National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

$PM_{2.5}$ monitoring strategy

RIVM Letter Report 680704018/2012

E. van der Swaluw | R. Hoogerbrugge

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Abstract

$PM_{2.5}$ monitoring strategy

By order of the Ministry of Infrastructure and the Environment, RIVM has set up a $PM_{2.5}$ monitoring strategy in order to measure the fine fraction of particulate matter, $PM_{2.5}$, within the Dutch National Air Quality Monitoring Network (NAQM). According to the European legislation from 2008, member states are required to measure PM2.5. The EU Directive 2008/50/EC prescribes measurements at 20 locations in the Netherlands. However, RIVM recommends the implementation of 28 monitoring stations in order to obtain a network which yields results with the same accuracy as the operational PM_{10} network in the Netherlands. The EU legislation for $PM_{2.5}$ is aimed at the protrection of human health.

During the whole process of the implementation of $PM_{2.5}$ measurements in the NAQM, a few crucial decisions needed to be made like buying the monitoring equipment and the set-up of the infrastructure. This whole process had a duration of a few years. This strategy is based on information which has been collected to make the above decisions.

Keywords: monitoring, strategy, particulate matter

Rapport in het kort

$PM_{2.5}$ monitoring strategie / Brief rapport

In opdracht van het ministerie van IenM heeft het RIVM een strategie op gezet om metingen naar de fijnere fracties van fijn stof, PM2,5, uit te voeren binnen het Landelijk Meetnet Luchtkwaliteit (LML). De Europee richtlijn voor luchtkwaliteit heeft dat in 2008 voorgeschreven. Deze richtlijn, 2008/50/EC, vereist dat in Nederland op minimaal 20 locaties wordt gemeten. Het RIVM geeft aan dat 28 locaties nodig zijn om voor PM2.5 gelijksoortige evaluaties te kunnen maken als voor fijn stof (PM10). De Europese normen voor PM2.5 zijn er voornamelijk op gericht om de volksgezondheid te beschermen.

De inrichting van het LML voor PM2.5-metingen kende een aantal cruciale beslissingsmomenten, zoals voor de hoeveelheid aan te schaffen meetapparatuur en voor de inrichting van de infrastructuur. Dit proces heeft enkele jaren geduurd. Deze strategie is gebaseerd op de informatie die gebruikt is om bovenstaande keuzes te kunnen maken.

Trefwoorden: meetnet, fijn stof

Contents

1 Introduction—7

2 Background of $PM_{2.5}$—9
2.1 Concentrations of $PM_{2.5}$ in the Netherlands—9
2.2 Emissions of $PM_{2.5}$ in the Netherlands—9

3 Constructing a $PM_{2.5}$ monitoring programme—11
3.1 The number of monitoring stations—11
3.1.1 Number of monitoring stations according to EU Directive 2008/50/EC—11
3.1.2 Number of monitoring stations as recommended by RIVM—11
3.2 Implementation of the measuring sites—11

4 The number of sites for the $PM_{2.5}$ monitoring programme—13
4.1 Type of sites in the Netherlands—13
4.2 The approach of the strategy—13
4.3 Rural background sites—15
4.4 Urban background sites—16
4.5 Traffic-related sites—16
4.6 Summary of the results—17

5 Proposal implementation of sites—19
5.1 Scenario GCN—20
5.2 Scenario Hot-Spots—21
5.3 Scenario No-History—22
5.4 Scenario Health—23
5.5 Scenario Balance—25
5.6 Scenarios for LML in collaboration with DCMR and GGD—26
5.7 Conclusion scenarios—27

6 Conclusion—29

References—31

Appendix A Current $PM_{2.5}$ monitoring stations—33

Appendix B Number of monitoring sites for particulate matter(PM)—36

Appendix C Results of the 4 scenarios—38

Appendix D Uncertainties in trend analysis—43

Appendix E Consequences of the number of rural and urban background stations on GCN—46

1 Introduction

This $PM_{2.5}$ measurement strategy has been used over a period of several years (starting in 2007) to guide intermediate decisions on locations, infrastructure and investments. Due to this historical context, at some places information is presented as was available at the time that intermediate decisions were necessary.

The Member States of the European Union are required to measure the finer fraction of particulate matter ($PM_{2.5}$) in accordance with EU Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 that became effective on 11 June 2008. In order to meet up with this new EU directive, the Ministry of Housing, Spatial Planning and the Environment (VROM) has asked the National Institute for Public Health and the Environment (RIVM) to construct a monitoring strategy for $PM_{2.5}$ in the Netherlands.

The main objective of the monitoring strategy for $PM_{2.5}$ presented in this report is the initiation of a long-term monitoring network. Once the $PM_{2.5}$ network is operational, its results are reported to the European Commission to assess the ambient air quality with respect to $PM_{2.5}$. Next to meeting Limit Values, the Directive also includes reduction targets for the average national $PM_{2.5}$ levels in the urban background.

On a different level the results of the $PM_{2.5}$ network will also be used to inform the Dutch public with real time hourly concentrations of $PM_{2.5}$. The measurement data of $PM_{2.5}$ will also be used for the validation and calibration of models. These model calculations are crucial in the Dutch system of demonstrations of compliance with air quality limit values and objectives. Currently air quality concentrations of critical components (PM_{10} and NO_2) are calculated in the "NSL-monitoring tool.

2 Background of $PM_{2.5}$

2.1 Concentrations of $PM_{2.5}$ in the Netherlands

Measurements of the concentration of $PM_{2.5}$ in the Netherlands have started in 2004 in the Netherlands. The indicative concentrations for yearly averaged $PM_{2.5}$ values over the period 2004-2006 in the Netherlands in regional, urban and traffic areas are respectively 12-16 µg/m^3; 16-19 µg/m^3; and 18-21 µg/m^3 as indicated in Figure 2.1 (from Matthijsen & ten Brink, 2007). The highest concentrations of $PM_{2.5}$ occur in the urban areas in 'De Randstad' and the Southern part of the Netherlands according to the latest calculations of the background concentrations for 2008 (GCN) as shown in the map of the Netherlands in Figure 2.1 (from Velders et al., 2009). The lowest values in the background concentration map of 2008 occur in the Northern part of the Netherlands.

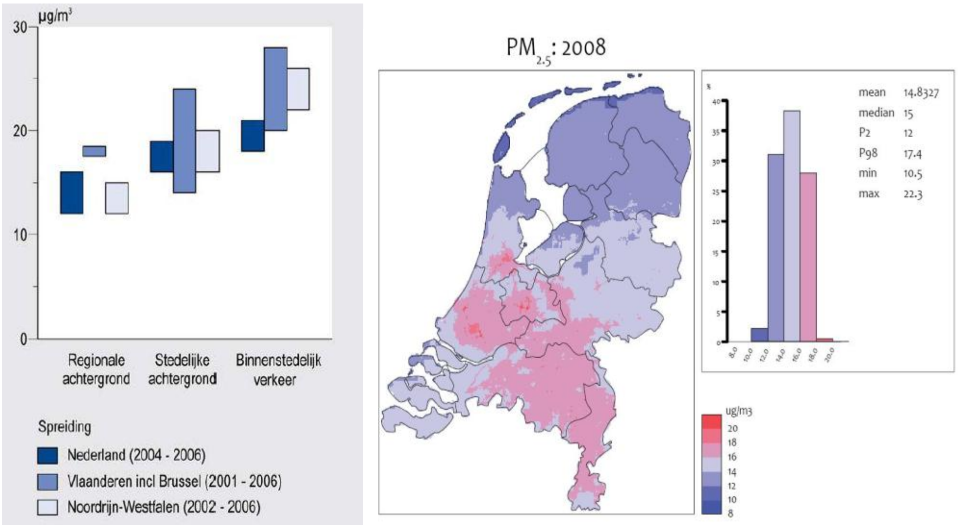

Figure 2.1 The concentrations of $PM_{2.5}$ in the Netherlands. Left panel: yearly averaged concentrations. Right panel: background concentration -map of $PM_{2.5}$ in the Netherlands.

2.2 Emissions of $PM_{2.5}$ in the Netherlands

The current emissions (in 2006) in the Netherlands are given in Table 2.1 (from Velders et al., 2009). In 2006 the total emission in the Netherlands equalled 27.2 million kilogram. 37% of the emission comes from traffic & transport, 25% comes from ship traffic, 18% comes from industry and 20% comes from the other sources. In the report by Matthijsen and ten Brink (2007), it is stated that about 20% of the origin of $PM_{2.5}$ is from national emitted sources. The other 80% comes from abroad and other sources. An explicit overview is given in Table 2.2

Table 2.1 Emissions of $PM_{2.5}$ in the Netherlands

Sector	**Emissions (in 10^6 kg)**
Agriculture	2.0
Industry	4.8
Traffic and transport	10.1
Construction, trade, service and government	0.6
Housekeeping	2.8
Total (NEC):	**20.3**
Ship traffic:	6.9
Total:	**27.2**

Table 2.2 Source of the $PM_{2.5}$ in the Netherlands

Source	**Contribution**
The Netherlands	19%
Foreign sources	49%
Sea salt, hemispheric background, mineral dust and other	32%

3 Constructing a $PM_{2.5}$ monitoring programme

3.1 The number of monitoring stations

3.1.1 Number of monitoring stations according to EU Directive 2008/50/EC

From the EU Directive 2008/50/EC the number of required monitoring stations for $PM_{2.5}$ can be calculated for each zone and agglomeration separately in the Netherlands. This minimum number scales directly with the number of inhabitants in a zone or agglomeration (see Table B1 in Appendix B). In this way a total number of 60 monitoring stations for PM in the Netherlands are obtained. European legislation prescribes that the ratio of PM_{10}:$PM_{2.5}$ has to be in between 2:1 and 1:2. In this way one obtains a minimum number of 20 monitoring stations for $PM_{2.5}$. From these 20 stations, a minimum number of 8 stations need to be located at urban background sites (see Table B2 in Appendix B).

3.1.2 Number of monitoring stations as recommended by RIVM

The recommended size of the monitoring network first of all has to fulfil the minimum number of sites required by European legislation as explained in section 3.1.1. Secondly the Ministry of Housing, Spatial Planning and the Environment (VROM) has asked the National Institute for Public Health and the Environment (RIVM) to construct a monitoring strategy for $PM_{2.5}$ in the Netherlands which has the same accuracy as the network for PM_{10} measurements. In order to achieve this same accuracy, several arguments have resulted in a recommended size of the monitoring network of 28 measuring stations. These stations are split up into 12 urban background sites, 8 rural background sites and 8 traffic-related sites. A summary of the reasoning behind the result mentioned above are given in section 4 of this report.

3.2 Implementation of the measuring sites

The recommended size of the monitoring network in the Netherlands equals 28 sites. An algorithm has been developed at RIVM which calculates the most efficient configuration of an air quality network in the Netherlands, given the number of measuring locations needed. In this way the algorithm selects the most appropriate sites of the Dutch National Air Quality Monitoring Network

(LML). The algorithm also allows to take into account the measuring sites of GGD Amsterdam, DCMR or new sites. In section 5 of this report several scenarios are presented which result in a network configuration.

4 The number of sites for the $PM_{2.5}$ monitoring programme

4.1 Type of sites in the Netherlands

The Dutch National Air Quality Monitoring Network (LML) performs measurements of air quality at three different types of monitoring sites:

- Rural background;
- Urban background;
- Traffic-related locations.

The number of current monitoring stations for $PM_{2.5}$ within the LML is given in the table 4.1 in column 2. The measurements within the LML are performed with the reference method NEN-EN 14907 and are based on daily sampling and weighting the samples at the RIVM laboratory. The new monitoring programme will be equipped with automatic measurements with sampling times of an hour. For completeness sake the *planned* number of monitoring stations of $PM_{2.5}$ at GGD (in both Amsterdam and Zaandam) and DCMR are given in the table below in the columns 3 and 4. The fifth column indicates the total number of monitoring stations for each type of monitoring site obtained in this way if *nothing* is changed in the current LML network. The exact locations of the different stations are given in Appendix A.

Table 4.1 The number of $PM_{2.5}$ stations in the Netherlands

	LML(current)	GGD(planned)	DCMR(planned)	Total
Rural	7	0	0	7
Urban	10	5	3	17
Traffic	8	3	2	14
Other	0	3	5	4
Total	**25**	**11**	**10**	**42**

4.2 The approach of the strategy

- In determining the number of sites for $PM_{2.5}$ necessary for the new network, the aim will be to achieve the same accuracy with the $PM_{2.5}$ network as is currently achieved with the PM_{10} network. The PM_{10} network consists of 40 measuring stations. The number of stations required for $PM_{2.5}$ to achieve the same accuracy as in the case of PM_{10} is less than 40 sites because, $PM_{2.5}$ is dominated even more by secondary inorganic aerosols (SIAs) than PM10 and these SIA are long transport components without steep gradients. The main difference between PM_{10} and $PM_{2.5}$ are the "course particles" that consist mainly of crustal material, road particles (elevated by traffic) and sea salt. The first two have important local contributions and therfore much steeper gradients.Due to the gradual difference in composition it can be expected that the modelling of $PM_{2.5}$ with a relative uncertainty comparable to PM_{10} will presumably be easier, as the components which are particularly difficult to model dominate the coarse fraction. This observation coincides with the general assumption that $PM_{2.5}$ gradients are smaller than PM_{10} gradients. Therefore the objective of achieving similar relative uncertainty presumably requires fewer measurements for model calibration. Quantification of the optimal ratio is difficult in scientific terms, but also because the modelling calibration should be robust for fall out of instruments and possible changes in locations, etc. As an expert judgement, a ratio $\#PM_{2.5}/\#PM_{10} = 0.6 - 0.8$ seems reasonable. To evaluate the above general considerations with some measurements, the following results in the Netherlands are available. The first two results argue in favour of smaller $PM_{2.5}$ gradients compared to PM_{10} gradients, the last one argues against this assumption:

- BOP: local gradients in the Rotterdam area for $PM_{2.5}$ are about 50% of the local gradients for PM_{10};
- The correlation distance for $PM_{2.5}$ (170 km) is nearly twice as large as the correlation distance for PM_{10} (90km);
- In the calibration of the GCN-maps the residual standard deviation of PM_{10} (2.3 μg/m^3) is comparable with the standard deviation of $PM_{2.5}$ in the GCN-maps (2.1 μg/m^3).It should be stressed that the above three considerations are all marked with large uncertainties.Apart from the aim to achieve the same accuracy for $PM_{2.5}$ as for PM_{10} other applications also have requirements for the number of stations to be chosen for the $PM_{2.5}$ strategy. These applications are:
- the production of large-scale concentration maps (GCN);
- the calculation of air pollution from road traffic model (CAR);the ability to determine trends over long time intervals

Table 4.2 Number of measuring stations for PM_{10} and NO_2 (source LML website)

	Rural	Urban	Traffic	Sum
PM_{10}	17	8	16	41
NO_2	22	8	13	43

For the first two applications, the data from the LML are used for calibrating the models. Expert advice give a minimum number of 8 rural measuring stations for the calibration of the GCN-maps and 8 street stations for the calibration of the CAR-model. For the last application, i.e. the ability to determine trends over long time intervals, we observe a minimum number of 8 stations, which is the current minimum number used in the LML (see table 4.2) for NO_2 and PM_{10}. The last years trend analyses has become very important for both NO_2 and $PM_{10.}$ Experience with such trend analysis shows that small data sets are very sensitive for local changes that influence the results from a single measurement station. For example in the last years stations were removed due to building activities (Wittevrouwen en Bibliotheek in Utrecht, road restructuring (Cabeljauw straat Amsterdam) replaced due to road restructuring (Amsterdamse veerkade) etc. Also changes in traffic or other local sources Florapark Amsterdam due to Noord Zuid lijn activities,..), local buildings (Utrecht Erzeystraat), trees (various statiosn) can severely influence concentrations at single stations. Such events are very likely to cause the loss or change of stations in periods for 10 -15 years and the representativeness of the trend observed will be critically dependent of the initial number of stations. Trends for 8 stations (currently NO2 and PM10 at Urban Background locations) are already conspicuous, lower numbers will be rather useless for trend analysis.

Below we will argue for the number of sites required for each type of measuring site. As a starting hypothesis we take the ratio of $PM_{2.5}$:PM_{10} like 1:2 unless there is clear evidence from the other three applications mentioned above, i.e. calibration of GCN and CAR and the determination of trends, that the ratio should be higher.

4.3 Rural background sites

Currently there are 17 rural background sites for PM_{10}. Taking the ratio of $PM_{2.5}$ to PM_{10} monitoring stations like 1:2, a total of 8 monitoring stations for the measurement of $PM_{2.5}$ at rural background sites is obtained. This number is in line with the minimum number of stations needed at rural sites to calibrate the GCN-maps for PM2.5 (according to expert judgement). Furthermore a number of 8 stations is the minimum number currently used in the Dutch National Air

Quality Monitoring Network in order to monitor long-term trends for other crucial components like NO_2 and PM_{10}.

4.4 Urban background sites

Taking the ratio of $PM_{2.5}$ to PM_{10} monitoring stations like 1:2, a total of 4 monitoring stations for the measurement of $PM_{2.5}$ at urban background sites is obtained. This number is already smaller than the 8 monitoring stations operational in the LML (as required by EU legislation) at the 1st of January 2008. The extension of this number of urban background stations to 12 sites was necessary in order to fill up the gap which existed before that in the Northeast part of the Netherlands. The emphasis of the EU directive is currently on monitoring background values of $PM_{2.5}$ at urban backgrounds. A reduction target value in between 10%-20% in 2020 as compared to 2010 is prescribed by European legislation. The exact value of the reduction depends on the average exposure indicator (AEI), which is the three-year (2009-2011) averaged $PM_{2.5}$ level measured at urban background locations in the Netherlands. The reduction target value equals 15% if the AEI is in between 13-18µg/m^3, 10% when the AEI is in between 8,5-13µg/m^3 and 20% when the AEI is larger than 18µg/m^3 (see Matthijsen et al., 2007). In order to measure these type of trends one needs sufficient monitoring stations. In appendix D it is argued that at least 12 stations are needed in order to allow for the trend determinations as required by European legislation. Finally this suggested increase from 9 to 12 urban background sites would also increase the quality of the GCN-maps: the maps are calibrated with the observed values of $PM_{2.5}$ concentrations at rural and urban background sites in the Netherlands: i.e. the uncertainty in the concentrations of the GCN-maps scales as $\sqrt{\frac{1}{n_{urban}+n_{rural}}}$.

Notice that in the case of $PM_{2.5}$ $n=n_{urban}+n_{rural}$ would equal 20 in the current proposal, whereas for PM_{10} there are currently $n=n_{urban}+n_{rural}=24$ stations. This ratio matches quite well with the earlier mentioned ratio of $\#PM_{2.5}:\#PM_{10}$ = 0.6-0.8. Further consequences of the choice for the number of rural and urban background stations are discussed in Appendix E.

4.5 Traffic-related sites

Currently there are 16 traffic-related sites for PM_{10}. Taking the ratio of $PM_{2.5}$ to PM_{10} monitoring stations like 1:2, a total of 8 monitoring stations for the measurement of $PM_{2.5}$ at traffic-related sites are obtained. This number is in line with the number of street stations needed to calibrate the CAR calculations for PM2.5 according to expert judgement. Furthermore a number of 8 stations is the minimum number used in the current Dutch National Air Quality Monitoring Network in order to monitor long-term trends for components like NO_2 and PM_{10}.

4.6 Summary of the results

Table 4.3 summarizes the proposal for the number of monitoring sites for the new $PM_{2.5}$ monitoring programme. The choice for these number of monitoring stations at the different measuring sites guarantee:

1. The requirements for EU directive 2008/50/EC are fulfilled;
2. The accuracy of the $PM_{2.5}$ monitoring network has a similar quality as the current PM_{10} monitoring network;
3. The number of rural and urban background stations allow for a sound calibration of the GCN-maps for $PM_{2.5}$;
4. The number of traffic-related sites allow for a check on the calibration of the CAR model;

The long-term trends at rural background, urban background and traffic-related sites of $PM_{2.5}$ can be traced with the same accuracy as other components in the LML.

Table 4.3 Summary of the strategy

	Current $PM_{2.5}$ network	**New $PM_{2.5}$ network**
Rural background	7	8
Urban background	10	12
Traffic-related	8	8
Total:	**25**	**28**

5 Proposal implementation of sites

The proposal is to implement 28 sites within the Dutch National Air Quality Monitoring Network. A template has been developed at RIVM to calculate the optimal measuring configuration.

The core of the template consists of objectives which have been formulated. The objectives should be ranked by a weighting factor such that the weighting factors of all objectives sum up to unity. Apart from the objectives, the template allows for a *separate ranking* of weighting factors (typically in between 0 and 100) for "The Dutch and European Requirements", "Areas in the Netherlands" and "Homogeneous distribution over the Netherlands".

The objectives for individual stations which have been selected are:

- large-scale concentration maps (GCN);
- measurement of $PM_{2.5}$ and PM_{10} at same sites (PM);
- CAR, input for dispersion model Calculation of Air pollution from Road traffic;
- trend;
- LML Processes, sites where black smoke, inorganics and metals are measured;
- Health, sites important for the health sector.

As stated above the core of the template are the formulated objectives. Each objective obtains a ranking between zero and unity. Next for each individual objective all stations considered for the measuring strategy are ranked in the following category:

- not important (0);
- very low (5);
- low (10);
- high (15);
- very high (20)
- extremely high (50).

For each objective an expert[1] in the field was consulted to rank the considered stations.

[1] The experts consulted are working in their field of expertise and using observations from the LML measurement locations for various components and all type of air quality data analysis tools: trends, wind roses, model/measurement consistencies, component/component consistencies, local complexity etc.

The objective "GCN" differs from the option "Homogeneous distribution over the Netherlands": the latter constructs the *total* number of stations in order to have the most homogeneous distribution over the Netherlands. The GCN objective selects individual stations according to their individual score for their ranking.

A calculation of a measuring strategy starts with selecting those stations with a non-zero rating for the sum of the objectives. The number of stations which have been selected in this way is N_{start}. The other important parameter for the algorithm is the total number of stations, N_{tot}, of which the configuration has to exist. Next the algorithm will calculate which station of the total of N_{start} stations contributes slightest to the total score: this station will be dropped from the list of selected measuring stations, so (N_{start}-1) stations are left. This procedure will be continued until the number of stations left equals the total number of stations required for the network configuration, i.e. N_{tot}.

Five different strategies have been calculated of which the ranking are mentioned in the table below. The last scenario "Balance" is the one recommended by RIVM since it satisfies exactly the division into 8 rural background, 12 urban background and 8 traffic stations. Furthermore this scenario fits in best with the current LML network for $PM_{2.5}$. Each strategy is discussed separately in the sections 5.1-5.5. Appendix C listst the stations which have been selected for each scenario.

Table Scenarios: Calculations of the configuration for $PM_{2.5}$

	GCN	Hot Spots	No History	Health	**Balance**
GCN	0.6	0.4	0.5	0.1	**0.4**
PM		0.2	0.1		
CAR		0.3	0.2	0.1	**0.25**
Trend	0.4	0.1		0.3	**0.25**
LML processes			0.2		
Health				0.5	**0.1**
Spread	Yes				**Yes**

5.1 Scenario GCN

The scenario puts the emphasis on the selected number of stations which are needed for constructing GCN-maps. Furthermore the scenario attaches importance to the trend history and a homogeneous spreading over the Netherlands. Table 5.1 states the division of the selected stations into rural background, urban background and traffic stations, whereas Figure 5.1 shows the spatial distribution. The biggest gap where no station is found equals 62 kilometres. With respect to the current $PM_{2.5}$ configuration 2 stations are removed. Table C1 in appendix C gives all selected stations in the 2nd column.

Table 5.1 Division for GCN-scenario

	Rural Background	Urban Background	Traffic	Total
Number	10	12	6	28

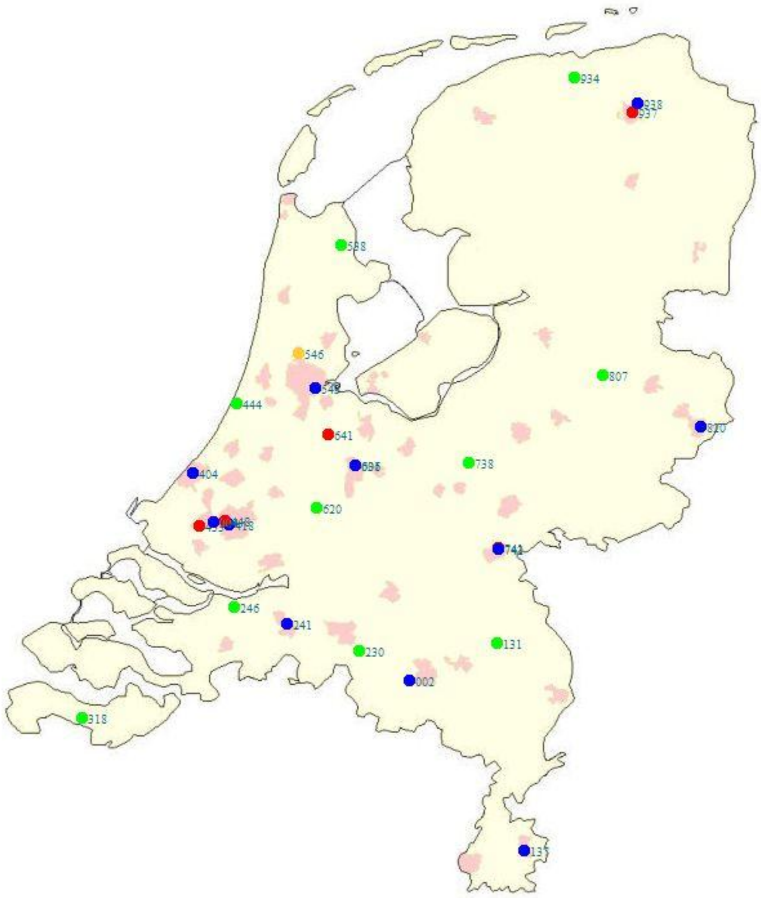

Figure 5.1 Configuration of the GCN-scenario

5.2 Scenario Hot-Spots

The scenario puts the emphasis on the selected number of stations which are needed for selecting the hot spots in the Netherlands: traffic stations and stations where currently PM_{10} is measured. Furthermore the scenario attaches importance to the construction of the GCN-map and the trend history. Table 5.2 states the division of the selected stations into rural background, urban background and traffic stations, whereas Figure 5.2 shows the spatial distribution. The biggest gap where no station is found equals 97 kilometres.

With respect to the current $PM_{2.5}$ configuration 5 stations are removed. Table C2 in appendix C gives all selected stations in the 2nd column

Table 5.2 Division for Hot-Spots scenario

	Rural Background	Urban Background	Traffic	Total
Number	7	6	15	28

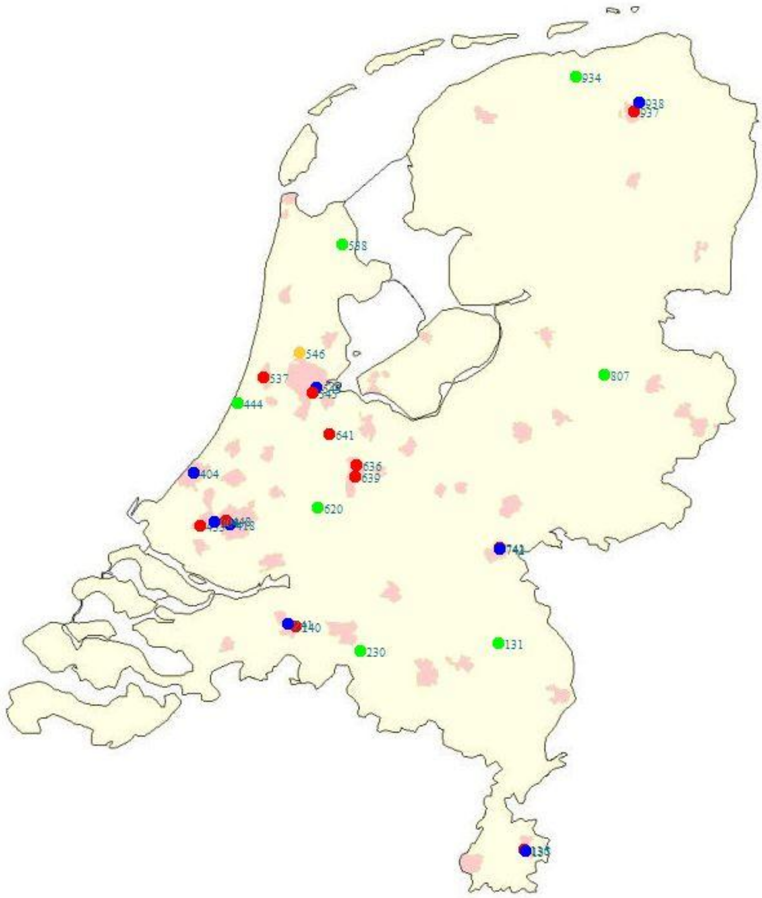

Figure 5.2 Configuration of the Hot-Spots scenario

5.3 Scenario No-History

The scenario puts the emphasis on the selected number of stations which are needed for the construction of GCN-maps and the determination of Hot Spots without taking into account the stations with a long history. Table 5.3 states the division of the selected stations into rural background, urban background and traffic stations, whereas Figure 5.3 shows the spatial distribution. The biggest gap where no station is found equals 97 kilometres. With respect to the current $PM_{2.5}$ configuration 6 stations are removed. Table C3 in appendix C gives all selected stations in the 2nd column.

Table 5.3 Division for No-History scenario

	Rural Background	Urban Background	Traffic	Total
Number	8	10	10	28

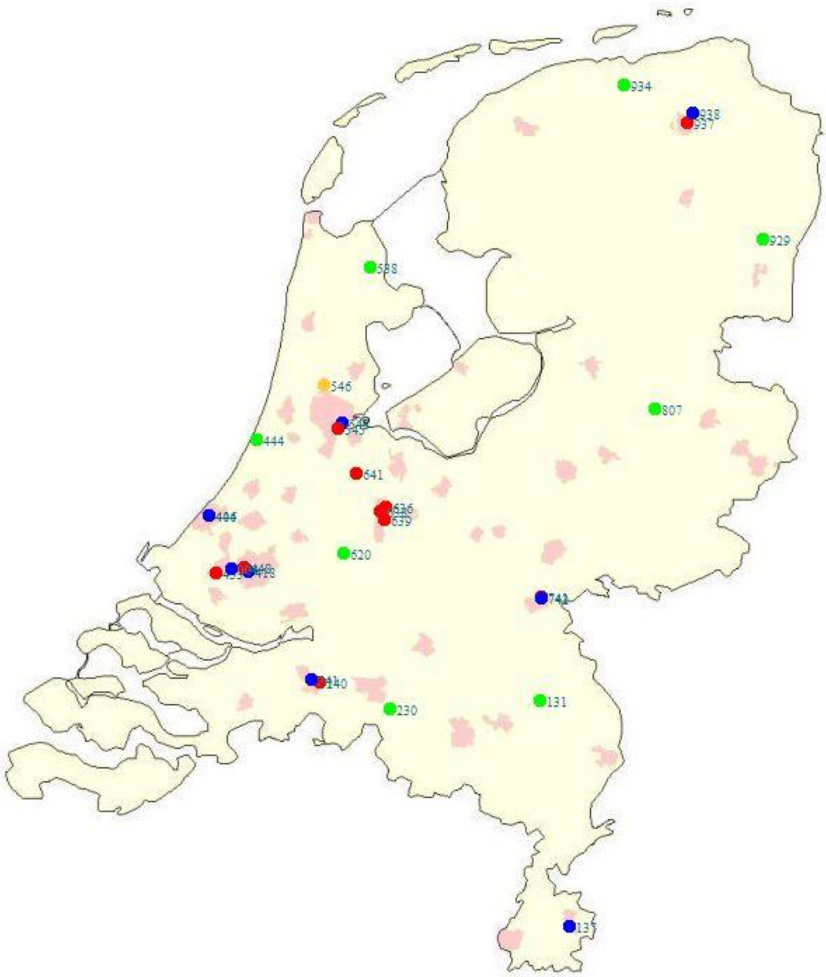

Figure 5.3 Configuration of the No-history scenario

5.4 Scenario Health

The scenario puts the emphasis on selecting stations for the health sector. Furthermore the scenario attaches importance to GCN, CAR and Trend. Table 5.4 states the division of the selected stations into rural background, urban background and traffic stations, whereas Figure 5.4 shows the spatial distribution. The biggest gap where no station is found equals 89 kilometres. With respect to the current $PM_{2.5}$ configuration 4 stations are removed. Table C4 in appendix C gives all selected stations in the 2nd column.

Table 5.4 Division for Health scenario

	Rural Background	Urban Background	Traffic	Total
Number	8	15	5	28

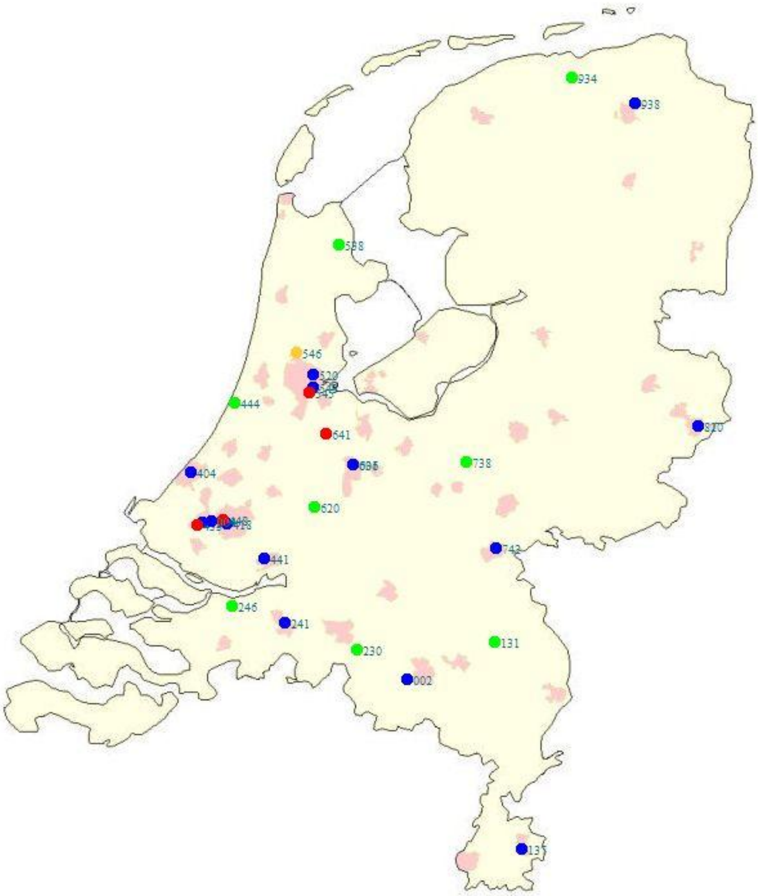

Figure 5.4 Configuration of the Spreading-scenario.

5.5 Scenario Balance

The scenario takes into account all important objectives. Furthermore the scenario has been fine-tuned such that one obtains 8 rural background stations, 12 urban background stations and 8 traffic stations (see Table 5.5). Figure 5.5 shows the spatial distribution. The biggest gap where no station is found equals 62 kilometres. With respect to the current $PM_{2.5}$ configuration 2 stations are removed. Table C5 in appendix C gives all selected stations in the 2nd column.

Table 5.5 Division for Balance scenario

	Rural Background	Urban Background	Traffic	Total
Number	8	12	8	28

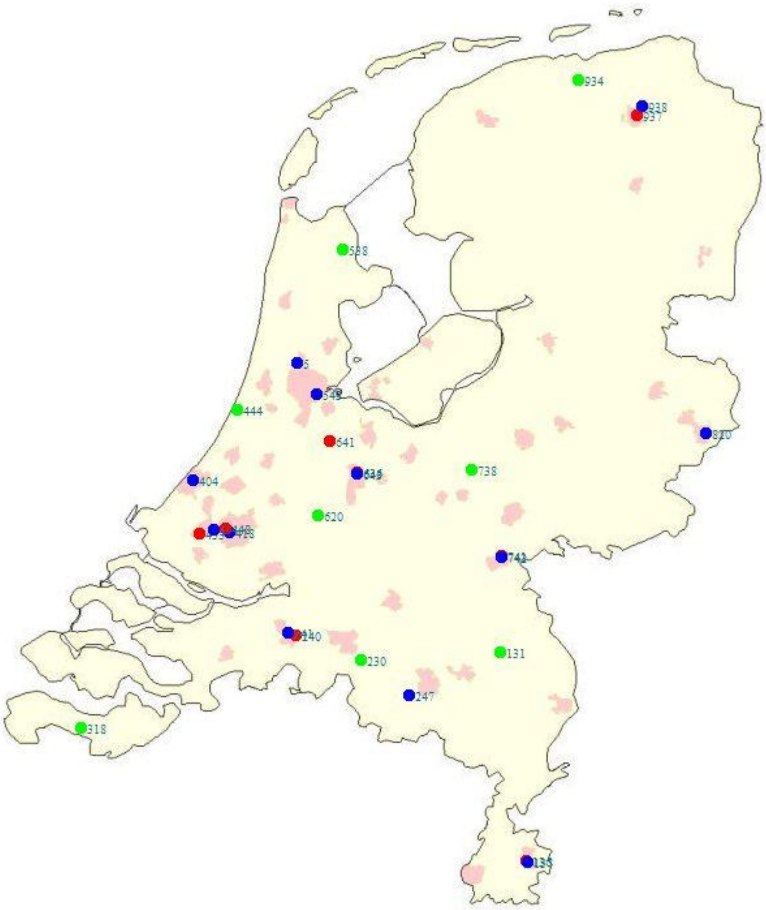

Figure 5.5 Configuration of the scenario Balance.

5.6 Scenarios for LML in collaboration with DCMR and GGD

Next we repeat all scenarios from 5.1-5.5 but this time it is assumed that the monitoring activities from DCMR and GGD Amsterdam suffice to cover the agglomerations of Amsterdam and Rotterdam such that *no sites need to be selected in these areas* for LML stations. Below we give the tables which yield the resulting number of LML stations required to monitor with the same accuracy and details as prescribed in the previous sections. This time however the presence of the networks of DCMR and GGD Amsterdam are taken into account. Table 5.5 shows the resulting number of monitoring stations from LML which are required.

Table 5.6 LML stations with same scenarios as before but with the help of DCMR and GGD

	Rural Background	Urban Background	Traffic	Total
Scenario GCN:	10	8	4	22
Scenario Hot-Spots:	7	2	11	20
Scenario No-History:	8	6	7	21
Scenario Health:	8	9	2	19
Scenario Balance	8	8	6	22

It is obvious that if one makes use of the monitoring results from monitoring network of the GGD Amsterdam and DCMR that there needs to be an additional effort in tuning in the results from these two networks into the network of the LML.

Finally we present a specific example of how the monitoring networks of GGD Amsterdam and DCMR can be used in the case of scenario Balance (section 5.5). In this scenario two monitoring positions are located in the agglomeration of Amsterdam: Amsterdam-Overtoom and Zaanstad. Both stations are already covered by the monitoring network of the GGD.
Four stations are located in the agglomeration Rotterdam:
418 Rotterdam-Schiedamseveste (urban background);
433 Vlaardingen-Floreslaan (traffic);
448 Rotterdam-Bentinckplein (traffic);
1119 Schiedam-DCMR (urban background).
The above four stations could be covered by the following DCMR stations:
HGV Hoogvliet (urban background);
RDO-Overschie A13 (traffic);
RID-Ridderkerk A16 (traffic;

SDM Schiedam (urban background).
It should be emphasized that the monitoring stations RDO and RID are located at *highways*, furthermore SDM is the same station as 1119 in the LML network.

5.7 Conclusion scenarios

PM2.5 measurements can be performed with different objectives. Using the algorithme described policymakers can judge scenarios with respect to the weighing of the different objectives. Using the number of stations that were indicated by the various experts on their field of expertise a balanced scenario is developed using a set of weighing factors that correspond with the ministries priorities.

6 Conclusion

By mutual agreement between RIVM and VROM it has been decided to take configuration Balance (subsection 5.5) as the configuration to be implemented into LML for the $PM_{2.5}$ monitoring network. A few changes have been implemented in this scenario explained below.

The $PM_{2.5}$ monitoring network will be exploited by a collaboration between RIVM, GGD Amsterdam and DCMR. Therefore a few LML stations as chosen in the scenario Balance are implemented by monitoring stations of one of these partners (indicated in Table 6.1).

Table 6.1 shows the chosen monitoring stations for the $PM_{2.5}$ monitoring network with the station which is replaced in column 3 and in column 4 the name of the partner.

The following stations have been replaced from 'Scenario Balance' to the final adopted configuration:

- Station 433 was replaced by station 445, because a second independent check on the *scenario Balance* showed that the EU legislation was otherwise not fulfilled
- Station 418 was replaced by Hoogvliet[2] since DCMR is monitoring $PM_{2.5}$ at this station which is representative for the location of LML station 418

Official agreements on the equivalence and quality of measurements exist between RIVM, DCMR and GGD-Amsterdam (see Agreements RIVM, DCMR and GGD-Amsterdam, 2009). In the implementation of this measurement strategy official agreement between the Ministry of VROM, DCMR, GGD-Amsterdam and Provincie Noord-Brabant on the continuity of the measurements and monitoring stations is strongly recommended.

[2] $PM_{2.5}$ measurements will most likely start at this location in March 2010

Table 6.1 The advised configuration for monitoring $PM_{2.5}$ in the Netherlands

Current	Proposed Stations	Clarification	Partner
131 Vredepeel	**131 Vredepeel**		
136 Heerlen	**136 Heerlen**		
137 Heerlen	**137 Heerlen**		
	230 Biest Houtakker		
240 Breda	**240 Breda**		
241 Breda	**241 Breda**		
246 Fijnaart			
247 Veldhoven	**247 Veldhoven**		
	318 Philipinne		
404 Den Haag	**404 Den Haag**		
418 Rotterdam			
	Hoogvliet (DCMR)	Replaces 418 Rotterdam	DCMR
433 Vlaardingen			
	445 Den Haag		
444 De Zilk	**444 De Zilk**		
448 Rotterdam	**448 Rotterdam**	Comparison station	DCMR
538 Wieringerwerf	**538 Wieringerwerf**		
620 Cabauw	**620 Cabauw**		
636 Utrecht	**636 Utrecht**		
641 Breukelen	**641 Breukelen**		
643 Utrecht	**643 Utrecht**		
738 Wekerom	**738 Wekerom**		
741 Nijmegen	**741 Nijmegen**		
742 Nijmegen	**742 Nijmegen**		
821 Enschede	**821 Enschede**[3]		
934 Kollumerwaard	**934 Kollumerwaard**		
937 Groningen	**937 Groningen**		
938 Groningen	**938 Groningen**		
543 Amsterdam	**543 Amsterdam**	Comparison station	GGD Amsterdam
GGD Zaanstad	**GGD Zaanstad**		GGD Amsterdam
1119 Schiedam	**1119 Schiedam**		DCMR

[3] station 821 Enschede-Winkelhorst has replaced station 820 Enschede-Espoortstraat

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Appendix A Current $PM_{2.5}$ monitoring stations

Table A1 Current official $PM_{2.5}$ monitoring stations of LML (September 2009)

Station number	Name station	Type
131	Vredepeel-Vredeweg	Rural background
136	Heerlen-Looierstraat	Traffic
137	Heerlen-Nicolayestraat	Urban background
240	Breda-Tilburgseweg	Traffic
241	Breda-Bastenakenstraat	Urban background
246*	Fijnaart-Zwingelspaansedijk	Rural background
247[4]	Veldhoven-Europalaan	Urban background
404	Den Haag-Rebecquestraat	Urban background
418	Rotterdam-Schiedamsevest	Urban background
433	Vlaardingen-Floreslaan	Traffic
444	De Zilk-Vogelaarsdreef	Rural background
448	Rotterdam-Bentinckplein	Traffic
538	Wieringerwerf- Medemblikkerweg	Rural background
543***	Amsterdam-Overtoom	Urban Background
620	Cabauw-KNMI	Rural background
636	Utrecht-de Jongweg	Traffic
641	Breukelen-A2	Traffic
643	Utrecht, Griftpark	Urban background
738	Wekerom-Riemterdijk	Rural background
741	Nijmegen-Graafseweg	Traffic
742	Nijmegen-De Ruyterstraat	Urban background
820	Enschede-Espoortstraat	Urban background
934	Kollumerwaard-Hooge Zuidwal	Rural background
937	Groningen-Europaweg	Traffic
938	Groningen-Nijesteinheerd	Urban background
018***	Amsterdam-Ringweg A10 zuid	Traffic
701***	Zaandam	Urban Background
1119**	Schiedam-Alphons Ariënsstraat	Urban Background

*Provincie Noord-Brabant; **DCMR; ***GGD Amsterdam

[4] Station 247 replaces station 242

Table A2 Current plans for $PM_{2.5}$ monitoring stations of DCMR

Station number	**Name station**	**Type**
1145	Maassluis-Kwartellaan	Urban Background/Industry
1191	Hoogvliet-Leemkuil	Urban Background
1119	Schiedam-Alphons Ariënsstraat	Urban Background
1043	Overschie-Oost-Sidelinge	Traffic
2069	Rotterdam-Statenweg/Bentinckplein	Traffic/Urban Background
1987	Ridderkerk	Traffic
5151*	Hoek van Holland-Berghaven	Industry
1083	Rotterdam-Pleinweg	Traffic/Urban Background
1081	Rotterdam-Zwartewaalstraat	Urban Background
	Rotterdam-Maasboulevard	Traffic/Urban Background

***LML station 432**

Table A3 Current plans for $PM_{2.5}$ monitoring stations of GGD Amsterdam (January 2010)

Station number	Name station	Type
007	Amsterdam-Einsteinweg	Traffic
012	Amsterdam-van diemenstraat	Traffic
014*	Amsterdam-Overtoom	Urban Background
016	Amsterdam-Westerpark	Urban Background
017	Amsterdam-Stadhouderskade	Traffic
701	Zaandam	Urban Background
703	Spaarnwoude	Urban Background
704	Hoogtij	Industry
553	Wijk aan Zee	Industry
551	IJmuiden	Industry
570	Beverwijk	Urban Background

* LML-station 543

Appendix B Number of monitoring sites for particulate matter(PM)

Table B1 Minimum number of sampling points per agglomeration/zone for concentrations above the upper assessment threshold, according to 2008/50/EC

Agglomeration/Zone	Inhabitants (×1000)	Number sites PM	Number sites $PM_{2.5}$	LML sites $PM_{2.5}$
Amsterdam	1500 -1999	7	2	0
Utrecht	250 - 749	3	1	1
The Hague/Leiden	1000 -1499	6	2	1
Rotterdam	1000 -1499	6	2	3
Eindhoven	250 - 749	3	1	1
Heerlen	0 - 249	2	1	2
Zone North	2750 - 3749	10	3	3
Zone Middle	4750 - 5999	13	5	6
Zone South	2750 - 3749	10	3	4
Total		60	At least 20	21

Table B2 Calculation of the minimum number of urban background sites

	Zone	Inhabitants	Number of sites Per 1-1-2008	Per 1-1-2009
Ede	Midden	107274		
Emmen	Noord	108711		
Zwolle	Noord	113857		
Zoetermeer	Zuid	117502		
Leiden	Midden	117777		
Maastricht	Zuid	119607		
's-Hertogenbosch	Zuid	135183		
Amersfoort	Midden	138026		
Arnhem	Midden	142382		
Enschede	Noord	154427		1
Apeldoorn	Midden	155807		
Nijmegen	Midden	160215		1
Breda	Zuid	170029	1	1
Almere	Noord	179695		
Groningen	Noord	181171	1	1
Tilburg	Zuid	200819		
Kerkrade/Heerlen	Heerlen	240326	1	1
Eindhoven	Eindhoven	427000		1
Utrecht	Utrecht	453619		1
The Hague/Leiden	The Hague	1061200	1	1
Rotterdam/Dordrecht	Rotterdam	1279364	2	2
Amsterdam/Haarlem	Amsterdam	1538435	2	2
Total		7302426	8	12

The air quality directive prescribes a minimum number of 1 station for each 1000.000 inhabitants in agglomerations and other urban area's > 100.000 inhabitants. To calculate this number of inhabitants the number of inhabitants in the agglomerations and all > 100.000 municipalyties are summed. This defined a minimum strategy which was applied on 1/1/2008 to start the ERT analysis. This strategy was limited by the availabilty of urban background locations. In this strategy the number of locations out site of the western part of the country was rather low and therefor new urban background stations were introduced in the cause of 2008 in the agglomerations of Utrecht and Eindhoven and the municipalities of Enschede and Nijmegen.

Appendix C Results of the 4 scenarios

Table C1 Scenario GCN

Current	**LML**
131 Vredepeel	131 Vredepeel
136 Heerlen	
137 Heerlen	137 Heerlen
	230 Biest-Houtakker
240 Breda	
241 Breda	241 Breda
246 Fijnaart	246 Fijnaart
247 Veldhoven	247 Veldhoven
	318 Philipinne
404 Den Haag	404 Den Haag
418 Rotterdam	418 Rotterdam
433 Vlaardingen	433 Vlaardingen
444 De Zilk	444 De Zilk
448 Rotterdam	448 Rotterdam
538 Wieringerwerf	538 Wieringerwerf
620 Cabauw	620 Cabauw
636 Utrecht	636 Utrecht
641 Breukelen	641 Breukelen
643 Utrecht	643 Utrecht
738 Wekerom	738 Wekerom
741 Nijmegen	741 Nijmegen
742 Nijmegen	742 Nijmegen
	807 Hellendoorn
820 Enschede	820 Enschede
934 Kollumerwaard	934 Kollumerwaard
937 Groningen	937 Groningen
938 Groningen	938 Groningen
543 Amsterdam	543 Amsterdam
546 Zaanstad	546 Zaanstad
1119 Schiedam	1119 Schiedam

Table C2 Scenario Hot Spots

Current	**LML**
131 Vredepeel	131 Vredepeel
136 Heerlen	136 Heerlen
137 Heerlen	137 Heerlen
	230 Biest-Houtakker
240 Breda	240 Breda
241 Breda	241 Breda
246 Fijnaart	
247 Veldhoven	
404 Den Haag	404 Den Haag
418 Rotterdam	418 Rotterdam
433 Vlaardingen	433 Vlaardingen
444 De Zilk	444 De Zilk
448 Rotterdam	448 Rotterdam
	537 Haarlem
538 Wieringerwerf	538 Wieringerwerf
	544 Amsterdam
	545 Amsterdam
620 Cabauw	620 Cabauw
636 Utrecht	636 Utrecht
	639 Utrecht
641 Breukelen	641 Breukelen
643 Utrecht	
738 Wekerom	
741 Nijmegen	741 Nijmegen
742 Nijmegen	742 Nijmegen
	807 Hellendoorn
820 Enschede	
934 Kollumerwaard	934 Kollumerwaard
937 Groningen	937 Groningen
938 Groningen	938 Groningen
543 Amsterdam	543 Amsterdam
546 Zaanstad	546 Zaanstad
1119 Schiedam	1119 Schiedam

Table C3 Scenario No-history

Current	LML
131 Vredepeel	131 Vredepeel
136 Heerlen	
137 Heerlen	137 Heerlen
	230 Biest-Houtakker
240 Breda	240 Breda
241 Breda	241 Breda
246 Fijnaart	
247 Veldhoven	
404 Den Haag	404 Den Haag
418 Rotterdam	418 Rotterdam
433 Vlaardingen	433 Vlaardingen
444 De Zilk	444 De Zilk
	446 Den Haag
448 Rotterdam	448 Rotterdam
538 Wieringerwerf	538 Wieringerwerf
	545 Amsterdam
620 Cabauw	620 Cabauw
636 Utrecht	636 Utrecht
	638 Utrecht
	639 Utrecht
641 Breukelen	641 Breukelen
643 Utrecht	
738 Wekerom	
741 Nijmegen	741 Nijmegen
742 Nijmegen	742 Nijmegen
	807 Hellendoorn
820 Enschede	
	929 Valthermond
934 Kollumerwaard	934 Kollumerwaard
937 Groningen	937 Groningen
938 Groningen	938 Groningen
543 Amsterdam	543 Amsterdam
546 Zaanstad	546 Zaanstad
1119 Schiedam	1119 Schiedam

Table C4 Scenario Health

Current	**LML**
131 Vredepeel	131 Vredepeel
136 Heerlen	
137 Heerlen	137 Heerlen
	230 Biest-Houtakker
240 Breda	
241 Breda	241 Breda
246 Fijnaart	246 Fijnaart
247 Veldhoven	247 Veldhoven
404 Den Haag	404 Den Haag
	416 Vlaardingen
418 Rotterdam	418 Rotterdam
433 Vlaardingen	433 Vlaardingen
	441 Dordrecht
444 De Zilk	444 De Zilk
448 Rotterdam	448 Rotterdam
	520 Amsterdam
538 Wieringerwerf	538 Wieringerwerf
	545 Amsterdam
620 Cabauw	620 Cabauw
636 Utrecht	636 Utrecht
641 Breukelen	641 Breukelen
643 Utrecht	643 Utrecht
738 Wekerom	738 Wekerom
741 Nijmegen	
742 Nijmegen	742 Nijmegen
820 Enschede	820 Enschede
934 Kollumerwaard	934 Kollumerwaard
937 Groningen	
938 Groningen	938 Groningen
543 Amsterdam	543 Amsterdam
546 Zaanstad	546 Zaanstad
1119 Schiedam	1119 Schiedam

Table C5 Scenario Balance

Current	LML
131 Vredepeel	131 Vredepeel
136 Heerlen	136 Heerlen
137 Heerlen	137 Heerlen
	230 Biest-Houtakker
240 Breda	240 Breda
241 Breda	241 Breda
246 Fijnaart	
247 Veldhoven	247 Veldhoven
	318 Philipinne
404 Den Haag	404 Den Haag
418 Rotterdam	418 Rotterdam
433 Vlaardingen	433 Vlaardingen
444 De Zilk	444 De Zilk
448 Rotterdam	448 Rotterdam
538 Wieringerwerf	538 Wieringerwerf
620 Cabauw	620 Cabauw
636 Utrecht	636 Utrecht
641 Breukelen	641 Breukelen
643 Utrecht	643 Utrecht
738 Wekerom	738 Wekerom
741 Nijmegen	741 Nijmegen
742 Nijmegen	742 Nijmegen
820 Enschede	820 Enschede
934 Kollumerwaard	934 Kollumerwaard
937 Groningen	937 Groningen
938 Groningen	938 Groningen
543 Amsterdam	543 Amsterdam
GGD Zaanstad	GGD Zaanstad
1119 Schiedam	1119 Schiedam

Appendix D Uncertainties in trend analysis

A reduction target value of in between 10%-20% in 2020 as compared to 2010 is prescribed by European legislation for the $PM_{2.5}$ concentrations at urban background stations. This implies an annual reduction of in between 1%-2% per year. In the BOP research program an estimate was made of the uncertainty in the trend analysis of time series for the annual mean value of PM_{10}. For this analysis 8 monitoring stations were available, the length of the period (in years) of the time series was varied. Figure D1 shows the plot taken from the BOP report, which shows that the uncertainty decreases as the period of the time series increases. Furthermore one can see that the uncertainty in the trend is in between 1%-2% for a period of 10 years. The latter implies that the reduction target value over 10 years as prescribed by European legislation would not be observed in the case of PM_{10} since the uncertainty is of the same order of magnitude as the trend which needs to be detected. However, the trend can be detected if the length of the time series is more than 15 years.

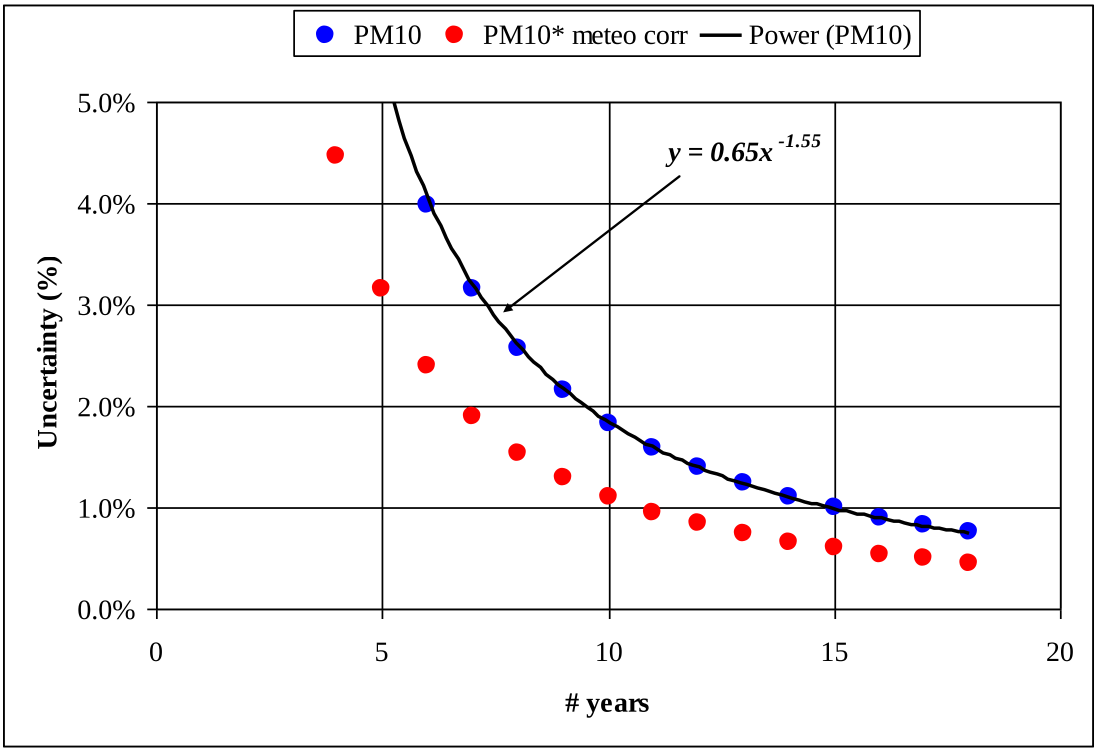

Figure D1 Relation between the expected uncertainty in the trend of a PM_{10} time series as function of the length of the time series.

The figure also shows data which have been meteo-corrected: it is seen that this reduces the number of monitoring years in order to detect a certain uncertainty.

Apart from the length of the time series, the number of stations will also decrease the uncertainty in the measured trend of a time series. Figure D2 shows the time series of PM_{10} concentrations for individual stations. From this figure it is clear that there is a distinct variation in the time series for each station (left panel). An increase of the number of stations will hence decrease the uncertainty in the overall mean value of the measured component (right panel). Hence we have performed a more detailed calculation on the same data series, which allows for the calculation of how many years one needs to measure in order to detect a certain trend when the number of stations is varied as well

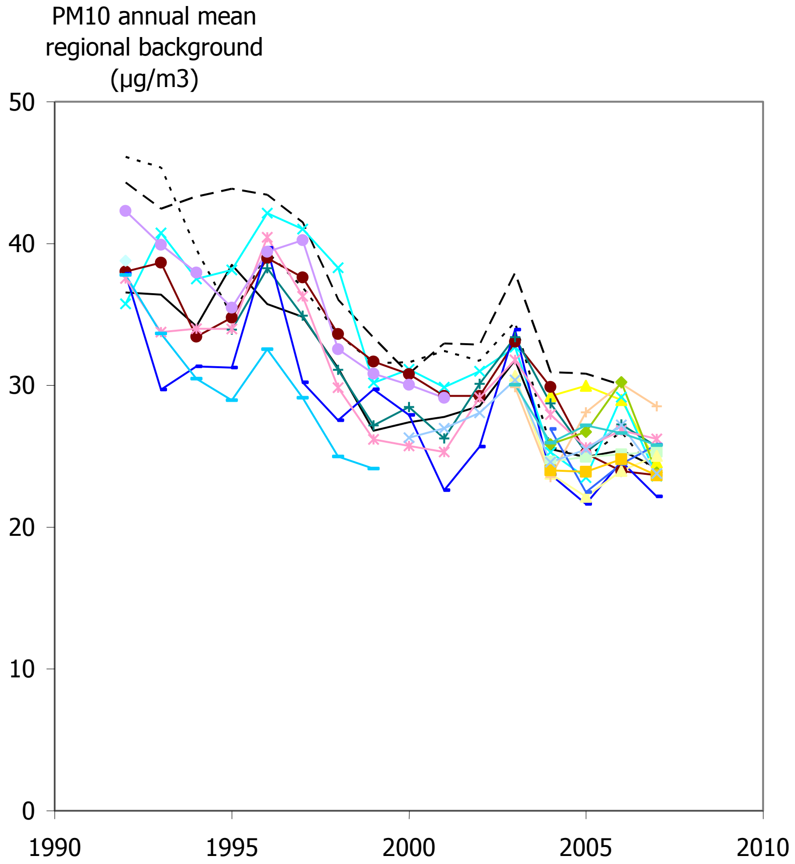

Figure D2 Annual mean PM_{10} concentrations ($\mu g/m^3$) in the Netherlands (1992-2007) for rural stations, left panel. Average annual mean PM10 concentrations (thick blue line), right panel. The thin blue line signify the lower estimate for the average concentration on rural stations for the years 1992-2003

Taking the dependency of the variation into account for the uncertainty in the mean value one can calculate the number of years which need to be detected in order to measure a certain reduction: a summary of the results are shown in Table D1.

Table D1 The minimum number of years required to measure data in order to detect a statistical significant (95%) trend in the time series

	Raw data			**Meteo-corrected**		
Number of stations:	**12**	**8**	**4**	**12**	**8**	**4**
1.0% reduction/year	16	16	18	12	13	15
1.5% reduction/year	12	13	13	9	10	11
2.0% reduction/year	10	10	11	8	8	9

The results from the calculations shown in Table A2 suggest that at least 12 monitoring stations are required in order to allow for a detection of trends which are prescribed by European legislation. It should be emphasised that the current calculation is an order-of-magnitude calculation. There are uncertainties in this estimation, for example the additional uncertainty due to monitor replacement is not included. However it is shown that the number of monitors need to be at least 12 in order to detect trends which have to satisfy the reduction target values. Of course this only proves that a trend significantly deviation from zero is present. To prove that the reduction target is obtained with a statistical significance of 95 % both a larger reduction and a larger number of stations is necessary.

Appendix E Consequences of the number of rural and urban background stations on GCN

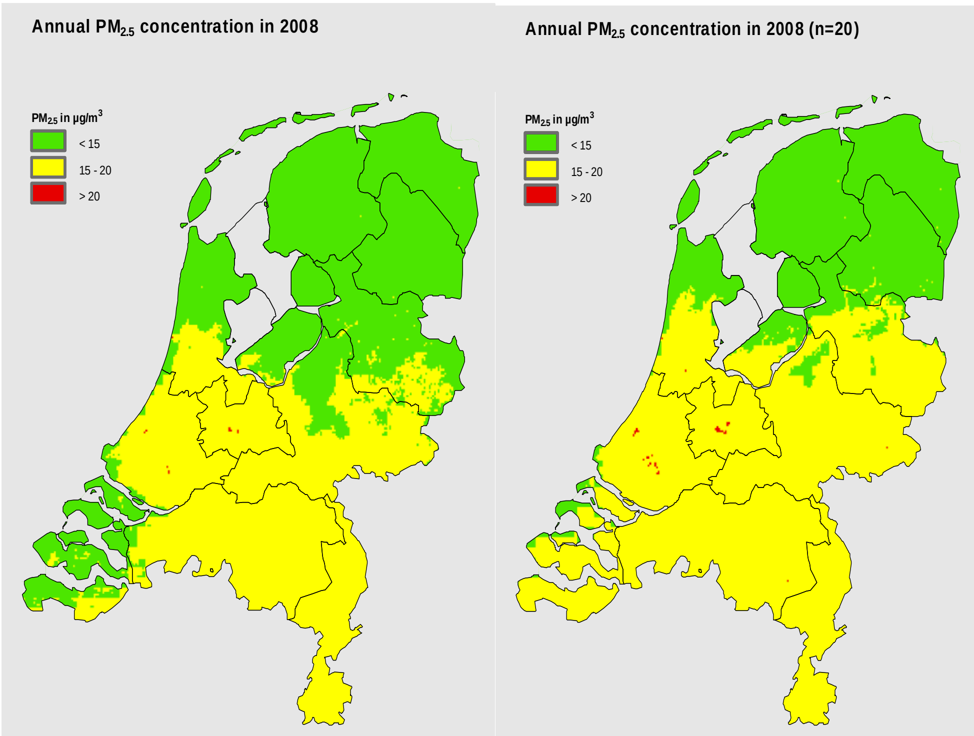

Figure E.1 The GCN-map of 2008 (left panel) and the upper limit of the 95 % confidence interval for 20 stations (right panel).

The influence of the number of stations $n=n_{urban}+n_{rural}$ on the GCN-map can be easily illustrated with the GCN-results of $PM_{2.5}$ for 2008. The concentration in a GCN-map equals $C_{gcn}\pm2\sigma$, where 2σ is the estimated expended uncertainty (95% confidence level) which scales with $n=n_{urban}+n_{rural}$ as mentioned above. Figure E.1 left panel shows the distribution of C_{gcn} where values higher than 20µg/m^3 (=limit value for the AEI in 2015) are red-shaded, the right panel shows $C_{gcn}+2\sigma$ with n=20. The two panels clearly illustrate that when one takes into account the uncertainty that the size of the critical areas (red-shaded) are increased and that the rate of increase is directly proportional with the number of background stations $n=n_{urban}+n_{rural}$. Table E.1 shows the size of the red-shaded area for the two maps in Figure E.1plus a map (not shown) with n=14 instead of n=20.

Table E.1 The size of the critical areas for $PM_{2.5}$ (in km^2) in 2008

	C_{gcn}	$C_{gcn}+2\sigma(n=20)$	$C_{gcn}+2\sigma(n=14)$
Area > 20 µg/m^3	11	36	46

The number of background stations additionally influences the possibility for determining the presence model inconsistencies. As an example of such a inconsistency a potential east west bias in the model calculation is studied. Figure E.2 shows the difference between calculated and observed values as a function of longitude. The figure seems to implies the existence of such a gradient over the east-west direction in the Netherlands. Already the possible gradient is dominated by only two locations and is difficult to determine. With a lower number of stations effective determination of model inconsistencies will be hampered.

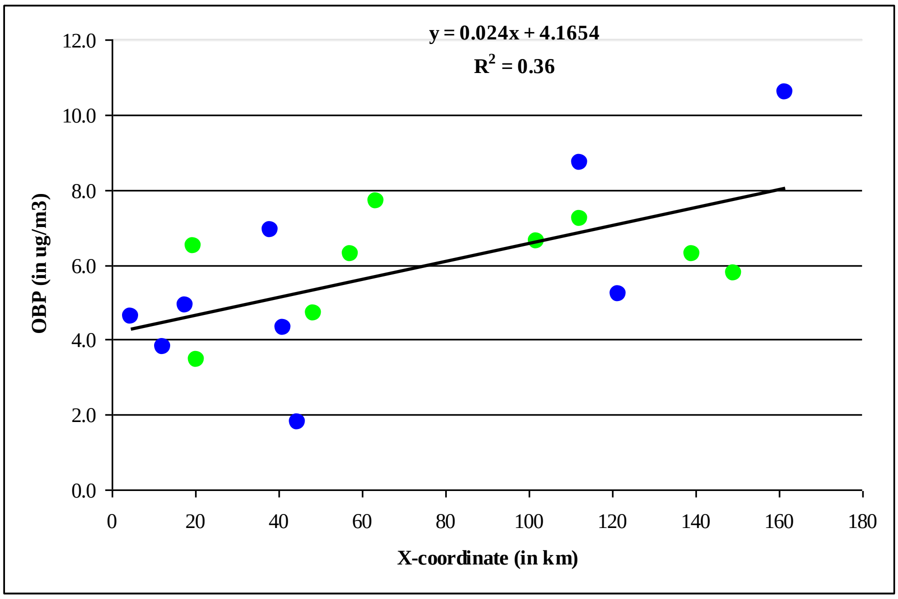

Figure E.2 The difference between observed and calculated annual mean value of $PM_{2.5}$ as a function of longitude in the Netherlands. Blue dots indicate urban background sites and green dots indicate rural background sites.

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