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Preliminary assessment of air quality for ozone in the Netherlands under EU legislation

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Abstract

Before implementing the third EU daughter directive, all member states should assess the air quality for ozone in their countries. The assessment for the Netherlands indicates that the target value for the protection of human health and vegetation in 2010 is not expected to be exceeded. However, the long-term objectives for ozone were exceeded in all zones and agglomerations. Therefore, to meet the information requirements of the EU, 31 sampling points for ozone are required if measurements are the sole source of information. At half of these stations nitrogen dioxide should also be measured. In addition, there must be at least one sampling point in the Netherlands for measuring (Highly) Volatile Organic Compounds (HVOC and VOC). A comparison of current numbers and locations of ozone sampling points showed a need for additional points for monitoring ozone and nitrogen dioxide particularly in suburban areas of zones and agglomerations. The LML is expected to meet the requirements for HVOC and VOC monitoring without difficulty.

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Samenvatting

De derde dochterrichtlijn voor ozon (O_3) is in maart 2002 in werking getreden en zal in september 2003 in de Nederlandse wetgeving moeten zijn geïmplementeerd. Voorafgaand aan de implementatie van deze richtlijn dienen de lidstaten van de Europese Unie in een Voorlopige Beoordeling de luchtkwaliteit van ozon in hun land, voor de verschillende zones en agglomeraties, te beoordelen. De huidige luchtkwaliteit in Nederland voor ozon is beoordeeld aan de hand van de streefwaarden voor 2010 en de langetermijndoelstellingen volgens de derde dochterrichtlijn. De luchtkwaliteit voor ozon in 2010 is op basis van modelberekeningen met verschillende scenario's beoordeeld.

In Nederland is in de jaren negentig een dalende trend geconstateerd in het voorkomen van hoge ozonconcentraties. Dit komt voornamelijk door de reductie van precursoremissies in Nederland en Europa. In de afgelopen vijf jaar (1997-2001) zijn er op geen van de meetstations voor ozon in Nederland overschrijdingen gemeten van de streefwaarden voor de bescherming van de gezondheid van de mens en de vegetatie. Met een verdere emissiereductie zoals voorzien in de Europese emissiedoelstellingen voor 2010 (NEC-richtlijn) zullen de ozonconcentraties nog verder dalen. Uit modelberekeningen blijkt dat hierdoor een overschrijding van de streefwaarden voor ozon in 2010 onwaarschijnlijk is.

De ozonmeetwaarden per station voor de jaren 1997-2001 zijn getoetst aan de langetermijndoelstellingen voor de bescherming van de gezondheid van de mens en van ecosystemen. Hieruit blijkt dat deze langetermijndoelstellingen in alle zones en agglomeraties worden overschreden. Daardoor worden alle zones en agglomeraties in het strengste regime (1) ingedeeld.

Indien metingen de enige informatiebron zijn voor de beoordeling van de luchtkwaliteit voor ozon dan geldt volgens de derde dochterrichtlijn voor regime 1 een meetverplichting van 31 meetstations die worden verdeeld over locaties in stadsgebied (3), voorstadsgebied (12) en platteland/regionaal (16).

Het aantal verplichte meetstations voor ozon, indien metingen de enige informatiebron is

Zone	Regime 1 (aantal meetpunten)		Agglomeratie	Regime 1 (aantal meetpunten)	
	Platteland	Voorstad		Voorstad	Stad
Noord	5	1	Amsterdam/Haarlem	2	1
Midden	6	1	Rotterdam/Dordrecht	2	1
Zuid	5	1	Den Haag/Leiden	2	1
			Utrecht	1	0
			Eindhoven	1	0
			Heerlen/Kerkrade	1	0

De derde dochterrichtlijn vereist om op minstens 50% van de ozonmeetstations, per zone of agglomeratie, eveneens stikstofdioxide te meten. Ook dient er één meetstation in Nederland te zijn voor het meten van concentraties van (Zeer)

Vluchtige Organische Stoffen (ZVOS en VOS). Uit een vergelijking met de huidige aantallen en locaties van de ozonmeetstations in het LML blijkt dat er met name meetstations voor ozon en stikstofdioxide in de voorstedelijke gebieden van zones en agglomeraties bij moeten komen. Voor het invullen van de meetverplichting voor ZVOS en VOS in het LML worden geen knelpunten verwacht.

Summary

The third daughter directive for ozone (O_3) came into force in March 2002 and will have to be incorporated into Dutch legislation by September 2003. Before incorporating the provisions of this directive into national legislation, the member states of the European Union (EU) are required to make a Preliminary Assessment of the ambient air quality for ozone in the various zones and agglomerations in their countries. The current ambient air quality for ozone in the Netherlands has been assessed under the provisions of the third daughter directive on the basis of the target values for 2010 and the long-term objectives. The assessment of ambient air quality for ozone in 2010 is based on model calculations under different scenarios.

A decline in the incidence of high ozone concentrations was observed in the Netherlands during the 1990s. This incidence is mainly a result of the reduction in precursor emissions in the Netherlands and Europe. During the last five years (1997–2001) none of the ozone monitoring stations recorded an exceedance of the target values for the protection of human health and vegetation. Further emission reductions in line with the EU emission targets for 2010 (NEC directive) will lead to a further decline in ozone concentrations. Model calculations have shown that in this case the target value for ozone is unlikely to be exceeded in 2010.

The ozone concentrations measured at each sampling point during the years 1997–2001 show that the long-term objectives for the protection of human health and vegetation were exceeded in all zones and agglomerations. As a consequence, all zones and agglomerations have been included in the strictest monitoring regime.

Where measurements are the sole source of information used to assess ambient air quality for ozone, the third daughter directive requires that under regime 1, data is to be obtained from 31 sampling points, divided between sites in urban areas (3), suburban areas (12) and rural (regional) areas (16).

The number of mandatory sampling points for ozone if measurements are the sole source of information.

Zone	Regime 1 (number of sampling points)		Agglomeration	Regime 1 (number of sampling points)	
	Rural	Suburban		Suburban	Urban
North	5	1	Amsterdam/Haarlem	2	1
Middle	6	1	Rotterdam/Dordrecht	2	1
South	5	1	The Hague/Leiden	2	1
			Utrecht	1	0
			Eindhoven	1	0
			Heerlen/Kerkrade	1	0

The third daughter directive requires nitrogen dioxide concentrations as well to be measured by at least 50% of the ozone sampling points in each zone and agglomeration. In addition, there must be one sampling point in the Netherlands

for measuring concentrations of (Highly) Volatile Organic Compounds (HVOC and VOC). A comparison of current numbers and locations of ozone sampling points showed a need for additional points for monitoring ozone and nitrogen dioxide particularly in suburban areas of zones and agglomerations. The LML is expected to meet the requirements for HVOC and VOC monitoring without difficulty.

1. Introduction

Known as the 'framework directive', *Directive 96/62/EG on ambient air quality assessment and management* provides a reference framework for ambient air quality assessment and management (EU, 1996). In force since 1996, this directive establishes objectives for preventing harmful effects of atmospheric pollution on human health and the environment. It also contains a list of thirteen atmospheric pollutants for which further EU legislation is to be developed in so-called 'daughter directives'.

The first daughter directive for sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and nitrogen oxides (NO_x), particulate matter (PM_{10}) and lead (Pb) came into force in 1999 (EU, 1999). The second daughter directive for carbon monoxide (CO) and benzene (C_6H_6) came into force in 2000 (EU, 2000). The third daughter directive for ozone (O_3) came into force in March 2002 and must be incorporated into Dutch legislation by 9 September 2003 (EU, 2002a). The third daughter directive is supported by the National Emissions Ceilings Directive (NEC directive) that came into force in 2001 (EU, 2001). One of the aims of the NEC directive is to bring about a reduction in ozone concentrations by setting national emission ceilings for NO_x and VOC (and other components) for the year 2010.

Member states are obliged to draw up a Preliminary Assessment of ambient air quality for the relevant components before the daughter directives come into force. The aim of the preliminary assessment is to determine the scope and nature of the required assessment instruments on the basis of an assessment of ambient air quality in zones and agglomerations. Preliminary assessments have already been drawn up under the first and second daughter directives (Van Breugel and Buijsman, 2001; Folkert et al., 2002). This report presents the preliminary assessment of ambient air quality for ozone under the third daughter directive.

The effects of short-term abatement measures in reducing high concentrations of ozone were investigated in a preparatory study for the implementation of the third daughter directive. The study indicated the effect of these measures as being too limited to make their introduction worthwhile (Smeets and Beck, 2001).

The instruments used for assessing ambient air quality, the National Air Quality Monitoring Network (LML) and a model, are described in Chapter 2. The zones and agglomerations in the Netherlands are defined and the assessment framework contained in the third daughter directive is presented. Chapter 3 provides a description of ambient air quality for ozone in the Netherlands in the years 2001 and 2010 based on measurements and modelling, and presents the relevant measurement data for ozone measured at all sampling points from 1997 to 2001. In Chapter 4 the measured and modelled atmospheric pollution levels are compared with the assessment values in the third daughter directive. This review of ambient air quality and the division of the country into zones and agglomerations is used to indicate the consequences for the future monitoring strategy. Chapter 5 contains the discussion and conclusions.

2. Data and methods

This chapter describes the National Air Quality Monitoring Network in which ozone measurements are carried out and the model used to forecast ozone concentrations in 2010. The assessment framework for ozone in the third daughter directive is then presented briefly.

2.1 Measurements

The National Air Quality Monitoring Network (LML) in the Netherlands consists of 54 monitoring stations (sampling points). These can be classified according to location and surrounding environment into (Van Elzakker, 2001):

- *Regional stations*, located outside urban areas in sites chosen to avoid influences from local sources
- *Urban stations*, located in urban areas such that the number of passing vehicles within a 35 metre radius of the station is less than 2,750 per 24 hours (Anonymous, 1987; Eerens et al., 1993)
- *Street stations*, located in urban areas such that the number of passing vehicles within a 35 metre radius of the station is at least 10,000 per 24 hours (Anonymous, 1987; Eerens et al., 1993)

The current numbers of ozone sampling points are shown in Table 2.1. The individual ozone sampling points in each zone and agglomeration are given in Annex C. Annex C also indicates at which of these sampling points nitrogen dioxide/nitrogen oxides and (highly) volatile hydrocarbons (VOC and HVOC) are measured. Annex A lists the technical specifications for the monitoring equipment of ozone and nitrogen dioxide, and the sampling and analytical methods for VOC and HVOC used in the LML. Implementation of the first, second and third daughter directives will lead to changes in the monitoring network.

All the LML monitoring stations are linked to the Computer Information System for Air (RIL), which stores all the sampling data. All the ambient air quality measurements presented in this report are taken from the RIL, unless otherwise stated.

Table 2.1. Number of ozone sampling points in the National Air Quality Monitoring Network in 2001 (Van Elzakker, 2001) by type of station.

Component	Regional	Urban	Street	Total
Ozone (O_3)	26	4	8	38

2.2 The model

The EUROS model was used to forecast ambient air quality for ozone in 2010. The model calculations were performed to indicate the extent to which the Netherlands could comply with the target values and thresholds in 2010 (Tables 2.3 and 2.5). Policy implications in the form of emission scenarios and the inherent uncertainties in the expected ozone concentrations due to the influence of meteorological conditions are mapped out.

EUROS

The atmospheric dispersion model EUROS is used to simulate emissions, transport processes, chemical transformations, and dry and wet deposition (Smeets and Beck, 2001; Mathijssen et al., 2002). EUROS simulates the spatial and temporal behaviour of O_3, SO_2, NO_x, VOC and PM_{10} in the troposphere above Europe. It can also be used to observe the effects of abatement measures on the concentration of air pollutants.

The horizontal and vertical domain of the model covers a large part of Europe and the base grid consists of 52x55 cells with a resolution of 0.55°x0.55° (approximately 60x60 km^2). The grid may be refined locally to four levels, with a maximum resolution of 0.069°x0.069° (approximately 7.5x7.5 km^2). The vertical structure consists of four layers: the surface layer, mixing layer, reservoir layer and the top layer, which delimits the model domain at a height of 3 km (Delobbe et al., 2001). Emissions of SO_2, NO_x and VOC are available on the base grid for six categories:PM_{10}-emissions are available for 10 categories. Additional information is available for various point sources. EUROS uses six-hourly observational and modelled meteorological data; land-use and land-cover data are available on a 0.17°x0.17° grid (approximately 18x18 km^2) from the European Land Use Database. Various elements of the model are under further development. The current state-of-the-art can be found in internal test reports. These include comparisons of modelling results with measurements and with results obtained from other models. Examination of the effects of, for example, various mixing layer heights, grid refinements and chemical mechanisms are also included. At present, EUROS is one of a number of models being studied in international comparative and validation studies for ozone and PM_{10}.

Scenarios

Ozone concentrations were calculated for two emission scenarios for the Netherlands in 2010 and one scenario for foreign emissions in 2010. The emission scenarios for the Netherlands comprise the NEPP4 scenario (VROM, 2001b), based on the national emission targets in the Fourth National Environmental Policy Plan (NEPP4), and the National Emissions Ceilings (NEC) scenario (Table 2.2). In the NEPP4 scenario the Netherlands aims to reduce NO_x and VOC emissions by more than what is legally required under the EU NEC directive. The model applies the 2010 NEC scenario to all the EU member states involved and the Gothenburg Protocol to all other countries. The NEPP4 and NEC scenarios contain emission totals per country for NO_x, VOC and other components, which are divided and assigned to the various target sectors in the same proportions as in the current situation. Other possible divisions of the country totals between the target sectors were not explored in the scenario studies, however, this aspect will be discussed later (section 5.1).

Table 2.2. National emission scenarios used in the model to forecast ozone levels in the Netherlands in 2010.

Component	Emissions [kton] NEPP4 scenario	NEC scenario
NO_x	231	260
VOC	155	185

Meteorological data

The choice of meteorological data used in the model is also very important because meteorological conditions have a highly significant influence on the formation of ozone. To illustrate this effect we present the model calculations for 2010 under the NEC scenario, using average and highly unfavourable meteorological data.

- Average meteorological data: the meteorological data for 1993 are representative for average conditions: the summer temperatures and number of hours of sunshine were just under the long-term average.
- Highly unfavourable meteorological data: 1994 was characterised by highly unfavourable meteorological conditions, i.e. conditions leading to a high rate of ozone formation. This year had one of the warmest summers of the 20th century, with an extremely sunny and hot July.

Effect of meteorology:

- When highly unfavourable meteorological conditions were used, the model generated exceedances of the target value (25 days) for the protection of human health in the south-east of the Netherlands (Annex D, Figure D1).
- No exceedances of this target value are expected when average meteorological conditions are used in the model (Annex D, Figure D2).
- Under highly unfavourable meteorological conditions the average number of days (with max. 8-h O_3 >120 µg/m^3) in the Netherlands is three times larger than under average meteorological conditions.
- Under highly unfavourable meteorological conditions the average AOT40 in the Netherlands is two times larger than under average conditions (not illustrated).

In calculating ozone concentrations for 2010 one has to take the requirement into consideration that 3- and 5-year average ozone concentrations have to be calculated to ensure compliance with the target values for the protection of human health and vegetation (section 2.3). This has been done using combinations of the meteorological conditions for 1993 and 1994, as described below:

- Three-year average: a combination of one year of average meteorological conditions and two years of highly unfavourable meteorological conditions.
- Five-year average: a combination of two years of average meteorological conditions and three years of highly unfavourable meteorological conditions.

Important note:

Both meteorological combinations are so extreme that they are unlikely to actually occur. It follows, therefore, that ozone concentrations calculated using these combinations will produce a worst-case picture of the situation in 2010.

2.3 Assessment framework

Target values and long-term objectives

The third EU daughter directive (EU, 2002a) provides a set of standards for assessing ambient air quality for ozone. The directive sets target values, long-term objectives and an information and alert threshold. The target values must, as far as possible, be achieved in 2010 (see Table 2.3). The benchmark year for the long-term objectives is 2020 (see Table 2.4).

The AOT40 takes account of both the exceedance of the 80 µg/m^3 threshold value (= 40 ppb) and the duration of exceedance, using only the one-hour values measured daily between 08:00 and 20:00 Central European Time.

Table 2.3. Target values contained in the third daughter directive.

Type of standard	Objective[1]	Standard	Starting date
Maximum daily 8-hour average	H	120 µg/m^3 not to be exceeded on more than 25 days per calendar year averaged over three years	1 January 2010
AOT40, calculated from 1-hour values from May to July	V	18,000 µg/m^3 * h averaged over five years	1 January 2010

[1] H: for the protection of human health. Applies everywhere in the Netherlands.
V: for the protection of vegetation. Does not apply to urban areas, but does apply to suburban, rural and rural background areas.

Table 2.4. Long-term objectives contained in the third daughter directive.

Type of standard	Objective[1]	Standard
Maximum daily 8-hour average	H	120 µg/m^3
AOT40, calculated from 1-hour values from May to July	V	6,000 µg/m^3 * h

[1] H: for the protection of human health.
V: for the protection of vegetation.

If the information or alert threshold for ozone (see Table 2.5) is exceeded, or if exceedance is predicted, the population must be provided with a minimum of information, including the observed exceedance, the forecast for the following day and specification of the sensitive population groups at risk. Detailed arrangements have been made for the hourly monitoring of exceedance of these thresholds and the provision of satisfactory information, and have been put into effect under the Smog regulation of 2001 (VROM, 2001a).

Table 2.5. Information and alert thresholds contained in the third daughter directive.

Type of standard	Objective[1]	Standard	Starting date
Information threshold	H	180 µg/m^3	September 2003
Alert threshold	H	240 µg/m^3	September 2003

[1] H: for the protection of human health.

Zones and agglomerations

The air quality in a country must be described in zones and agglomerations. The division into zones and agglomerations allows for a more specific description and management of the air quality in that area. The Netherlands was divided into a number of zones and agglomerations in the preliminary assessment for the first daughter directive (Figure 2.1, Table 2.6, Van Breugel and Buijsman, 2001).

Figure 2.1. Zones and agglomerations in the Netherlands.

The following criteria were used when determining the number and boundaries of the zones and agglomerations in the Netherlands:

- The boundaries follow the borders of the local air quality authorities, responsible for taking measures to prevent exceedances of the air quality standards in their areas.
- Adjacent areas with comparable air quality should be combined where possible because measures must be coordinated to be effective. The air quality in one zone may depend on the air quality in another zone if the dispersal of pollutants across a border has a substantial impact on local air quality or if areas have the same source characteristics and/or densities.
- All the various limit values and assessment thresholds for pollutants in the EU daughter directives should be considered when defining zones. This will improve the chances of compiling a clear overall picture of air quality. It also makes reporting more efficient by reducing the number of zones.
- Scientific considerations alone do not determine the division into zones, which must be as practical and convenient as possible.

A global view of the air quality for ozone roughly shows a gradient with increasing ozone concentrations from the north to the south (see section 3.1). This information, together with the criteria mentioned above, is the reason for dividing the Netherlands up into the same zones and agglomerations for ozone as those established under the first and second daughter directives (Figure 2.1, Table 2.6).

Table 2.6. Zones in the Netherlands (CBS, 2002).

No.	Zone	Provinces	Population[1] (x 1000)
1	North	Groningen, Friesland, Drenthe, Overijssel, Flevoland	3 ,120
2	Middle	Gelderland, Utrecht, Noord-Holland, Zuid-Holland	4 ,788
3	South	Limburg, Noord-Brabant, Zeeland	3, 246

[1] The populations of the agglomerations are not included in the population figures for the zones; see also Table 2.7.

The number and location of the agglomerations are based on the spatial distribution of the population density on a scale of 1x1 km^2. A continuous area with a population density greater than 750 inhabitants per km^2 was nominated as an agglomeration if the total population of the area was above 250,000. In the Netherlands this results in six agglomerations (Table 2.7). The population of Heerlen/Kerkrade is just below 250,000, but in view of its location (a transboundary urban area) and the demographic trends, it was decided to designate Heerlen/Kerkrade as an agglomeration.

Table 2.7. Agglomerations in the Netherlands (CBS, 2002).

No.	Urban centre	Municipalities	Population (x 1000)
1	Amsterdam/ Haarlem	Amsterdam, Aalsmeer, Amstelveen, Uithoorn, Ouder Amstel, Diemen, Zaanstad, Heemskerk, Beverwijk, Velsen, Haarlem, Bloemendaal, Zandvoort, Heemstede, Bennebroek, Haarlemmerliede and Spaarnewoude, Haarlemmermeer	1,512
2	Rotterdam/ Dordrecht	Rotterdam, Schiedam, Vlaardingen, Maassluis, Rozenburg, Spijkenisse, Albrandswaard, Capelle a/d IJssel, Ridderkerk, Barendrecht, Heerjansdam, Zwijndrecht, Hendrik-ido-Ambacht, Dordrecht, Papendrecht, Sliedrecht	1,274
3	The Hague/ Leiden	The Hague, Monster, s'Gravenzande, Naaldwijk, De Lier, Maasland, Schipluiden, Wateringen, Delft, Rijswijk, Leidschendam and Voorburg, Wassenaar, Voorschoten, Leiden, Oegstgeest, Katwijk, Valkenburg, Rijnsburg, Leiderdorp	1,065
4	Utrecht	Utrecht, Houten, Nieuwegein, IJsselstein, Maarssen, Vleuten-De Meern	433
5	Eindhoven	Eindhoven, Best, Veldhoven, Geldrop, Mierlo, Nuenen, Gerwen and Nederwetten, Helmond	420
6	Heerlen/ Kerkrade	Heerlen, Kerkrade, Landgraaf, Brunssum, Voerendaal, Nuth	246

The Netherlands has a high population density and contains many urban areas within a relatively small territory. The zones also include urban areas outside the designated agglomerations (Figure 2.2), which means that a more refined approach is required when describing ambient air quality in the zones. First, the air quality in the regional (rural) part of the zone, the largest area, is determined. Consideration is then given to the urban areas in the zone, where the air quality for ozone is generally slightly better (see section 3.1). The EU directive requires these areas to be examined separately because of the exposure potential of high population densities to ozone.

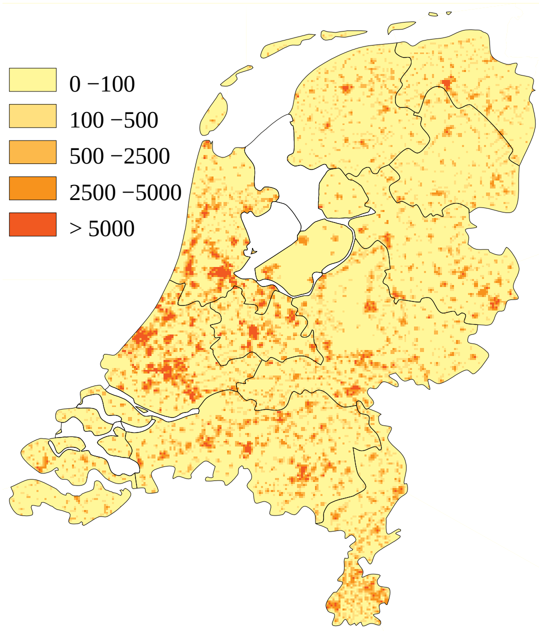

Figure 2.2. Population densities in the Netherlands expressed as numbers of inhabitants per km² (CBS, 2000).

Assessment of ozone concentrations in ambient air

The framework directive and the third daughter directive state that the degree of monitoring required in zones and agglomerations will depend on whether the ozone concentrations are higher or lower than the long-term objective.

- Regime 1: used when ozone concentrations in zones and agglomerations have exceeded a long-term objective during any of the previous five years of measurement. Continuous measurement at a number of fixed sites is mandatory. The number of sampling points depends on the type of area – whether it is a zone or an agglomeration – and the population size (see Table 2.8).

- Regime 2: used when ozone concentrations in zones and agglomerations haven't exceeded a long-term objective during any of the previous five years of measurement. The number of sampling points for ozone must, in combination with other means of supplementary assessment such as air-quality models and nitrogen dioxide measurements in the same place, be sufficiently large for examining the trend of ozone pollution and checking compliance with the long-term objectives. The number of fixed continuous sampling points may be reduced to one-third of the number specified in Table 2.8.

Table 2.8. Minimum number of sampling points in zones and agglomerations where measurements are the sole source of information (EU, 2002a)[1].

Population of the zone/agglomeration	Zone (suburban and rural)[2]	Agglomeration (urban and suburban)[2]
In thousands	Number of sampling points	
0–250	1	0
250–500	2	1
500–1000	2	2
1000–1500	3	3
1500–2000	4	3
2000–2750	5	4
2750–3750	6	5
>3750	1 additional sampling point per 2 million inhabitants	1 additional sampling point per 2 million inhabitants

[1] NO_2 concentrations should also be measured by at least 50% of the sampling points in each zone or agglomeration. Each member state should have at least one operational sampling point for collecting data on concentrations of volatile organic hydrocarbons.
[2] At least one sampling point in suburban areas where the highest exposure of the population is likely to occur. In agglomerations at least 50% of the sampling point should be in suburban areas.

Urban, suburban, rural and rural background areas
The third daughter directive on ozone distinguishes monitoring stations into urban, suburban, rural and rural background areas. These station types are described below.

Urban:

Objective	protection of human health
Represents	a few km^2
Location	in urban areas where the population density and ozone concentrations are relatively high

Suburban:

Objective	protection of human health and vegetation
Represents	some tens of km^2
Location	at a certain distance from the area of maximum emissions on the periphery of the urban area/agglomeration, where the population or vegetation may be exposed directly or indirectly to the highest concentrations of ozone

Rural:

Objective	protection of human health and vegetation
Represents	a few hundred km^2
Location	an area outside urban areas and agglomerations and beyond the influence of local emissions, where the population, crops and natural ecosystems are exposed to ozone concentrations on the subregional scale.

Rural background:

Objective	protection of vegetation and human health
Represents	a few thousand km^2
Location	areas far removed from urban and industrial areas, and local emission sources; population density is lower but there are natural ecosystems.

3. Results

This chapter provides an overview of measured and modelled ozone concentrations in the Netherlands in relation to target values and long-term objectives for the protection of human health and vegetation. Maps and a trend figure of ozone give a general overview of the spatial and temporal variability of ozone concentrations in the Netherlands. The ozone measurements of 1997 to 2001 are presented. They will be used for the preliminary assessment in the next chapter. Modelling results show the forecast for ozone concentrations in 2010. The results will be used in the next chapter to indicate the extent to which the Netherlands could comply with the target values in 2010.

3.1 Ozone in the Netherlands

Ozone concentration maps

The map of the Netherlands in Figure 3.1 shows the exceedance of the standard for the protection of human health in 2001: the number of days in which the maximum daily 8-hour average ozone concentration exceeded 120 μg/m^3. The average and maximum number of days were 10 and 19, respectively. The target value of 25 days has not been exceeded. The map of the Netherlands in Figure 3.2 shows AOT40 values in 2001: the standard for the protection of vegetation. The average and maximum AOT40 values were7,000 and 10,800 μg/m^3*h, respectively. The target value of 18,000 μg/m^3*h has not been exceeded. The maps are based on interpolated data from regional ozone sampling points (Hammingh et al., 2002).

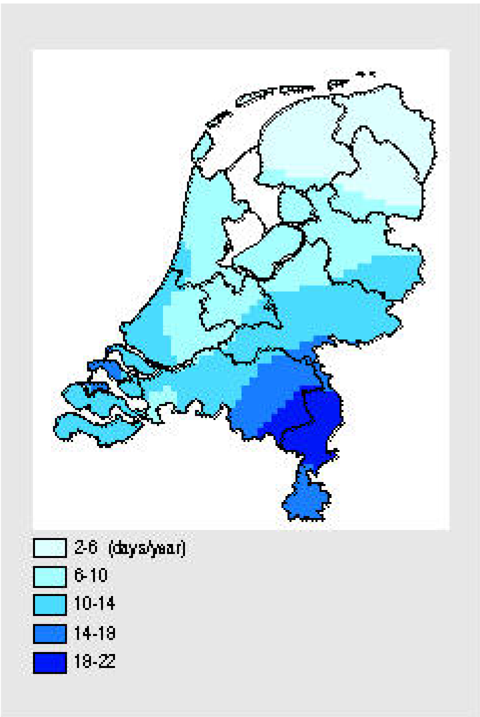

Figure 3.1. Number of days in 2001 in which the maximum 8-hour average ozone concentration exceeded 120 μg/m^3.

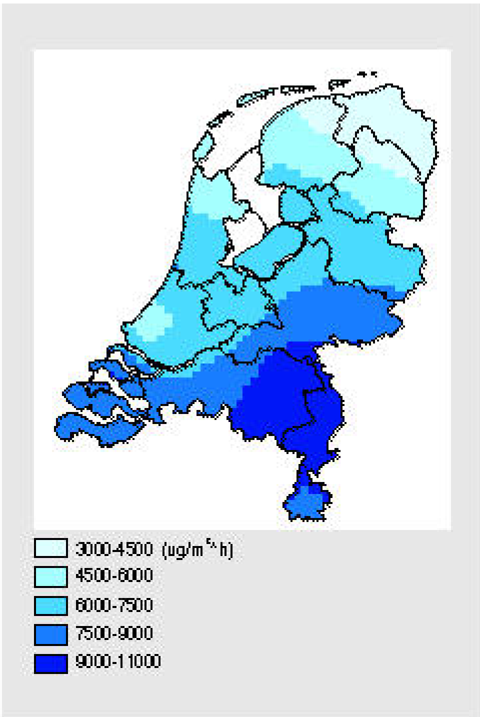

Figure 3.2. AOT40 in 2001.

The map of the Netherlands in Figure 3.3 shows the exceedance of the standard for the protection of human health averaged over the period 1999-2001: the number of days in which the maximum daily 8-hour average ozone concentration exceeded 120 µg/m^3. The average and maximum number of days were 10 and 17, respectively. The target value of 25 days has not been exceeded. The map of the Netherlands in Figure 3.4 shows AOT40 values averaged over the period 1997-2001: the standard for the protection of vegetation. The average and maximum AOT40 values were 5,000 and 10,300 µg/m^3*h, respectively. The target value of 18,000 µg/m^3*h has not been exceeded.

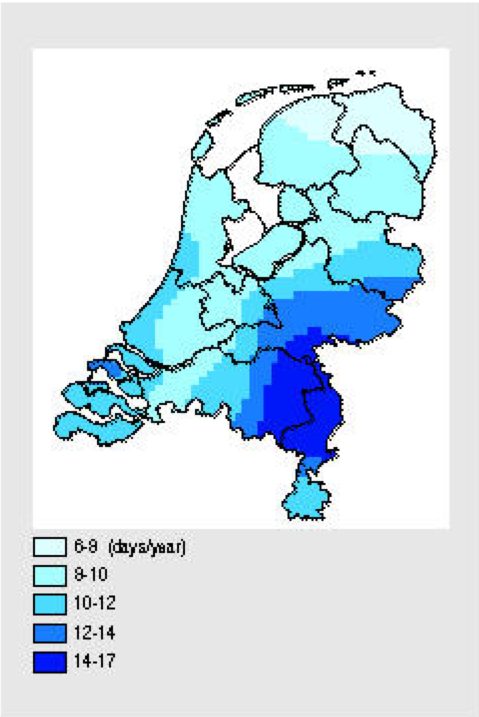

Figure 3.3. Number of days in which the maximum 8-hour average ozone concentration exceeded 120 µg/m^3 averaged over the period 1999-2001.

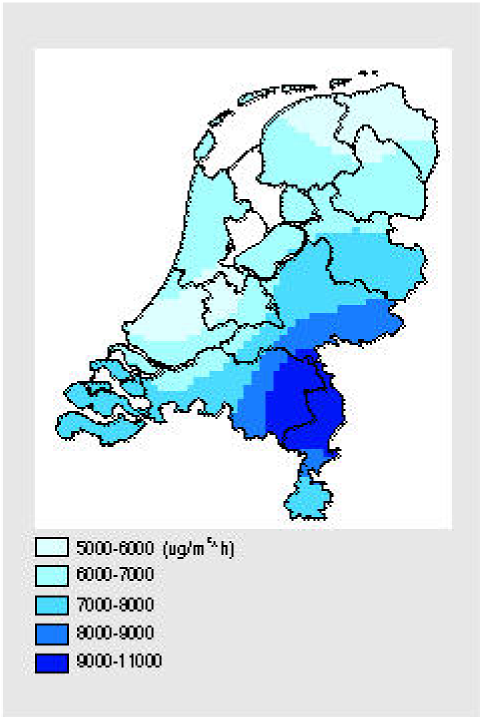

Figure 3.4. AOT40 averaged over the period 1997-2001.

In general, high concentrations of ozone occur more frequently in the south-east Netherlands than in the north and the Randstad. The high ozone concentrations in the south-east Netherlands are produced mainly by photochemical reactions involving ozone precursors, nitrogen oxides and hydrocarbons emitted in the Netherlands and in neighbouring countries. Important emission areas outside the Randstad are to the east and south of the Netherlands in Germany and Belgium. These emissions are transported by the wind to the south-east Netherlands; the sources are far enough away for the chemical reactions involved to generate high concentrations of ozone by the time they arrive in the Netherlands.

Days with high ozone concentrations occur on average less often in the Dutch agglomerations than in the regional (rural) areas (see Tables 3.1 and 3.2 and Annex B). This is the outcome of two processes. First, time is needed for ozone to be formed from precursor emissions as they travel downwind from areas of heavy traffic in city centres. The Dutch agglomerations, however, are not very large and so the residence time of the emissions in these agglomerations is too short to allow ozone to be formed there. Second, lower ozone concentrations are characteristic of Dutch agglomerations because the ozone reacts with nitrogen oxide and is quickly broken down (the 'NO titration effect'). This process is most pronounced in the centre of an agglomeration, where the highest NO emission densities are found.

The highest ozone concentrations in the Netherlands, therefore, are found mainly outside the agglomerations. The highest concentrations within the agglomerations probably occur on the periphery as a result of an influx of ozone from the region(rural area), combined with a still relatively low NO titration effect.

Trend in ozone concentrations

A downward trend in the number of days –in which the maximum 8-hour average ozone concentrations exceeded 120 µg/m^3–was observed in the Netherlands during the 1990s (Figure 3.5). Two other studies (De Leeuw, 2000; Roemer, 2001) also found indications of a slight downward trend in the high ozone concentrations. The reduction in precursor emissions in the Netherlands and Europe was mentioned as the most likely cause of this.

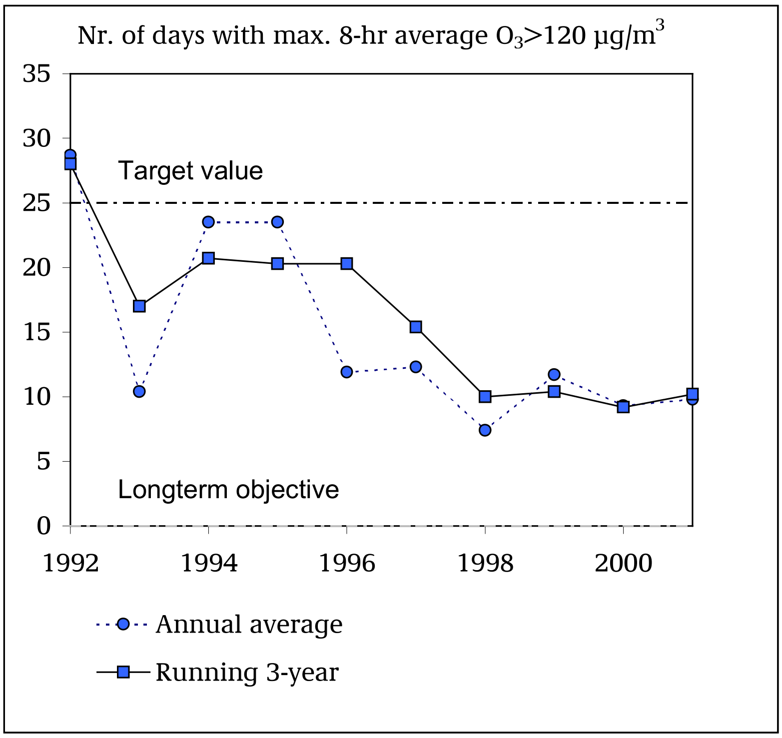

Figure 3.5. Trend in the number of days in which the maximum 8-hour average ozone concentration exceeded 120 µg/m^3.

3.2 Ozone measurements 1997–2001

The relevant statistical parameters (measured values) for ozone at all stations from 1997 to 2001 inclusive are given in Annex B. The criteria included in the third daughter directive were used when aggregating and calculating these parameters. Annex B (Table B1) lists the number of days –in which the maximum 8-hour average ozone concentration exceeded 120 µg/m^3 –at all sampling points. The measured AOT40 values for the regional and urban sampling points are given in Annex B (Table B2). Annex B is summarised in Tables 3.1 and 3.2.

Table 3.1. Minimum and maximum numbers of days in which the maximum 8-hour average concentration exceeded 120 μg/m^3 at regional, urban and street sampling points during 1997–2001.

Station type		1997	1998	1999	2000	2001
Regional	min	6	3	4	6	6
	max	24	18	20	14	19
Urban	min	12	6	7	4	6
	max	20	10	15	10	11
Street	min	4	2	1	1	2
	max	11	9	8	7	7

Table 3.2. Minimum and maximum AOT40 values at regional and urban sampling points during 1997–2001.

Station type		1997	1998	1999	2000	2001
Regional	min	4247	4109	4790	4051	4650
	max	14535	15603	12505	9277	11208
Urban	min	5349	6860	5914	3982	4062
	max	7839	7211	6442	6139	6243

3.3 Forecasting ozone concentrations in 2010

The general picture of ozone concentrations in the Netherlands calculated by the model (Figures 3.6 and 3.7) is consistent with the monitoring results (section 3.1). On average, higher levels of ozone occur more often in the south-east Netherlands and less often in the north and the Randstad. The model using the 2010 NEPP4 scenario and 3-year average meteorological data results in exceeding the target value for the protection of human health, with 26 days, in two grid cells near Eindhoven. The model using the 2010 NEC scenario and 3-year average meteorological data results in an exceedance of the target value for the protection of human health of 26 days in three grid cells near Eindhoven.

The following results are based on the NEPP4 scenario, with the accompanying figures included in Annex D. The target value for the protection of vegetation (AOT40) was not exceeded when five-year average meteorological data were used (Figure D3). The maximum calculated AOT40 value is 15,600 μg/m^3*h in one grid cell in the east of the country. The maximum exceedance of the information threshold (1-hour average of 180 μg/m^3) under highly unfavourable meteorological conditions was 16 hours (Figure D4). On the evidence of the model calculations, it is not expected that the alert threshold (1-hour average of 240 μg/m^3) will be exceeded under highly unfavourable meteorological conditions. The highest 1-hour average under highly unfavourable meteorological conditions is about 220 μg/m^3 in one grid cell in the east of the country (Figure D5).

The target value for AOT40 is not exceeded in the NEC scenario using five-year average meteorological data (not illustrated). The maximum AOT40 value is 15,700 μg/m^3*h in one grid cell in the east of the country.

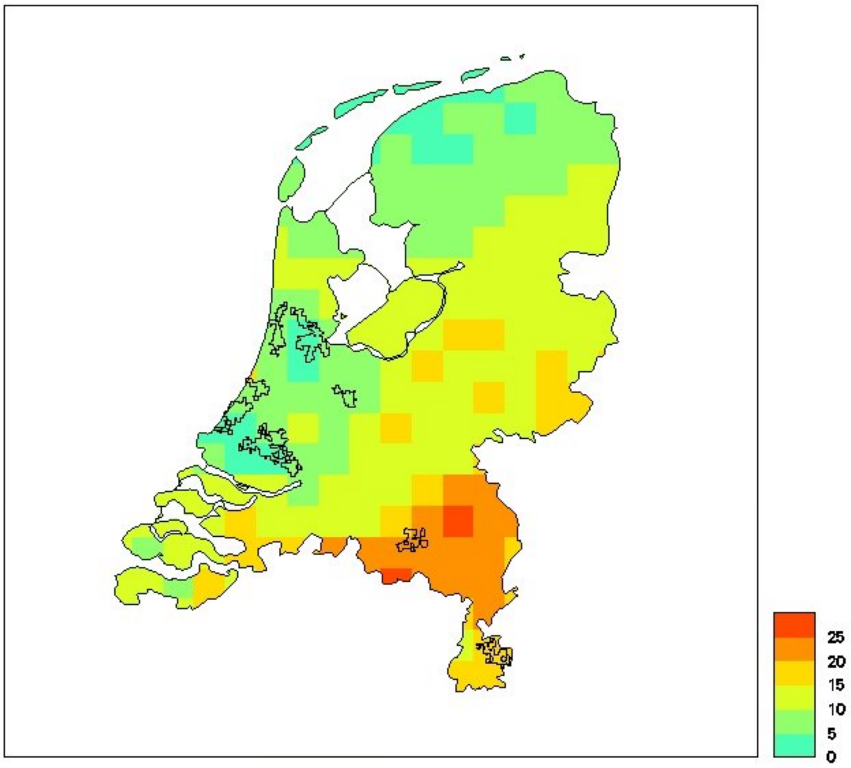

Figure 3.6. Number of days in 2010 in which the maximum 8-hour average ozone concentration exceeds 120 µg/m³ in the NEPP4 scenario using three-year average meteorological data.

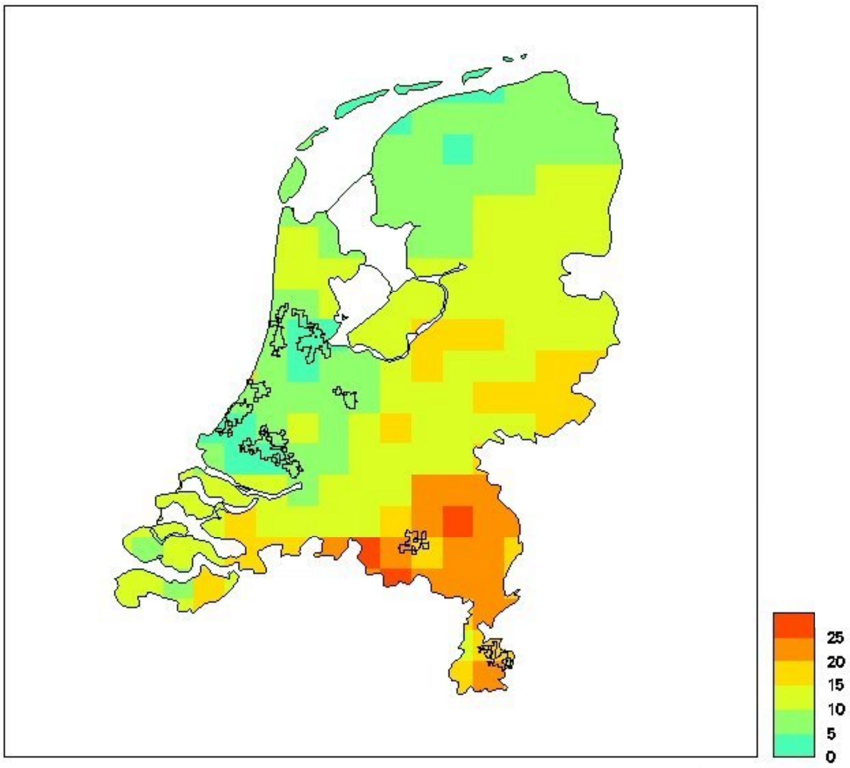

Figure 3.7. Number of days in 2010 in which the maximum 8-hour average ozone concentration exceeds 120 µg/m³ in the NEC scenario using three-year average meteorological data.

4. Preliminary assessment

The measured and modelled ozone concentrations in the Netherlands presented in chapter 3 were tested against the target values and long-term objectives for the protection of human health and vegetation (Annex B). The outcome was used to establish a regime for assessing air quality in the Dutch zones and agglomerations. This in turn will have important implications for the monitoring and reporting obligations.

4.1 Compliance with the target values

Target values for the protection of human health
At none of the sampling points was the target value (25 days) exceeded in any one year, and therefore, on average, not over a three-year period either. The model calculations indicate that if the EU emission reductions are realised (NEC directive) and extreme meteorological conditions do not occur, the target value for the protection of human health in 2010 will be achieved.

Target value for the protection of vegetation
At none of the sampling points was the target value (18,000 $\mu g/m^3{*}h$) exceeded in any one year, and therefore, on average, not over a five-year period either. The model calculations indicate that if the EU emission reductions are realised (NEC directive) and extreme meteorological conditions do not occur, the target value for the protection of vegetation in 2010 will be achieved.

4.2 Compliance with the long-term objectives

Long-term objectives for the protection of human health
The long-term objective (no exceedance of maximum 8-hour average ozone concentration above 120 $\mu g/m^3$ on any day) was exceeded almost every year at all stations in all zones. According to the model calculations for the NEPP4 and NEC scenarios, the long-term objectives for the protection of human health will be exceeded in 2010, under both average and unfavourable meteorological conditions.

Long-term objectives for the protection of vegetation
The long-term objective (6000 $\mu g/m^3{*}h$) is exceeded throughout almost the entire country. The model calculations for the NEPP4 and NEC scenarios indicate that the long-term objective for the protection of vegetation will be exceeded in 2010, under both average and unfavourable meteorological conditions.

4.3 Assessment and measurement regime

The measurements, the declining ozone concentrations (section 3.1) and the model results indicate that the target values for the protection of human health and vegetation will not be exceeded in 2010.
The measurements in the period 1997-2001 show that the long-term objectives for the protection of human health and vegetation are exceeded in all zones and agglomerations. For this reason all the zones and agglomerations will have to be assigned to regime 1, the strictest regime (Table 4.1). Where measurements are the sole source of information for the assessment of ambient air quality, the

assessment regime required by the third daughter directive is to be used (see Table 2.8).

Table 4.1. Assessment regimes for ozone.

Zone	Regime	Agglomeration	Regime
North	1	Amsterdam/Haarlem	1
Middle	1	Rotterdam/Dordrecht	1
South	1	The Hague/Leiden	1
		Utrecht	1
		Eindhoven	1
		Heerlen/Kerkrade	1

Assessment system
Regime 1
minimum number of required sampling points as listed in Table 2.8

Regime 2
a minimum of 1/3 of the number of sampling points listed in Table 2.8 and supplementary assessment

4.4 Consequences for the National Air Quality Monitoring Network

Ozone

All zones and agglomerations have been assigned to regime 1. The minimum number of ozone sampling points required under this regime are listed in Table 2.8. This has been translated into the numbers of sampling points required in urban, suburban and rural (regional) locations in the Netherlands, as shown in Table 4.2.

Table 4.2. Number of required ozone sampling points where measurement is the sole source of information.

Zone/ Agglomeration	Required total number[1] of sampling points	Required in agglomerations [2]		Required in other areas [3]		Existing in LML 2001[4,5]
		urban	suburban	rural	suburban	
Agglomerations						
Amsterdam/Haarlem	3	1	2			1
Rotterdam/Dordrecht	3	1	2			2
The Hague/Leiden	3	1	2			1
Utrecht	1	0	1			4
Eindhoven	1	0	1			2
Heerlen/Kerkrade	1	0	1			0
Zones						
North	6			5	1	7
Middle	7			6	1	12
South	6			5	1	9
Total	31	3	9	16	3	38

[1] NO_2 must also be measured by at least 50% of the sampling points in each zone or agglomeration.
[2] In agglomerations at least 50% of the sampling points should be located in suburban areas.
[3] In other zones (suburban and rural) at least one sampling point should be located in suburban areas.
[4] Including eight street stations where ozone is measured.
[5] Numbers according to Van Elzakker (2001).

Very few of the existing sampling points in the National Air Quality Monitoring Network (LML) are located in suburban areas (see also section 5.1), but the LML does include eight street sampling points not required for ozone monitoring under the third daughter directive. An option worth considering, therefore, is to move some of these street sampling points to locations in suburban areas.

Ozone precursors

The third daughter directive requires nitrogen dioxide as well to be measured at least 50% of the ozone sampling points in each zone or agglomeration. The number of nitrogen dioxide sampling points required in the Netherlands are stipulated on the basis of the information in Table 4.2. Table 4.3 indicates the number of ozone sampling points where NO_2 must also be measured.

Table 4.3. Number of ozone sampling points where NO_2 should also be measured, as required by the third daughter directive.

Zone / Agglomeration	Required number of ozone sampling points where NO_2 should also be measured	Existing ozone sampling points in the LML[1,2] where NO_2 is also measured
Agglomerations		
Amsterdam/Haarlem	2	1
Rotterdam/Dordrecht	2	2
The Hague/Leiden	2	1
Utrecht	1	4
Eindhoven	1	2
Heerlen/Kerkrade	1	0
Zones		
North	3	7
Middle	4	12
South	3	9
Total	19	38

[1] Including eight street sampling points
[2] Numbers according to Van Elzakker (2001)

The existing provisions in the LML for monitoring NO_2 are currently being revised to meet the requirements of the first daughter directive. These changes may satisfy some of the requirements of the third daughter directive for the location of NO_2 sampling stations, but not all. Notably, further sampling stations will have to be installed in suburban locations.

The third daughter directive obliges each member state to have at least one sampling station operational for collecting data on concentrations of volatile organic compounds (VOC) and highly volatile organic compounds (HVOC). The main objective of measuring VOC is to analyse trends and assess the effectiveness of emission reduction strategies. The main sources of VOC are traffic, industry and the use of solvents.

Under the second daughter directive for carbon monoxide and benzene it is likely that the concentrations of benzene, toluene (methyl benzene) and xylene (dimethyl benzene) (BTX) will be measured at street, urban and regional locations by BTX monitors. According to anEU working group that provides support for the implementation of the third daughter directive, this monitoring data can be used to provide an adequate analysis of the trends and reductions in VOC emissions from traffic (EU, 2002b). The working group has recommended placing the compulsory sampling point in an urban background location not directly influenced by major emission sources such as traffic and large industrial plants. The group recommends having this sampling point measure the full spectrum of VOC, as listed in Annex 6 of the third daughter directive.

On the list of LML sampling stations in Annex C it can be seen which stations measure VOC and HVOC concentrations. Table A1 in Annex A lists the volatile and highly volatile organic compounds measured at the sampling stations. At the moment the LML amply meets the requirements for measuring VOC. HVOCs are measured at one regional sampling station in the northern zone. Although the current (ample) monitoring capacity for VOC and HVOC in the LML will probably be altered, this will pose no obstacles to meeting the obligations under the third daughter directive.

5. Discussion and conclusions

5.1 Discussion

Monitoring results

A downward trend in the occurrence of high ozone concentrations was observed in the Netherlands during the 1990s. The most likely cause is thought to be a reduction in the emissions of precursors in the Netherlands and Europe.

Modelling results

According to the calculations the meteorological conditions in particular are shown to have a highly significant influence on ozone concentrations (section 2.2). If ‘worst-case’ meteorological conditions are used in the model, ozone formation rates are high and the target value for the protection of human health (25 days) is exceeded in the south-east of the Netherlands. When using average meteorological conditions the target value is not exceeded. Changes in meteorological conditions from year to year can lead to differences in the number of days (with max. 8-h O_3 >120 µg/m^3) of up to three times.

The modelling results for the 2010 NEPP4 and NEC scenario show the target value for the protection of human health (25 days) to be only just exceeded. The used meteorological conditions are however so extreme that they are unlikely to actually occur. The difference between the NEPP4 and NEC scenarios in spatially averaged exceedances (of days with max. 8-h O_3 >120 µg/m^3) over the Netherlands is less than 3%. So, if the NEPP scenario is not achieved and the situation in the Netherlands resembles the NEC scenario, ozone concentrations will be slightly higher. The small effect on the calculated ozone concentrations between the various emission scenarios for 2010 is also found in the report on Evaluation of the acidification reduction targets (in Dutch; Beck et al., 2001).

Emission scenarios (NEPP4 and NEC) were applied to the total sum of emissions using a fixed distribution over the target sectors (e. g. traffic, industry, energy, consumers). Other possible distributions between target sectors were not explored. From the above-mentioned discussion (on the small effect of the scenarios) it can be inferred that a different distribution of the total emissions over the target sectors will have little effect.

The ozone concentrations away from the agglomerations are generally higher in the NEC scenario than in the NEPP4 scenario. This is caused by the higher NO_x and VOC emissions that lead to higher rates of ozone formation some distance away from the agglomerations (section 3.1). However, ozone concentrations in the agglomerations are lower (see Figure 3.7, Randstad and around Eindhoven). This is due to the higher NO emissions that lead to a stronger titration effect (decomposition) on ozone in the agglomerations.

The model calculations show that the target values for ozone in 2010 will be achieved if the stated policy is successfully pursued and exceptional meteorological conditions do not occur.

Consequences for the National Air Quality Monitoring Network

The third daughter directive on ozone distinguishes between urban, suburban, rural and rural background areas. Sampling stations for ozone (and all other atmospheric pollutants) in the Netherlands are classified and sited according to a different system of street, urban and regional (rural) locations. Suburban areas as such have not been identified. The distinction between urban and suburban areas stated in the third daughter directive requires further interpretation for the Dutch situation.

The reasoning behind the EU requirement to monitor ozone levels in suburban areas has to do with the link between their high population densities (high exposure) and the regular occurrences of the highest ozone concentrations. In the Netherlands the highest ozone concentrations do not occur within the agglomerations, but outside them, in regional (rural) areas (see section 3.1). Within the agglomerations, the higher concentrations probably occur on the periphery as a result of an influx of ozone from the region, (rural area) combined with a still relatively low NO titration effect.

Definition of suburban areas

On the basis of the information above and in section 3.1, the distinction between suburban and urban areas in the Netherlands is observed as being relatively small for high ozone levels and high levels of exposure. It goes without saying, though, that the sampling points inside the agglomerations should be located to give the most complete picture possible of the exposure of the population to ozone. In the Netherlands this can be achieved by introducing the category, 'suburban' stations:

- within the agglomerations, in a suburb or outlying centre some distance from the centre of the agglomeration, where stations are not subject to undue influence from local traffic;
- within the zones, in medium-sized towns in an urban background location or in a suburb that is not subject to undue influence from local traffic.

In addition, it should be mentioned that the National Air Quality Monitoring Network does not just provide the data required to meet legislative obligations, but satisfies other information needs as well (international obligations, validation of models, monitoring of trends, spatial analysis; see Buijsman, 1995). Although the monitoring obligation under the EU directive also meets many of these other information requirements, it is conceivable that additional sampling points will be needed, both now and in future.

5.2 Conclusions

The ozone measurements in the assessment period 1997 to 2001 show no exceedances of the target value for the protection of human health and vegetation in 2010. The ozone measurements from 1992 to 2001 show a downward trend in the occurance of high ozon concentrations. These results indicate that the target value for the protection of human health and vegetation in 2010 will not be exceeded.
The model calculations support this conclusion provided that the emission targets in the NEC directive are achieved and no extreme meteorological conditions occur.

The measurements in the assessment period 1997-2001 show the long-term objectives for the protection of human health and vegetation to be exceeded in all zones and agglomerations. For this reason all zones and agglomerations have been included in the strictest regime. Where measurements are the sole source of information for assessing ambient air quality for ozone, 31 monitoring stations will be required under this regime: 3 in urban areas, 12 in suburban areas and 16 in rural/regional areas.

A comparison with the current numbers and locations of ozone sampling stations in the National Air Quality Monitoring Network (LML) reveals that especially additional sampling points for ozone and nitrogen dioxide will be required in suburban areas in zones and agglomerations. The current number of ozone sampling points in street locations can be reduced. Although changes to the current provisions in the National Air Quality Monitoring Network for monitoring VOC and HVOC are likely, these will not present an obstacle to meeting the obligations under the third daughter directive.

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Annex A: Measurement methods in the National Air Quality Monitoring Network (LML)

Measurement of ozone

Type	: automatic analyser
Measuring instrument	: Thermo Electron 49W
Analysis method	: ultraviolet absorption
Measuring range	: 0–1000 µg/m^3 O_3
Detection limit	: 4 µg/m^3 O_3
Duration	: 1 hour

Measurement of nitrogen oxides

Type	: automatic analyser
Measuring instrument	: Thermo Electron 42W
Analysis method	: chemoluminescence
Measuring range (NO)	: 0–1248 / 2496/ 6242# µg/m^3 NO
Measuring range (NO_2)	: 0–1915 / 3830 / 9574# µg/m^3 NO_2
Detection limit	: 1 µg/m^3 NO_2
Duration	: 1 hour

** higher range at a few street stations*

Sampling and measurement of Volatile Organic Compounds (VOC)

Type	: active sampling
Sampler	: universal sampler, made by RIVM
Sampling	: continuous during a day or week)
Adsorption medium	: active carbon (SKC, coconut-based, 150 mg)
Flow	: 0.65 l/min[1] (daily samples) 0.10 l/min[1] (weekly samples)
Analysis	: elution with CS_2 followed by gas chromatography and flame ionisation or electron capture detection, see Table A1 for components
Detection limit	: 0.1 µg/m^3
Duration	: 1 day, 1 week

Sampling and measurement of Highly Volatile Organic Compounds (HVOC)

Type	: automatic analyser
Sampler	: Chrompack VOC-AIR, cryogenic concentration on an adsorption column filled with a combination of 3 adsorbents, thermal desorption and cold trap focusing.
Sampling	: 50% of the time (every other hour: continuous for 1 h)
Flow	: 30 ml/min[1] (ambient air from central inlet), 10 ml/min[1] pre-concentrating
Analysis	: capillary gas chromatography with flame ionisation Detection, see Table A1 for components
Detection limit	: 8 ppt (C_2–C_4), 12 ppt (C_5–C_8), 20 ppt (aromatics)
Duration	: 1 hour
Remarks	: Inlet point 8 m above ground level, 720 l/min monitoring by TNO-MEP in Apeldoorn.

Table A.1. List of (HIGHLY) VOLATILE ORGANIC COMPOUNDS

VOLATILE ORGANIC COMPOUNDS (VOC)	
Alkanes:	Aromatics:
Decane	benzene
Dodecane	1.2-dimethylbenzene (o-xylene)
Heptane	1.2-ethylmethylbenzene
Hexadecane	1.2.3-trimethylbenzene
Hexane	1.2.4-trimethylbenzene
Nonane	1.3-dimethylbenzene (m-xylene)
Octane	1.3-ethylmethylbenzene
Pentadecane	1.3.5-trimethylbenzene
Propyl benzene	1.4-dimethylbenzene (p-xylene)
Tetradecane	1.4-ethylmethylbenzene
Tridecane	1.4-methyl-i-propylbenzene
Undecane	Ethyl benzene
	i-propyl benzene
Chlorinated alkanes:	Butyl benzene
1.1.1-trichloroethane	Styrene
1.1.2-trichloroethane	
1.2-dichloroethane	Chlorinated aromatics:
1.2-dichloropropane	Toluene
Trichloromethane (chloroform)	1.2-dichlorobenzene
Tetrachloroethene	1.2.3-trichlorobenzene
Tetrachloromethane	1.2.4-trichlorobenzene
Trichloroethene	1.3-dichlorobenzene
Others:	1.3.5-trichlorobenzene
2-methylnaphthalene	1.4-dichlorobenzene
4-isopropenyl-1-methylcyclohexene (limonene)	Chlorobenzene
Naphthalene	
Phenol	

HIGHLY VOLATILE ORGANIC COMPOUNDS (HVOC)	
C_2-C_4:	C_5-C_8:
But-1-ene	2-methylbuta-1,3-diene
Butane	2-methylbut-2-ene
Cis-but-2-ene	2-methylbutane
Ethane	2-methylpent-2-ene
Ethene	2-methylpentane
Ethyne	2- and 3-methylhexane
Methyl propane	3-methylpentane
Methyl propene	Cyclohexane
Propane	Cyclopentane
Propene	Cyclopentene
Trans-but-2-ene	Heptane
Aromatics:	Hexane
Benzene	Methylcyclopentane
Toluene	octane
Ethylbenzene	pentane
m/p-xylene	
o-xylene	

Annex B: Monitoring data

Table B1 lists the measured exceedances of the long-term objective for the protection of human health in the period 1997–2001 in number of days in which maximum daily 8-hour average ozone concentration exceeds 120 $\mu g/m^3$. Table B2 lists the measured AOT40 values in the period 1997–2001, and shows the exceedances of the long-term objective for protection of vegetation (6000 $\mu g/m^3 \cdot h$).

Values found below the long-term objective are shown in black; exceedances of the long-term objective are shown in red.

The criteria stated in the third daughter directive were used when aggregating and calculating these exceedances. The tables B1 and B2 show lack of data in case these criteria were not met.

Table B.1. Measured exceedances of the long-term objective for protection of human health (red) ; numbers of days in which the maximum daily 8-hour average ozone concentration exceeded 120 µg/m^3.

Station name	Station nr.	1997	1998	1999	2000	2001
Regional stations						
Posterholt-Vlodropperweg	107	22		20	13	15
Vredepeel-Vredeweg	131					19
Wijnandsrade-Opfergeltstraat	133	12	11		8	8
Budel-Toom	227		18		12	16
Biest Houtakker-Biestsestraat	230				7	10
Volkel-Heikantsepad	232	23	15	16	14	
Huijbergen-Vennekenstraat	235	24		15		9
Zierikzee-Lange Slikweg	301	14	11	11	10	13
Philippine-Stelleweg	318	17	11	11	9	11
Schipluiden-Groeneveld	411	17	12	9	8	
Westmaas-Groeneweg	437	15	10		8	
De Zilk-Vogelaarsdreef	444	6	7		11	14
Wieringerwerf-Medemblikkerweg	538	11	7	7	7	7
Cabauw-Zijdeweg	620	17	10			7
Biddinghuizen-Hoekwantweg	631	17	7	8	8	9
Zegveld-Oude Meije	633	9	3	4	6	8
Eibergen-Lintveldseweg	722		10		12	13
Wageningen-Binnenhaven	724	20	12	12	13	15
Loenen-Eerbeeksedijk	733	21	14		13	
Hellendoorn-Luttenbergerweg	807		11		10	
Barsbeek-De Veenen	818		9	11	10	9
Sappemeer-Borgercompagnie	913	12	9	10	8	7
Balk-Trophornsterweg	918	15	10	9		8
Witteveen-Talmaweg	928	14	9	8		
Valthermond-Noorderdiep	929					
Kollumerwaard-Hooge Zuidwal	934	6	5	6	6	6
Urban stations						
Den Haag-Rebecquestraat	404	14	10	8		6
Dordrecht-Frisostraat	441	20		15	10	11
Amsterdam-Florapark	520	12			4	7
Utrecht-Universiteitsbibliothe	640	15	6	7	5	8
Street stations						
Eindhoven-Genovevalaan	236	5	5	4	3	2
Eindhoven-Piuslaan	238	5	3	3	2	3
Vlaardingen-Floreslaan	433	8			3	4
Utrecht-de Jongweg	636	7	2	2	2	3
Utrecht-Vleutenseweg	638	4		1	1	2
Utrecht-Erzeijstraat	639		2	1	2	
Breukelen-Snelweg	641			7	4	
Apeldoorn-Arnhemseweg	729	11	9	8	7	7

*Table B.2. Measured AOT40 values (in µg/m^3*h), showing exceedances of the long-term objective for protection of vegetation in red.*

Station name	Station nr.	1997	1998	1999	2000	2001
Regional stations						
Posterholt-Vlodropperweg	107	13720	12784	10856		9378
Vredepeel-Vredeweg	131					11208
Wijnandsrade-Opfergeltstraat	133	11427	10721	8344	6296	6635
Budel-Toom	227		15603		9277	9360
Biest Houtakker-Biestsestraat	230				6405	7497
Volkel-Heikantsepad	232	14535	13407	10562	8652	
Huijbergen-Vennekenstraat	235			12505		
Zierikzee-Lange Slikweg	301		11891	8094	7558	7805
Philippine-Stelleweg	318		10903	8376		7747
Schipluiden-Groeneveld	411	10175	9316			5051
Westmaas-Groeneweg	437	7499	6808		5284	
De Zilk-Vogelaarsdreef	444	7596	8084		8421	7794
Wieringerwerf-Medemblikkerweg	538		5463	5883	6115	5843
Cabauw-Zijdeweg	620		11239	8403		6179
Biddinghuizen-Hoekwantweg	631	9678	9478	8139	5727	
Zegveld-Oude Meije	633	8539	7403		4051	4650
Eibergen-Lintveldseweg	722		11918		7149	
Wageningen-Binnenhaven	724		13105	10329	7602	
Loenen-Eerbeeksedijk	733		12559	10018	8205	7891
Hellendoorn-Luttenbergerweg	807		13992	9652		
Barsbeek-De Veenen	818	7169	7010	7320		7063
Sappemeer-Borgercompagnie	913	7468	7369	7344	6629	6127
Balk-Trophornsterweg	918	8226			7146	6776
Witteveen-Talmaweg	928					
Valthermond-Noorderdiep	929					
Kollumerwaard-Hooge Zuidwal	934	4247	4109	4790	5068	4716
Urban stations						
Den Haag-Rebecquestraat	404	7063	7211	5914		4438
Dordrecht-Frisostraat	441	7839		6417	6139	6243
Amsterdam-Florapark	520	5349			4133	4483
Utrecht-Universiteitsbibliothe	640	7018	6860	6442	3982	4062
Street stations						
Eindhoven-Genovevalaan	236	4185	4245	3929	2971	2845
Eindhoven-Piuslaan	238	2232	2256	2414	1875	2230
Vlaardingen-Floreslaan	433	4953	5082	4101	3092	3161
Utrecht-de Jongweg	636		5274		2914	3179
Utrecht-Vleutenseweg	638		2711	2193		1719
Utrecht-Erzeijstraat	639	3320	2965	2216		
Breukelen-Snelweg	641		4508	4432	3387	3276
Apeldoorn-Arnhemseweg	729	6422	6424		4311	4577

Annex C: Sampling points in the zones and agglomerations

The table below lists the operational ozone sampling points in each zone and agglomeration in the National Air Quality Monitoring Network (LML) (Van Elzakker, 2001). The table indicates at which sampling points nitrogen dioxide, nitrogen oxides and volatile organic hydrocarbons are measured.

Sampling points	Type	Ozone (O_3)	Nitrogen dioxide (NO_2) [1]	Volatile organic hydrocarbons
Amsterdam-Haarlem agglomeration				
520-Amsterdam-Florapark	Urban	x	x	
The Hague –Leiden agglomeration				
404-The Hague	Urban	x	x	
Rotterdam-Dordrecht agglomeration				
433-Vlaardingen-Floreslaan	Street	x	x	
441-Dordrecht	Urban	x	x	
Utrecht agglomeration				
636-Utrecht-de Jongweg	Street	x	x	x
638-Utrecht-Vleutenseweg	Street	x	x	x
639-Utrecht-Erzeijstraat	Street	x	x	x
640-Utrecht-University Library	Urban	x	x	x
Eindhoven agglomeration				
236-Eindhoven-Genovevalaan	Street	x	x	
238-Eindhoven-Piuslaan	Street	x	x	
Heerlen-Kerkrade agglomeration				

[1] Also for nitrogen oxides (NO_x)

Sampling point	Type	Ozone (O_3)	Nitrogen dioxide (NO_2) [1]	(Highly) Volatile organic hydrocarbons
Northern zone				
631-Biddinghuizen	Regional	x	x	
807-Hellendoorn	Regional	x	x	
818-Barsbeek	Regional	x	x	
913-Sappemeer	Regional	x	x	
918-Balk	Regional	x	x	
929-Valthermond	Regional	x	x	
934-Kollumerwaard	Regional	x	x	x [2]
Middle zone				
411-Schipluiden	Regional	x		
437-Westmaas	Regional	x	x	
444-De Zilk	Regional	x	x	
538-Wieringerwerf	Regional	x	x	
620-Cabauw	Regional	x	x	
627-Bilthoven	Regional	x	x	
633-Zegveld	Regional	x	x	x
641-Breukelen	Street	x	x	
722-Eibergen	Regional	x	x	
724-Wageningen	Regional	x	x	
729-Apeldoorn-Arnhemseweg	Street	x	x	
733-Loenen	Regional	x	x	
Southern zone				
107-Posterholt	Regional	x	x	
131-Vredepeel	Regional	x	x	
133-Wijnandsrade	Regional	x		
227-Budel	Regional	x	x	
230-Biest-Houtakker	Regional	x	x	x
232-Volkel	Regional	x	x	
235-Huijbergen	Regional	x	x	
301-Zierikzee	Regional	x	x	
318-Philippine	Regional	x	x	

[1] Also for nitrogen oxides (NO_x)
[2] Also for HVOC

Annex D: Modelling results

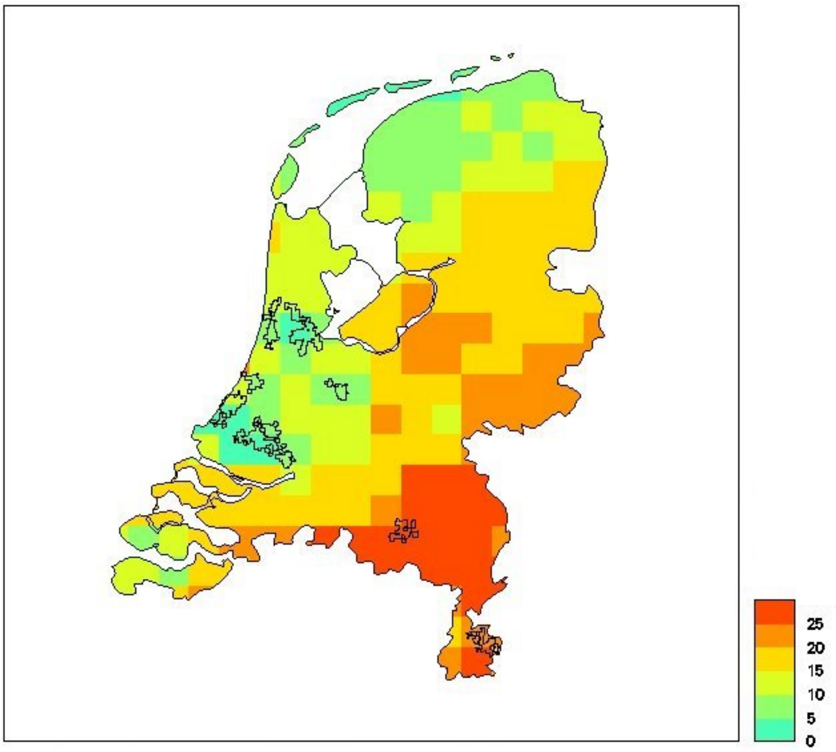

Figure D1: Number of days in 2010 in which the maximum 8-hour average ozone concentration exceeds 120 μg/m^3 (using highly unfavourable meteorological data and the NEC scenario).

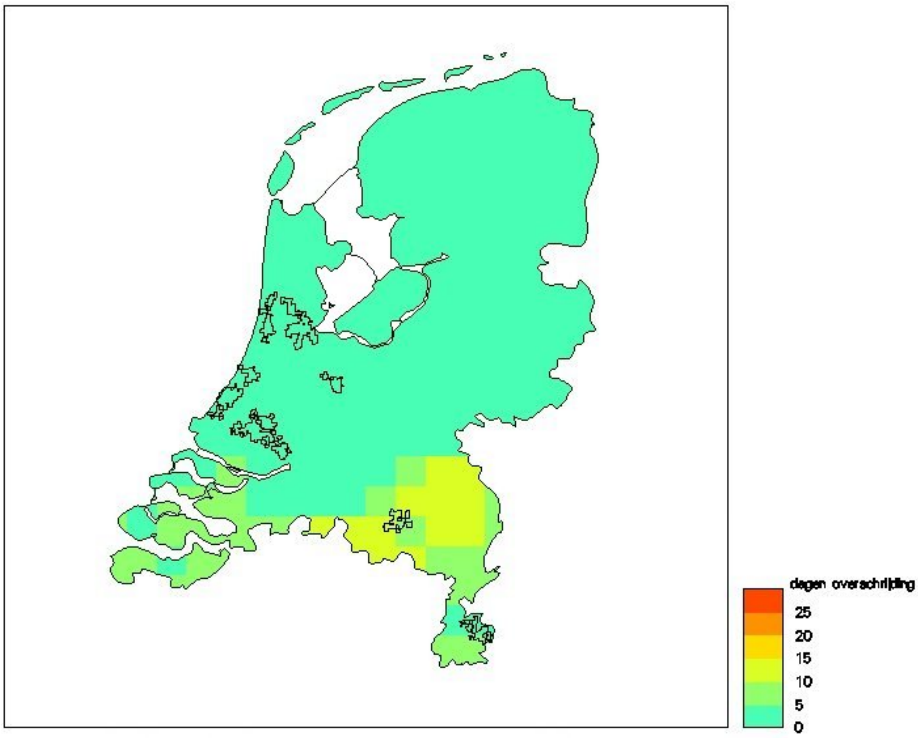

Figure D2: Number of days in 2010 in which the maximum 8-hour average ozone concentration exceeds 120 μg/m^3 (using average meteorological data and the NEC scenario).

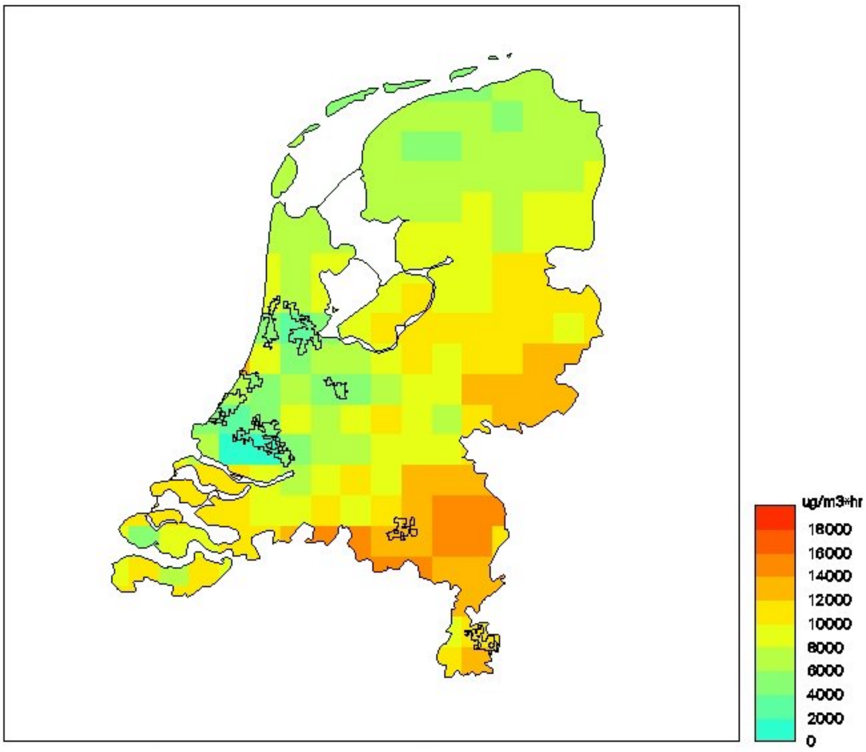

*Figure D3: Expected AOT40 values for 2010 in the NEPP4 scenario using five-year average meteorological data (target value is 18,000 μg/m³ *h).*

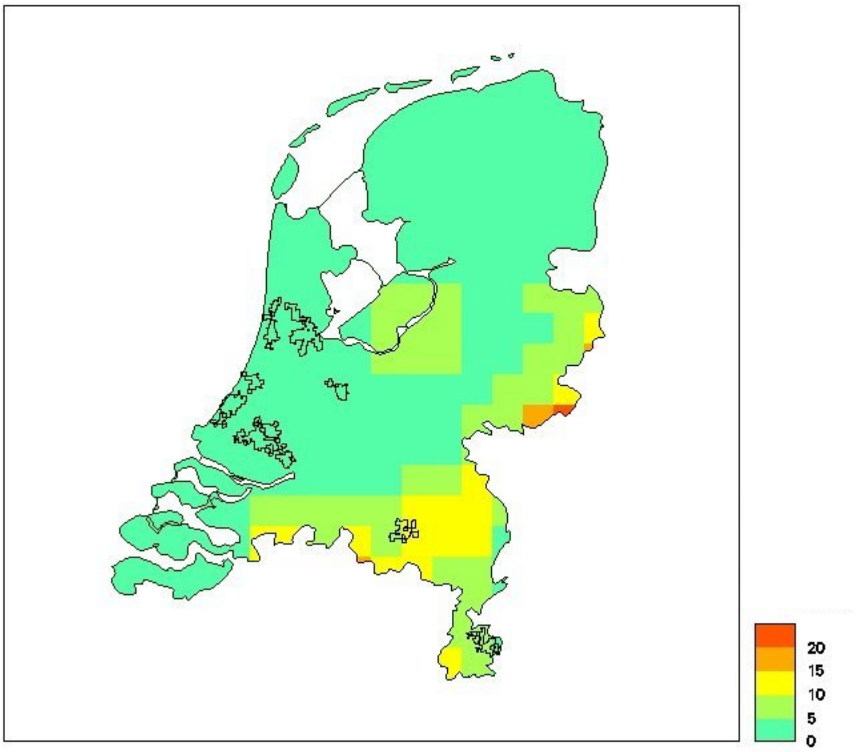

Figure D4: Expected number of hours in 2010 when the information threshold for ozone (180 μg/m³) is exceeded (using the NEPP4 scenario and very unfavourable meteorological data).

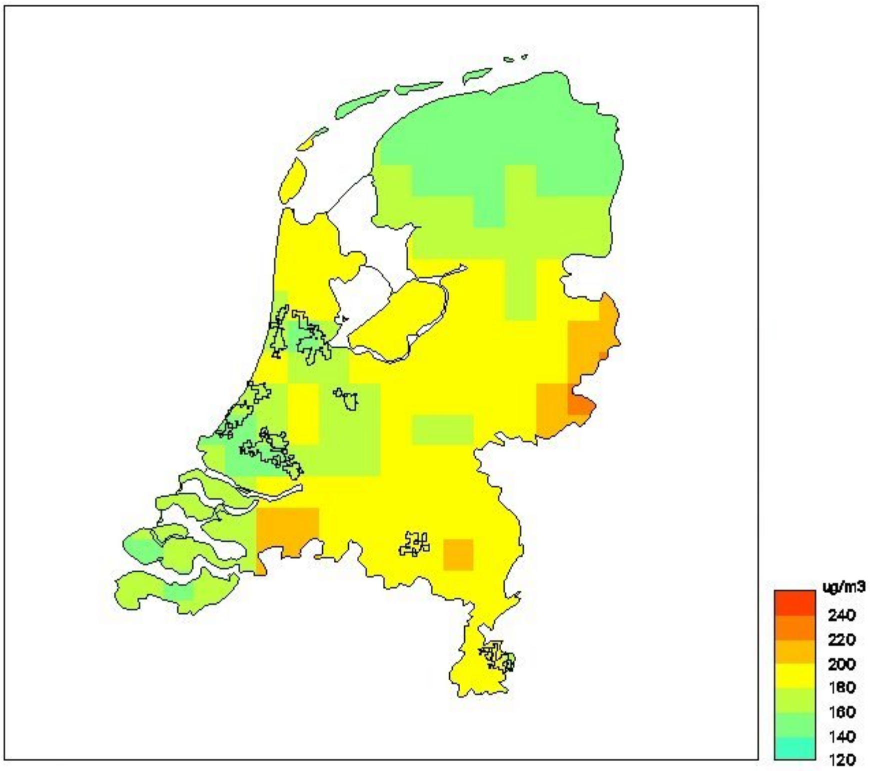

Figure D5: Expected maximum 1-hour average ozone concentrations for 2010 (using the NEPP4 scenario and very unfavourable meteorological data).

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