In-situ air quality measurements on existing and innovative noise barriers

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Abstract

From literature and wind tunnel studies it had already been concluded that noise barriers might make a significant contribution to improving air quality. Within the Dutch Air Quality Innovation Programme (IPL) several trials have been conducted at a test site along a highway to assess the impact of noise barriers on air quality along arterial roads. In 2007 IPL did organise a competition challenging companies to come up with innovative barrier designs having an additional impact on air quality compared with conventional barriers. M+P – consulting engineers was commissioned to measure the impact of standard and optimised barriers on concentrations of NO_2, NOx, PM_{10} and $PM_{2.5}$ behind the barrier. In five monitoring sessions each lasting around three months, the performance of nine different barriers was investigated. The measurements were done at thirteen different positions. From the results it became clear that noise barriers reduce concentrations of nitrogen oxides and airborne particulates along motorways significantly. For example, effects of 20% for NOx were found at 10 m behind the reference barrier. The measurements show that the barrier height is a relevant parameter for the effect of the barrier. A 7m-barrier shows considerably higher reductions compared to the 4m-barrier. From the results it is also clear that the measured effects of the innovative barriers were consistently lower than for the "reference barrier". It should be kept in mind that because of the major uncertainties involved, in many cases the effects statistically do not differ significantly. It is unknown why the reference barrier performs somewhat better than the other 4-meter-high innovative barriers.

Keywords: barriers, mitigation, nitrogen oxides, airborne particulates, innovation, measurements.

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1 Dutch air quality innovation programme

Under the Dutch Air Quality Innovation Programme (IPL) a series of trials have been conducted at a test site along the A28 at Nulde Beach to assess the impact of noise barriers on air quality along arterial roads. As part of this effort M+P – consulting engineers were commissioned to measure the impact of standard and optimised barriers on concentrations of NO_2, NOx, PM_{10} and $PM_{2.5}$ behind the barrier. [1] The Air Quality Innovation Programme was coordinated by Rijkswaterstaat, The Netherlands, Directorate-General for Public Works and Water Management. At the moment the IPL is transferring its know-how on measures to improve air quality along motorways to the project principals (the ministries of Transport and Environment), knowledge institutes, engineering consultancies and the market. The know-how has been built up in the course of a series of unique and large-scale practical trials carried out under the innovation programme. [2, 3]

2 The test site

The IPL Test Site was located on the Dutch west coast, in the municipality of Putten, on the west side of the A28 motorway between exit 10 to Nulde Beach and exit 11 to Horst Beach. The A28 is a motorway with two carriageways each comprising two traffic lanes and an emergency lane. Traffic intensity averages around 65,000 vehicles a day, around 16% is heavy vehicles. The barriers and measurement apparatus were installed on the west side of the road. Figure 1 shows a model of the test site.

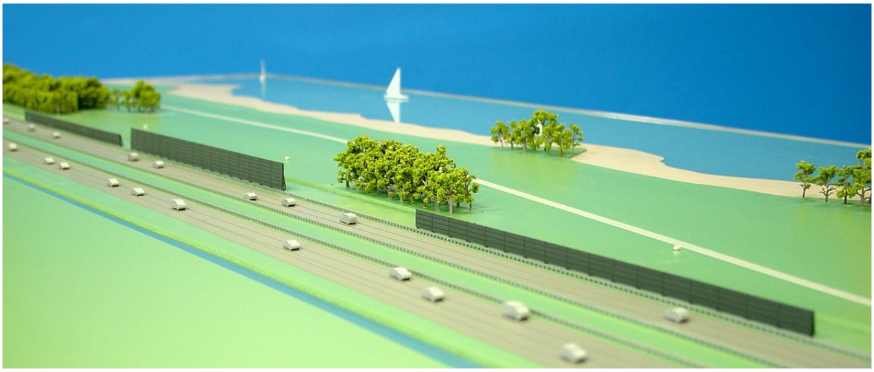

Figure 1: Model of the IPL test site with illustrative barriers, viewed from the north (photo: Maquette Studio Stens).

3 Measurement principle

To establish the effect of the noise barriers on pollutant concentrations, the road contribution was measured at three different positions behind each barrier as well as in the zero situation. In situations in which the wind is blowing from the opposite side of the road, the road contribution is the difference between the reading at the measurement position behind the barrier in question and that at the measurement position on the other side of the road. The barrier effect is obtained by comparing the road contribution at a particular position behind the barrier with the contribution at the equivalent position in the zero situation. The configuration of measurement positions is shown schematically in Figure 2.

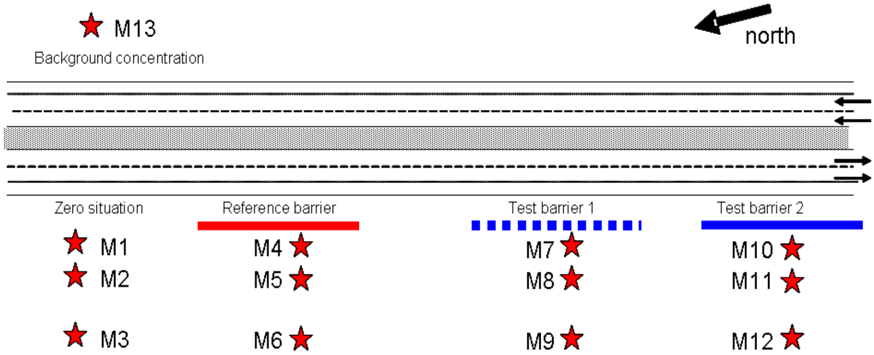

Figure 2: Schematic view of the measurement positions.

4 Measurement equipment

To comply with the requirements and wishes regarding the measurements, the following measurement apparatus were selected for use:

- Low Volume Samplers (LVS), make Derenda, for reference measurements of PM_{10} and $PM_{2.5}$. These monitors collect the particles on a filter for a 24-hour period; after laboratory weighing the average concentration over that period can then be calculated.
- continuous TEOM particulate samplers, make Thermo (1400a series), for real-time measurement of PM_{10}. The TEOM uses an oscillating filter to collect the PM. As this builds up it alters the natural frequency of the filter, from which the change in mass can be calculated and thus the airborne PM concentration.
- continuous Osiris particulate samplers, manufactured by Turn-key instruments. The Osiris uses the principle of light scattering, with the angle of diffraction of the scattered light being used to estimate particle size and calculate ambient concentration.

The effects for PM_{10} in this paper are based on the measurements with the TEOM's and are therefore only availably for the fourth and fifth measurement period. The uncertainties in the Osiris measurement data turned out to be so high that these data are not usable for any conclusions with respect to the barrier effect for PM_{10}.

NOx and NO_2 were measured with continuous Airpointer samplers, based on chemiluminescence, manufactured by the Austrian firm Recordum.

Figure 3: Particulate and Nox samplers: from left to right LVS, TEOM and Airpointer.

5 Barriers tested

During five monitoring sessions between July 2007 and March 2009 nine different barriers were tested for their impact on the road contribution of NOx, NO_2 and PM_{10} at the Test Site. In the course of these fifteen months of measurement over 11,000 hourly readings of each of around 65 parameters were made, with 1,740 relevant hourly values of each parameter being used for detailed analyses. The following table provides a summary of the barriers tested.

Table 1: Barriers tested at the IPL test site.

session	period	barrier 1	barrier 2	barrier 3
1	July - October 2007	7-metre-high standard barrier	fibreboard concrete with TiO_2 coating (Durisol)	
2	December 2007 – March 2008	T-top barrier	vegetated barrier (Mostert de Winter)	
3	April – August 2008	Cleanscreen (Redubel)	Active Green noise barrier (Aacoustics)	4-metre-high reference barrier
4	August – November 2008	Cleanstone (Tauw/Holland)	Greenbreath (MOWI/Bos variant)	
5	December 2008 - March 2009	7-metre-high standard barrier	no barrier	

6 Uncertainties

Calculation of the barrier effects based on the measurement results obviously involves various uncertainties. In each of the figures in this chapter an indication is given of the total estimated uncertainty. The error bars for the barrier effect are the sum of three main sources of uncertainty:

- instrument-related uncertainty (calibration differences, drift);
- statistical uncertainty;
- uncertainty due to differences in local structure between the measurement lines.

The total uncertainty is given by quadratic summation of the above items for each regression analysis. In all cases the error bars represent the 95% confidence interval.

If we consider the barrier effect for NOx at some arbitrary measurement position, for example, then the total uncertainty is given by quadratic summation of the statistical uncertainty, the instrument-related uncertainty and the measurement-line uncertainty, with values of 8, 6 and 3.5%, respectively. In this example the total uncertainty is thus about 11%.

7 Results 4m-reference barrier

One barrier, a modular glass barrier, was taken as a reference. See figure 4.

Figure 4: Reference barrier at the IPL test site.

The following figures show the effect of this four-meter high reference barrier at the three different positions behind the barrier for NOx (top), NO_2 (center) and PM_{10} (bottom). These average percentage effects for the reference barrier are valid for this particular barrier, at this location, in this configuration, during the period July 2007 to March 2009. The uncertainty in the effect (the error bars represent the 95% confidence interval) is the estimated total uncertainty due to the measurement equipment and differences between the respective measurement lines.

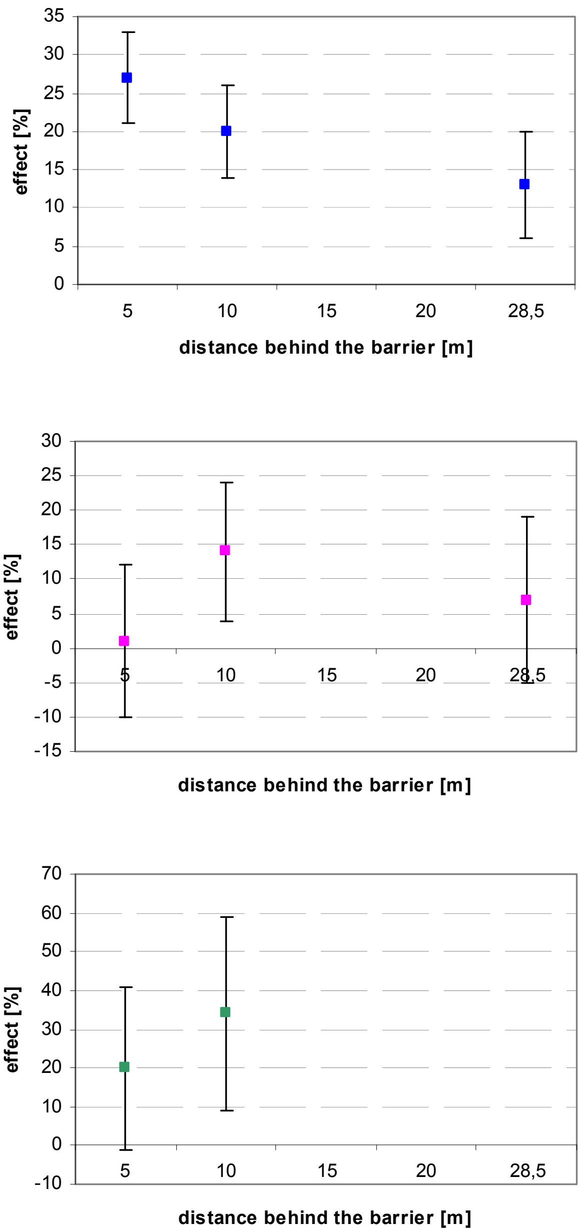

Figure 5: Effect of the 4m reference barrier versus the distance behind the barrier, for NOx (top), NO_2 (center) and PM_{10} (bottom).

These results show that, particularly for the measurement point closest to the barrier, the effect of the barrier is lower for NO_2 than for NOx. This is explained by the (extra) ozone mixed in from the ambient air. The PM_{10} measurements show a remarkably high barrier effect at 10 meter distance behind the reference barrier. It is expected that PM_{10} behaves like an inert gas; therefore it is not likely that the barrier effect for PM_{10} differs significantly from the effect for NOx. The results thus cannot be fully explained.

8 Results 7m-standard barrier

The graphs below indicate the barrier effect at various distances behind the 7m-barrier, for NOx (top), NO_2 (center) and PM_{10} (bottom). These effects are based on measurements performed over a period of three months, in the fifth measurement session, and are corrected for a "seasonal effect" in order to obtain results comparable to the effects of the 4m-barrier.

Figure 6: 7m-standard barrier at the IPL test site.

From the measurements, it is clear that the barrier height is a relevant parameter for the effect of the barrier. The 7m-barrier shows considerably higher reductions compared to the 4m-barrier. The measurement results for PM_{10} show no significantly different barrier effect than the effect for NOx.

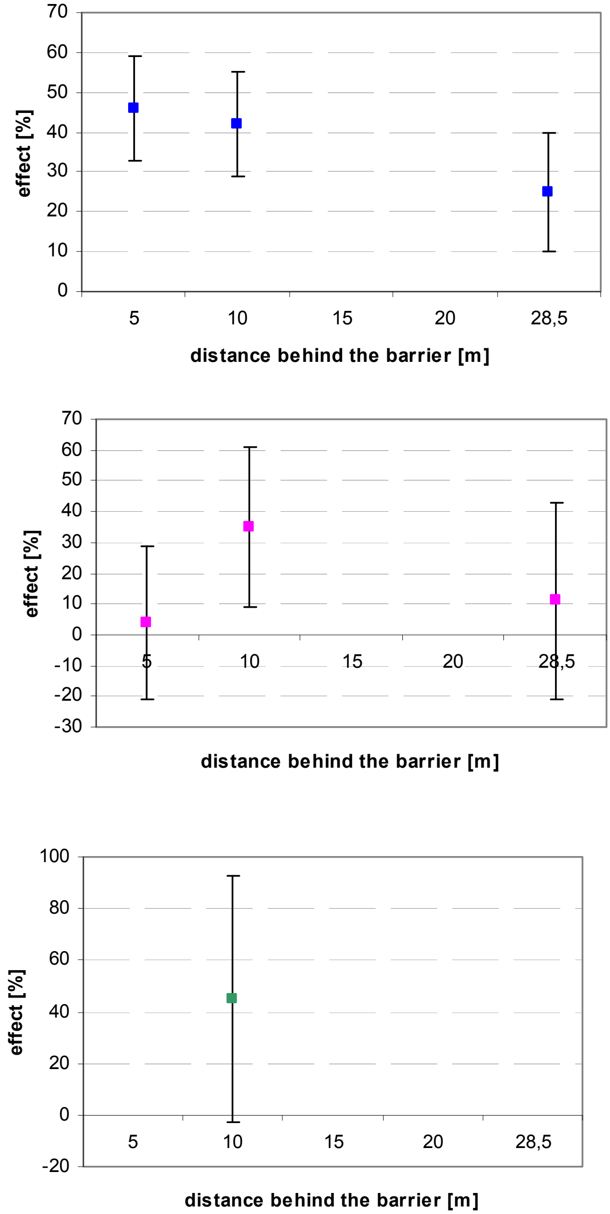

Figure 7: Effect of the barrier versus the distance behind the 7 meter high standard barrier in the fifth measurement session, for NOx (top), NO_2 (center) and PM_{10} (bottom).

9 Seasonal correction

Given the fluctuations in (above all) meteorological conditions, the barrier effect is not constant throughout the year. When comparing the measured effect of a barrier in a given monitoring session with the average effect of the reference barrier, a correction can be made using the measured effect of the reference barrier in that period. This is done by multiplying the ratio between the measured effect and the effect of the reference barrier in a certain (shorter) period by the average effect of the reference barrier over the entire monitoring campaign. Figure 8 shows the barrier effect for NO_2 at a distance of 10 metres behind the reference barrier. The measurements indicate that the barrier performs better in the winter months than in the summer months.

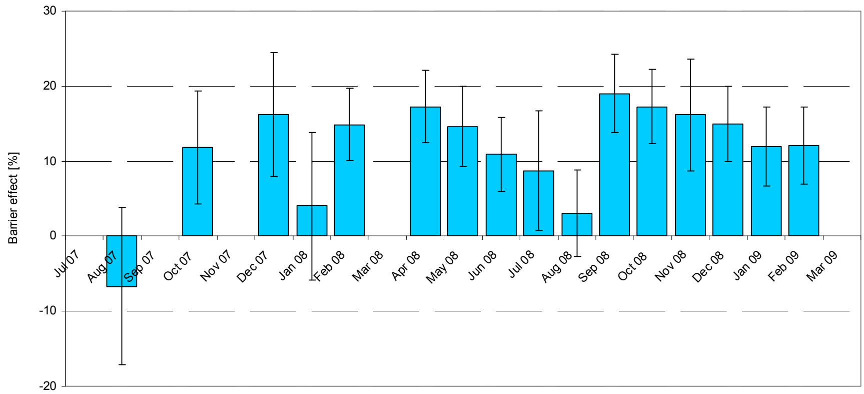

Figure 8: Barrier effect for NO_2, by month, 10 metres behind reference barrier.

Assuming differences in barrier effect in different months are due (above all) to meteorological influences, a barrier investigated in a given session can be corrected using the value of the reference barrier in that period.

10 Optimized barriers

The following table shows the results 10 metres behind the other barriers compared to the situation without any barrier.

These barriers were tested for a shorter period and a “seasonal correction” was therefore made, allowing the effect of each to be compared with that of the reference barrier. The effects for PM_{10} are based on the measurements with the TEOM’s and are therefore only available for the fourth and fifth measurement period.

Table 2: Effect of the optimized barriers.

session	barrier	corrected barrier effect for NO_2 [%]	corrected barrier effect for NOx [%]	corrected barrier effect for PM_{10} [%]
2	Mostert de Winter	-8 (± 23)	2 (± 13)	
3	Active Green	8 (± 17)	12 (± 12)	
4	Greenbreath	3 (± 20)	9 (± 13)	7 (± 57)
2	T-top	7 (± 22)	15 (± 12)	
3	Cleanscreen	5 (± 17)	15 (± 12)	
4	Cleanstone	2 (± 19)	11 (± 12)	25 (± 54)

Figure 9: Photos of the optimised barriers. Mostert de winter (top left), Active Green (top center), Greenbreath (top right), T-top (bottom left), Cleanscreen (bottom center) and Cleanstone (bottom right).

From these results it is clear that, with the exception of the 7-metre-high standard barrier, the measured effects were consistently lower than for the "reference barrier". It should be borne in mind that because of the major uncertainties involved, in many cases the effects statistically do not in fact differ significantly. It is unknown why the reference barrier performs somewhat better than the other four-metre-high innovative barriers. Possibly, the shape and material of the barrier (and barrier edge) play a part, though this has not been investigated.

11 Conclusions

From the results it became clear that noise barriers reduce concentrations of nitrogen oxides and airborne particulates along motorways significantly. For example, effects of 20% for NOx were found at 10 m behind the reference barrier. The measurements show that the barrier height is a relevant parameter for the effect of the barrier. A 7m-barrier shows considerably higher reductions compared to the 4m-barrier. From the results it is also clear that the measured effects of the innovative barriers were consistently lower than for the "reference barrier". It should be kept in mind that because of the major uncertainties involved, in many cases the effects statistically do not differ significantly. It is unknown why the reference barrier performs somewhat better than the other 4-meter-high innovative barriers.

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