calculated at receptor points at 38 and 250 m from the centre of the road were compared with the measured values for benzene, NO₂ and PM₁₀. The third station (E3) west of the high way was used as a background station during the model development measurements.



Calculated concentrations are derived from vehicle emissions based on traffic intensities and velocities, a background concentration, and meteorological conditions. The DSS was built in such a way that depending on the prevailing direction of the wind one of the existing monitoring sites in the wider Rotterdam area is used as a background station. Usually this provides good results. However, on rare occasions, for example during road works near the station that is used by wind from the north, this leads to completely wrong background concentrations. In a future version the background concentration will have to be determined independently from the direction of the wind as an average of all regional stations. This will reduce the impact of freak background concentrations.¹ In the test period it was mainly benzene that occasionally suffered from exaggerated background concentrations and two obviously extreme values (based on visual inspection of the data) were discarded.

Concentration measurements were carried out with conventional equipment. PM₁₀ measurements were carried out with a TEOM instrument. It is commonly known that automatic PM₁₀-monitors underestimate the actual PM₁₀-concentration and correction factors have to be applied. In principal these factors are season and location specific but only a year

¹ A further check on the comparability of the three concentrations can be included to isolate incidents at a single station. This improvement has been implemented in November 2002.

average correction factor for the Rijnmond area is available. This factor was used for the calculations in section 3.¹

The evaluation guidelines suggest the use of selected wind direction sectors for validation. This was not done for the reason that if the system works properly the calculated concentrations should be correct irrespective of the direction of the wind. A second deviation from the suggested procedure is that all calculations are based on hour by hour comparisons. Except for the two benzene cases the whole data set was used and checks for outliers were not applied.

The indicator for success is called the average deviation (ΔC). The average deviation during the validation period is calculated as:

$$\Delta C = (\sum ((C_c - C_m) / C_m)) / n$$

with n being the number of observations and C_c and C_m the calculated and the measured concentrations respectively.

ΔC defined in this way might give very optimistic results as positive and negative errors cancel out. This can be rectified by using the absolute value of $(C_c - C_m)$ as in:

$$\Delta C_a = (\sum (|(C_c - C_m)| / C_m)) / n$$

with ΔC_a being the absolute average deviation.

¹ The PM₁₀-data reported by TNO (and summarised in section 4. of this report) rely on a combination of TEOM and gravimetric measurements. The data published by TNO are the final concentrations. The final, published, data were used in section 4. of this report without further application of a correction factor.

3. Results of the validation

The results of the comparison between the log file of the dispersion model and the measured values in the first three weeks of July 2002 are shown in table 1. The case where the indicator does not meet the evaluation criteria is marked grey. The table shows indeed that using ΔC leads to overly optimistic results and the performance of the model should be judged by ΔC_a .

Table 1: Measured and calculated concentrations at two distances from the centre of the highway

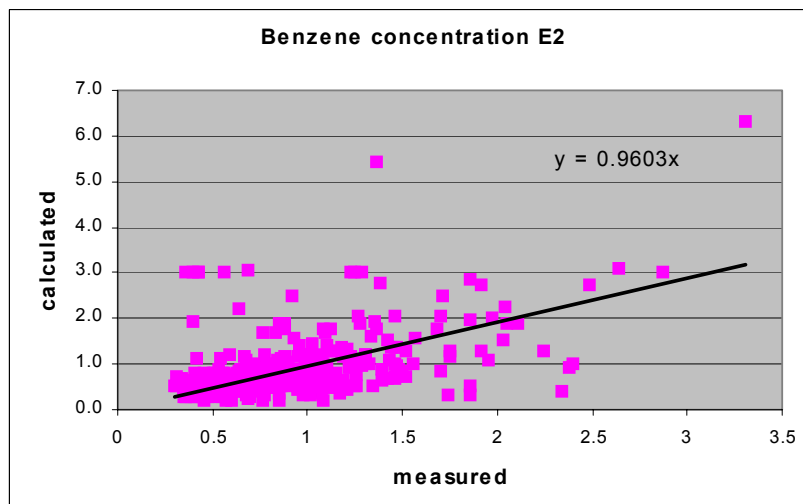
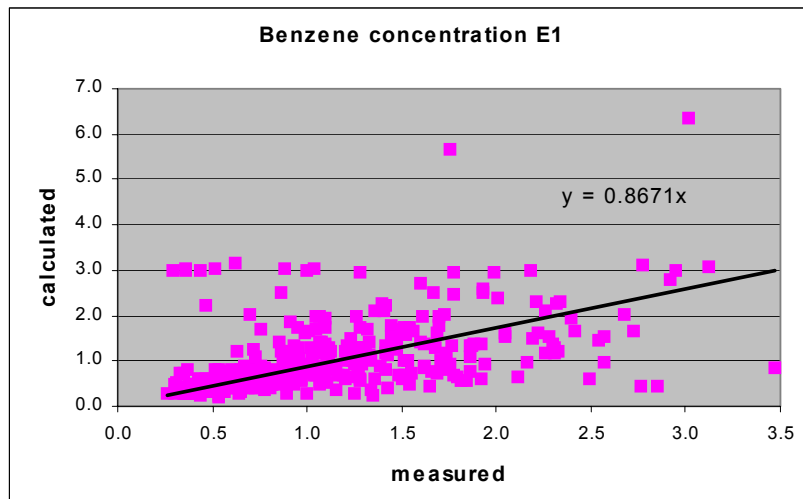
Site	Number hourly observations	of Pollutant	Concentration ($\mu\text{g}/\text{m}^3$)		ΔC	ΔC_a	Criteria ΔC
			Measured	Calculated			
E1	368	NO ₂	36.5	41.2	0.07	0.30	0.6
E2	368	NO ₂	33.4	27.9	0.23	0.37	0.6
E1	376	PM ₁₀	42.6	39.3	0.12	0.20	0.5
E2	376	PM ₁₀	39.2	36.2	0.12	0.21	0.5
E1	344	Benzene	1.13	1.05	0.31	0.53	0.5
E2	374	Benzene	0.90	0.90	0.24	0.46	0.5

It should be borne in mind that the nearest receptor point to E2 is some 40 m further away from the road than E2 itself so this comparison is not entirely fair. Still using the general approach outlined above, the measured and calculated results correspond within the desired limits of accuracy at both E1 and E2. If the evaluation had been narrowed down to specific wind sectors and the use of the corresponding background concentrations the performance is likely to be even higher.

In section 2. it was mentioned that the DSS currently uses the measurements of one of the permanent monitoring sites as a background concentration. These monitoring stations are not truly background stations as they are designed to pick up the impact of the industrial activities in residential areas as well. Therefore heightened industrial activity or incidents might influence the station that was used as DSS background. The Rotterdam ring road (Ruit) which is subject to the DSS modelling passes nearby industrial areas so for some parts of the Ruit the background concentration transmitted to the system is indeed the true background. However, the DSS monitoring sites are located further away from the main petrochemical areas. This occasionally leads to background concentrations that are too high and hence to calculated concentrations that are too high. This effect occurs more frequently in the case of benzene as traffic emissions are relatively small.

3.1 Benzene

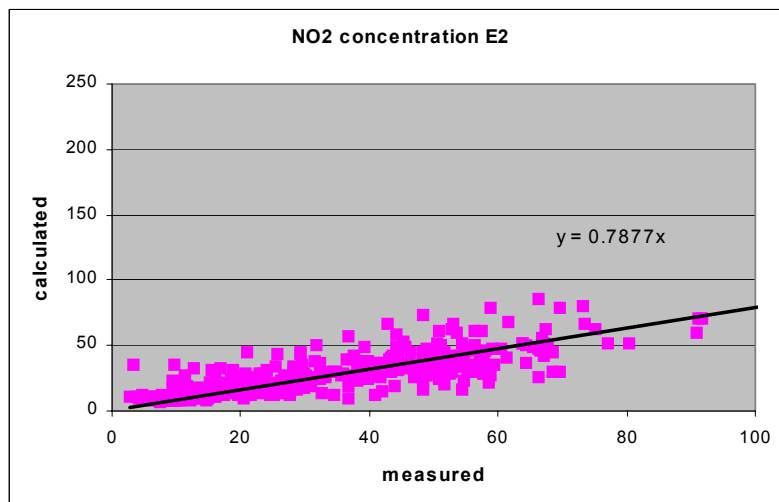
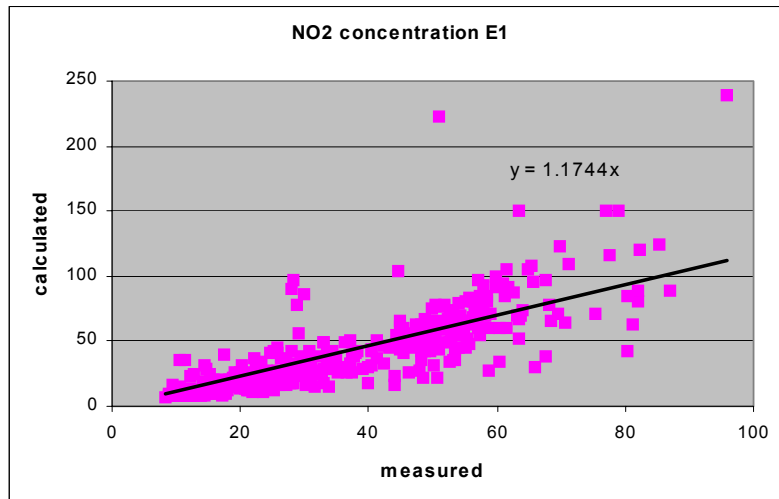
For benzene two cases with calculated concentrations above $20 \mu\text{g}/\text{m}^3$ have been discarded but the scatter plots show that there are still a number of suspect cases in the data set. For example the series of points with a calculated concentration around $3 \mu\text{g}/\text{m}^3$ irrespective of the measured concentration are likely due to erroneous background concentrations. The values above 5 probably have the same problem as these concentrations are not affected by the distance from the road.



Note that the regression line was forced through the origin.

3.2 Nitrogen dioxide

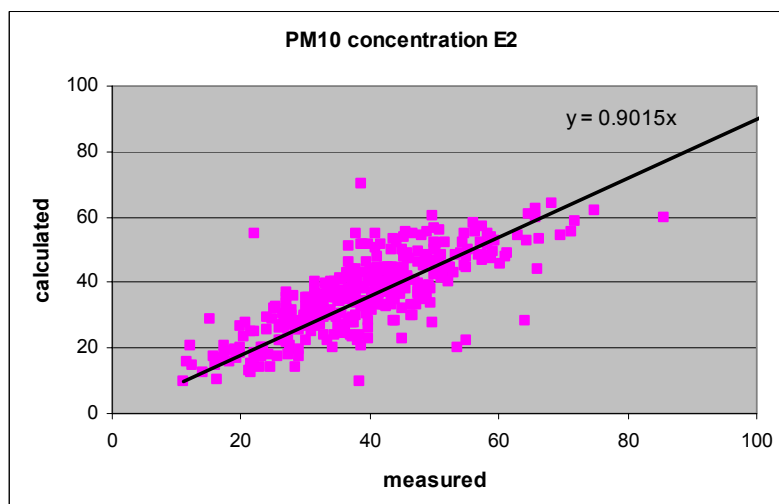
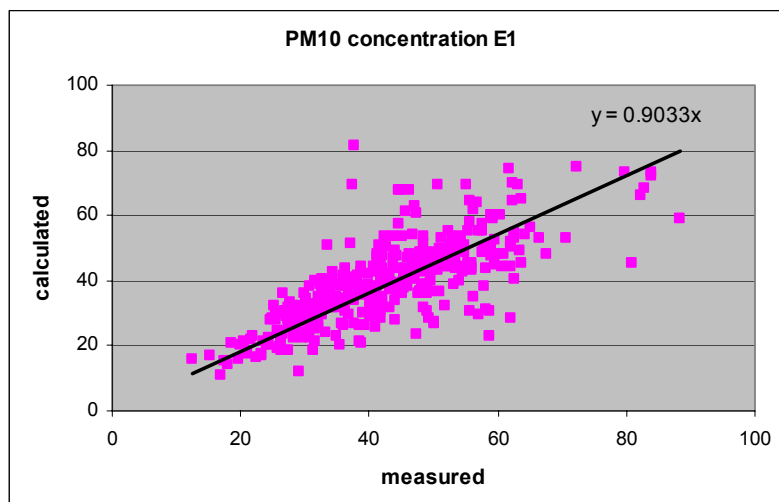
The same applies to NO₂ but to a lesser extent: the traffic related NO₂ concentration is substantial compared to the background concentration so undue background variation has a smaller impact than in the case of benzene. The graph at E1 probably suffers from two outliers. At E2 the model predictions seem low but this can be attributed (at least partly) to the fact that E2 is closer to the road than the point of calculation.



Note that the regression line was forced through the origin.

3.3 Particulate matter

The PM₁₀-concentrations correspond very well. The PM₁₀ background is rather stable and substantial so the impact of the vehicle emissions on the concentrations is less than for example in the case of NO₂. The calculated concentrations are smaller than the measured concentrations at both distances. This is probably due the correction factor, which was applied to the measured concentrations. This factor tends to be higher in the winter than in the summer. Applying the year average correction factor to the July measurements will overestimate the measured concentrations.



Note that the regression line was forced through the origin.

4. Discussion and conclusions

Summarising the findings one might conclude that the overall concentration prediction in the DSS as it was tested in July 2002 performed up to expectation. Some part of the observed deviation can be explained by the adopted approach and by verification set up, implying that the dispersion model as such performs better than the indicators in table 1.

This assumption can be checked by comparing the performance of the model during verification, to the performance of the DSS during validation. The results during verification are shown in the table 2.¹ If tables 1 and table 2 are compared, the latter results are slightly better (except for benzene at E2). This is expected as dedicated background concentrations and selected wind sectors were used. The differences are minor indicating that the DSS can easily cope with other wind directions and general background concentrations.

Table 2: Urban highway verification measurements (Data: TNO 2002)

Site	Pollutant	ΔC	ΔC_a	Criteria ΔC
E1	NO ₂	0.04	0.28	0.6
E2	NO ₂	0.28	0.33	0.6
E1	PM ₁₀	0.06	0.15	0.5
E2	PM ₁₀	0.05	0.15	0.5
E1	Benzene	0.23	0.38	0.5
E2	Benzene	0.64	0.72	0.5

July - August 2001, wind sector 210-340.

The shaded cells don't meet the evaluation criteria.

NB: See annex B for the original TNO report

The overall conclusion is that the urban highway model performs consistently up to expectation under a wide range of conditions.

The observed problems with the incidents of freak values of measured background concentrations have been rectified in a new version by adding some additional logic to the software which selects the background concentration.

¹ The data are the averages from those reported by Spoelstra et al. (see note in the introduction).

ANNEX B Development of a new atmospheric dispersion model

Excerpts of:

TNO-report R2002/377



Heaven Project

Report on the TNO measuring and modelling results in 2000 and 2001 for use of the development of a new atmospheric dispersion model

July 2002

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1. Introduction

In the HEAVEN-project TNO has the specific task to deliver (1) a modified dispersion model for the prediction of the air quality downwind of highways in urban areas and (2) a dispersion model for inner urban roads (street canyons). The dispersion models should model air pollutant concentrations on an hour-to-hour basis.

For the *first* task, the TNO highway traffic model has been improved for two different types of locations. The first location is a so-called undisturbed “open” field location. At this location a highway runs through a rural area, where the dispersion of traffic emissions is not hindered by obstacles (buildings, sound-screens and so on), so the dispersion modelling is relative simple. The second location is at in urban area, where the dispersion and modelling of air pollutants is more complex as buildings and sound screens are on both sides of the highway.

At the “open-field” location the ambient air quality for NO, NO₂ CO, PM₁₀ and benzene has been monitored around the highway A13 between Rotterdam and Delft during a five-month period in 2000. The “urban” location was situated in the district of Overschie (North of Rotterdam), where the highway A13 runs into the city of Rotterdam, where the ambient air quality was monitored at three measuring stations during 2001 (April to December).

For the *second* task, the TNO CAR model has been modified for a street canyon, with actual measuring data from a station established in the southern part of Rotterdam at the “Pleinweg” with a substantial amount of traffic (~41.000 vehicles/day).

The monitoring of the various air quality parameters was performed in a close cooperation with DCMR Environmental Services Rotterdam.

This report describes and presents the results of this ambient air monitoring and briefly, the results of the improvement and validation of the TNO traffic model as well the TNO CAR model.

2. Ambient air quality monitoring

2.1 Introduction

The ambient air quality monitoring has been performed in a close cooperation with DCMR. DCMR was mainly responsible for the operation and maintenance of the gas analysers (NO_x, O₃, CO, BTX and the PM₁₀ -TEOM), while TNO-MEP was responsible for the operation of the “manual” methods (BS, EC/OC PM₁₀ and PM_{2,5} gravimetric). The “open field” measuring period lasted for about 4,5 months in 2000 (August to December), while the urban area measurements took place from April to December 2002.

At the “open field” location, three measuring stations were located around the A13 highway from Rotterdam to Delft. With the prevailing southwesterly winds in the Netherlands, one station (A1) was located wind upward of the A13 highway, while the two other stations (A2 and A3) were located down wind of the A13 highway. The measuring results of the ambient air quality have also been reported by DCMR Environmental Services [2].

At the urban area in Overschie, three measuring stations were established. One station (E1) 15 m east of the highway A13. The second one (E2) about 200 m east of the highway and one “background” station about 500 m windward of the A13. The fourth measuring station (E4) was located at a street canyon “Pleinweg” in Rotterdam.

2.2 Measured parameters

In table 1, the measured parameters at the different measuring stations are summarized.

Table 1. Overview of the measured parameters.

Parameter	Sampling duration/frequency	Measuring site location ¹⁾						
		Open field			Urban			Street-canyon
		A1	A2	A3	E1	E2	E3	E4
Wind direction	Continuous	x	x	x	-	-	x	-
Wind speed	Continuous	x	x	x	-	-	x	-
Temperature	Continuous	x	x	x	-	-	-	-
NO and NO _x	Continuous	x	x	x	x	x	x	x
O ₃	Continuous	-	-	-	-	-	-	-
CO	Continuous	-	-	-	-	-	-	-
BTX	Continuous	x	x	x	x	x	x	x
PM ₁₀ TEOM	Continuous	x	x	x	x	x	x	x
PM ₁₀ gravimetric	48 hour (wds) ²⁾	x	x	x	x	x	x	-
	48 hours	-	-	-	-	-	-	x
PM _{2,5} gravimetric	48 hour (wds) ²⁾	x	x	x	-	-	-	-
	48 hours	-	-	-	-	-	-	x
BS	48 hour (wds) ²⁾	x	x	x	x	x	x	-
	48 hours	-	-	-	-	-	-	x
EC/OC	48 hour (wds) ²⁾	x	x	x	x	x	x	-
	48 hours	-	-	-	-	-	-	x

¹⁾ x= parameter measured;

- = parameter not measured

²⁾ wds = wind direction selected

A full description of the type of instruments used at the measuring stations is presented in Annex A and in annex B a description of the QA/QC procedure of the measured parameters is given.

The manual sampled components (PM_{10} & $PM_{2.5}$ gravimetric, EC/OC and BS) were sampled only at westerly wind directions ($180^{\circ} - 280^{\circ}$ at the open field location and $210^{\circ} - 330^{\circ}$ in the rural area). At these wind directions traffic emissions are transported from the highway to the measuring stations A1/A2 in the open field and E1/E2 in the urban area. As wind directions vary, the 48-hour periods can consist of multiple samplings during a number of days.

3 Model development

3.1 Introduction

In this report, the development of the model is described in terms that are more general. In a separate report, the details of the specific modelling aspects are described in more detail, including the model verification [3].

3.2 Basis of the model

The newly developed TNO atmospheric dispersion model for traffic emissions is based on the Dutch National Model. The Dutch National Model was developed in 1998 and is used for the calculation of the atmospheric dispersion of point and area sources on an hourly basis by means of gaussian dispersion modelling. For the HEAVEN project, this model has been extended with a module (the Traffic Dispersion Model, TDM) to make it applicable for highways (i.e. line sources).

3.3 Model description and adaptation

The Dutch National Model is a bi-gaussian dispersion model. The transport of pollutants is described by the following formula:

$$C_{(x,y,z,H)} = \frac{PQ}{2\pi u \sigma_y \sigma_z} \cdot \left[e^{-\frac{(z-H)^2}{2\sigma_z^2}} + e^{-\frac{(z+H)^2}{2\sigma_z^2}} \right] \cdot e^{-\frac{y^2}{2\sigma_y^2}} \cdot C_{ls}$$

- C_{ls} - reflection term for the mixing layer
- H - effective source height (m)
- P - penetration fraction into the inversion layer (above the mixing layer)
- Q - emission (g/s)
- u - average wind speed at plume height (m/s)
- y - horizontal distance to the plume axis (m)
- z - distance above surface area (m)
- σ_y and σ_z - horizontal and vertical dispersion parameter (m)

A special traffic dispersion module (TDM) was added to Dutch National Model to model the dispersion of highway traffic emissions, which may be regarded as a set of line sources. The highway is partitioned into a number of road segments. For every calculated hour, these segments are projected onto the governing wind direction. In this way a box is constructed, perpendicular to the wind, in which homogeneous mixing of the traffic emissions is assumed. The side of the box then acts as an (vertical) area source. The dispersion from this (vertical) area source is then calculated in a standard way using an analytic expression for the contribution of every road segment to every receptor. Care has been taken to partition the road into an appropriate number of segments in order to avoid numerical problems at small angles. Later optimisations of the model will focus, among others, on the best partitioning algorithm to minimize computing time. The height of the box is essentially a measure of the turbulence over the road. A comparison with literature and another existing TNO traffic model

indicates a height of 2.5 - 5.0 meters is appropriate, but , further investigations have shown that the actual range is 3.5 – 5.5 meters, depending on the local situation. A highway segment is treated as a single line source, representing a small part of the highway, with a certain hourly emission, instead of treating each individual traffic lane in the highway segment as an individual line source. Tests have shown that the differences for most practical applications are negligible between modelling the highway with a number of separate traffic lanes and modelling it as a single line source. A highway segment is therefore treated as a single box with the width of the sum of all the encompassed traffic lanes. In special cases where there is a very large difference in the nature of traffic on the different lanes or when an empty lane separates lanes, it may become necessary to treat the different lanes within a highway segment separately.

3.4 Calculation of the dispersion parameters σ_y and σ_z

For the calculation of the concentration $C_{(x,y,z,H)}$ at point x,y,z and height H , the dispersion coefficients σ_y and σ_z are needed. Using the meteorological parameters: wind speed, wind direction, temperature, cloud cover, precipitation and solar radiation the stability of the atmosphere is calculated by means of a meteorological pre-processor for each hour in which meteorological data is available.

The output variables of the meteorological pre-processor are the friction velocity , the heat flux at the surface, the Monin-Obukhov length and the mixing height. With these output variables and the profiles for wind speed, the dispersion coefficients σ_y and σ_z are calculated. By means of this procedure the model calculates the concentration $C_{(x,y,z,H)}$ for each hour with meteorological data and the traffic emissions for that specific hour.

Using the model the contribution of a highway to a receptor point is calculated. The predicted total ambient air concentration is calculated by adding the background concentration, which is taken from measurements of a background station.

3.5 Calculation of traffic emissions and chemical conversion of NO to NO₂

The emissions were calculated on basis of the measured traffic intensity, measured driving speed and emission factors. The actual traffic intensity and driving emission for each hour were obtained from the Dutch Highway Authority, which provided the number of vehicles, type of vehicle and their driving speed per lane of the highway. The emission factors were obtained from the TNO Automotive institute.

Vehicles emit both NO en NO₂. Part of the NO is converted to NO₂ because of chemical reactions with O₃ in ambient air. This reaction is influenced by photochemistry due to solar radiation. The chemistry of nitrogen components is complex, due to the great variety of reactions that may lead to formation of NO₂. Within the Dutch National Model this conversion is modelled, but this modelling scheme is mainly applicable for point sources, not traffic sources. Several methods of modelling the nitrogen chemistry have recently been tested by TNO in the framework of the European HEAVEN project. It was shown that the method formerly developed by TNO is still a good compromise among speed, robustness en accuracy. Therefore, this method has been included into the HEAVEN-model.

4. Measuring results

4.1 Introduction

For the determination of contribution of the *highway* traffic at the measuring stations only that wind sector is relevant, in which the emissions from the traffic are transported in the direction of the measuring stations. The measured data presented in this report were preselected for the wind directions 180° - 280° at the open field location and 210° to 330° in the urban area as the highway A13 is roughly located in the direction from southeast to northwest. The presented data is shown for wind speeds above 1 m/s. These wind direction selected data has been used as input for the modelling.

4.2 Results for the continuous measurements

In annex C and annex D, the results of the continuous measurements are presented for each month. In annex C, the hourly values for the are presented (annex C1 to C5 for the open field locations and annex C6 to C14 the urban locations). In annex D the differences between the results at the measuring stations are given, which are a measure for the traffic contribution (annex D1 to D5 for the open field locations and D6 to D14 the urban locations). The results of the measurements in the street canyon (Pleinweg E4) are given in annex E. (*NB: annexes are not included in this WP8.8 document!*). The numerical results from the annexes are summarized in the following tables. Table 2 (open field 2000), table 3 and 4 (urban location 2001) and table 5 (street canyon 2001).

Table 2. Summarized results of the continuous measured parameters (monthly averages O₃, NO, NO₂, Benzene, PM₁₀) for the *open field in 2000*. Results are wind direction and wind speed selected.

2000	Site(s)	Concentrations in µg/m ³				
		O ₃	NO	NO ₂	Benzene	PM ₁₀
August	A1	-	51,5	57,8	2,2	24,3
	A2		13,7	27,3	1,4	20,6
	A3		7,1	20,2	1,2	20,2
September	A1	-	61,6	52,1	1,7	24,7
	A2	17,2	15,7	25,4	1,2	20,0
	A3	42,1	6,1	20,2	0,5	19,5
October	A1	-	66,3	54,6	1,8	22,2
	A2	16,4	16,3	27,1	1,3	18,3
	A3	33,9	7,6	22,7	0,9	17,4
November	A1	-	64,3	52,1	2,0	19,2
	A2	12,5	27,2	40,3	1,9	16,5
	A3	24,4	7,6	29,2	1,7	15,2
December	A1	-	64,0	50,6	1,8	21,3
	A2	18,6	24,9	42,1	1,5	18,6
	A3	33,9	9,6	22,8	1,4	16,9

		Concentration differences in $\mu\text{g}/\text{m}^3$				
		O ₃	NO	NO ₂	Benzene	PM ₁₀
August	A1-A3	-	51,7	42,5	0,8	4,8
	A2-A3		8,2	8,1	0,1	-0,4
	A1-A2	-	44,2	34,2	0,8	5,9
September	A1-A3	-	55,1	31,9	1,8	5,0
	A2-A3	28,2	9,6	5,3	1,1	0,4
	A1-A2	-	47,8	27,6	0,5	4,7
October	A1-A3	-	58,0	31,8	0,9	4,6
	A2-A3	17,5	8,4	4,5	0,4	0,9
	A1-A2	-	50,5	27,6	0,5	3,8
November	A1-A3	-	56,7	22,8	0,4	3,9
	A2-A3	12,0	19,7	11,3	0,2	1,3
	A1-A2	-	36,9	11,5	0,2	2,7
December	A1-A3	-	54,4	27,8	0,4	4,3
	A2-A3	14,7	15,3	19,4	0,1	1,7
	A1-A2	-	39,1	8,5	0,4	2,7

Table 3. Summarized results of the continuous measured parameters (monthly averages NO₂, benzene and PM₁₀) for the *urban locations in 2001*. Results are wind direction and wind speed selected.

2001	Site(s)	Concentration in $\mu\text{g}/\text{m}^3$		
		NO ₂	Benzene	PM ₁₀
April	E1	40,2	1,9	24,8
	E2	41,7	1,3	19,6
	E3	27,9	1,3	16,9
May	E1	33,7	1,3	29,4
	E2	34,9	1,4	23,3
	E3	25,2	1,2	21,7
June	E1	-	1,1	29,3
	E2	-	1,5	22,1
	E3	-	1,3	21,0
July	E1	48,3	1,5	26,2
	E2	33,3	1,2	22,3
	E3	23,4	1,0	20,4
August	E1	49,3	1,8	25,0
	E2	40,2	1,5	21,5
	E3	20,6	1,4	20,7
September	E1	54,3	1,9	24,2
	E2	44,6	1,5	19,1
	E3	25,2	1,2	18,0
October	E1	55,6	2,0	28,4
	E2	49,5	1,7	24,1
	E3	28,1	1,7	23,8
November	E1	61,5	2,5	24,6
	E2	57,3	2,0	19,6
	E3	32,6	1,9	18,5
December	E1	52,1	1,8	21,4
	E2	48,9	1,3	17,0
	E3	25,0	1,3	15,8

Table 4. Concentration differences of the continuous measured parameters (from table 4) for NO₂, benzene and PM₁₀) for the *urban locations in 2001*. Results are wind direction and wind speed selected.

2001	Sites	Concentration differences in µg/m ³		
		NO ₂	Benzene	PM ₁₀
April	E1-E3	9,9	0,6	6,7
	E2-E3	14,1	0,0	1,5
	E1-E2	-0,9	0,6	5,1
May	E1-E3	8,5	0,2	8,1
	E2-E3	9,7	0,2	1,9
	E1-E2	-1,3	0,0	6,1
June	E1-E3	-	-0,1	8,3
	E2-E3	-	0,1	1,2
	E1-E2	-	-0,2	7,2
July	E1-E3	25,0	0,5	5,8
	E2-E3	9,9	0,4	1,9
	E1-E2	13,7	0,1	4,2
August	E1-E3	28,6	0,4	4,6
	E2-E3	18,1	0,1	1,0
	E1-E2	11,7	0,2	3,5
September	E1-E3	30,2	0,6	6,2
	E2-E3	20,5	0,2	1,1
	E1-E2	9,7	0,4	5,1
October	E1-E3	27,4	0,3	4,5
	E2-E3	21,4	0,0	0,3
	E1-E2	6,0	0,3	4,2
November	E1-E3	28,7	0,6	6,0
	E2-E3	24,5	0,1	0,8
	E1-E2	4,2	0,5	5,0
December	E1-E3	27,1	0,5	5,5
	E2-E3	23,9	0,0	1,2
	E1-E2	3,1	0,5	4,4

Table 5. Summarized results of the continuous measured parameters (monthly averages of NO₂, benzene and PM₁₀) at the *street canyon in 2001*. No selection on wind direction and wind speed.

2000	Site	Concentrations in µg/m ³		
		NO ₂	Benzene	PM ₁₀
April	E4	67,0	3,0	21,4
May	E4	58,9	2,8	19,8
June	E4	69,4	3,8	26,3
July	E4	71,7	4,1	25,0
August	E4	74,4	3,6	-
September	E4	67,7	4,2	21,9
October	E4	78,3	4,7	28,7
November	E4	89,5	4,8	23,2
December	E4	84,7	3,9	23,4

4.3 Results of the manual measured parameters

The individual results of the manual measured parameters BS, PM₁₀ and PM_{2,5} gravimetric and EC/OC are given in annex F. The summarized results are presented in table 6 (open field 2000, A1, A2, A3), table 7 (urban locations 2001, E1, E2, E3) and table 8 (street canyon Pleinweg, E4).

Table 6. Summarized results of the manual measured parameters for the *open field* in the period August – December 2000 (averages of the 48 hour samplings black smoke, PM₁₀ and PM_{2,5} gravimetric, EC/OC).

Parameter	Site(s)	Concentrations in $\mu\text{g}/\text{m}^3$ ¹⁾				
		PM ₁₀ -gravimetric	PM _{2,5} -gravimetric	BS	EC	C in OC
Wind-direction selected	A1	30,3 (6)	21,4 (7)	22,8 (7)	2,6 (7)	10,9 (7)
	A2	25,8 (8)	15,5 (8)	8,6 (8)	1,3 (8)	12,9 (8)
	A3	22,6 (8)	12,9 (8)	3,2 (8)	0,2 (8)	11,8 (8)
	Concentration differences in $\mu\text{g}/\text{m}^3$ ¹⁾					
	A1-A3	8,1 (6)	8,5 (7)	19,6 (7)	1,4 (7)	-2,1 (7)
	A2-A3	2,9 (8)	2,2 (8)	4,9 (8)	0,9 (8)	1,5 (8)
	A1-A2	4,8 (6)	6,0 (7)	14,2 (7)	2,5 (7)	-1,0 (7)

¹⁾ Value in brackets denotes number of samples

Table 7. Summarized results of the manual measured parameters for the *urban locations* in the April 2001 – December 2001 (averages of the 48 hour samplings black smoke, PM₁₀ and PM_{2,5} gravimetric, EC/OC).

Parameter	Site(s)	Concentrations in $\mu\text{g}/\text{m}^3$ ¹⁾				
		PM ₁₀ -gravimetric	PM _{2,5} -gravimetric	BS	EC	C in OC
Wind-direction selected	E1	36,9 (6)	24,4 (5)	31,0 (6)	3,7 (6)	5,3 (6)
	E2	29,2 (6)	19,4 (6)	11,1 (6)	1,6 (6)	4,3 (6)
	E3	40,1 (6)	23,1 (6)	11,9 (6)	1,3 (6)	5,6 (6)
	Concentration differences in $\mu\text{g}/\text{m}^3$ ¹⁾					
	E1-E3	-3,2 (6)	1,3 (6)		2,4 (6)	-0,3 (6)
	E2-E3	-10,9 (6)	-3,7 (6)		0,3 (6)	-1,3 (6)
	E1-E2	7,7 (6)	5,0 (6)		2,1 (6)	1,0 (6)

Table 8. Summarized results of the manual measured parameters at the *street canyon Pleinweg* in the period May – December 2001 (averages of the 48 hour samplings PM₁₀ and PM_{2,5} gravimetric, black smoke and EC/OC).

Parameter	Site	Concentrations in $\mu\text{g}/\text{m}^3$ ¹⁾				
		PM ₁₀ -gravimetric	PM _{2,5} -gravimetric	BS	EC	C in OC
No wind-	E4	29,0 (16)	20,7 (16)	22,6 (16)	2,5 (7)	6,1 (7)

¹⁾ Value in brackets denotes number of samples

5. Modelling results

5.1 Introduction

In this chapter only a brief overview is given of the modelling results. The specific details of the modelling as well as a more detailed analysis of the results will be described in another TNO-report [3].

5.2 Highway line source and receptor points

The A13 highway has been modelled over a length of about 3 kilometres. The modelling has taken place for the periods with westerly winds. The measuring stations A1, A2 and E1, E2 were used as the receptor down wind points and the measured concentrations at station A3, E3 as the background level.

5.3 Emissions from the highway traffic

The emission of pollutants by highway traffic is calculated on hourly basis of the traffic intensity and driving speed. The emission factors are based on a research project of TNO-Automotive. In the project of TNO-Automotive, the influence of congestion on the emission factors is determined. The study was conducted for NO_x, PM₁₀, and benzene. Knowing the traffic intensity of light, mid weight and heavy-duty vehicles with the corresponding driving speeds per hour, the total emission of the vehicles is calculated for that hour. The decision whether there was congestion or not is based on the average driving speed and the amount of vehicles per hour. In total eight different driving categories are distinguished. The emission factors of benzene were not measured by TNO-automotive but are calculated on basis of the emission factors of HC. Assumed is a constant ratio between benzene and HC (0.0393 for light vehicles and 0.0188 for heavy duty vehicles).

The study of TNO-Automotive is performed for a small amount of cars. Furthermore, the results of the research study are transposed to the Dutch fleet. The step is very crucial because a car without a catalyst emits about 30 times more NO_x than a car with a catalyst. Therefore, a difference in the assumed percentage of vehicles in the Dutch fleet without a catalyst can lead to quite different emission factors.

The information about the traffic intensities and driving speeds are measured by an automatic system owned by the Ministry of Transport, Public Works and Water Management, AVV Transport Research Centre. The system is called Monica (monitoring Casco system). In Monica, the different categories are measured based on the length of the vehicle. A large vehicle means heavy-duty traffic and a short vehicle means a passenger car. The emission factors given by TNO-automotive are given per weight category. The length category of Monica and the weight category by TNO-automotive do not match one to one. Assigning the emission factors of TNO-Automotive the vehicle categories of Monica is therefore less reliable.

During the day, a trend is clearly visible. In the night the emission on the highway is low, at around 5 o'clock in the morning rush hour is starting and the emission climbs to emission that is more than 5 times higher than during the night. During the daytime, the emission is more

or less constant while from around 14 hour the emission grows again. After the evening rush hour, the emission drops rapidly to low values again (see figure 1).

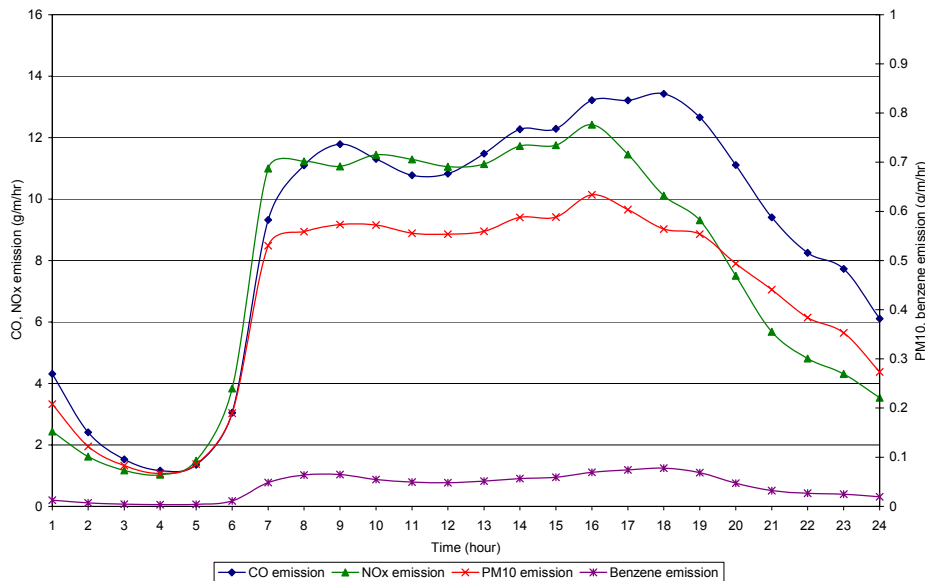


Figure 1. Characteristic hourly-averaged emission (period taken from September-December 2000).

Figure 2 shows the emission averaged per day. In figure 4 one can see that the emission climbs during the week from Monday to Friday and is the lowest in the weekend. The NO_x-emission drops quite dramatically in the weekend due to the (almost) absence of heavy-duty traffic. The NO_x-emission per vehicle is for heavy-duty is in general more than ten times higher than lightweight traffic. This counts also for PM10 where the emission per vehicle of heavy-duty traffic is 5-10 times higher than the emission of lightweight vehicles. The CO-emission drops less dramatically in the weekends due to the relatively large contribution of the lightweight vehicles to the total CO-emission. In the weekends, the amount of lightweight vehicles is only around 10%-15% lower than during the working days.

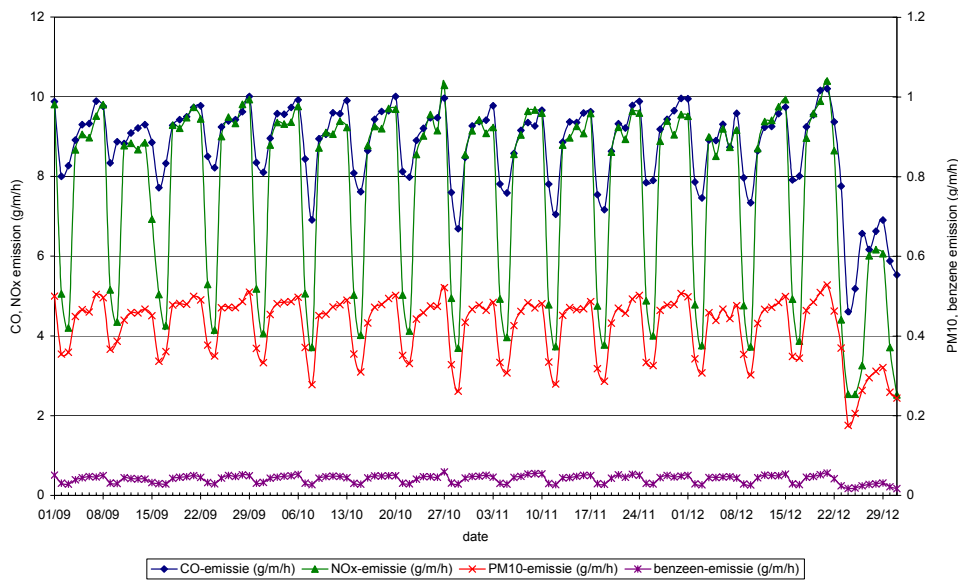


Figure 2. Characteristic daily averaged emissions (period taken from September-December 2000).

More or less the same emission patterns occur at the urban area location Overschie (in 2001 from April to December), as this location is at the same highway A13, only a few kilometres further south.

5.4 Meteorological data

As the Rotterdam airport is relative close to the measuring location, meteorological data was retrieved from the official Dutch Meteorological Office (KNMI). The meteorological data were pre-processed (as already described in paragraph 4.3) and were transferred to the local conditions at the measuring site.

5.5 Concentration calculations

The concentrations are modelled using the method described in chapter 4. The calculated contribution concentrations are compared against the measured contribution concentrations. The measured contribution concentrations are calculated by subtracting the measured concentration at A3/E3 from the measured concentration at A1/E1 or A2/E2. Due to the set up of the measurement experiment, only the hours with a wind direction between 180° - 280° (open field) and 210°-330° (Overschie) and were taken into account. In the other hours, A3/E3 could not be regarded as a true background site.

5.6 Comparison aspects between modelling results and measurements

The comparison between measured concentrations and modelled results is done in the following ways. In paragraph 6.7 the comparison is shown in correlation plots, while in paragraph 6.8 the numerical difference between modelling and measurements is given.

It is emphasized that the model itself only calculates the *contribution* of the traffic emissions to the existing ambient air concentrations. In order to obtain the predicted ambient air concentrations, the calculated contribution from the model is added to the measured background concentration. In the correlation plots shown in paragraph 6.7 the predicted ambient air concentration is shown.

The scatter in the plots (paragraph 6.7) and the calculated differences (paragraph 6.8) is therefore not only due to the model calculations, but also due to variations in the level of background concentrations (stations A3 and E3) and the measured ambient air concentrations at the receptor points A1/E1, A2/E2).

At the Pleinweg the comparison between modelling and measurements is much more difficult, as there was measurement data available at background stations within a reasonable distance from the Pleinweg. Therefore only measurements data from the background station E3 have been taken during wind sector within 300 to 360 degrees.

5.7 Correlation plots

NO_2

In figures 3 and 4 the correlation plots between the modelled and measured results for NO_2 at the rural area (2000) are shown.

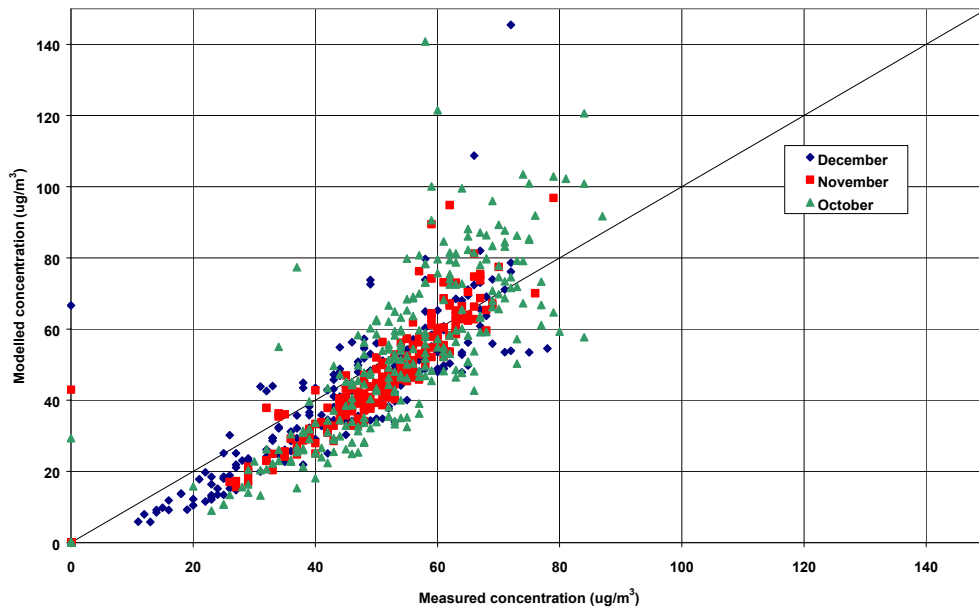


Figure 3. Hourly measured and modelled NO₂-concentration at station A1 (rural area, 2000).

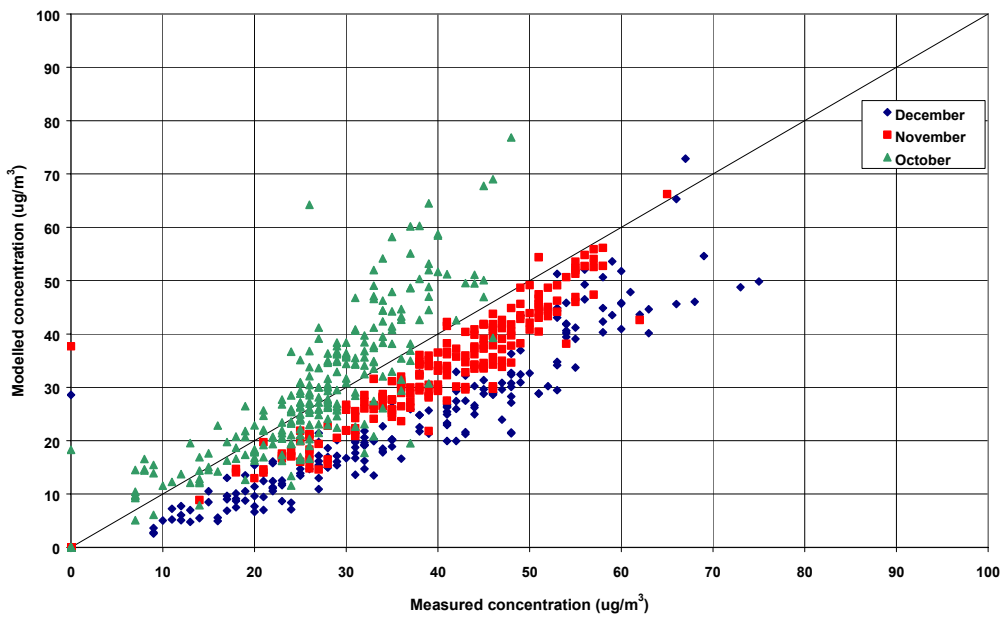


Figure 4. Hourly measured and modelled NO₂-concentration at station A2 (rural area, 2000).

In figures 5 and 6 the results for the urban area in Overschie (2001) are shown.

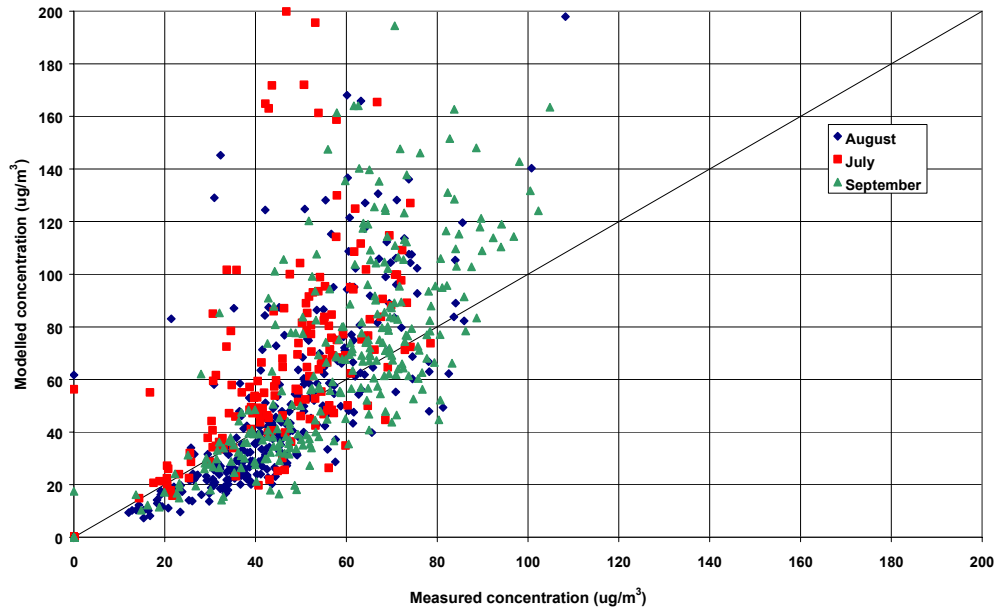


Figure 5. Hourly measured and modelled NO₂-concentration at station E1 (urban area, 2001).

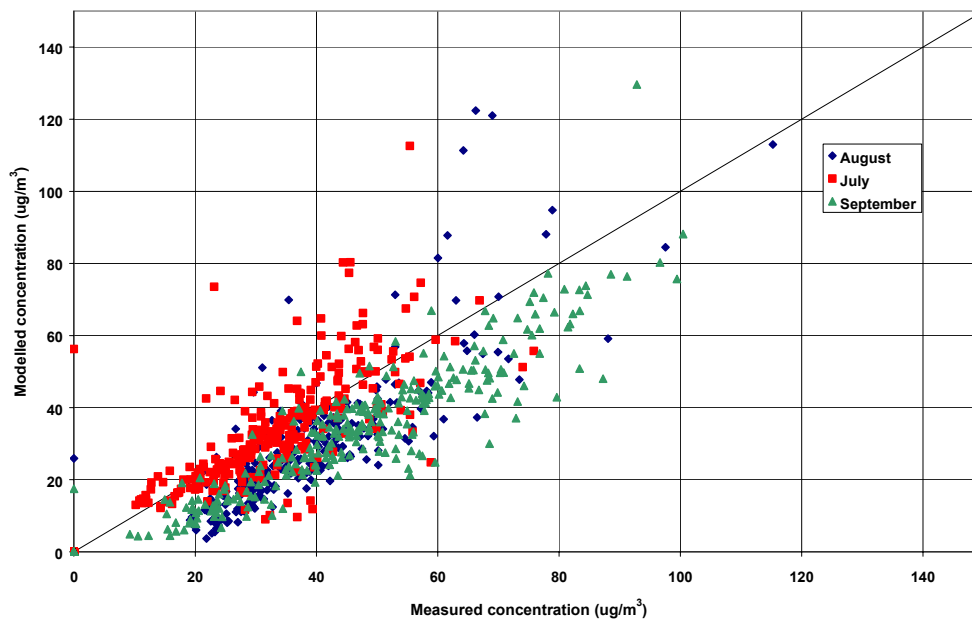


Figure 6. Hourly measured and modelled NO₂-concentration at station E2 (urban area, 2001).

Figure 5 shows that the correlation at E1 between the calculated and measured NO₂ is reasonable, but that for a substantial number of hours the concentrations are overestimated. This phenomena is still not yet resolved completely. One possible cause is the effect of specific local influences, such as exact position of buildings, streets and corridors and wind directions, which are not (yet) fully accounted for in the model. Another cause could be the effect of very low wind speeds $\sim < 1$ m/s, for which the model prediction has a large uncertainty.

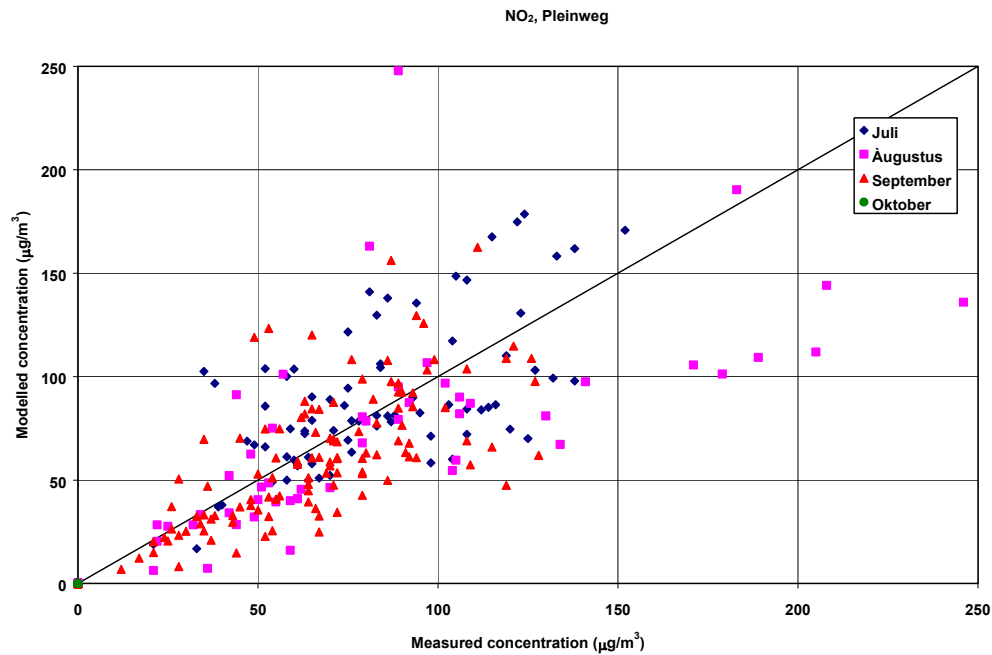


Figure 7. Hourly measured and modelled NO₂-concentration at the Pleinweg (E4, street canyon, 2001, with wind sector 300° to 360°, with data from background station E3).

PM₁₀

In figures 8 to 12 the correlation graphs between modelling results and measurements for PM₁₀ are shown.

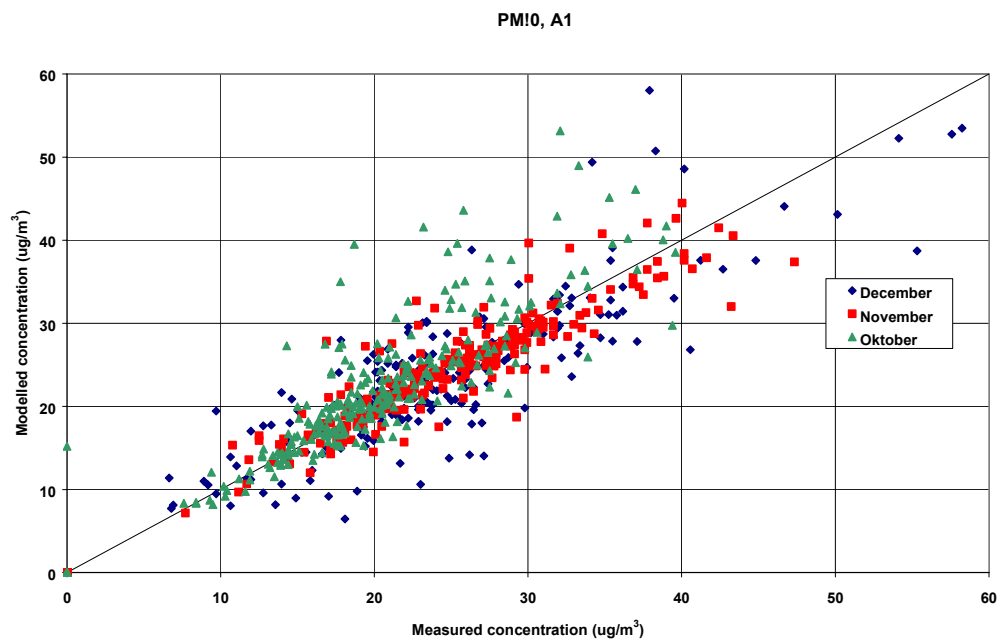


Figure 8. Hourly averaged PM₁₀ concentrations at the rural area (A1, 2000).

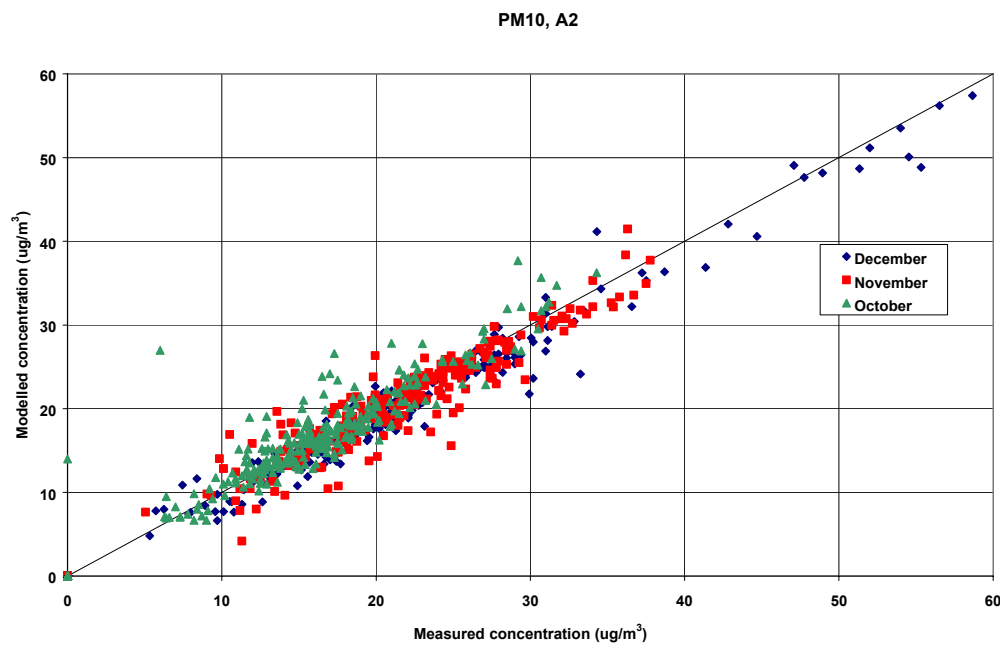


Figure 9. Hourly averaged PM₁₀ concentrations at the rural area (A2, 2000).

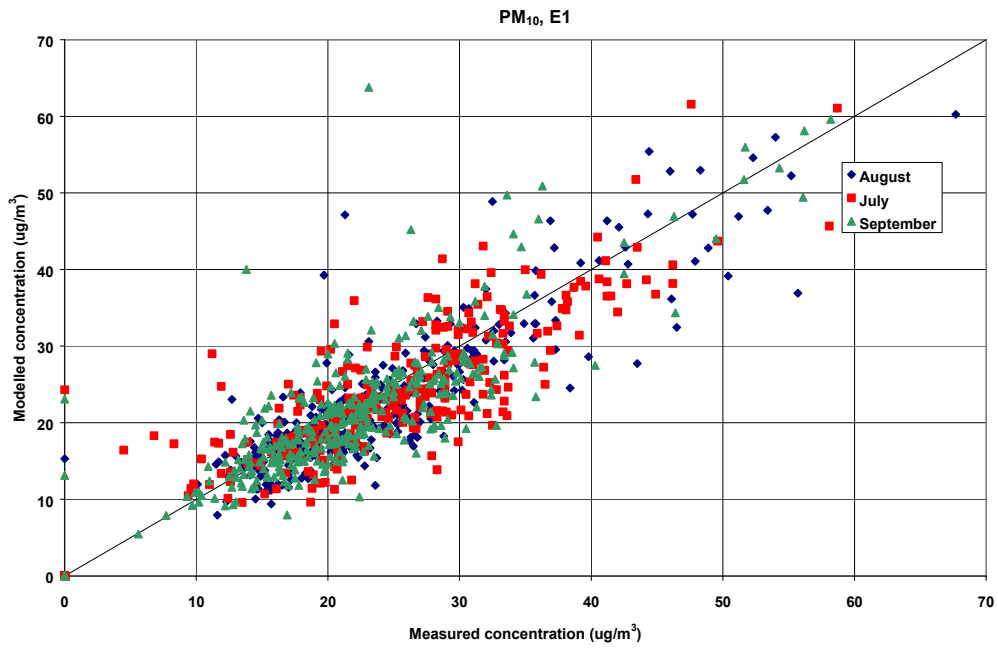


Figure 10. Hourly averaged PM₁₀ concentrations at the urban area (E1, 2001).

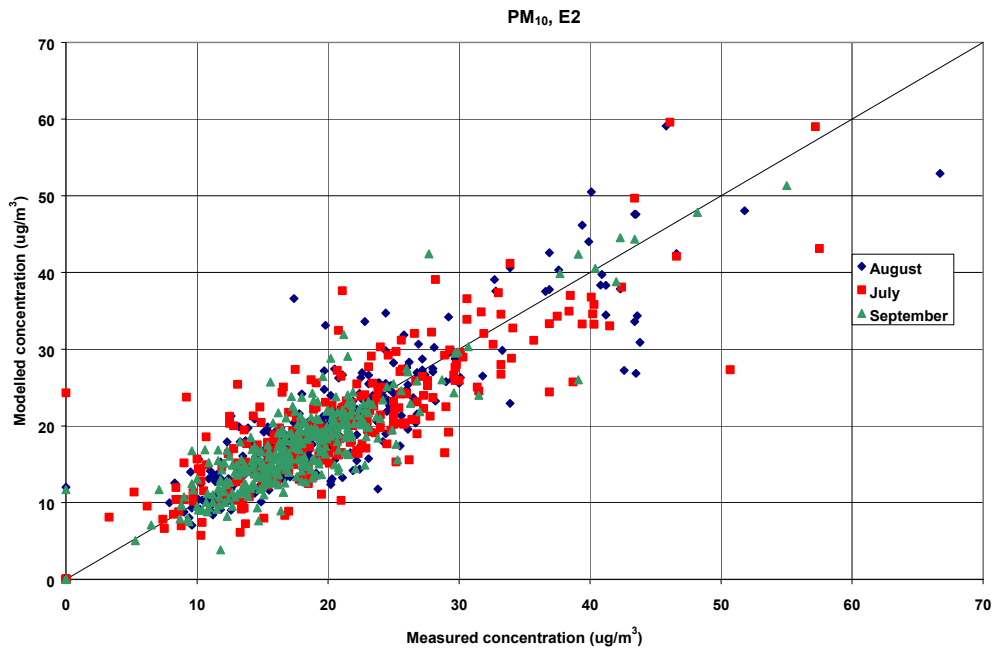


Figure 11. Hourly averaged PM₁₀ concentrations at the urban area (E2, 2001).

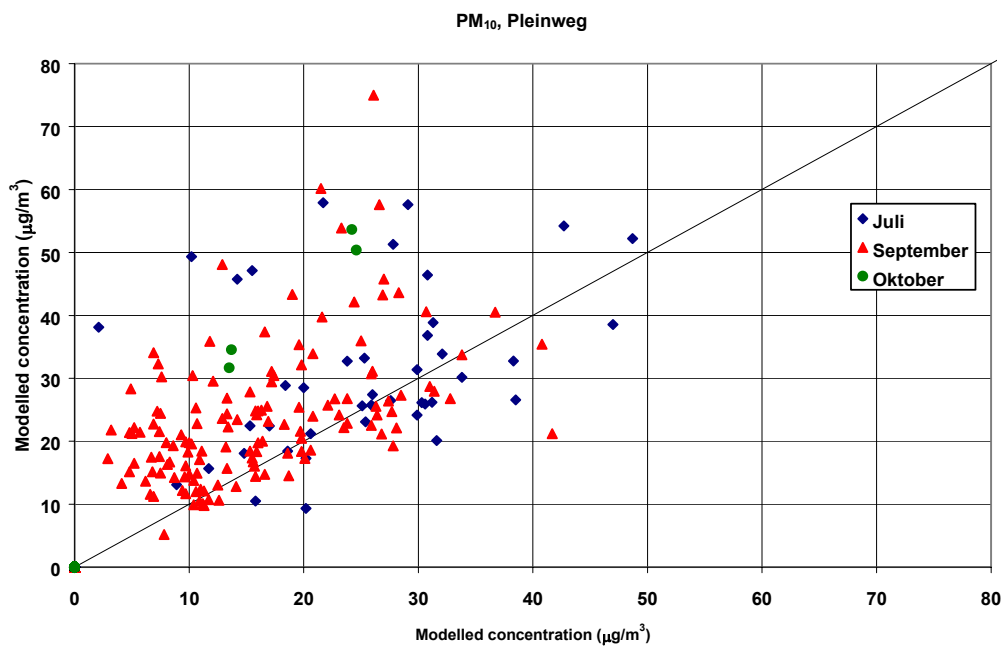


Figure 12. Hourly averaged and modelled PM₁₀-concentration at the Pleinweg (E4, street canyon, 2001, with wind sector 300° to 360°, with data from background station E3).

Figures 8 to 12 show a good correlation with some scatter. In paragraph 6.8 this scatter is quantified in more detail.

Benzene

In figures 13 and 14 the correlation for benzene at the first receptor points A1/E1 are shown.

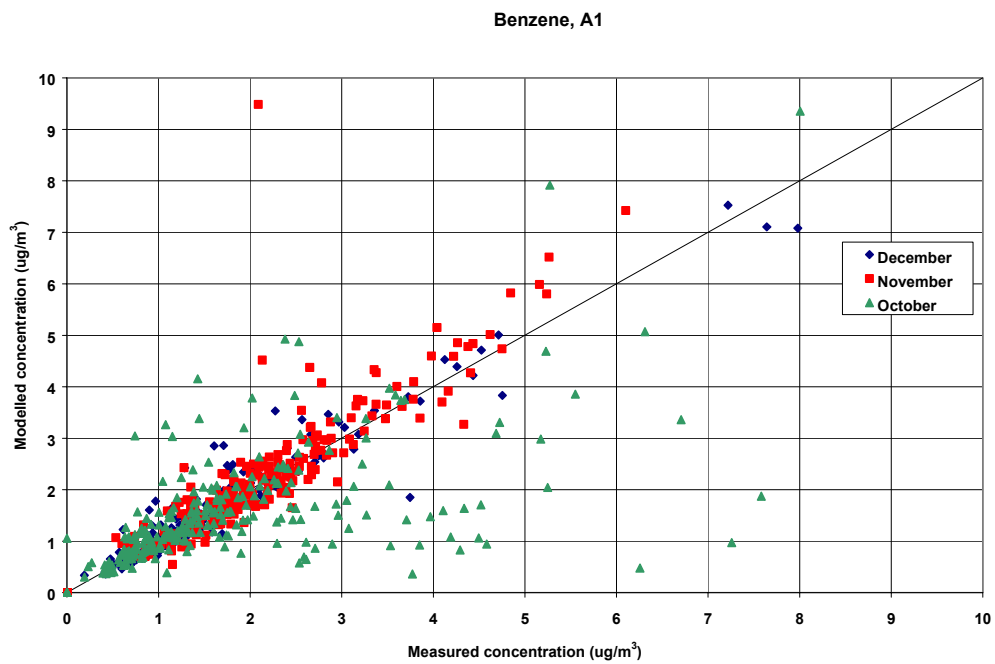


Figure 13. Hourly averaged benzene at the rural area (A1, 2000).

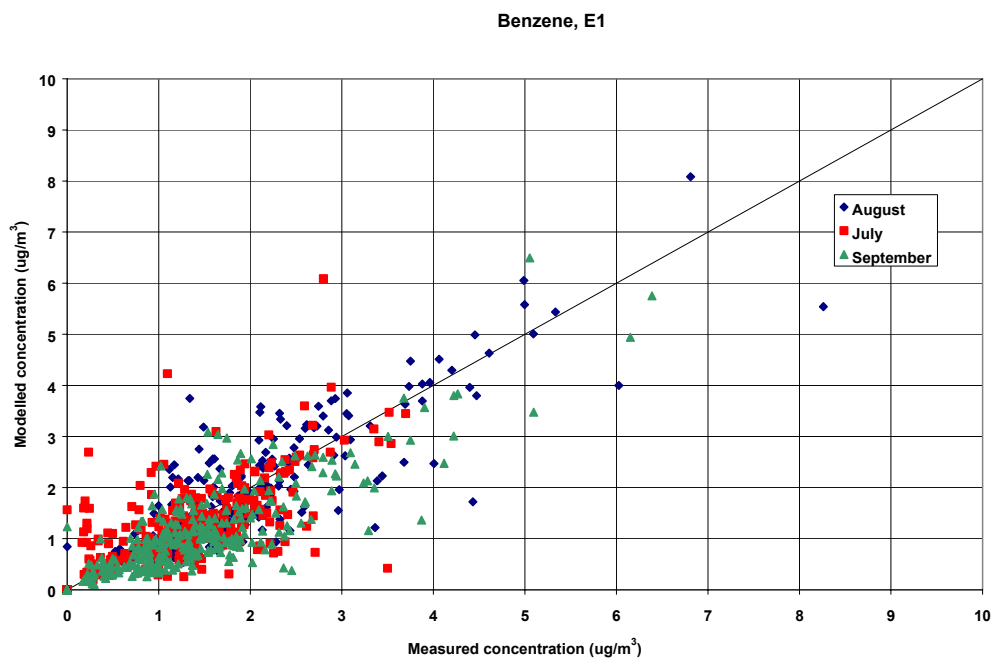


Figure 14. Hourly averaged benzene at the urban area (E1, 2001).

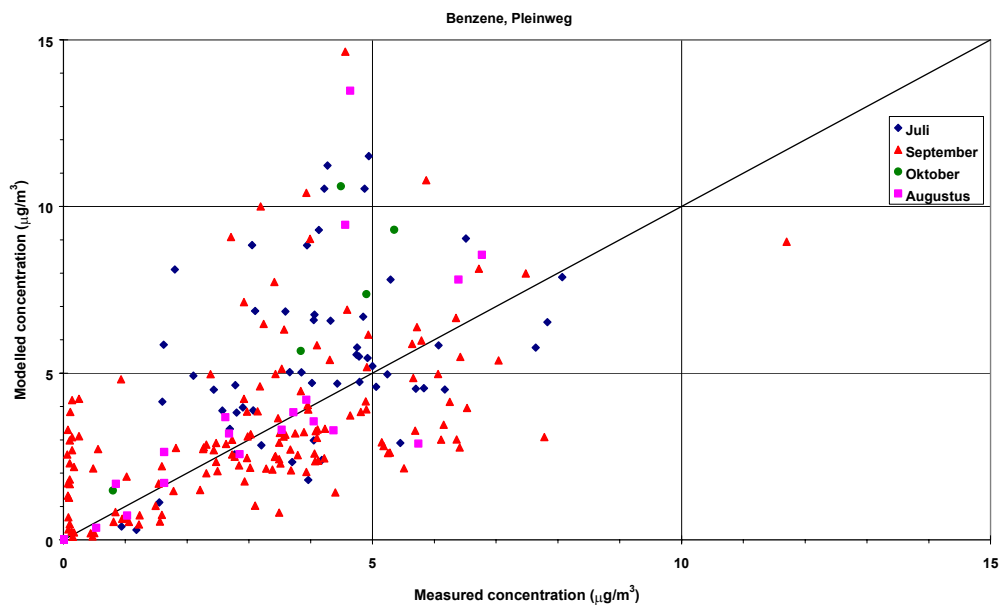


Figure 15. Hourly averaged and modelled benzene-concentration at the Pleinweg (E4, street canyon, 2001, with wind sector 300° to 360°, with data from background station E3).

5.8 Overall evaluation of the modelling results

Within the HEAVEN project, criteria have been set to the maximum deviations between modelling results and measurements. The calculation of the deviation between modelling and measurements is defined as:

$$\Delta C = \frac{\sum \frac{(C_{meas} - C_{calc})}{C_{calc}}}{n} \quad (1)$$

in which:

- ΔC - average difference between modelling and measurement
- C_{meas} - measured concentration
- C_{calc} - modelled concentration
- n - number of comparisons

With equation (1), the average difference between modelling and measurements is calculated. A small drawback with this equation is in the case that ΔC is zero, which would indicate a perfect match between modelling and measurements, (big) positive differences could compensate (big) negative differences, without influencing the average difference ΔC .

Therefore, also an alternative average difference has been calculated by taking the absolute values of the differences, by which the positive differences are not compensated by the negative differences but added together. This gives a measure for the scatter in the differences:

$$\Delta C_{abs} = \frac{\sum (C_{meas} - C_{calc})}{n} \quad (2)$$

Both types of average differences (ΔC and ΔC_{abs}) have been calculated, but only ΔC is tested against the stated criterion in the HEAVEN project. In the following tables the numerical values of ΔC and ΔC_{abs} are presented, table 9 for the rural area, table 10 for the urban location and table 11 for the street canyon (Pleinweg).

It is noted that the calculations of the differences are based on only valid and available measurement data for the measured components, traffic intensity data and meteorological data (data series with faulty or missing values for one of the parameters have been omitted). As the model calculates the traffic contribution **only** at A1/E1 and A2/E2, the background level has to be added to this contribution for comparison with the **measured** concentrations. To this the measured concentrations at A3/E3 have been taken as the background level.

In table 9 the calculated differences are related to a wind sector between 209° and 340°. Within this wind sector, the measuring stations A1 and A2 are influenced by the traffic emissions.

Table 9. Average differences between model and measurements at the open field location (calculations based on hourly averages).

Open field	Month	ΔC	ΔC_{abs}	Maximum difference ΔC criterion	Pass (✓) or Fail (-)
NO ₂ , A1	October	0,08	0,27	0,6	✓
	November	0,11	0,19	0,6	✓
	December	0,21	0,27	0,6	✓
NO ₂ , A2	October	0,04	0,20	0,6	✓
	November	0,23	0,25	0,6	✓
	December	0,69	0,72	0,6	-
PM ₁₀ , A1	October	0,02	0,10	0,5	✓
	November	0,02	0,09	0,5	✓
	December	0,07	0,19	0,5	✓
PM ₁₀ , A2	October	0,01	0,08	0,5	✓
	November	0,05	0,11	0,5	✓
	December	0,07	0,10	0,5	✓
Benzene, A1	October	0,35	0,55	0,5	✓
	November	0,001	0,15	0,5	✓
	December	0,02	0,13	0,5	✓
Benzene, A2	October	0,44	0,55	0,5	✓
	November	0,24	0,33	0,5	✓
	December	0,03	0,11	0,5	✓

From the table; it shows that agreement between measurements and modelling is good, besides a few cases. In November, the difference between modelling and measurement for NO₂ at A2 is rather high. The cause is unknown for the time being. In general, the scatter in

NO₂ differences ranges from 19% to 27% (ΔC_{abs}), which indicates that the modelled results vary from hour-to-hour up to about 30%.

In table 10 the average differences for the urban location are given. The relevant wind sector is between 209° and 340°.

Table 10. Average differences between model and measurements at the urban location (calculations based on hourly averages).

Urban location	Month	ΔC	ΔC_{abs}	Maximum difference ΔC criterion	Pass (√) or Fail (-)
NO ₂ , E1	July	-0,09	0,16	0,6	√
	August	0,08	0,34	0,6	√
	September	0,14	0,35	0,6	√
NO ₂ , E2	July	0,06	0,18	0,6	√
	August	0,46	0,49	0,6	√
	September	0,32	0,32	0,6	√
PM ₁₀ , E1	July	0,07	0,16	0,5	√
	August	0,07	0,16	0,5	√
	September	0,05	0,13	0,5	√
PM ₁₀ , E2	July	0,09	0,20	0,5	√
	August	0,03	0,15	0,5	√
	September	0,04	0,11	0,5	√
Benzene, E1	July	0,21	0,45	0,5	√
	August	0,16	0,29	0,5	√
	September	0,33	0,40	0,5	√
Benzene, E2	July	1,48	1,52	0,5	-
	August	0,20	0,35	0,5	√
	September	0,23	0,30	0,5	√

In table 11 the average differences for the street canyon are given. For the background level data from station E3 were taken, as no data was available from other stations in the vicinity. Station E3 is located north of E4, so only data obtained at a wind sector of 300° to 360° were taken in the evaluation. Nevertheless as a comparison also data at a wind sector from 180° to 360° were taken as well. The results for these calculations are shown in table 11 as well.

Table 11. Average differences between model and measurements at the street canyon (Pleinweg, E4, calculations based on hourly averages).

Street canyon, E4		Month	ΔC	ΔC_{abs}	Maximum difference ΔC criterion	Pass (✓) or Fail (-)
Wind sector 300°-360°	NO ₂	July	0,00	0,26	0,6	✓
		August	0,38	0,52		✓
		September	0,23	0,26		✓
		October	-	-		
	PM ₁₀	July	-0,10	0,30	0,5	✓
		August	no data	no data		✓
		September	0,23	0,26		✓
		October	-	-		
	Benzene	July	-0,05	0,43	0,5	✓
		August	-0,03	0,31		✓
		September	0,13	0,58		✓
		October	-	-		
Wind sector 180°-360°	NO ₂	July	-0,24	0,33	0,6	✓
		August	-0,12	0,31		✓
		September	0,00	0,23		✓
		October	0,41	0,52		✓
	PM ₁₀	July	-0,34	0,35	0,5	✓
		August	no data	no data		
		September	0,00	0,33		✓
		October	0,27	0,28		✓
	Benzene	July	-0,15	0,70	0,5	-
		August	-0,32	0,44		✓
		September	-0,11	0,52		✓
		October	-0,22	0,41		✓

6. Conclusions

One of the objectives in the HEAVEN project was to develop a dispersion model for air quality in urban areas. The measuring results presented in this report have served as a basis for the development for two different air quality dispersion models.

With both models hourly ambient air quality levels are calculated for NO₂, PM₁₀ and benzene in the urban areas are calculated. One model calculates the dispersion of traffic emissions from an highway in urban area, and the other model for a street canyon. Both models use actual hourly traffic and meteorological data for the calculation of ambient air concentrations of the mentioned air constituents.

The development of the “highway” model has been performed in two stages. In the first stage the model was developed for a so-called “open field” location in which traffic emissions could disperse freely into an undisturbed flat area. In the second stage the model was improved for an urban location in which typical local disturbances, such as sound screens, apartment buildings, house blocks and so-on, were present.

For the development of these models actual measurements were performed at an open-field” location, an urban location and in a street canyon. Modelling was performed on basis of actual traffic data (intensities, speeds and category), related emission factors and meteorological data.

This report describes the measurement set-up, the actual measurement data and the comparison between measurements and modelling. Within the HEAVEN project criteria have been set for the performance of the models. This performance is expressed as a maximum average difference between the modelled concentration and measured concentration.

The comparison between modelling and measurements and thus performance of the models show the following results:

- At each location it showed that in all - except but one – situations the (monthly) average deviation was below the prescribed 60% for NO₂ and below the prescribed 50% for PM₁₀ and benzene.
- For the *open field location* it showed that in 50% of the cases the average difference was even below 10%. Furthermore the *hourly* deviation between modelling and measurements was around 20% in 50% of the cases.
- For the *urban location* it showed that in 50% of the cases the average difference was below 12%. The *hourly* deviation was around 30% in 50% of the cases.
- For the *street canyon* It showed that in 50% of the cases the average difference was below 10%. The *hourly* deviation was around 30% in 50% of the cases.

From the comparison between modelling and measurements it shows that the agreement is reasonable, encouraging and is within the demands laid down in the HEAVEN-project. Nevertheless there is still room for further refinement. More detailed analysis of the modelling results will be presented in a separate report [3].

The final validation of the model with actual traffic intensity data, actual meteorological data and comparison with on-line measurement data in the urban area in Overschie will take place in 2002 and is still on-going and will be reported separately.

The vast amount of data presented here will serve as a for further analysis of traffic related air pollution studies in urban areas and specific in the City of Rotterdam.

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ANNEX C Heaven project, the impact of a 80 km/h speed limit

HEAVEN project, the impact of a 80 km/h speed limit



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Summary

This report is part of the evaluation procedures of the HEAVEN project. The report discusses the impact of the 80 km/h speed limit that was introduced on the national highway A13. This is a provisional assessment of the impact. A final and official evaluation will be provided by TNO in the course of 2003.

The assessment of the impact shortly after the introduction of the speed limit poses several methodological problems. These will be extensively discussed and they provide the background against which the results will have to be interpreted.

There are two reasons to make a provisional assessment of the impact, despite its methodological problems. One reason is the HEAVEN project time frame with an evaluation in October-November 2002. To meet the evaluation obligations it is simply impossible to wait for more data to become available. The second reason is of political nature: the speed limit is controversial and the road managers were anxious to know if the predicted effects did indeed occur.

The analysis shows that the speed limit does have an effect. However, due to the complex treatment of the data to compensate natural trends in the concentrations, it is impossible to quantify the impact. The provisional results show that the likely impact is of the same magnitude as the modelled impact.

1. Introduction

The A13 is a busy highway passing through a residential area called Overschie. Epidemiological research¹ has shown that the lung capacity of children attending a school adjacent to the highway was less than the national average. Modelled concentrations along the highway indicated that current EU air quality standards were not met, possibly explaining the observed health effects. The city of Rotterdam participates in the European HEAVEN project. The project aims to achieve a **H**ealthier **E**nvironment through the **A**batement of **V**ehicle **E**missions and **N**oise. So the Overschie area and the A13 were an obvious choice for project activities. One of the mitigating measures was a speed limit. The maximum speed was reduced from 100 to 80 km/h and this is rigorously enforced. This document analyses the monitoring data before and after the speed limit to assess its impact.

Figure 1: The Overschie area and the three air-quality monitoring sites for the HEAVEN project

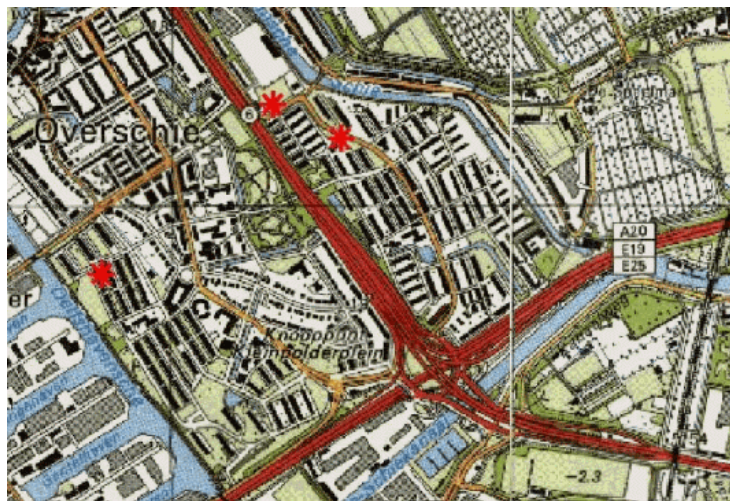


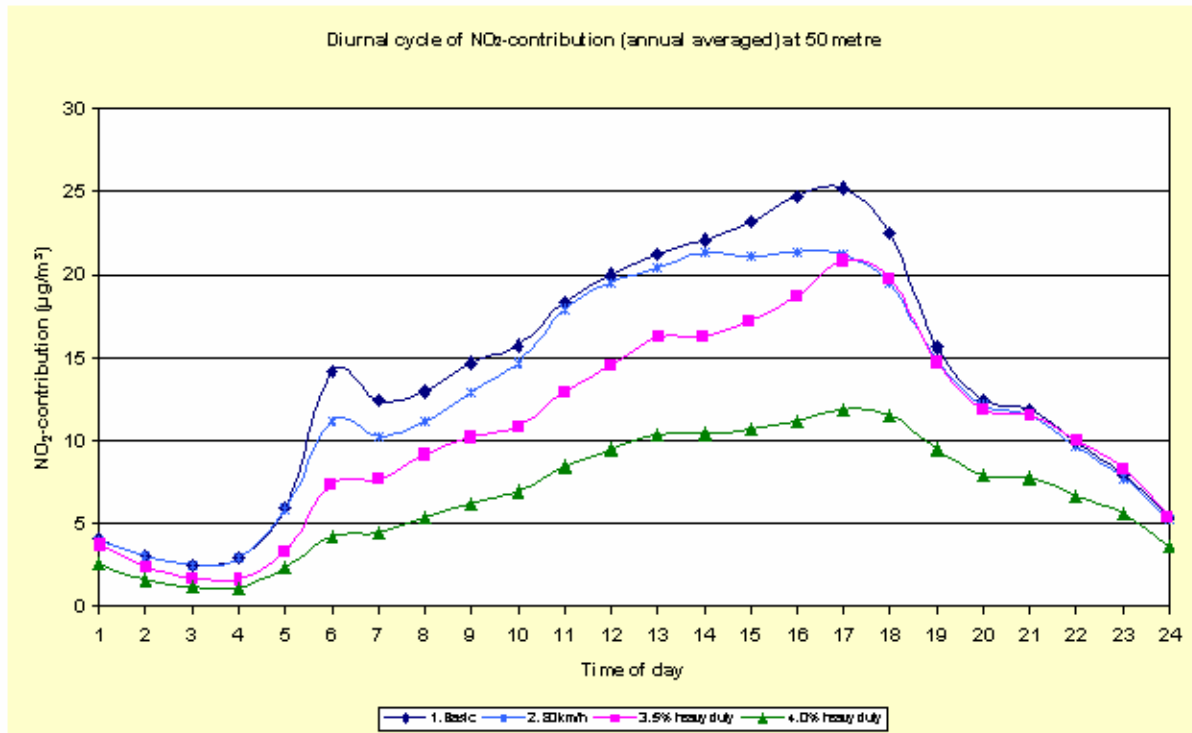
Figure 2: The A13 highway leading into the city centre after introduction of the speed limit



¹ Aarts, F.J.H., van Vliet, R.H.N., Janssen, N.A.H., Harssema, H., Brunekreef, B. 1999. Nader onderzoek naar de effecten van verkeersgerelateerde luchtverontreiniging op de luchtwegen van kinderen wonend nabij snelwegen (luchtweg 2). Wageningen Universiteit.

The speed limit, as a mitigating measure, resulted from scenario analysis using the air quality models that were built/improved as part of the HEAVEN project. According to the model calculations by TNO this would lead to a 7 % reduction in the ambient NO₂ concentrations. See figure 3 (the second highest line). The other scenario's (reducing the amount of heavy trucks) lead to higher reductions but could not be implemented due to lack of alternative routes.

Figure 3: The likely impact of traffic changes on ambient NO₂ concentrations at 50 m from the road



Source: TNO/MEP ¹

It is not uncommon to attach more credibility to measured results than to results based on computer models. However, measuring changes in the quality of ambient air poses a considerable amount of problems as several factors affect the concentrations and it might be difficult, if not impossible, to isolate the effect of the speed limit from the other sources of variation. These problems will be discussed extensively and the results will have to be judged against this background. Due to these methodological problems the results of this analysis are provisional. If a longer period before and after the introduction can be compared the credibility of the results will improve.

There are two reasons to make a provisional assessment of the impact, despite its methodological problems. One reason is the HEAVEN project time frame with an evaluation in October-November 2002. To meet the evaluation obligations it is simply impossible to wait for more data to become available. The second reason is of political nature: the speed limit is controversial and the road managers were anxious to know if the predicted effects did indeed occur.

¹ Spoelstra, H. en Wesseling, J.P. 2002. *Luchtqualiteitsmetingen Overschie. Fase 1: Nulmetingen. 2002.* TNO-rapport R2002/340. Concept.

2. Comparing air quality, methodological considerations

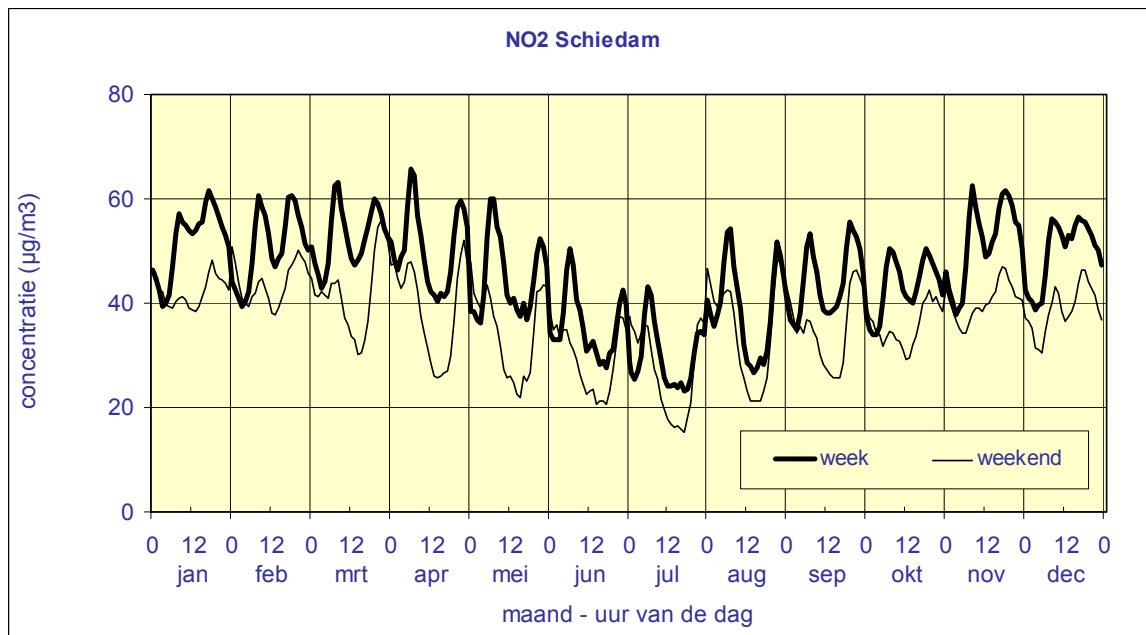
To properly assess the impact of the speed limit on air quality, all other conditions affecting air quality before and after the introduction of the speed limit should remain identical. This is virtually impossible. As a consequence, the concept of measuring as an objective tool to verify model calculations loses some of its appeal: what is being measured, is it due to the speed limit or due to something else? In table 1 some of the potential sources of influence are enumerated. Most of these sources of variation cannot be controlled but strategies can be identified to minimise their impact. Some of these strategies will be used in this provisional analysis. Others will be employed by TNO in the final evaluation.

Table 1. Aspects influencing pollutant concentrations in the air

<p>Weather conditions</p> <ul style="list-style-type: none"> - Solar radiation, temperature - Rain - Wind speed and direction 	<p>Affect chemical reactions in the air</p> <p>Kind of rains the air and reduces concentrations</p> <p>The wind direction determines the kind of pollution that arrives from other sources and the wind speed determines whether there is a build-up of pollution or whether the pollution is quickly diluted and dispersed.</p>
<p>Season</p>	<p>The season obviously has an impact on the weather but also on the so-called mixing height. As a consequence most concentrations are lower in the summer season than in the winter season. Furthermore, in the winter months there is an additional source of pollution: the heating of houses.</p>
<p>Traffic</p> <ul style="list-style-type: none"> - Speed and intensity - Type of vehicle 	<p>The number of vehicles plays an important role, but also the velocity and the traffic dynamic. Steady rolling traffic with hardly any lane changes produces less pollution than accelerating and breaking traffic. Frequent lane changes cause this process of accelerating and breaking. The main effect of the speed reduction is that it reduces the incentive to change lanes and thereby lowers the traffic dynamic.</p> <p>The average age of vehicles plays a role; modern cars are much more clean and efficient. Lorries and other heavy vehicles are also a much greater source of pollution than passenger cars.</p>
<p>Other sources of air pollution</p>	<p>Industries and economic activity in general are also a source of pollution. Which sources contribute to the concentration at a monitoring site depends on wind direction. Heavy industries generally operate on a 24-hour basis but also in the industrial emissions there may be periodical or seasonal changes (seasonal change in demand, maintenance, etc.)</p>
<p>Background concentrations</p>	<p>The background concentration is the concentration that exists anyway, irrespective of local pollution. This might be pollution arriving by wind from other sources but it is also used to sum a large amount of small (diffuse) sources such as the gas cookers in individual households.</p>
<p>Day of the week, hour of the day</p>	<p>Day of the week and hour of the day have an impact on the concentration of pollutants because they are related to traffic intensity and to the intensity of economic activities but also to temperature and radiation</p>

Especially the impact of the weather can be substantial. TNO has run a series of model calculations with the same emission of pollutants but with the different Dutch weather circumstances of a number of years. The same emissions led to concentration differences of up to 20 %. The impact of the season, the hour of the day and the day of the week on NO₂ concentrations can be seen in figure 4. The graph shows, in each month, the diurnal changes (0 to 23 h) of the concentrations. There are separate lines for week and weekend days. The graph presents the average values for 1996-2000.

Figure 4: Diurnal pattern of NO₂ concentrations in each month of the year



The graph shows that, on average, the NO₂ concentrations tend to drop in May, which is also the time the speed limit was introduced. This drop is due to the fact that the mixing height increases in summer and the heating of houses is less. So the choice of the 11th of May for the introduction of the speed limit is, in itself, a complicating aspect.

From the above, it is evident that it will be extremely difficult to assure that none of the above mentioned influences change, except the average speed of the passing vehicles. Simply measuring concentrations before and after the 11th of May might lead to erroneous results. There are several ways to control potential disturbances.

A long series of measurements before and after the speed limit (preferably a year). This should cancel out the seasonal cycles. If the weather is fairly similar in both years the approach might lead to a valid comparison. Measurements in Overschie started in June 2001 so by June 2003 this comparison can be made. The disadvantage of this method is that in the mean time cars become cleaner and more efficient, transport fluxes might change (usually: grow), and something might change in the background or in the industrial setting. So even if the climate is identical in both years it is not evident that the comparison is completely honest.

The other option is to compare two short periods, just before and just after the measure. In this case the weather plays an important role but changes in traffic patterns and background concentrations are less likely.

Correct the measurements for known influences. This is a powerful method to isolate the effect under consideration. However, the method has two disadvantages: firstly, assumptions have to be made about the behaviour of pollutants. The measurements are corrected by these calculated parameters so the verification becomes a hybrid between modelling and measuring. As such it is no longer the fully objective check on findings based on models. A second disadvantage is that by correcting measurements the assessment of the impact under real conditions becomes complicated: the impact is only known for the stylised (corrected) conditions.

Finally, if the aim of the research is to establish whether or not the speed limit has had an impact, the research could be limited to a number of selected hours when the phenomenon is most likely to occur, for example on weekdays during rush hours. By using a selection of hours the impact, if any, becomes relatively more prominent compared to other variation in the data. The disadvantage of this method is that the overall effect of the speed limit is hard to assess. This method can be combined with all of the other methods.

3. Provisional results

3.1 Introduction

The question to be answered is: does the speed limit have an impact that can be measured? In chapter 2 it has been argued that it will be very difficult to answer this question and several methodological options have been discussed. In this chapter a short term comparison will be made: the period 1/4/2002 -10/5/2002 will be compared to the period 12/5/2002 -30/6/2002. The long term, final, comparison will be made by TNO in the course of 2003. The results of this analysis are therefore provisional.

There are three project monitoring sites in the area (see figure 1):

E1 is immediately next to the highway A13. The dispersion models predict an effect at this point.

E2 is at some 210 m from the A13. In case of wind from the south E2 is likely to be influenced by the A20 as well. An effect from the speed limit on the concentrations at E2 is not expected.

E3 served as a dedicated background station during model development, especially in the case of wind from the west.

Apart from these three project sites DCMR has three regular monitoring stations in the wider Rotterdam area. These stations are used as regional background.

As the change from winter to summer coincides with the evaluation period, a correction of the data for seasonal influences seems unavoidable. The necessity of this correction and the way it is done will be discussed.

3.2 Differences before and after the speed limit: the need for correction

3.2.1 Traffic

The average traffic characteristics before and after the speed limit are shown in table 2. The first block presents the average data, the second block refers to a subset of the morning and evening rush hours and the third block to hours with a westerly wind direction.

It is interesting to examine these subsets as the effects are potentially more pronounced during rush hour. The hours with westerly winds are interesting as in these instances the wind blows directly from the highway to the monitoring sites. These analyses have been

made but in this document only the most general situation is presented. The results of the analysis of the subsets broadly confirm the more general findings as presented here.

Table 2: Traffic differences before and after the speed limit

	Traffic density			Velocity (km/hour)		
	Passenger car	Light truck	Heavy truck	Passenger car	Light truck	Heavy truck
Total average:						
Before	5375	352	281	96	87	80
After	5283	369	275	75	73	72
$\Delta B - A$	92	-17	6	21	14	8
Rush hour:						
Before	7745	542	445	88	79	73
After	7964	576	460	71	69	67
$\Delta B - A$	-229	-34	-15	17	10	6
Wind from the west:						
Before	5219	356	296	97	87	80
After	5531	313	270	74	73	72
$\Delta B - A$	-312	-13	26	22	14	8

NB: Shaded cells indicate significant differences

The table shows that there have been some significant changes in the traffic characteristics. All velocities have gone down, as expected. However, the drop in average speed is generally less than 20 km/hour. Secondly, the vehicle numbers have also changed. Especially during rush hours and with wind from the west the number of cars has gone up after the introduction of the speed limit. This will obviously reduce any beneficial effects of the speed limit. Though it is not shown in the table, the product 'velocity * density' has gone down in all cases.

3.2.2 Weather conditions/seasonal changes

As was discussed before, one might expect a natural drop in ambient concentrations due to a change in the meteorological conditions. It turns out that in 2002 the pattern was not as clear cut as for example in figure 4. See table 3.

Table 3: Monthly average NO₂ concentrations ($\mu\text{g}/\text{m}^3$) in Overschie in 2002

Site	January	February	March	April	May	June
E2	64	46	58	46	42	42
E3	46	32	48	28	37	36

Site E1 was left out of the table as it might have been influenced by the speed limit. The table shows that concentrations in April were lower than expected. This is due to some periods with northerly winds. As there are no sources of pollution, especially to the north of E3, the ambient concentrations will be below average. The DCMR monitoring sites do have some sources of pollution to their north so some caution in using these sites to correct the concentrations on E1, E2 and E3 is warranted. The danger of over-correction exists.

The seasonal effects are due to many reasons (see table 1.) One of the effects is the way temperature affects the chemical equilibrium $\text{NO} + \text{O}_3 \leftrightarrow \text{NO}_2 + \text{O}_2$. This part of the problem can be avoided by looking at NO_x ($\text{NO} + \text{NO}_2$) instead of NO_2 . The other influences can not be avoided and will have to be corrected for.

3.2.3 Correction methods

A pollutant concentration at site E1 can be thought of as a background concentration, C_b + a traffic related concentration, C_t . The observed (total) concentration, $C_o = C_b + C_t$ is subject to the seasonal meteorological effects. Seasonal effects can be corrected in two ways:

A 'strong' correction can be made by using the pattern in the background to correct the observed concentrations. The observed concentration is divided by the background concentration:

$$C_{cor} = C_o / C_b = (C_t + C_b) / C_b$$

This creates a dimensionless factor (C_{cor}) close to unity. The difference: $\Delta = C_{cor} - 1$ is a traffic related concentration corrected for seasonal influences (In fact $\Delta = C_t / C_b$).

If for some reason (such as exceptional weather conditions) the background concentrations used for the correction are not the true local background concentrations over-correction easily occurs. (See annex 2 for an example).

A 'weak' correction can be made by subtracting the background concentration from the observed total concentration. $C_t = C_o - C_b$

The remaining result is traffic a traffic related concentration. This method is less likely to over-correct seasonal patterns. It is a weak correction as the traffic related component remains uncorrected.

As mentioned in the previous section, there has been some exceptional weather so the weak correction seems the more appropriate one.

3.3 The effect of the speed limit

The effects of the speed limit will be examined in two ways. First a regression analysis is done on the uncorrected data. This will broadly indicate the impact of the speed limit and demonstrates that indeed some kind of correction is needed. The second analysis compares corrected concentrations before and after the speed limit.

3.3.1 Regression analysis

As was mentioned in the previous section, the observed concentration can be described as $C_o = C_b + C_t$. Changes before and after the speed limit are examined by the use of dummy variables for both C_b and C_t . The dummies are 0 before the speed limit and are free to vary after the speed limit. If they are still zero after the speed limit this indicates that no changes have taken place.

C_t can be thought of as traffic emissions * traffic density: $C_t = T_e * T_d$; and, if the speed limit is effective the traffic emission will change so a dummy variable ΔT_e is needed as well. To account for a seasonal change in the background concentration a dummy variable ΔC_b is introduced. The regression equation can now be described as:

$$C_o = C_b + \Delta C_b + (T_e + \Delta T_e) * T_d$$

A regression analysis was made using the traffic density of heavy trucks.¹ Heavy trucks account for roughly half of the emissions so they are the most important proxy variable for total traffic. See table 4.

Table 4: Regression analysis of concentrations ($\mu\text{g}/\text{m}^3$ except NO_x : ppb) and traffic density of trucks

	C_b	T_e	ΔT_e	ΔC_b	R^2
NO	17.7	129.9	-35.7	-8.9	0.40
Std	3.0	8.0	9.9	3.7	
NO_2	47.2	50.8	-3.7	-11.2	0.39
Std	1.5	3.9	4.9	1.8	
NO_x	38.6	130.6	-29.2	-13.0	0.46
Std	2.9	7.4	9.4	3.6	
PM_{10}	36.8	47.4	-4.7	-5.3	0.25
Std	1.7	4.6	5.7	2.1	
C_6H_6	1.8	0.07	-0.04	-0.18	0.05
Std	0.1	0.02	0.03	0.19	

NB: Shaded cells indicate significant regression coefficients

The table shows that indeed there is a significant downward trend in the background concentrations except for benzene. The table also shows that the traffic related part of the concentrations has gone down after the introduction of the speed limit ($\Delta T_e < 0$). However, for benzene and PM_{10} these effects are not significant (at the 5% level). The main effect was expected for NO_x and the regression analysis confirms that the drop in NO_x is significant.

The preliminary conclusion might be that the speed limit indeed had an effect on the vehicle emissions. As heavy vehicles were used as a proxy for total traffic and not all traffic was included, this method cannot be used to establish the magnitude of the effect of the speed limit.

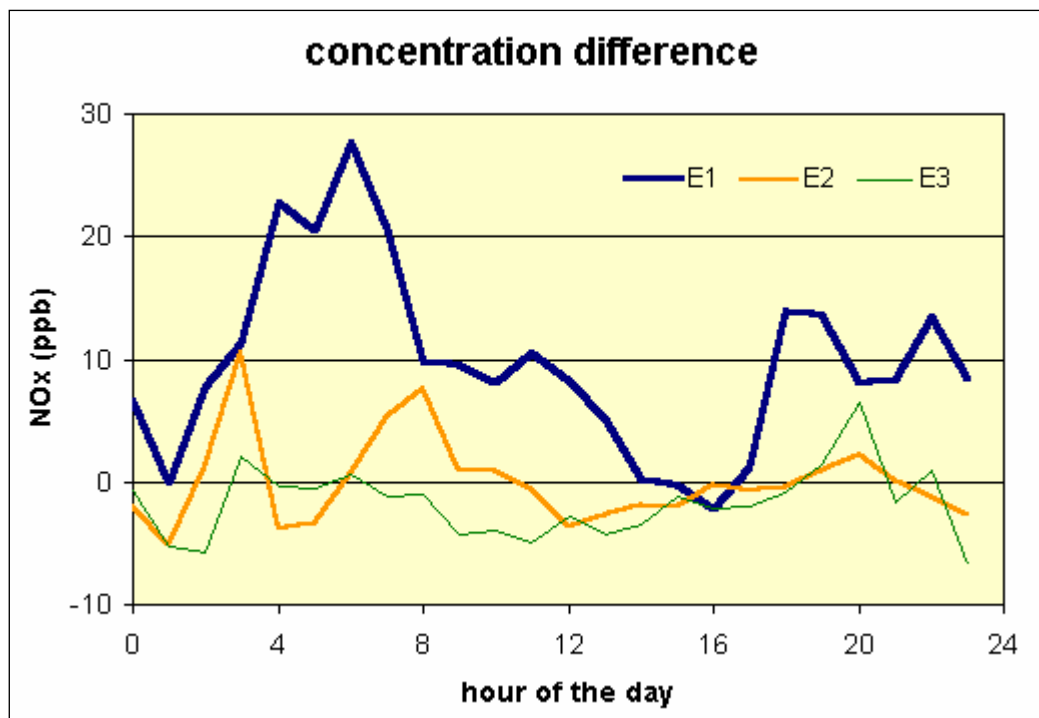
3.3.2 Concentrations before and after the speed limit

In the previous section uncorrected concentration data were analysed and it was concluded that (a) there is a drift in the background that needs to be corrected, and (b) there is an effect of the speed limit. In this section the magnitude of the effect is established using corrected data.

A weak correction is applied by subtracting the average concentrations in the Rotterdam area from the concentrations at the three project sites. Occasionally this leads to negative concentrations: this is the case with northerly winds when the project sites receive relatively clean air but the background stations do receive some pollution from sources to their north. These negative values have been discarded from the analysis. Furthermore, the analysis is also restricted to weekdays. Hourly average concentrations of NO_x were calculated before and after the speed limit. The concentration differences were calculated and plotted in a graph. See figure 4.

¹ Due to the fact that traffic densities for different types of cars are not sufficiently independent they cannot be combined into one equation. This could be done by summing them after the application of a weighting factor for emissions of different vehicle types. This involves making assumptions on traffic emissions so this was not done.

Figure 4: Difference in NO_x concentration before and after the speed limit at the 3 project sites



The graph shows several things:

- At E1, where an effect is expected the difference between the concentrations before and after the introduction of the speed limit is substantial and it mainly occurs during the rush hours. This is as expected.
- Site E2 is influenced by the highway A13 but an effect of the speed limit is not expected and indeed the line hovers around 0, indicating no change.
- At E3 no impact of the road is expected and this line should also hover around 0. The graph shows that this is the case, though there is a slightly negative bias. This implies that at E3 the concentrations have risen after the introduction of the speed limit. Apparently the background correction as it was applied was not entirely correct (if it had been correct the average concentration difference at E3 would have been 0).

Overall, the graph confirms the regression findings and the expectations based on the computer model: Close to the highway A13 (at E1) the speed limit has an impact on the ambient concentrations of NO_x. The impact is visible at hours where it was expected and is absent where the impact was not expected. At a distance from the highway the differences before and after the speed limit are absent or negligible, indicating that on average the applied correction was adequate.

The data are also presented in table 5. Average data for each hour of the day were compared in a one-sided t-test to see if the observed difference was significant. During the morning rush hour and in the evening several differences are significant. A T-test of the pairwise comparison of hourly averages over the whole day was very significant.

Table 5: NO_x concentration differences before and after the introduction of a speed limit

Hour of the day	Seasonally corrected NO _x concentrations (ppb)			T-test (one sided)
	Before	After	Difference	
0	22.4	15.7	6.6	0.14
1	17.0	17.0	0.0	0.50
2	22.3	14.5	7.8	0.16
3	21.8	10.4	11.4	0.06
4	67.4	44.6	22.9	0.01
5	116.1	95.5	20.6	0.15
6	97.6	69.9	27.7	0.02
7	81.7	61.1	20.6	0.06
8	72.4	62.4	10.0	0.26
9	60.2	50.6	9.6	0.13
10	58.1	50.0	8.1	0.21
11	57.4	46.9	10.5	0.14
12	55.6	47.3	8.3	0.18
13	50.5	45.2	5.3	0.27
14	46.6	46.2	0.4	0.48
15	43.7	43.9	-0.2	
16	40.9	43.0	-2.1	
17	40.5	39.3	1.3	0.43
18	43.7	29.8	13.9	0.04
19	38.3	24.6	13.7	0.02
20	31.6	23.5	8.2	0.09
21	27.6	19.2	8.5	0.06
22	28.0	14.5	13.5	0.03
23	25.2	16.7	8.5	0.18
Average	48.6	38.8	9.8	
T-test: paired hours				0.00

The table can be used to calculate the impact of the speed limit. Recall that the table refers to weekdays and that hours with a regional background concentration, which was higher than the concentrations observed at the traffic monitoring sites were put aside. The hours in the table represent only 69 % of the hours so the observed effect is slightly smaller than appears from the table. The overall average impact of the speed limit on NO_x is estimated at 14%.

If, to be absolutely sure, only the hours with a significant (at 5 % level) difference are considered the average impact of the speed limit drops to 5%. On the other hand, looking back at the negative bias on E3 one might conclude that the correction that was applied has been too strong. This implies that in reality the effect might have been slightly (2%) larger. So, the likely effect is 14 % with an interval from 5 to 16 %.

As the analysis is done for NO_x the results can not be compared directly to those of TNO as shown in figure 1. However they are in the same range as TNO estimates the year average impact on NO₂ at 7 %. The ratio NO:NO₂ differs in the course of the day and is influenced by the season. In the test period, the daily averages of NO and NO₂ were approximately the same so the estimated average impact on NO₂ as observed in this study would range from 2.5 to 8 %.

3.4 Conclusions

An analysis of the uncorrected data showed that (a) the speed limit had an impact, and (b) there was a seasonal change in the concentrations that needed correction. The impact on NO_x was significant. The impacts on PM₁₀ and benzene were not significant. This does not mean that the speed limit does not affect PM₁₀ and benzene but that the effect was too small to be established undisputedly in this analysis.

After a weak correction of the data the concentrations before and after the introduction of the speed limit were compared. This analysis showed that there is a significant difference in the NO_x concentrations before and after the introduction of the speed limit at monitoring site E1. The differences occur at the hours when traffic densities are high. This is according to expectation and it is also a clear sign that the observed effect is traffic related. Furthermore: the observed effect does not occur at E2 and E3. Again this is expected and it indicates that the correction has been effective to eliminate seasonal influences and, at the same time, is not a source of bias in itself.

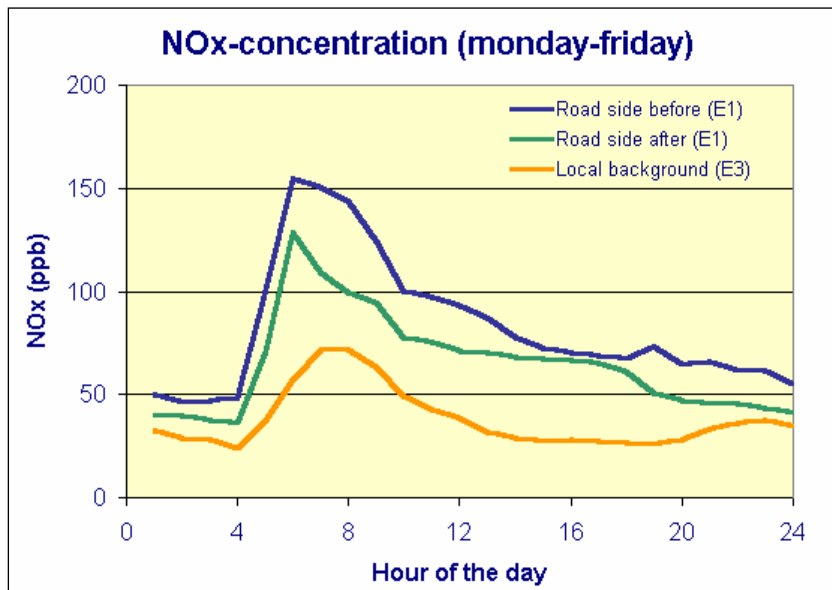
The average effect of the speed limit on the NO_x concentration in the study period is estimated at 14 %. The range is estimated at 5 to 16 %. The results correspond well to the modelled predictions.

The results are provisional and a full evaluation over the period of a whole year will lead to more definite conclusions. If the observation period is longer the need for correction is less. This implies that evaluation can be done by 'true' measurements.

Annexes ¹

Annex 1: NO_x concentrations in the course of the day

Traffic related NO_x concentrations before and after the introduction of the speed limit and local background. Note that this graph cannot be compared to figure 3 in the main text as the NO₂ daily pattern differs strongly from the NO_x pattern.



¹ To Annex C of D 8.8

The figure shows that although the traffic related NO_x concentrations are substantial (the gap between E1 and E3), the background makes up half of the total NO_x concentration: completely eliminating the highway would achieve at best a 50 % reduction in total ambient NO_x concentrations.

Annex 2: Correction for seasonal influences: an example

Example of a strong correction: the PM₁₀ concentration shows a strong downward trend (green line) with daily averages going down from around 50 to less than 40 µg/m³. In the corrected data (using strong correction) this effect is eliminated. However, the correction introduces a small upward trend. This is obviously also undesirable. The example shows that correction does improve matters but also creates some bias of its own.

