5 Air regulation

5.1 Overview

In industrialized countries like the Netherlands, air is often polluted. One of the main forms of air pollution is particulate matter, which comes from sources such as traffic, industry and intensive livestock farming. Particulates can cause respiratory conditions, including some serious diseases (Brunekleef & Holgate, 2002, Pope III et al., 2002). In this model, we focus on particulate matter of up to 10 micrograms (PM_{10}). Mitigating PM_{10} emissions from transport and agriculture should be the main focus in tackling this environmental issue. But in highly populated areas, vegetation and especially forests can also play a role because they affect airflow, turbidity and the deposition of PM_{10} (e.g. Beckett et al. 1998, Powe & Willis, 2004, Tiwary et al., 2008).

Table 5.1. Output maps generated for the ecosystem service 'air regulation'.

Output map	Unit	Short description
PM_{10} retention	kg ha^{-1} yr^{-1}	The amount of PM_{10} retained by vegetation
Monetary value of air regulation	€ ha^{-1} yr^{-1}	The avoided health costs due to the retaining of PM_{10} by vegetation.

Table 5.2. Input maps applied to estimate the ecosystem service 'air regulation'.

Input	Unit	Short description	Source
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017
Concentration of PM_{10}	µg/m^3	Concentration of PM_{10} in 2015	RIVM 2017
Trees	% cover per cell	Percentage of a 10m raster cell that is covered by trees taller than 2.5 metres.	RIVM (Appendix I)
Bushes and shrubs	% cover per cell	Percentage of a 10m raster cell that is covered by bushes and shrubs between 1 and 2.5 metres tall.	RIVM (Appendix I)
Low vegetation	% cover per cell	Percentage of a 10m raster cell that is covered by vegetation that is shorter than 1 metre.	RIVM (Appendix I)
Percentage non-green area	% cover per cell	Percentage of a 10m raster cell that is not covered by vegetation (the inverse of the sum of the tree cover, bushes and shrubs and low vegetation cover maps).	VITO

Scientific literature shows inconclusive evidence for the influence of vegetation on the reduction of PM_{10}, especially single trees and small patches of vegetation. Recent reviews and experimental studies show that the impact of green infrastructure on air quality depends on the local situation (Janhall, 2015; Chen et al., 2016, Abhijith et al., 2017; Baldauf, 2017). The studies show that different types of vegetation can retain fine particulate matter because of the roughness of their surface. The ecosystem service model 'air regulation' builds on the findings that deposition rates of particulate matter increase with vegetation roughness, and hence is removed from the air.

For the ecosystem service 'air regulation', two output maps have been developed for the Atlas of Natural Capital. Tables 5.1 and 5.2 provide an overview of the input and output maps for the ecosystem service 'air regulation'.

5.2 Modelling the ecosystem service

The service 'air regulation' results in two output maps. The modelling of these maps is described in the following sections. Figure 5.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps.

5.2.1 Monetary value of air regulation

The monetary value of air regulation is estimated for PM_{10} as follows:

$$\boldsymbol{€_{PM10} = Retention_{PM10} \times ExtCosts_{PM10}}$$

Where:

- $€_{PM10}$, the monetary value [€/ha.year];
- $Retention_{PM10}$, the retention of PM_{10} in vegetation [kg/ha.year];
- $ExtCosts_{PM10}$, the external costs of PM_{10} [€/kg].

Milieuprijzen 2017 (CE-Delft 2017) gives, for the external costs of $PM_{10,}$ a lower, central and upper value of resp. 31.80, 44.60 and 69.10 €/kg [2015 € values]. This value is the same for all the Netherlands and does not take into account the differences in inhabitant densities. As ambient PM_{10} concentrations affect every inhabitant living in an area, population distribution and density should be taken into account in a spatial model (see, for example, Künzli et al. 2000). Therefore, the external costs should increase as population densities increase, as was done in an earlier study of CE-Delft (2014). In this study, a difference is recognized between metropolitan, urban and rural areas. In metropolitan areas, the external costs are 247.36€/kg, in urban areas 79.76 €/kg and in rural areas 48.34 €/kg [converted from 2010 to 2016 € values].
In order to correct for spatial discontinuities between metropolitan, urban and rural areas, a linear relation has been developed between the external costs and the population density (Figure 5.1):

$$\boldsymbol{ExtCosts_{PM10} = 48.34 + 1.32 \times PopulationDensity}$$

In which:

- $ExtCosts_{PM10}$, the external costs of PM_{10} [€/kg];
- *PopulationDensity,* the population density in inhabitants/ha.

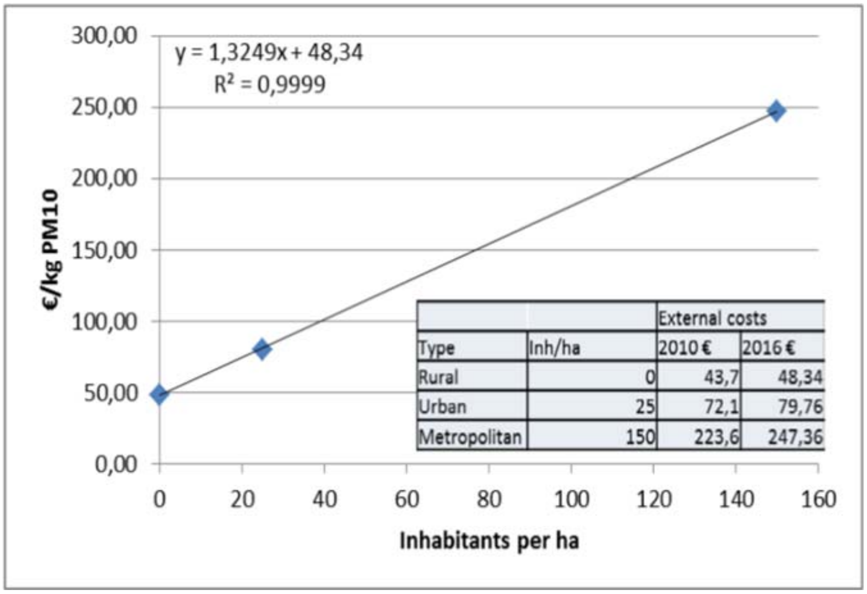

Figure 5.1. Linear relation between the inhabitant densities and external cost of PM_{10}. The blue points are estimates for average rural, urban and metropolitan population densities for the Netherlands (per ha).

5.2.2 *Retention of PM_{10}*

The retention of PM_{10} is estimated according to:

$$\boldsymbol{Retention_{PM10} = V_{dep} \times C_{PM10} \times fr_{Resuspension} \times UnitCorrection}$$

Where:

- *$Retention_{PM10}$*, is the amount of PM_{10} retained by vegetation [kg/ha.year]
- *V_{dep}*, is average deposition velocity [m/s];
- *C_{PM10}*, is the concentration of PM_{10} [$\mu g/m^3$]
- *$fr_{Resuspension}$*, is the fraction of resuspension of PM_{10} [-]
- *UnitCorrection*, is 3.1536 to correct the units from cm/s x $\mu g/m^3$ to kg/ha. year

The fraction of resuspension is assumed to be 0.5 for all land cover types except for water, for which it is 0.0 (De Nocker et. al., 2016).

The concentration of PM_{10} is based on the large-scale PM_{10} maps (in Dutch: Grootschalige Depositiekaart Nederland, GDN), as reported by RIVM (2017). As these large-scale concentration maps are used on a much smaller scale. The concentrations in the maps are linearly smoothed over a distance of 100m.

The deposition velocity depends on the type of vegetation and land cover. The type of vegetation is based on the maps showing the percentage of trees, shrubs and low vegetation (Appendix I). The land cover is taken from the LCEU map.

The average deposition velocity of a grid cell is estimated as:

$$V_{dep} = fr_{tree}V_{tree_i} + fr_{shrub}V_{shrub} + fr_{low-veg}V_{low-veg} + fr_{non-veg}V_{landcover_i}$$

$$fr_{non-veg} = 1 - (fr_{tree} + fr_{shrub} + fr_{low-veg})$$

Where:

- fr_x, is the fraction of trees, shrubs, low vegetation and non-vegetated area of a cell;
- V_x, is the deposition velocity of trees, shrubs, low vegetation and non-vegetated area.

The deposition velocity for the relevant land cover and vegetation types according to De Nocker et al. (2016) are given in Table 5.3. For V_{tree} default, a deposition velocity of 0.5 m/s for deciduous forest is assumed, and 0.7 for coniferous forest. Mixed forest was assigned the average value of deciduous and coniferous forests: 0.6 m/s.

Table 5.3. Average deposition velocities for various vegetation types (De Nocker et al., 2016).

Vegetation type	Deposition velocity (m/s)
no vegetation*	0.0 - 0.2
deciduous forest	0.5
coniferous forest	0.7
shrubs & bushes	0.3
meadows & grassland	0.2
arable land	0.2
water	0.1
low natural vegetation	0.2
low-stem orchard	0.2
mixed forest	0.6

*The value depends on the type of land cover assigned in the LCEU map. All built-up areas in the LCEU map receive value 0.0, water and forest area 0.1 and agriculture 0.2

The maps showing the fractions of trees, shrubs and low vegetation are maps developed by RIVM (Appendix I), with the fraction of vegetation > 2.5 m for trees, between 2.5 and 1m for shrubs and < 1m for low vegetation. These maps are based on the location of vegetation as reflected in the infrared aerial photographs and the height of the vegetation based on the available LiDAR data in the Netherlands.

5.3 Remarks and potential model improvements

- Forests affect the airflow, which in turn affects the possible retention of PM_{10} by vegetation. In the current model, a linear relation between the retention of PM_{10} and the extent of (a group of) trees is assumed, and a single tree also has a (small) positive effect on PM_{10} retention. Whether this is actually the case depends on the exact location and local circumstances. Street trees can also locally increase the PM_{10} concentration by trapping particulates under their canopy. These local effects have not yet been incorporated in the model. Model results on a local scale should therefore be handled with care.

5.4 References

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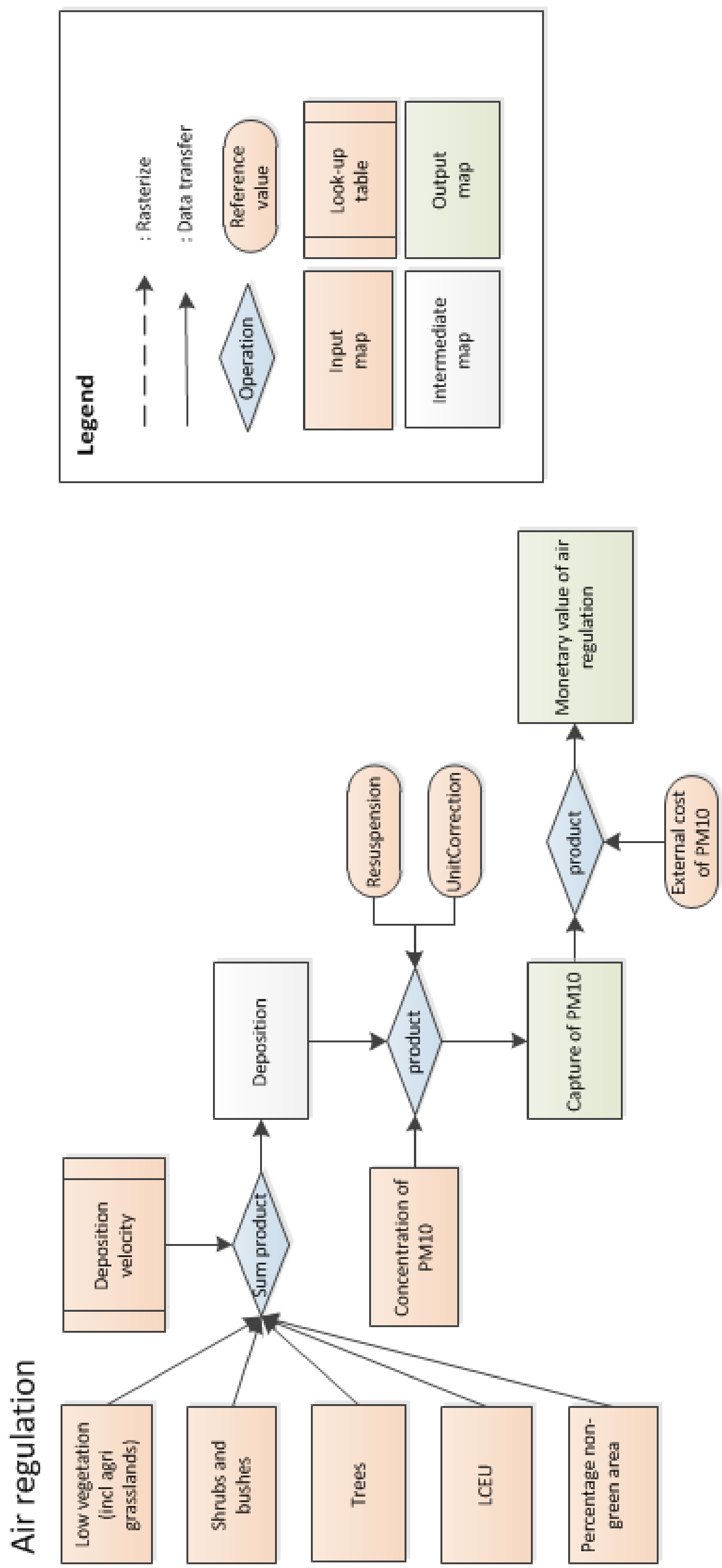

Figure 5.1. Schematic overview of the 'air regulation' model.