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

Natural Capital Model

Technical documentation of the quantification, mapping and monetary valuation of urban ecosystem services

RIVM Report 2017-0040

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Synopsis

Natural Capital Model

Urban green and water (natural capital) is important for Dutch towns and cities. It contributes to a healthy, attractive living environment and has benefits for residents and companies. Urban green and water receive insufficient attention in city planning, compared to economic interests. The 'societal benefits' of urban green and water can be lost as a result. RIVM presents models that map eight social benefits of urban green and water.

The model captures the effects of green and water in terms of urban cooling, health, air quality, the effects of water and urban green on house prices, the effects of urban green on energy-saving due to the shelter provided by trees, energy generated from green waste (pruning), wood production and lastly the presence of urban green in order to absorb carbon dioxide and counteract the effects of climate change. The models also show which effects urban development plans will have on the presence of greenery and water in towns and cities.

The models are used for maps that have been developed for the Atlas of Natural Capital. They also provide input for the national Natural Capital Model. This national model is being developed so that the way the societal benefits are calculated is the same for each policy issue.

RIVM has been asked to manage the calculation tool for the social benefits of urban green and water (TEEB-Stad) and is going to continue developing it. This report describes how the models have been structured and which outcomes they generate. It describes the initial versions of the model and clarifies future developments of the Natural Capital Model.

Keywords: urban green and water, Natural Capital Model, natural capital, ecosystem services, spatial model, technical documentation

Publiekssamenvatting

Natural Capital Model

Groen en water (natuurlijk kapitaal) is belangrijk voor de Nederlandse steden. Het draagt bij aan een gezonde, aantrekkelijke leefomgeving en heeft voordelen voor bewoners en bedrijven. Bij stedelijk ontwikkeling is daar vaak onvoldoende aandacht voor en krijgen de economische belangen voorrang. De 'maatschappelijke baten' van groen en water kunnen daardoor verloren gaan. Het RIVM presenteert modellen die acht maatschappelijke baten van stedelijk groen en water in beeld brengen.

Het gaat om effecten van groen op de verkoeling van de stad, op de gezondheid, en op de luchtkwaliteit, effecten van water en groen op huizenprijzen, effecten van groen op energiebesparing door de beschutting van bomen, energieopwekking uit (snoei)restanten van groen, houtproductie, en ten slotte de aanwezigheid van groen om koolstofdioxide af te vangen om effecten van klimaatverandering tegen te gaan. De modellen geven ook aan welke effecten stedenbouwkundige plannen zullen hebben op de aanwezigheid van groen en water in steden.

De modellen worden gebruikt voor de kaarten die zijn ontwikkeld voor de Atlas Natuurlijk Kapitaal. Ook leveren ze input voor het landelijke Natuurlijk Kapitaal Model. Dit landelijke model wordt ontwikkeld zodat de manieren om maatschappelijke baten te berekenen voor elke beleidsvraag hetzelfde zijn.

Het RIVM heeft de rekentool voor baten van groen en water in de stad (TEEB-Stad) in beheer gekregen en zal hem verder ontwikkelen. In dit rapport staat beschreven hoe de modellen zijn opgezet en welke uitkomsten de modellen leveren. De eerste versies van de modellen worden beschreven en toekomstige ontwikkelingen van het Natuurlijk Kapitaal Model worden belicht.

Kernwoorden: stedelijk groen, Natuurlijk Kapitaal Model, natuurlijk kapitaal, ecosysteemdiensten, ruimtelijk model, technische documentatie

Contents

Summary

Natural capital plays an essential role in our society by making invaluable contributions to, for example, food production, reducing heat stress, carbon sequestration, drinking water production and nature recreation. These contributions are known as ecosystem services. Natural capital is under increasing pressure in urban areas, as cities continue to expand and become ever more compact. At the same time, natural capital provides multiple benefits to city dwellers, which is gaining increasing attention from urban planners and policy makers. Efforts to incorporate the improvement of natural capital and the development of urban green in urban planning are increasing. Location-based information on the benefits of natural capital in urban areas is often missing. To facilitate such efforts, spatially explicit urban natural capital models have been developed as a part of the Netherlands Natural Capital Model. The Natural Capital Model consists of baseline information on natural capital (input data) and separate sub-models for the different ecosystem services and societal benefits provided by natural capital. The sub-models together comprise the full model, which provides spatial information on a range of ecosystem services and connected benefits. The urban sub-models provide insight into the effects that changes in urban areas have on the benefits provided by urban natural capital.

This report presents the technical descriptions of the first versions of eight urban sub-models of the Natural Capital Model, which have been developed as a part of the project 'Doorontwikkeling TEEB-Stad', by VITO (the Flemish institute for technological research) and the National Institute for Public Health and the Environment (RIVM). The project is an integral part of the City Deal 'Waarde van groen en blauw in de stad', in which a consortium of municipalities, knowledge partners, companies and NGOs work together to express the value of green and water in urban areas. This project aims to further develop the TEEB-Stad tool (www.teebstad.nl), a calculation tool to provide insight into the value of vegetation and water in urban planning projects. To enhance the TEEB-Stad tool, spatially explicit versions of the calculations have been developed to provide more accurate calculations for a specific location. These spatial calculations will form the basis for the spatially explicit version of the TEEB-Stad tool: the Green Benefit Planner. The Green Benefit Planner is a decision-support tool that calculates the effects of spatial planning on natural capital. The urban sub-models of the Natural Capital Model are applied in the first version of the Green Benefit Planner. In addition, the urban models of the Natural Capital Model have been developed to improve ecosystem service maps for the Atlas of Natural Capital, a national atlas that provides maps on ecosystem services and natural capital in the Netherlands.

Five of the current sub-models are based on TEEB-Stad calculations and have been adapted in order to function with spatial data. These adapted sub-models are 'air regulation', 'urban green and health effects', 'influence of urban green and water on residential property values' and 'energy savings in homes due to shelter provided by trees'. For these models, the reference values from the TEEB-Stad tool have been applied. The sub-models that were originally developed for the Atlas of

Natural Capital and that are presented here are ‘wood production’, ‘biomass for energy’, ‘carbon sequestration’ and ‘cooling by vegetation and water in urban areas’. To model the ecosystem services, publicly available maps and datasets have been used along with relevant scientific research. The Natural Capital Model provides maps as output that can be used to assess the current and potential future situations of urban natural capital.

The presented eight sub-models embody the core of Natural Capital Model for urban natural capital. Together, these sub-models provide planners with a broad overview of the benefits that natural capital can provide in urban areas. The Natural Capital Model is still in the development phase and this report has described the initial set-up of eight sub-models. These models are ready to implement in spatial planning. Pilot projects are being carried out to apply and test the first version of the Natural Capital Model. These pilot projects will be used to further improve the sub-models and to expand the set of sub-models.

The models will be further developed in collaboration with national partners (including the Netherlands Environmental Assessment Agency (PBL), Wageningen Environmental Research (WEnR) and Statistics Netherlands (CBS)) by integrating state-of-the-art national data and (inter)national scientific knowledge on the different ecosystem services. A collaborative Dutch Natural Capital Model has multiple advantages. The modelling results for different national institutes will have the same basis and therefore will not conflict. Also, collaboration will enhance the speed of model development and integrate a broader knowledge base. The approach will enhance overall support and the credibility of the model output. The set of urban ecosystem service models is expected to be extended in 2018. All presented models will be subject to improvement based on newly available knowledge and data. The Natural Capital Model will gradually become a comprehensive national model that is applicable in a broad range of spatial planning issues and policy contexts.

1 Introduction

Natural capital plays an essential role in our society by making invaluable contributions to, for example, food production, reducing heat stress, carbon sequestration, drinking water production and nature recreation. These contributions are known as ecosystem services (see Box 1 for further explanation of terminology). Natural capital is under increasing pressure in urban areas, as cities continue to expand and become ever more compact. At the same time, natural capital provides multiple benefits to city dwellers, which is gaining increasing attention from urban planners and policy makers. Urban green provides multiple benefits in cities, including public health benefits, recreation opportunities, the reduction of pollutants, the reduction of heat stress and the provision of products, including food and raw materials. Efforts to incorporate the improvement of natural capital and the development of urban green in urban planning are increasing. Location-based information on the benefits of natural capital in urban areas is often missing. To facilitate such efforts, urban natural capital models have been developed as a part of the Netherlands Natural Capital Model. These urban models provide insight into the effects that any changes in urban areas have on the benefits provided by urban natural capital.

The Natural Capital Model is being developed to provide location-based spatial calculations of the benefits of natural capital for the Netherlands. The Natural Capital Model assesses the current provision of ecosystem services and the societal benefits from natural capital at the national level in order to inform policy makers, businesses and citizens. In addition, the model provides opportunities to calculate changes in ecosystem service provision and the societal benefits in future scenarios. By feeding the model with altered input, such as spatial plans, future scenarios can be calculated. Such information is highly relevant for decision makers involved spatial planning, such as local and regional governments, city planners and landscape architects. Currently, information on natural capital and ecosystem services is rarely included in spatial planning in the Netherlands. The development of the Natural Capital Model provides tools with which to explore these possibilities and ensure that decision makers can make more balanced assessments when assessing the sustainability and economic implications of a plan.

In this report, we present the models for urban areas that have been developed as a part of the project ‘Doorontwikkeling TEEB-Stad’. The project is an integral part of the City Deal ‘Waarde van groen en blauw in de stad’, in which a consortium of municipalities, knowledge partners, companies and NGOs work together to express the value of green and water in urban areas. This project aims to further develop the TEEB-Stad tool (www.teebstad.nl), a calculation tool to provide insight into the value of vegetation and water in urban planning projects. To enhance the TEEB-Stad tool, spatially explicit versions of the calculations have been developed to provide more accurate calculations for a specific location. These spatial calculations will form the basis for the spatially explicit version of the TEEB-Stad tool: the Green Benefit Planner. The Green Benefit Planner is a decision-support tool that calculates the effects of spatial planning on natural capital. The urban sub-models of the Natural Capital Model are applied in the first version of the Green Benefit Planner. In addition, the urban models of the Natural Capital Model have been developed to improve ecosystem service maps for the Atlas of Natural Capital, a national atlas that provides maps on ecosystem services and natural capital in the Netherlands. The Atlas of Natural Capital provides maps of the Dutch natural capital based on current scientific knowledge. The Natural Capital Model will be used to systematically map and update the current state of Dutch natural capital and will model the flows that result from this natural capital.

The Natural Capital Model consists of baseline information on natural capital (input data) and separate sub-models for the different ecosystem services and the societal benefits provided by natural capital. Taken together, the sub-models comprise the full model, which provides spatial information on a range of ecosystem services and connected benefits. These models produce maps that are in line with the cascade model for ecosystem services (Figure 1.1, developed by Haines-Young & Potschin, 2010). Biophysical processes, in combination with socio-economic input, are used to model the ecosystem services, which leads to societal benefits. These benefits are then modelled as monetary values of the services. The full model will be capable of spatially modelling both urban and rural ecosystem services, depending on the wishes of the user. The presented ecosystem service models have been developed by VITO (the Flemish institute for technological research) together with the National Institute for Public Health and Environment (RIVM). In this report, the technical documentation of the models for the urban ecosystem services will be presented. Urban ecosystem services focus predominantly on providing a clean and healthy living environment for inhabitants (e.g. reducing heat stress, improving property values and improving the energy efficiency of cities). In addition, urban areas also provide services that are provided by more rural areas as well, such as carbon sequestration and the production of biomass for energy production (for example from urban forests).

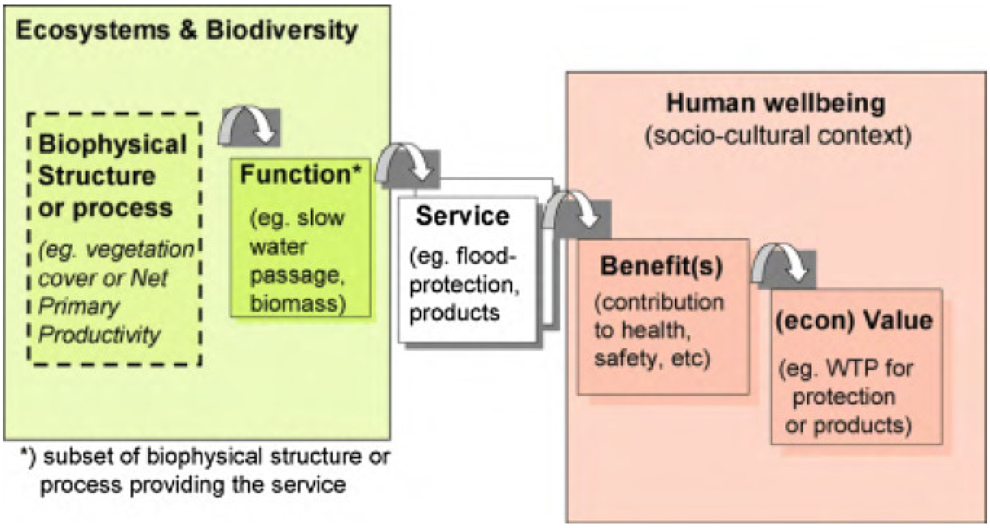

Figure 1.1. The ecosystem service cascade (Haines-Young & Potschin, 2010).

This report describes the first versions of the first eight sub-models and provides a baseline for the urban ecosystem services in the Natural Capital Model. As the Natural Capital Model develops, the sub-models will be improved as new data and knowledge becomes available and additional sub-models may be added. Five of the current sub-models are based on TEEB-Stad calculations and have been adapted in order to function with spatial data. These adapted sub-models are 'air regulation', 'urban green and health effects', 'influence of urban green and water on residential property values' and 'energy savings in homes due to shelter provided by trees'. For these models, the reference values from the TEEB-Stad tool have been applied. Sub-models that were originally developed for the Atlas of Natural Capital and are presented here are 'wood production', 'biomass for energy', 'carbon sequestration' and 'cooling by vegetation and water in urban areas'. To model the ecosystem services, publicly available maps and datasets have been used along with relevant scientific research. The Natural Capital Model provides maps as output. All sub-models were calculated on a 10x10m grid size for the whole of the Netherlands. All monetary values have been corrected to 2016 € values, based on the Consumer Price Index (CPI)[1]. This report presents the technical documentation of each model, but does not present model output or simulations that are done with the model. Output maps and further information on the Natural Capital Model can be found on the Atlas of Natural Capital website: www.atlasnaturalcapital.nl.

Each sub-model provides at least one, but usually multiple output maps, presenting monetary value, relevant actual biophysical flows and, in several cases, potential provision. The maps are produced in various stages in each sub-model. Output maps can be both end-points and mid-points. In the latter case, the output maps are used in further calculations of the sub-model. Each chapter of this report presents a sub-model, describing the steps that have been taken to develop the model, the input data used, the output maps the models produce and the scientific knowledge that has been incorporated. The models are presented in a bottom-up manner, presenting the final map and moving back through the model to describe each step that was necessary to produce this map, and describing the production of the maps preceding the final map. Most model descriptions can be read as stand-alone technical descriptions, with the exception of the 'biomass for energy' model (Chapter 3) and the 'carbon sequestration' model (Chapter 4), which use maps from the 'wood production' model (Chapter 2) as input.

[1] Derived from CBS, 2018. StatLine, annual rate of change CPI; since 1963. Retrieved from:
http://statline.cbs.nl/Statweb/publication/?DM=SLEN&PA=70936eng&D1=0&D2=493,506,519,532,545,558,571,584,597,610,623,636,649,662,675,688,701,l&LA=EN&HDR=T&STB=G1&VW=T

Box 1: Glossary with key terms

This box presents an overview of the key terms that are applied in this report. Terminology is applied as defined by the H2020 ESMERALDA project on mapping and assessing European ecosystem services (Potschin & Burkhard, 2015), unless stated otherwise.

Term	Definition
Actual ecosystem service	The rate at which ecosystem services are supplied to some beneficiary (cf. 'ecosystem service flow' in Potschin & Burkhard, 2015).
Biophysical suitability	A relative score to assess the capacity of an area to provide an ecosystem service based on biophysical environmental variables, such as soil information, groundwater level and climate.
Benefits	Positive change in well-being from the fulfilment of needs and wants (TEEB, 2010).
Ecosystem service	The direct and indirect contributions of ecosystems to human well-being (TEEB, 2010).
Green infrastructure	A strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services (ES). It incorporates green spaces (or blue spaces if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, green infrastructure is present in rural and urban settings.
Monetary valuation	The process whereby people express the importance or preference they have for the service or benefits that ecosystems provide in monetary terms.
Natural capital	The elements of nature that directly or indirectly produce value for people, including ecosystems, species, fresh water, land, minerals, air and oceans, as well as natural processes and functions. The term is often used synonymously with natural asset, but in general implies a specific component.
Potential ecosystem service	The hypothetical maximum yield of selected ecosystem services (cf. 'ecosystem service potential' in Potschin & Burkhard, 2015).
Urban green	All vegetated areas (both public and private) in and directly surrounding areas with medium to high population densities. Urban green includes large vegetated areas such as parks and urban forests, as well as flower beds, street trees and private gardens.

2 Wood production

2.1 Overview

Forest biomass provides a range of ecosystem services, e.g. through the provision of round wood for construction and furniture production. The 'wood production' ecosystem service model calculates round wood production that is used to produce wood products. Although there are fewer productive forests in urban areas than in rural areas, some city trees can also be used in the context of wood production. In addition, the wood production model is a necessary input for two other models: biomass production for energy and carbon sequestration. For this reason, the model has been included in the urban ecosystem service set.

Four output maps (i.e. actual wood production, biophysical suitability for wood production, the monetary value of actual wood production, potential wood production) have been produced for the ecosystem service 'wood production' (see Table 2.1). These maps have been produced to show what the capacity of an area is for wood production (suitability and potential), given environmental characteristics and how much is actually growing in an area (actual production and the incremental monetary value). The biophysical suitability and potential wood production maps are included in the model output to provide insight into which areas can potentially provide higher service flows, which can facilitate spatial planning processes.

The output map has been produced by combining existing spatial data for the Netherlands with maps developed by RIVM for the Natural Capital Model. Tables 2.1 and 2.2 provide an overview of the input and output maps to model the ecosystem service 'wood production'. The original input maps for groundwater levels and soil biophysical units (Alterra, 2006 and Alterra, 2016) contained data gaps for most built-up areas. These maps have been adjusted to cover urban areas as well, using additional datasets from TNO (2015).

Table 2.1. Output maps generated for the ecosystem service 'wood production'.

Output map	Unit	Short description
Biophysical suitability wood production	Score between 0 and 1	Biophysical suitability for wood production based on potential wood production.
Potential wood production	m^3 wood ha^{-1} yr^{-1}	Potential wood production, given soil texture, drainage and current land use.
Actual wood production	m^3 wood ha^{-1} yr^{-1}	Actual wood production in currently forested areas.
Monetary value actual wood production	€ ha^{-1} yr^{-1}	Monetary value of the actual wood production.

Table 2.2. Input maps applied to estimate the ecosystem service 'wood production'.

Input	Unit	Short description	Source
Agricultural crop parcels	Land cover types for crops	Types of crops found on arable fields	RVO 2013
Groundwater level from the soil map*	Groundwater level in cm	Spatial information on groundwater level and soil structure to roughly 1 metre depth	Alterra 2006
Soil biophysical units*	Soil biophysical units	Defines areas with similar soil characteristics and hydrological activity (BOFEK2012)	Alterra 2016
Min & max Groundwater level	Groundwater level in cm	Defines maximum and minimum average groundwater levels	NHI 2016
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017

*The original maps have been supplemented with data from TNO (2015), so that the maps also fully cover urban areas.

2.2 Modelling the ecosystem service

The service 'wood production' results in four output maps. The modelling of these four maps is described in the following sections. Figure 2.2 provides a schematic overview of the way input data has been modelled in order to produce the output maps for the ecosystem service 'wood production.'

2.2.1 Monetary value of actual wood production

The monetary value of the actual wood production is calculated according to (Function 4, Figure 2.2):

$$\boldsymbol{Monetary\ value\ of\ wood\ production = wood\ price\ \times actual\ wood\ production}$$

Given the available information on forest cover in the Netherlands, a distinction is made between three forest types: coniferous, deciduous and mixed forest. The average wood price, based on data provided by Demey et al. (2013) and Liekens et al. (2013), has been estimated as 46.15 €/m^3 for coniferous, 42.63 €/m^3 for deciduous and 44.39 €/m^3 for mixed wood (corrected from 2010 to 2016 € value).

2.2.2 Actual wood production

The actual wood production depends on the annual increment and the fraction of wood that is harvested per year (Function 3, Figure 2.2):

$$\boldsymbol{Actual\ wood\ production = annual\ increment\ \times harvest\ factor}$$

The fraction harvested (*harvest factor)* is based on the 6th National Forest Inventory and is estimated as: 0.373 for deciduous, 0.531 for coniferous and 0.466 for mixed forest (Schelhaas et al., 2014). The annual increment can be estimated, given specific soil texture and soil drainage groups, for different forest types (Table 2.3) according to Vandekerkhove et al. (2014).

Soil texture
Four soil texture groups have been defined, based on the texture codes given in the map with the soil biophysical units (BOFEK2012, see Alterra 2016). These four texture groups have been grouped into two texture types: light soils and heavy soils, used for the definition of the drainage classes. Table 2.4 gives the reclassification of the soil types found in the map with the soil biophysical units (BOFEK2012) into eight main texture classes. Table 2.5 shows the reclassification of these 8 texture classes into 4 texture groups and two texture types.

Soil drainage
Input maps with the average minimum (GLG) and maximum (GHG) groundwater level (NHI, 2006) have been reclassified into nine soil drainage classes, according to Finke et al. (2010) as given in Figure 2.1. As the groundwater level maps do not cover the Wadden islands in the north of the Netherlands, the groundwater level from the soil map has been reclassified into the same nine hydrological classes according to a reclassification table based on expert judgement (available on request). In both cases, a distinction has been made between two texture types: light soils and heavy soils as defined in Table 2.5. The nine drainage classes have been regrouped into four drainage groups according to Table 2.6 in order to estimate the annual increment.

Table 2.3. Wood increment (m^3/ha/yr) per soil texture and drainage class combination for three forest types.

Soil texture/drainage	***Texture***	***Drainage***			
		very dry	**dry**	**moist-wet**	**wet**
Mixed forest	class/class	1	2	3	4
peat & sandy soils	1	4	6	6	5
loamy sand soils	2	5	8	8	6
(sandy) loam soils	3	3	11	10	7
(heavy) clay soils	4	3	9	10	6
Coniferous forest	class/class	very dry	dry	moist-wet	wet
peat & sandy soils	1	7	9	7	2
loamy sand soils	2	8	10	8	2
(sandy) loam soils	3	4	10	7	2
(heavy) clay soils	4	4	8	6	0
Deciduous forest	class/class	very dry	dry	moist-wet	wet
peat & sandy soils	1	4	6	6	5
loamy sand soils	2	5	8	8	6
(sandy) loam soils	3	3	11	10	7
(heavy) clay soils	4	3	9	10	6

Table 2.4. Reclassification of the soil classes from the BOFEK map (soil physical properties) into soil texture classes.

BOFEK Code	Texture	BOFEK Code	Texture	BOFEK Code	Texture	BOFEK Code	Texture
101	V	303	S	321	S	412	E
102	V	304	Z	322	Z	413	E
103	V	305	Z	323	Z	414	E
104	V	306	Z	324	Z	415	U
105	V	307	S	325	S	416	L
106	V	308	S	326	Z	417	L
107	V	309	Z	327	Z	418	E
108	V	310	Z	401	E	419	E
109	V	311	Z	402	E	420	E
110	V	312	S	403	E	421	E
201	U	313	S	404	U	422	U
202	E	314	S	405	U	501	E
203	V	315	S	406	L	502	L
204	V	316	S	407	E	503	U
205	Z	317	S	408	L	504	L
206	Z	318	S	409	L	505	L
301	Z	319	S	410	E	506	L
302	Z	320	Z	411	E	507	A

Table 2.5. Classification of soil texture classes into four texture groups and two texture types.

Texture class	Code	Texture group	Code	Texture type	Code
A: loam soils	1	(sandy) loam soils	3	Heavy	2
E: clay	2	(heavy) clay soils	4	Heavy	2
L: sandy loam soils	3	(sandy) loam soils	3	Heavy	2
P: light sandy loam soils	4	loamy sand soils	2	Light	1
S: loamy sand soils	5	loamy sand soils	2	Light	1
U: heavy clay soils	6	(heavy) clay soils	4	Heavy	2
V: peat	7	peat & sandy soils	1	Heavy	2
Z: sandy	8	peat & sandy soils	1	Light	1

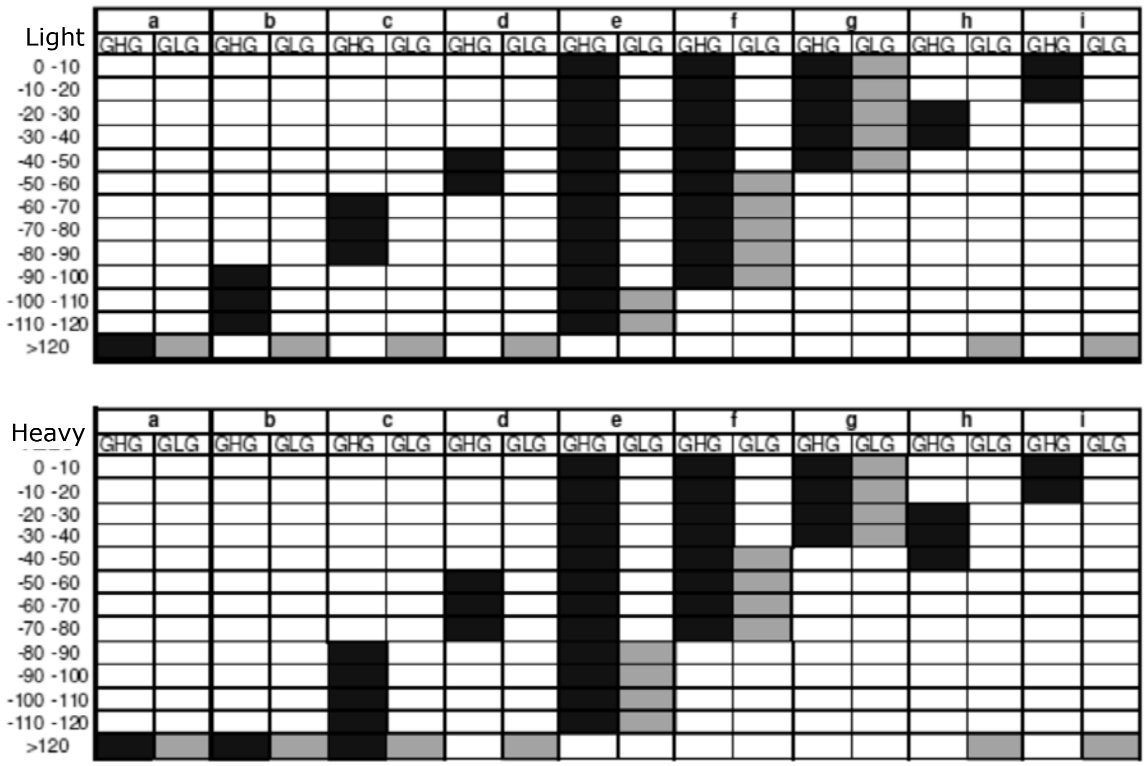

Figure 2.1. Definition of the average minimum (GLG, grey boxes) and maximum (GHG, black boxes) groundwater levels for the nine drainage classes for light (sandy & loamy soils) and heavy (clay & peaty) soils according to Finke et. al. (2010).

Table 2.6 Information from 'Drainage group' knowledge table necessary for reclassification (Function 1, Figure 2.2).

Drainage class	Description	Drainage group	Code
A	excessively drained soils (very dry)	Very dry	1
B	well-drained soils (dry)	Dry	2
C	moderately well-drained soils (medium dry)	Dry	2
D	insufficiently drained soils (moderately wet)	Moist-wet	3
E	rather poorly drained soils with groundwater permanently (wet)	Moist-wet	3
F	poorly drained soils with groundwater permanently (very wet)	Wet	4
G	extremely poorly drained soils (very wet)	Wet	4
H	poorly drained soils with backwater (temporary groundwater) (very wet)	Moist-wet	3
I	rather poorly drained soils with backwater (temporary groundwater) (wet)	Wet	4

Table 2.7. Applied maximum growth rates (m^3/ ha. year) for the agricultural and non-agricultural soils for various drainage and texture classes according to Vandekerkhove et al., (2014).

Non-agricultural soils				
Texture / Drainage	Very dry	dry	moist-wet	wet
peat & sandy soils	12	16	9	6
loamy sand soils	12	16	12	11
(sandy) loam soils	10	16	18	9
(heavy) clay soils	10	15	20	7
Agricultural soils				
Texture / Drainage	Very dry	dry	moist-wet	wet
peat & sandy soils	15	20	12	9
loamy sand soils	15	20	15	14
(sandy) loam soils	11	18	20	12
(heavy) clay soils	11	17	22	9

2.2.3 *Potential wood production*

The simulation of the potential wood production [m^3/ha. year] is based on Vandekerkhove et al. (2014). According to this study, the potential wood production differs between agricultural soils that have been fertilized and non-agricultural soils as shown in Table 2.7. For each texture group and drainage group, the most productive tree species has been selected to calculate potential wood production. The locations of the agricultural areas are based on the input map with the agricultural crop parcels. Given the crop-type, the parcels are reclassified as agricultural; the rest of the area is defined as non-agricultural.

2.2.4 *Biophysical suitability for wood production*

The map with the potential wood production is normalized to generate the map with the biophysical suitability for wood production as follows (Function 2, Figure 2.2):

$$\begin{aligned}&\boldsymbol{Biophysical\ suitability\ for\ wood\ production}\\ &\qquad = \boldsymbol{potential\ wood\ production}\\ &\qquad / \boldsymbol{maximum\ of\ the\ map\ with\ the\ potential\ wood\ production}\end{aligned}$$

2.3 Remarks and points for improvement

- The new data on vegetation (Appendix I, coverage of each grid cell with trees and tree height) could be combined with information on forest type from the LCEU map and incorporated into the model.
- The National Forest Inventory (Nederlandse Bosinventarisatie, NBI) could be used to improve the input maps. The 6th National Forest Inventory (Schelhaas et al., 2014) was finished in 2014, providing statistical data for approximately 3,000 sites. More comprehensive was the 4th NBI (then named Bosstatistiek), but the dataset is older (1980s). The 6th NBI can be found by clicking on the following link: http://www.probos.nl/publicaties/overige/1094-mfv-2006-nbi-2012. CBS and Wageningen University & Research have

developed a wood production model based on the 6th NBI data that should be compared (and possibly integrated) with this model.
- The national model STONE (Wolf et al. 2003) can be used to incorporate fertilization data (N and P). This is preferable to the current reclassification made using the LCEU dataset.
- Currently, Belgian data on wood prices is used. Wageningen Economic Research also provides similar data that could be used in future versions of the model. See: http://agrimatie.nl/Binternet_Bosbouw.aspx?ID=1005&Lang=0&sectorID=3303

2.4 References

- Alterra 2006. Bodemkaart van Nederland 1:50000. Available at http://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/1032583a-1d76-4cf8-a301-3670078185ac?tab=contact
- Alterra 2016. Bodemfysische Eenhedenkaart (BOFEK 2012). Available at https://www.wur.nl/nl/show/Bodemfysische-Eenhedenkaart-BOFEK2012.htm
- CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- Demey, A., Baeten, L., and Verheyen, K., 2013. Opbouw methodiek prijsbepaling hout. ANB. Brussels, Belgium.
- Finke, P.A., Van de Wauw, J. and Baert, G., 2010. Ontwikkelen en uittesten van een methodiek voor het actualiseren van de drainageklasse van de bodemkaart van Vlaanderen. Universiteit Gent, vakgroep Geologie en Bodemkunde.
- Liekens, I., Van der Biest, K., Staes, J., De Nocker, L., Aertsens, J., & Broekx, S., 2013. Waardering van ecosysteemdiensten, een handleiding. VITO. Mol.
- NHI, 2006. GxG kaarten, Gemiddelde Grondwaterstanden van modelversie LHM 3.0.2 voor 1998-2006. Available at http://www.nhi.nu/nl/index.php/data/
- RVO 2013. Basisregistratie Gewaspercelen (BRP), 2013. Available at http://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/%7B25943e6e-bb27-4b7a-b240-150ffeaa582e%7D
- Schelhaas, M.J., Clerkx, A.P.P.M., Daamen, W.P., Oldenburger, J.F., Velema, G., Schnitger, P., Schoonderwoerd, H. & Kramer, H., 2014. Zesde Nederlandse Bosinventarisatie. Methoden en basisresultaten. Wageningen, Alterra Wageningen UR, Alterra-rapport 2545.
- TNO, 2015. Oppervlaktegeologie, geologische kaart onder INSPIRE. Available at http://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/80630ee7-3a15-4ea0-bdc0-a8aebfa2f204?tab=relations
- Van de Walle I., van Camp N., Perrin D., Lemeur R., Verheyen K., van Wesemael B., Laitat E., 2005. Growing stock-based assessment of the carbon stock in the Belgian forest biomass. Annals of Forest Science 62: 1-12.

- Vandekerkhove, K., De Keersmaeker, L., Demolder, H., Esprit, M., Thomaes, A., Van Daele, T., & Van der Aa, B., 2014. Hoofdstuk 13 - Ecosysteemdienst houtproductie. In M. Stevens (Ed.), Natuurrapport - Toestand en trend van ecosystemen en ecosysteemdiensten in Vlaanderen. Brussels: Instituut voor Natuur-en Bosonderzoek.
- Wolf, J., Beusen, A.H.W., Groenendijk, P., Kroon, T., Rötter, R., van Zeijts, H., 2003. The integrated modeling system STONE for calculating nutrient emissions from agriculture in the Netherlands. Environmental Modelling & Software 18:7, 597-617.

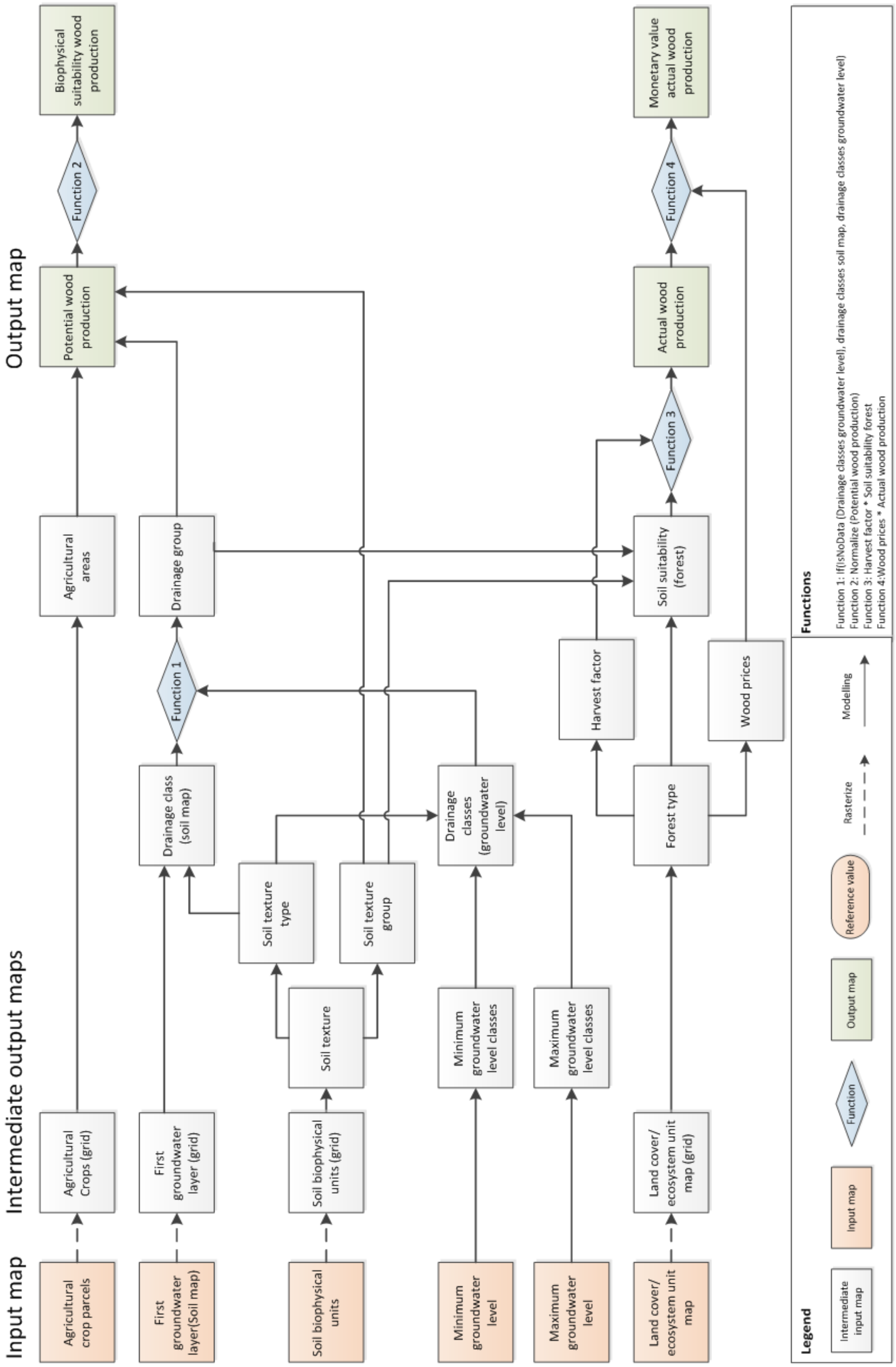

Figure 2.2 Schematic overview of 'wood production' model.

3 Biomass for energy

3.1 Overview

Biomass is the general name given to organic material from plants and animals. Nature produces biomass in the form of wood and plants, for example. The agricultural industry also produces biomass in forms such as animal feed, crop residues, straw and manure. Biomass may be in an unprocessed form (e.g. tree trunks) or a processed form (furniture or paper). Biomass can be used for a variety of purposes, including agricultural fertilization, manufacturing and energy generation. This model focusses on the use of biomass for energy production purposes. The energy extracted from biomass is known as bio-energy and it may be used as electricity, heat or gas. Biomass-based energy is obtained by the combustion, gasification or fermentation of the biomass. Biomass that people eat is not referred to within the ecosystem service classification system as biomass, but rather as food, and is not included in this sub-model.

At the current stage, five output maps (i.e. actual production from crops, actual production from forests, potential energy production from crops, potential energy production from cultivated grassland, potential energy production from forests) have been produced for the Atlas of Natural Capital for the ecosystem service 'biomass for energy'. Tables 3.1 and 3.2 provide an overview of the input and output maps to model the ecosystem service 'biomass for energy production'. These maps have been produced to show what the capacity of an area is for energy production from biomass (potential maps) given the environmental characteristics and how much is actually being produced in an area (actual production). The potential biomass production maps are included in the model output to provide insight into which areas can potentially provide higher service flows, which can facilitate spatial planning processes.

Table 3.1. Output maps generated for the ecosystem service 'biomass for energy'.

Output map	Unit
Potential energy production from crops	GJ/Ha·yr
Potential energy production from cultivated grassland	GJ/Ha·yr
Potential energy production from forests	GJ/Ha·yr
Actual energy production from crops	GJ/Ha·yr
Actual energy production from forests	GJ/Ha·yr

Table 3.2. Input maps applied to estimate the ecosystem service 'biomass for energy'.

Input	Unit	Short description	Source
Agricultural crop parcels	Land cover types for crops	Crops produced on agricultural fields	RVO 2013
Biophysical suitability crops	Score between 0 and 1	Biophysical suitability for crop production based on soil characteristics and groundwater level.	Natural Capital Model (Remme 2017)
Biophysical suitability grassland	Score between 0 and 1	Biophysical suitability values for grass production based on soil characteristics and groundwater level.	Natural Capital Model (Remme 2017)
Potential wood production	m^3 wood ha^{-1} yr^{-1}	Potential wood production	Natural Capital Model (see Section 2.2.3)
Actual wood production	m^3 wood ha^{-1} yr^{-1}	Actual wood production	NKN (see Section 2.2.2)
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017

3.2 Modelling the ecosystem service

The service biomass for energy production results in five output maps. The modelling of these maps is based on the NARA study conducted by Van Kerckvoorde & Van Reeth (2014) and is the described in the following sections. Figure 3.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps for this ecosystem service.

3.2.1 Potential energy production from crops and cultivated grassland

The potential energy production from crops and permanent cultivated grassland is estimated according to (Function 1 and Function 2, Figure 3.1):

$$\boldsymbol{Potential\ energy\ production = Biophysical\ suitability \times energy\ content}$$

The biophysical suitability maps for crops and permanent grassland form an output from the ecosystem service 'food production' (see Remme, 2017 for technical description). The biophysical suitability maps show the suitability of areas for crop production based on soil characteristics and groundwater level, regardless of the current land use. The energy content for permanent grassland is 111.2 GJ/ha according to the Phyllis database (www.ecn.nl/phyllis). For crops, the energy content is assumed to be 157.8 GJ/ha based on the average energy content of crops as shown is Table 3.3 (Van Kerckvoorde & Van Reeth 2014).

Table 3.3. Energy content of crops based on Van Kerckvoorde & Van Reeth (2014).

Crop type	Energy content GJ/ha
potatoes	207.5
rapeseed	95.4
maize (grains)	235.4
linseed	66.3
oil seeds (sunflower)	66.3
other cereals	130.9
maize (silo)	206.3
sugar beets	254.0

3.2.2 *Actual energy production from crops and cultivated grassland*

The actual energy production from crops and cultivated grassland is based on the maps for the potential energy production from crops and grassland and the parcels where these crops are currently being grown for energy production. The map filters out all other parcels that are currently not being used for energy crops. Given the map with agricultural crop parcels, the following crops have been selected as energy crops: miscanthus (elephant grass), linseed, rapeseed, maize for energy and fast-growing trees with short turnover time (e.g. willow coppice). Some crops, such as potatoes and sugar beets, have residual flows that are used for energy production. These are not included in this estimate.

3.2.3 *Potential energy production from forests*

The potential energy production from forests estimates the total annual energy increment of the aboveground biomass, except for the stem wood (stem wood and branches with a diameter > 7 cm). This estimate is based on the potential wood production in which the annual increase in stem wood is estimated for the optimal tree type given the local soil and drainage class. To estimate the potential energy production from forests, the following equation is used (Function 3, Figure 3.1):

$$\begin{aligned}\boldsymbol{Potential\ energy\ production} \\ = \boldsymbol{Potential\ wood\ production} \times \boldsymbol{Wood\ energy\ content} \\ \times \boldsymbol{Wood\ density} \times \boldsymbol{R2S}\end{aligned}$$

Where:

- *Potential wood production* is the potential wood production in m3/ha.year as explained in Section 2.2.3
- *Wood energy content* is the wood energy content of 18 GJ/m³ (Van Kerckvoorde & Van Reeth 2014);
- *Wood density* is the applied average density of wood of 0.5 ton/m^3 (actually it should be 0.47 for coniferous, 0.57 for

deciduous and 0.52 for mixed stem wood according to Van Kerckvoorde & Van Reeth (2014));

- *R2S* is the rest to stem wood ratio, defined as the number of small branches with a diameter < 7 cm and leaves relative to the amount of stem wood. R2S can be estimated using the biomass expansion factor (BEF) as:
  (total wood – stem wood) / stem wood =
  (BEF * stem wood – stem wood) / stem wood= (BEF – 1)
  Given the average above-ground biomass expansion factor of 1.315 (Table 3.4 and Van de Walle et al., 2005), the R2S ratio becomes 0.315.

Table 3.4 Characteristics of coniferous, deciduous and mixed forests, based on characteristics of Dutch tree types.

Forest type	Cover (%)*	Biomass expansion factor (BEF)**	BEF above ground **
Pine	33.6	1.50	1.32
Douglas fir	5.1	1.71	1.28
Larch	4.9	1.75	1.30
Spruce	3.4	1.75	1.29
Other coniferous	0.9	1.75	1.33
Coniferous forest	47.9	1.57	1.31
Beech	4.1	1.67	1.34
Oak	19.5	1.50	1.32
Poplar	3.3	1.50	
Mixed noble	4.5	1.50	1.29
other deciduous	13.3	1.50	1.32
Deciduous forest	44.7	1.52	1.32
Mixed forest	-	-	-

*Schelhaas & Clerkx 2015
**Van de Walle et al. 2005

3.2.4 *Actual energy production from forests*

The actual energy production from forests is estimated in the same way as the potential energy production from forests using the map with actual wood production in m^3/ha.year from Section 2.2.2, with a correction for the yield loss.
To estimate the actual energy production from forests, the following equation is used (Function 5, Figure 3.1):

$$\begin{aligned}\boldsymbol{Actual\ energy\ production} \\ &= \boldsymbol{Actual\ wood\ production}\ \times \boldsymbol{wood\ energy\ content} \\ &\times \boldsymbol{wood\ density}\ \times \boldsymbol{R2S\ ratio}\ \times (\boldsymbol{1} - \boldsymbol{yield\ loss})\end{aligned}$$

Where:

- *Actual wood production* is the actual wood production in m^3/ha.year as explained in Section 2.2.2.
- *Wood energy content* is the wood energy content of 18 GJ/m^3 (Van Kerckvoorde & Van Reeth 2014)
- *Wood density* is the applied average density of wood of 0.5 ton/m^3 (actually it should be 0.47 for coniferous, 0.57 for deciduous and 0.52 for mixed stem wood according to Van Kerckvoorde & Van Reeth (2014))
- *R2S* is the rest to stem wood ratio, defined as the number of small branches with a diameter < 7 cm and leaves relative to the amount of stem wood. R2S can be estimated using the biomass expansion factor (BEF) as:

  (total wood – stem wood) / stem wood =

  (BEF * stem wood – stem wood) / stem wood= (BEF – 1)
- Given the average above-ground biomass expansion factor of 1.315 (Table 3.4 and Van de Walle et al., 2005) the R2S ratio becomes 0.315.
- *R2Yield loss* is a correction factor on the actual energy production for the small branches and leaves that cannot be harvested. A yield loss of 30% is applied.

3.3 References

- CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- Remme, R., 2017. Netherlands Natural Capital Model – Technical Documentation. Food Production. Atlas of Natural Capital (www.atlasnatuurlijkkapitaal.nl/en).RVO 2013.
- Basisregistratie Gewaspercelen (BRP), 2013. Available at http://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/%7B25943e6e-bb27-4b7a-b240-150ffeaa582e%7D
- Schelhaas & Clerkx, 2015. Het Nederlandse bos in cijfers: resultaten van de 6e Nederlandse Bosinventarisatie. Vakblad Natuur Bos Landschap 12, 23-27.
- Van de Walle I., van Camp N., Perrin D., Lemeur R., Verheyen K., van Wesemael B., Laitat E., 2005. Growing stock-based assessment of the carbon stock in the Belgian forest biomass. Annals of Forest Science 62: 1-12.
- Van Kerckvoorde A., & Van Reeth W., 2014. Hoofdstuk 14 - Ecosysteemdienst productie van energiegewassen. In M. Stevens (Ed.), Natuurrapport - Toestand en trend van ecosystemen en ecosysteemdiensten in Vlaanderen. Brussel: Instituut voor Natuur-en Bosonderzoek.

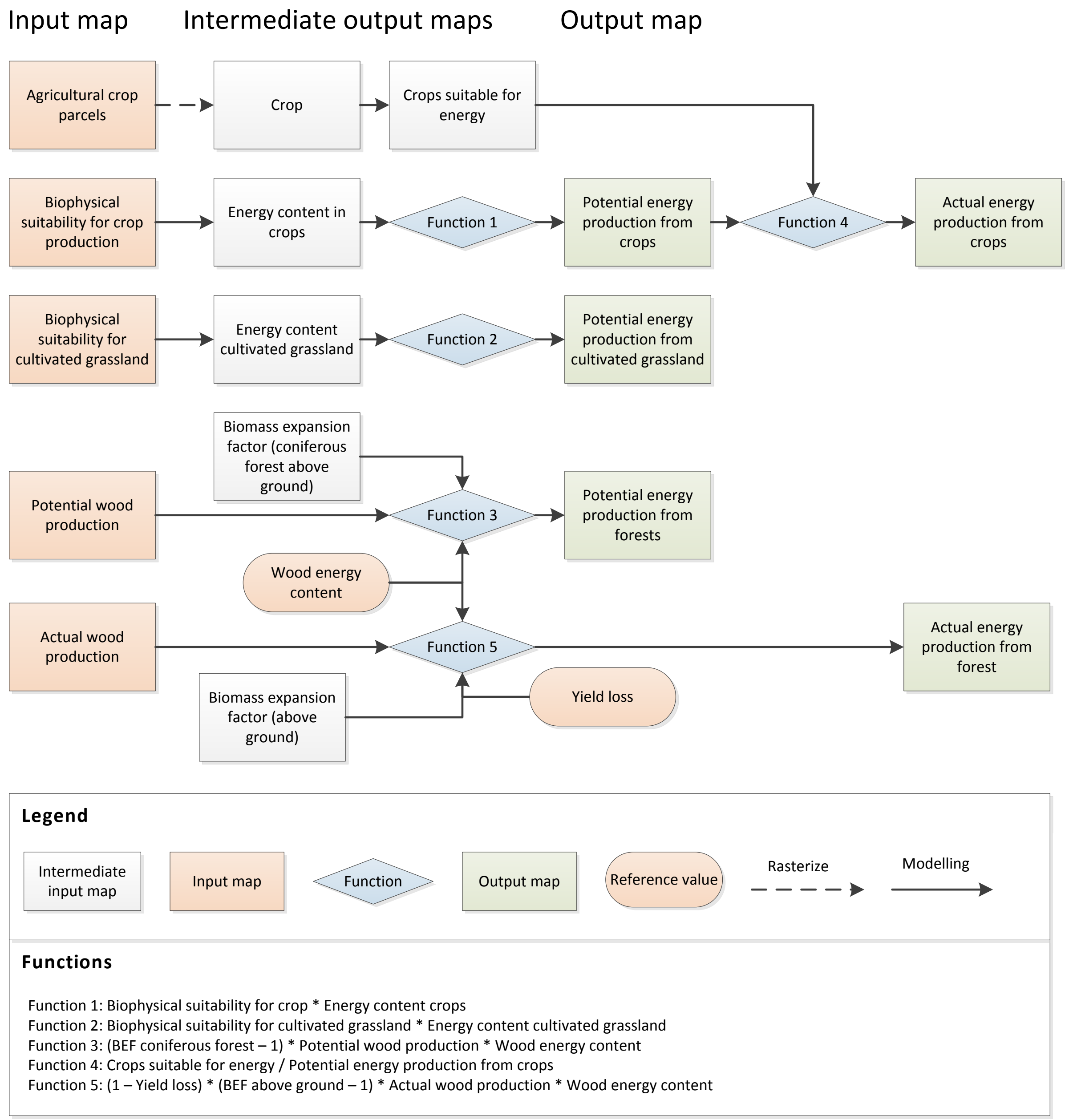

Figure 3.2 Schematic overview of 'biomass for energy' model

4 Carbon sequestration

4.1 Overview

Vegetation provides an important climate regulating service by sequestering carbon from the atmosphere and converting it into biomass. Carbon sequestration in biomass decreases the amount of carbon in the atmosphere and therefore helps to mitigate further climate change. The models indicate the potential and actual carbon sequestration in biomass and the avoided monetary damage costs based on carbon sequestration in forests.
Three output maps for the ecosystem service 'carbon sequestration' have been developed for the Atlas of Natural Capital (see Table 4.1). The output map has been produced by combining existing spatial data for the Netherlands with maps developed by RIVM for the Natural Capital Model. Tables 4.1 and 4.2 provide an overview of the input and output maps for the ecosystem service model 'carbon sequestration'.

Table 4.1. Output maps generated for the ecosystem service 'carbon sequestration'.

Output map	Unit	Short description
Potential carbon sequestration in biomass	Ton C ha^{-1} yr^{-1}	The amount of carbon that can potentially be sequestered in biomass.
Actual carbon sequestration in biomass	Ton C ha^{-1} yr^{-1}	The current level of carbon sequestered in woody biomass.
Monetary value carbon sequestration in biomass	€ ha^{-1} yr^{-1}	The monetary value of the current level of carbon sequestered in woody biomass.

Table 4.2. Input maps applied to estimate the ecosystem service 'carbon sequestration'.

Input	Unit	Short description	Source
Biophysical suitability for wood production	Score between 0 and 1	Indicates the biophysical suitability for wood production based on soil characteristics and groundwater table.	Natural Capital Model (see Section 2.2.4)
Potential wood production	m^3 wood ha^{-1} yr^{-1}	Potential wood production	Natural Capital Model (see Section 2.2.3)
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017

4.2 Modelling the ecosystem service

The ecosystem service 'carbon sequestration' results in three output maps. The modelling of these three maps is described in the following sections. Figure 4.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps for the ecosystem service 'carbon sequestration'.

4.2.1 Monetary value carbon sequestration in biomass

Carbon sequestration reduces the amount of CO_2 in the atmosphere that could further enhance climate change. The reduction of CO_2 therefore leads to avoided damages. These avoided damages can be monetized, as has been done by Aertsen et al. (2012) in a Flemish study. Aertsen et al. (2012) valued avoided damage costs at €20/ton CO_2 [in 2010 €], which is equivalent to €73.20/ton C (molecular conversion rate of 3.66). This equals €80.98/ton C when converted to 2016 € value. This value is used in this model, but it should be noted that avoided damage costs for carbon vary widely in literature (see, for example, Anthoff & Tol, 2013 and Nordhaus, 2017). The amount of carbon sequestered in a certain forest area is multiplied by the avoided damage costs per ton C to obtain the monetary value for that area, as follows (see also Function 3 in Figure 4.1):

$$\boldsymbol{Monetary\ value\ of\ carbon\ sequestration} \\ = \boldsymbol{80.98} \times \boldsymbol{Actual\ carbon\ sequestration}$$

This calculation results in the map 'Monetary value carbon sequestration in biomass'.

4.2.2 Actual carbon sequestration in biomass

The actual carbon sequestration in biomass is the amount of carbon that is actually sequestered by forests on an annual basis. For this calculation only, forested areas (as delineated by the LCEU map) are used; all other areas are excluded from the calculation. Three LCEU forest types are used for the model: coniferous forests, deciduous forests and mixed forests. To determine the actual carbon sequestration in forests, information is needed on the annual increment of biomass in the forest in a certain location, the carbon density of the forest and the ratio of the total biomass of a tree type (including branches, roots, etc.) compared with the stem. The annual carbon sequestration is calculated as follows (see also Function 2 in Figure 4.1):

$$\boldsymbol{Actual\ carbon\ sequestration} = \boldsymbol{BEF} \times \boldsymbol{C_{density}} \times \boldsymbol{Potential\ wood\ production}$$

Where

- *BEF* is the biomass expansion factor of a forest type. The BEF describes the expansion of the total biomass of a tree (including branches and roots) in relation to the annual increment of the stem biomass.
- $C_{density}$ is the carbon density factor of a forest (ton C/m^3).
- *Potential wood production* is an output map of the wood production model (see Section 2.2.3 for the model description). This map shows the potential wood production that can be acquired in a certain area.

The potential wood production calculation is used as the model and carries the assumption that carbon is maintained in both standing stock, as well as harvested wood. This assumption can be debated, as not all harvested wood may be left intact in the long term. To obtain the BEF and carbon density of the different forest types, data on the characteristics of different tree species was used based on the 6th Dutch Forest Inventory (Schelhaas & Clerkx 2015) and Van de Walle et al. 2005), see Table 4.3 for details. Mixed forests are calculated based on a 50/50 ratio between coniferous and deciduous forests.

Table 4.3. Characteristics of coniferous, deciduous and mixed forests, based on the characteristics of Dutch tree types.

Forest type	Cover (%)*	Biomass expansion factor (BEF)**	BEF above ground **	Wood density (t dry matter/ m^3) **	Carbon content (t C/t dry matter) **	Carbon density (ton C/m^3)
Pine	33.6	1.50	1.32	0.48	0.50	
Douglas fir	5.1	1.71	1.28	0.45	0.50	
Larch	4.9	1.75	1.30	0.47	0.50	
Spruce	3.4	1.75	1.29	0.38	0.50	
Other coniferous	0.9	1.75	1.33	0.40	0.50	
Coniferous forest	47.9	1.57	1.31	0.47	0.50	0.28
Beech	4.1	1.67	1.34	0.56	0.49	
Oak	19.5	1.50	1.32	0.60	0.50	
Poplar	3.3	1.50		0.41	0.50	
Mixed noble	4.5	1.50	1.29	0.59	0.50	
other deciduous	13.3	1.50	1.32	0.55	0.50	
Deciduous forest	44.7	1.52	1.32	0.57	0.50	0.23
Mixed forest	-	-	-	-	-	0.26

*Schelhaas & Clerkx 2015
**Van de Walle et al. 2005

4.2.3 *Potential carbon sequestration in biomass*

Parallel to the actual carbon sequestration, the potential carbon sequestration is also modelled. This calculation eliminates the restriction to calculate only areas that are currently forest and calculates the maximum possible carbon sequestration in the whole of the Netherlands if the most suitable type of forest were to grow in a given location. The calculation uses information from Table 4.3 and is as follows (see also Function 1 in Figure 4.1):

$$\mathbf{Potential\ carbon\ sequestration} = \mathbf{BEF} \times \mathbf{C_{density}} \times \mathbf{Suitability\ for\ wood\ production}$$

Where

- *BEF* is the biomass expansion factor of a forest type. The BEF describes the expansion of the total biomass of a tree (including branches and roots) in relation to the annual increment of the stem biomass.
- $C_{density}$ is the carbon density factor of a forest (ton C/m^3).
- *Suitability for wood production* is an output map of the wood production model (see Section 2.2.4 for the model description). This map shows the potential wood production that can be acquired in a certain area.

4.3 Remarks and potential model improvements

- The monetary value of avoided damage costs related to carbon sequestration vary widely in (academic) literature and a more thorough assessment should be done to check whether the current value is the most appropriate.
- RIVM has developed a method to map carbon sequestration based on satellite imagery, which is most suitable to assess past and present carbon sequestration. To predict carbon sequestration based on future changes, the current model is more suitable.

4.4 References

- Aertsens J., De Nocker L., Lauwers H., Norga K., Simoens I., Meiresonne L., Turkelboom F., Broekx S., 2012. Daarom groen! Waarom u wint bij groen in uw stad of gemeente. Studie uitgevoerd in opdracht van: ANB – Afdeling Natuur en Bos.
- Anthoff, D. & Tol, R.S.J., 2013. The uncertainty about the social cost of carbon: a decomposition analysis using fund. Climatic Change 117:3, 515-530.
- CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- Nordhaus, W.D., 2017. Revisiting the social cost of carbon. PNAS 114:7, 1518-1523.
- Schelhaas & Clerkx, 2015. Het Nederlandse bos in cijfers: resultaten van de 6e Nederlandse Bosinventarisatie. Vakblad Natuur Bos Landschap 12, 23-27.

Van de Walle I., van Camp N., Perrin D., Lemeur R., Verheyen K., van Wesemael B., Laitat E., 2005. Growing stock-based assessment of the carbon stock in the Belgian forest biomass. Annals of Forest Science 62: 1-12.

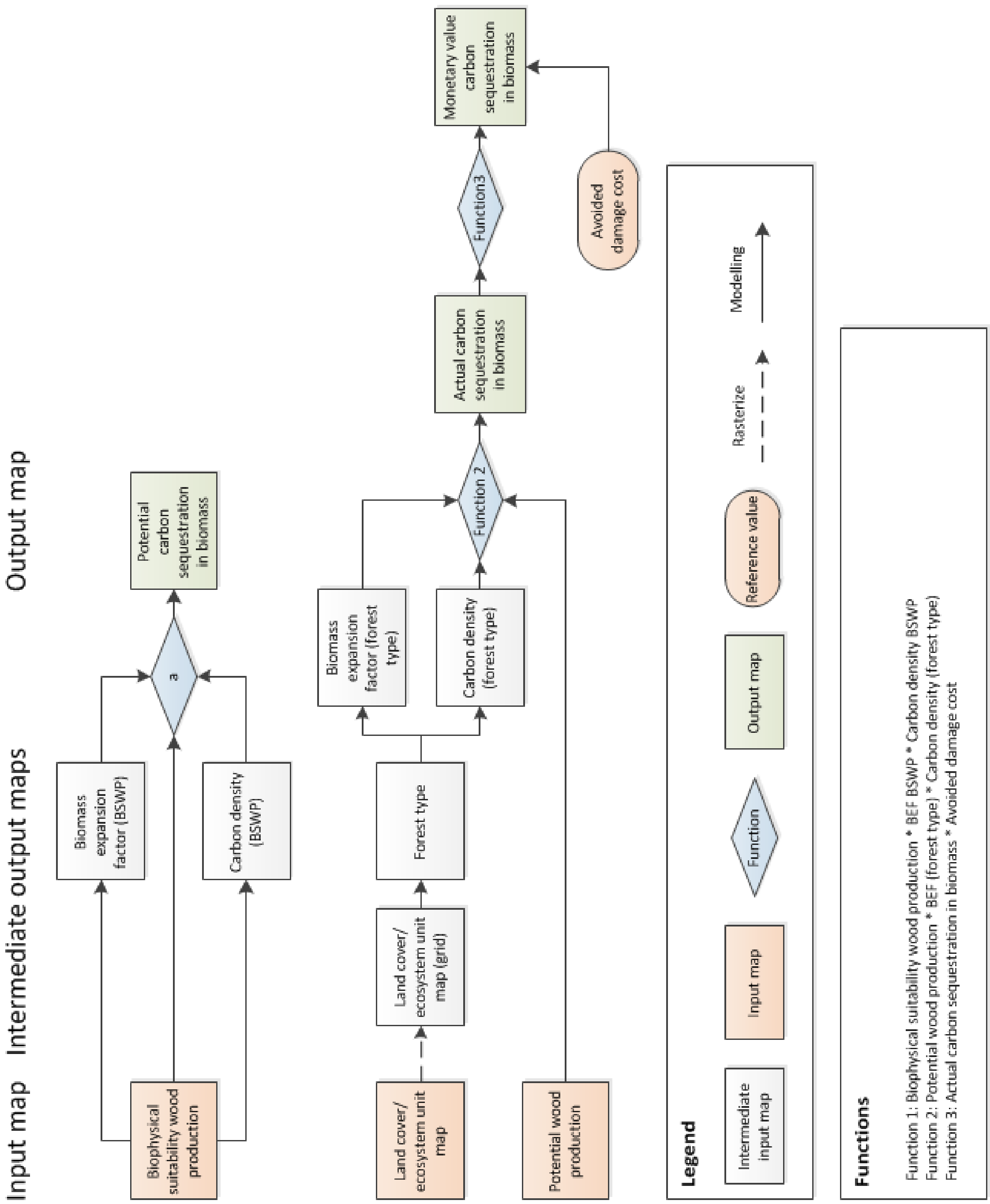

Figure 4.1 Schematic overview of the 'carbon sequestration' model.

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:

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

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.

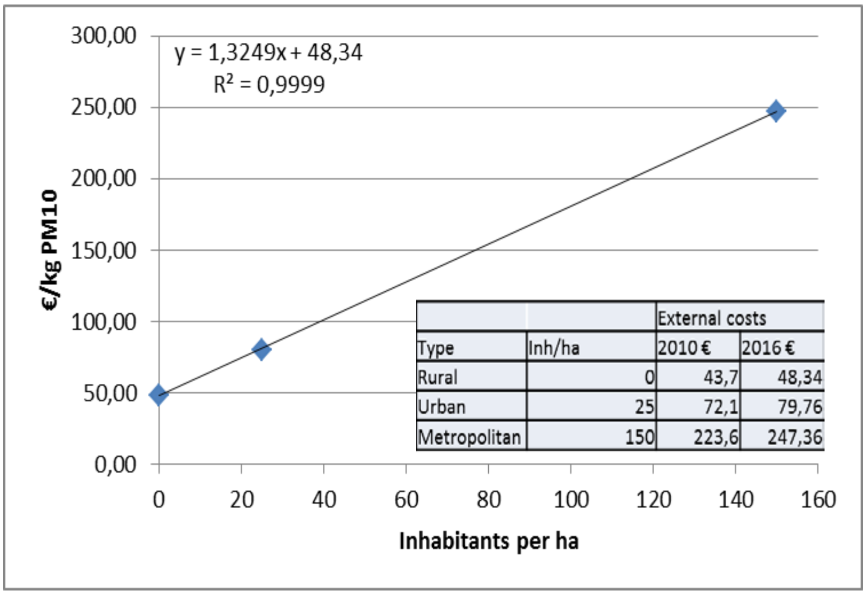

Figure 5.1. Linear relation between the inhabitant densities and external cost of PM_{10}. The blue points are estimates for average rural, urban and metropolitan population densities for the Netherlands (per ha).

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:

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

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

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

- Abhijith, K.V., Kumar, P., Gallagher, J., McNabola, A., Baldauf, R., Pilla, R., Broderick, B., Di Sabatino, S., Pulvirenti, B., 2017. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments - A review. Atmospheric Environment 162, 71-86.
- Baldauf, R., 2017. Roadside vegetation design characteristics that can improve local, near-road air quality. Transportation Research Part D 52, 354–361.
- Beckett, K.P., Freer-Smith, P.H., Taylor, G., 1998. Urban woodlands: their role in reducing the effects of particulate pollution. Environmental Pollution 99:3, 347-360.
- Brunekleef, B. & Holgate, S.T., 2002. Air pollution and health. Lancet, 360:9341, 1233-1242.
- CBS, 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- CE-Delft, 2017. Handboek Milieuprijzen 2017. Methodische onderbouwing van kengetallen gebruikt voor waardering van emissies en milieu-impact. Publicatienummer: 17.7A76.64, Delft.
- CE-Delft, 2014. Externe en infrastructuurkosten van verkeer. Een overzicht voor Nederland in 2010. Publicatie 14.4485.35, Delft.
- Chen, L., Liu, C., Zou, R., Yang, M., Zhang, Z., 2016. Experimental examination of effectiveness of vegetation as bio-filter of particulate matters in the urban environment. Environmental Pollution, 208, 198-208.
- De Nocker, L. & Viaene P., 2016. Methode ecosysteemdienst fijn stof afvang, ECOPLAN. VITO.
- HEATCO, 2006. Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO). Deliverable D5: Proposal for Harmonised Guidelines, Stuttgart: IER, University of Stuttgart.
- Janhall, S., 2015. Review on urban vegetation and particle air pollution – Deposition and dispersion. Atmospheric Environment 105, p130-137.
- Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Jorak Jr, F., Puybonnieux-Texier, V., Quénel, P., Schneider, J., Seethaler, R., Vergnaud, J-C., Sommer, H., 2000. Public-health impact of outdoor and traffic-related air pollution: a European assessment. The Lancet, 356, 9232, p795-801.
- Pope III, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. Journal of the American Medical Association 287:9, 1132-1141.
- Powe, N.A., Willis, K.G., 2004. Mortality and morbidity benefits of air pollution (SO_2 and PM_{10}) absorption attributable to woodland in Britain. Journal of Environmental Management 70:2, 119-128.

- RIVM, 2017. Grootschalige concentratie- en depositiekaarten Nederland. Rapportage 2016. RIVM Rapport 2016-0068. RIVM, Bilthoven, the Netherlands.
- Tiwary, A., Reff. A., Colls, J.J., 2008. Collection of ambient particulate matter by porous vegetation barriers: sampling and characterization methods. Journal of Aerosol Science 39, 40-47.

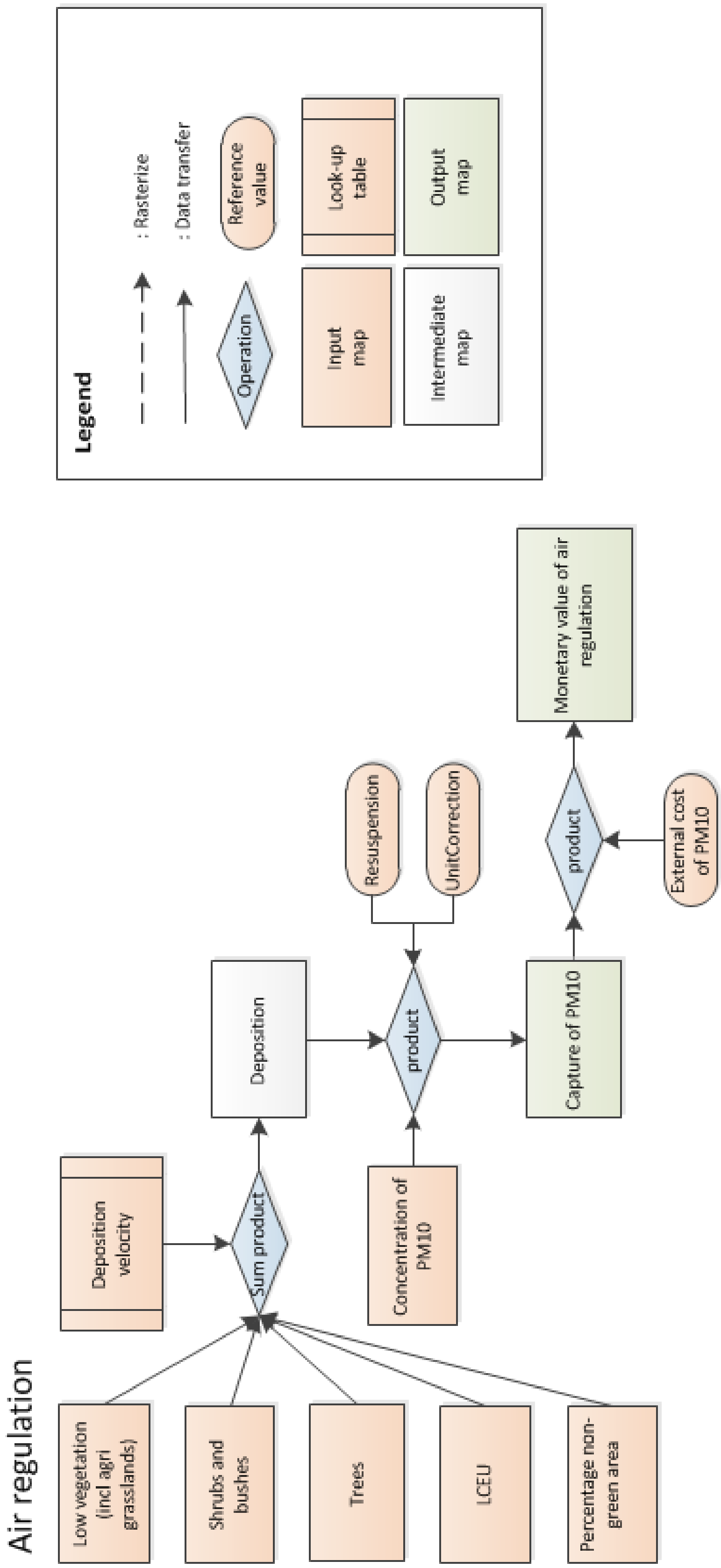

Figure 5.1. Schematic overview of the 'air regulation' model.

6 Cooling by vegetation and water in urban areas

6.1 Overview

Urban areas heat up more than the surrounding rural areas due to the Urban Heat Island (UHI) effect. This additional heating occurs due to the higher absorption of sunlight by darker materials such as asphalt and concrete, and a slower release of this heat by these materials, a reduced wind speeds between buildings and less natural evaporation because of soil sealing. The additional heat can cause health problems during warm periods, especially for the elderly and young infants (e.g. Kovats & Hajat, 2008).
The availability of vegetation and water can have a positive effect on the cooling capacity of urban areas, as they increase the evaporation capacity of an area, can provide shade and release heat quicker than sealed areas. In this model, the cooling effect of vegetation and water on the UHI are calculated.
Five output maps have been developed for the Atlas of Natural Capital for the ecosystem service 'cooling in urban areas' (see Table 6.1). The output map has been produced by combining existing spatial data for the Netherlands with maps developed by RIVM for the Natural Capital Model. Tables 6.1 and 6.2 provide an overview of the input and output maps in order to model the ecosystem service 'cooling in urban areas'.
The five output maps show what the maximum UHI effect in an area would be based on population density and average wind speed, and how vegetation, water and soil sealing affect the UHI at different scales (1 km, 30 m, single cell), as well as the overall cooling effect of urban green and water.

Table 6.1. Output maps generated for the ecosystem service 'cooling in urban areas'.

Output map	Unit	Short description
Maximum UHI effect	°C/cell	Maximum average annual urban heat island effect that could occur, given population density and average wind speeds.
Potential UHI effect	°C/cell	The UHI effect that can be expected based on the amount of soil sealing in a 1 km radius.
In situ cooling effect of urban green and water	°C/cell	The cooling effect of land cover in a given cell, without taking into account its surroundings.
Actual local UHI effect	°C/cell	The cooling effect of vegetation and water in the direct surroundings of a location (30 metres).
Cooling effect of urban green and water	°C/cell	The cumulative cooling effect of vegetation and water in urban areas.

Table 6.2. Input maps applied to estimate the ecosystem service 'cooling in urban areas'.

Input	Unit	Short description	Source
Wind speed	m s-1	Average wind speed at 100 m height in the period 2004-2013.	KNMI (Geertsema & van den Brink 2014)
Inhabitants	# inhabitants per cell	Shows the number of inhabitants per cell	RIVM (Appendix II)
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017
Trees	% cover per cell	Shows the percentage of a cell that is covered by trees taller than 2.5 metres.	RIVM (see Appendix I)
Bushes and shrubs	% cover per cell	Shows the percentage of a cell that is covered by bushes and shrubs between 1 and 2.5 metres tall.	RIVM (see Appendix I)
Low vegetation	% cover per cell	Shows the percentage of a cell that is covered by vegetation that is lower than 1 metre.	RIVM (see Appendix I)
Vegetation cover	% cover per cell	Shows the percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined).	RIVM (see Appendix I)
Percentage non-green area	% cover per cell	Shows the percentage of a cell that is not covered by vegetation (the inverse of the map 'Vegetation cover').	VITO

6.2 Modelling the ecosystem service

The service 'cooling by vegetation and water in urban areas' results in five output maps. The modelling of these five maps is described in the following sections. The model assesses the effects of paved surfaces, vegetation and water at three levels: local (within 30m, Sections 6.2.2 and 6.2.3), neighbourhood (within 1 km, Section 6.2.4) and city (within 10km, Section 6.2.5). The method presented in Section 6.2.1 show the cumulative result of these three levels. Figure 6.2 provides a schematic overview of the way input data has been modelled in order to produce the output maps for the ecosystem service 'cooling in urban areas'.

6.2.1 Cooling effect of urban green and water

The cooling effect of urban green and water can be calculated as the difference between the maximum Urban Heat Island (UHI) effect in an urban area and the actual local UHI effect:

$$\textit{Cooling effect urban green and water} = \textit{Maximum UHI effect} - \textit{Actual local UHI effect}$$

As the cooling effect of green and water is modelled for urban areas, in the output map only areas with at least 20% sealed areas in a one km radius around a cell have been included, using the intermediate map for *%soil sealing1km* variable that is described in Section 6.2.4 and imposing a minimum threshold of 20%. This threshold was chosen to include all urban areas and some of the direct surroundings, but to exclude predominantly rural areas for which the UHI effect is not relevant. The threshold was applied predominantly for visual purposes and does not affect the values in cells that have a higher soil sealing percentage than 20%. The calculation results in the map 'Cooling effect of urban green and water'.

6.2.2 *Actual local UHI effect*

Vegetation and water have a cooling effect on their direct surroundings (e.g. by providing shade and circulating moisture). As the distance at which the effect can be felt is still under discussion in scientific literature, a conservative estimate of 30 m has been applied for this model. To calculate the local cooling effect of vegetation and water, the percentages of all land uses in a 30 m radius around a pixel was calculated and the respective reductions from Tables 6.3 and 6.4 were applied. The local UHI was calculated as follows (Function 3, Figure 6.2):

$$\textit{Actual Local UHI}_i = \textit{Potential UHI}_i * \left(1 - \sum \textit{fr Reduction}_{type30m}\right)$$

Where *Actual Local* UHI_i is the local UHI effect of cell *i*, taking into account the cooling effect of local vegetation and water in a 30m radius, *Potential* UHI_i is the potential UHI effect of cell *i* as calculated in Section 1.2.4, and $frReduction_{type30m}$ is the percentage reduction of the UHI effect of the land cover types in a 30m radius around cell *i*, following Tables 6.3 and 6.4. For example, in a cell with a potential UHI of 3°C that has 20% trees, 20% grass, 10% water and 50% built-up area within a 30m radius, the local UHI is obtained as follows:

3 * (1 – (0.2*0.5 + 0.2*0.2 + 0.1*0.3 + 0.5*0) = 2.49°C.

UHI reduction rates of land cover types

Based on expert judgement, the vegetation from the vegetation cover maps (trees, bushes and low vegetation cover maps (Appendix I)) were assigned maximum UHI effect reduction rates in percentages (Table 6.3) and the land cover types in the LCEU map were assigned reduction rates (Table 6.4).

Table 6.3. Applied reduction of UHI effect by vegetation types from vegetation cover maps based on expert judgement. These percentages were used as input for the model.

Vegetation maps	Reduction UHI effect (%)
Trees	50
Shrubs and bushes	30
Low vegetation	20

Table 6.4. Applied reduction of UHI effect by LCEU land cover classes based on expert judgement. These percentages were used as input for the model.

Land cover type LCEU map	Reduction UHI effect (%)
Built-up area	0
(Semi)natural vegetation	20
Inland water	30
Sea	100
Agricultural land	15-30
Bare soil	0

6.2.3 *In situ cooling effect of vegetation and water*

To calculate the cooling effect of a cell on its surroundings, the in situ cooling effect needs to be calculated. The vegetation types and water have a different impact on cooling and most types cannot completely compensate for the UHI effect (Tables 6.3 and 6.4). To determine the UHI reduction per cell, four input maps were used: the tree cover map, the bushes and shrubs cover map, the low vegetation cover map and the map with the percentage of non-green area. The map showing the percentage of non-vegetated areas was generated as the inverse of the summed-up vegetation cover map. To calculate the UHI reduction of from the non-green area map, the LCEU land cover types are used. The in situ cooling effect of vegetation and water is calculated as follows (Function 2, Figure 6.2):

$$\boldsymbol{In\ situ\ cooling\ effect\ vegetation\ and\ water_i = Potential\ UHI_i \times fr\ Reduction_{type\ i}}$$

Where the *In situ cooling effect of vegetation and water*$_i$ is the cooling effect of vegetation and water for cell *i* in °C, *Potential UHI*$_{i,}$ is the potential UHI effect of cell *i, frReduction*$_{type\ i}$ is the reduction fraction of the UHI effect of the land cover type in cell *i,* following Tables 6.3 and 6.4. The result of this calculation is the map ‘In situ cooling effect of urban green and water’.

6.2.4 *Potential UHI effect*

The potential UHI effect is determined by refining the city level analysis (Section 6.2.5), by analysing the effects of paved and unpaved surfaces within a one km radius of a certain location. To determine whether the

maximum UHI effect was reached in a given cell, the percentage of soil sealing was determined for the surrounding one km. The UHI effect only exists in built-up areas, so a certain degree of soil sealing must be present in the surroundings. The percentage of soil sealing is used to determine the potential UHI effect that can occur in a given area, based on a linear relation between the maximum UHI and zero. The radius of one km was based on expert judgement.
The percentage of soil sealing is determined on the basis of the LCEU land cover map (for built-up areas and water) and the vegetation cover map. The LCEU map is reclassified on a binary soil sealing map based on whether a land cover type is built-up or not (look-up table for 'soil sealing'). Built-up areas in the LCEU map were considered to have 100% soil sealing. The vegetation cover map was used to correct for the percentage of soil sealing in built-up areas based on the inverse of the percentage of coverage by vegetation of a pixel. For example, a road side with 30% vegetation was given a soil sealing value of 0.7 (1 – 0.3).
The potential UHI for a given location was calculated as follows:

$$\boldsymbol{Potential\ UHI_{i,j} = Maximum\ UHI_{i,j} \times frSoil\_sealing_{1km}}$$

Where *Potential UHI*$_i$ is the potential UHI effect of cell *i, Maximum UHI*$_i$ is the maximum UHI effect in cell *i* (based on the Maximum UHI effect map), and *frSoil_sealing*$_{1km}$ is the percentage of soil sealing in a one km radius around cell *i.* The result of this calculation is the 'Potential UHI effect' map.

6.2.5 *Maximum UHI effect*

The UHI effect is limited to a certain maximum on an annual average basis, given several constraints. To determine the maximum UHI effect that can occur in an area, an equation based on the relationship between the UHI effect, on the one hand, and the combination of wind speed and population density, on the other, was used. The equation resulted from the UrbClim model that was validated and used during the EU FP7 project RAMSES for 100 European cities (De Ridder et al., 2015; Lauwaet et al., 2015; Lauwaet et al., 2016). Results from the RAMSES project show that the maximum UHI effect can be estimated accurately based on two variables: (1) annual average wind speed at 10m above ground and (2) population size within a 10 km radius (Figure 6.1). Therefore, these variables have been adopted in this model. The equation used to model the maximum UHI is (Function 1, Figure 6.2):

$$\boldsymbol{Maximum\ UHI = -1.605 + 1.062 \times \log(population_{10km}) - 0.356 \times wind\ speed_{10m}}$$

Where *population*$_{10km}$ is the total population that lives within a 10 km radius around a given cell and *wind speed*$_{10m}$ is the average wind speed at 10m above ground. The low asymptote has been set at 0.
The average wind speed map at 100 metres above ground for the Netherlands, developed by KNMI, has been downscaled to a wind speed map for 10m above ground with a 10m spatial resolution. To downscale the wind speed at 100m above ground to wind speed at 10m above ground, the LCEU land cover map and the corresponding land cover types were used. Each land cover type has a corresponding 'roughness length for momentum' (z0m), which is equivalent to the height at which

the wind speed theoretically becomes zero for the given land cover type. The z0m for the LCEU land cover types were determined based on De Ridder & Schayes (1997) and are found in the look-up table 'Roughness length for momentum'. The wind speed at 10m above ground was determined, based on the following equation (Wieringa, 1986):

$$\boldsymbol{wind\ speed_{10m}} = \boldsymbol{wind\ speed_{100m}} \times \ln(10/\boldsymbol{z0m_{lc}})\ /\ \ln(100/\boldsymbol{z0m_{lc}})$$

Where *wind speed*$_{10m}$ is the average wind speed at 10m above ground, *wind speed*$_{100m}$ is the average wind speed at 100m above ground and *z0m*$_{lc}$ is the roughness length for momentum of a given land cover type. The wind speed map was smoothed by calculating the value of the average wind speed in a 50m radius around a given cell and applying this value to the cell. This map was used for the variable *wind speed*$_{10m}$. Note: this step is not shown in the schematic diagram (Figure 6.2). The population in a 10km radius was calculated by summing the inhabitants in a 10km radius around a given cell on the inhabitants map developed by RIVM (Appendix II). This map was used for the variable *population*$_{10km}$.

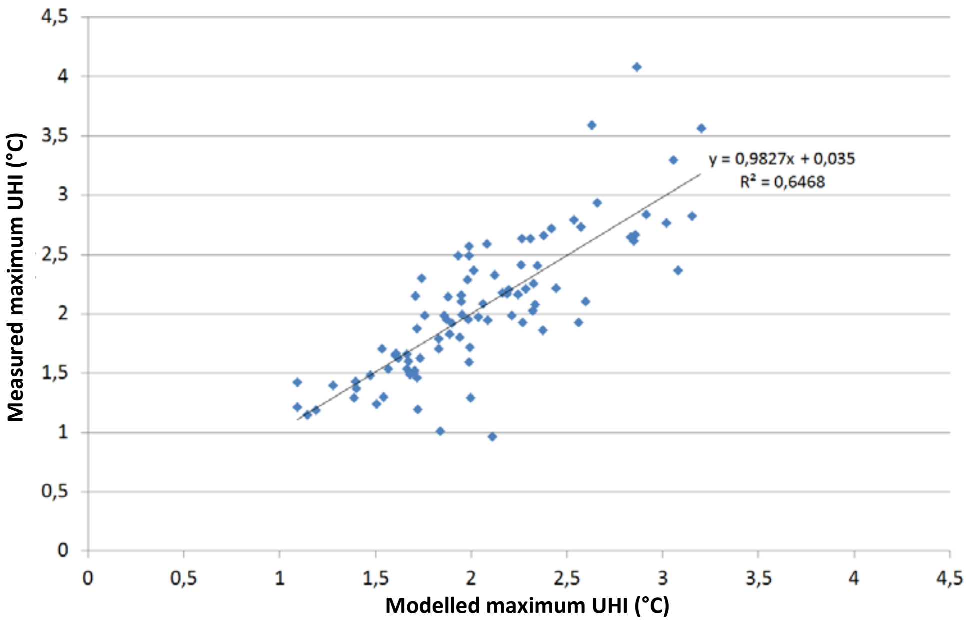

Figure 6.1. Relationship between the maximum UHI effect of a city and the variables 'wind speed' and 'population'. The blue dots indicate separate cities from the RAMSES project.

6.3 Remarks and points for improvement

- An important note for this model is that it shows the annual average UHI effect and takes into account both day and night temperatures. Temperature differences for a single period (e.g. a hot summer night) between an urban area and its surroundings could be much greater.
- The exact cooling effects of different types of vegetation have now been estimated based on expert knowledge, but not on empirical data. When such data becomes available for specific

vegetation and land cover types, the cooling effects in the model can be updated.

- The radius of local effects of vegetation and water has been conservatively estimated to be 30m. Some studies have estimated the effect could potentially have a cooling effect up to 250m distance, although current evidence is inconclusive. The distance effects in the model can be updated if new knowledge becomes available.

6.4 References

- CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- De Ridder, K., and G. Schayes, 1997: The IAGL land surface model. J. Appl. Meteor., 36, 167–182.
- De Ridder K., Lauwaet D., Maiheu B., 2015. UrbClim – a fast urban boundary layer climate model. Urban Climate, 12, 41-58.
- Geertsema, G.T., & van den Brink H.W., 2014. Windkaart van Nederland op 100 meter hoogte. Technisch rapport TR-351, KNMI, De Bilt.
- Kovats, R.S. & Hajat, S., 2008. Heat stress and public health: a critical review. Annual Review of Public Health 29, 41-55.
- Lauwaet D., Hooyberghs H., Maiheu B., Lefebvre W., Driesen G., Van Looy S., De Ridder K., 2015. Detailed Urban Heat Island projections for cities worldwide: dynamical downscaling CMIP5 global climate models. Climate, 3, 391-415.
- Lauwaet D., De Ridder K., Saeed S., Brisson E., Chatterjee F., van Lipzig N.P.M., Maiheu B., Hooyberghs H., 2016. Assessing the current and future urban heat island of Brussels. Urban Climate, 15, 1-15.
- Wieringa J., 1986. Roughness-dependent geographical information of surface wind speed averages. QJRMS, 112, 876-889.

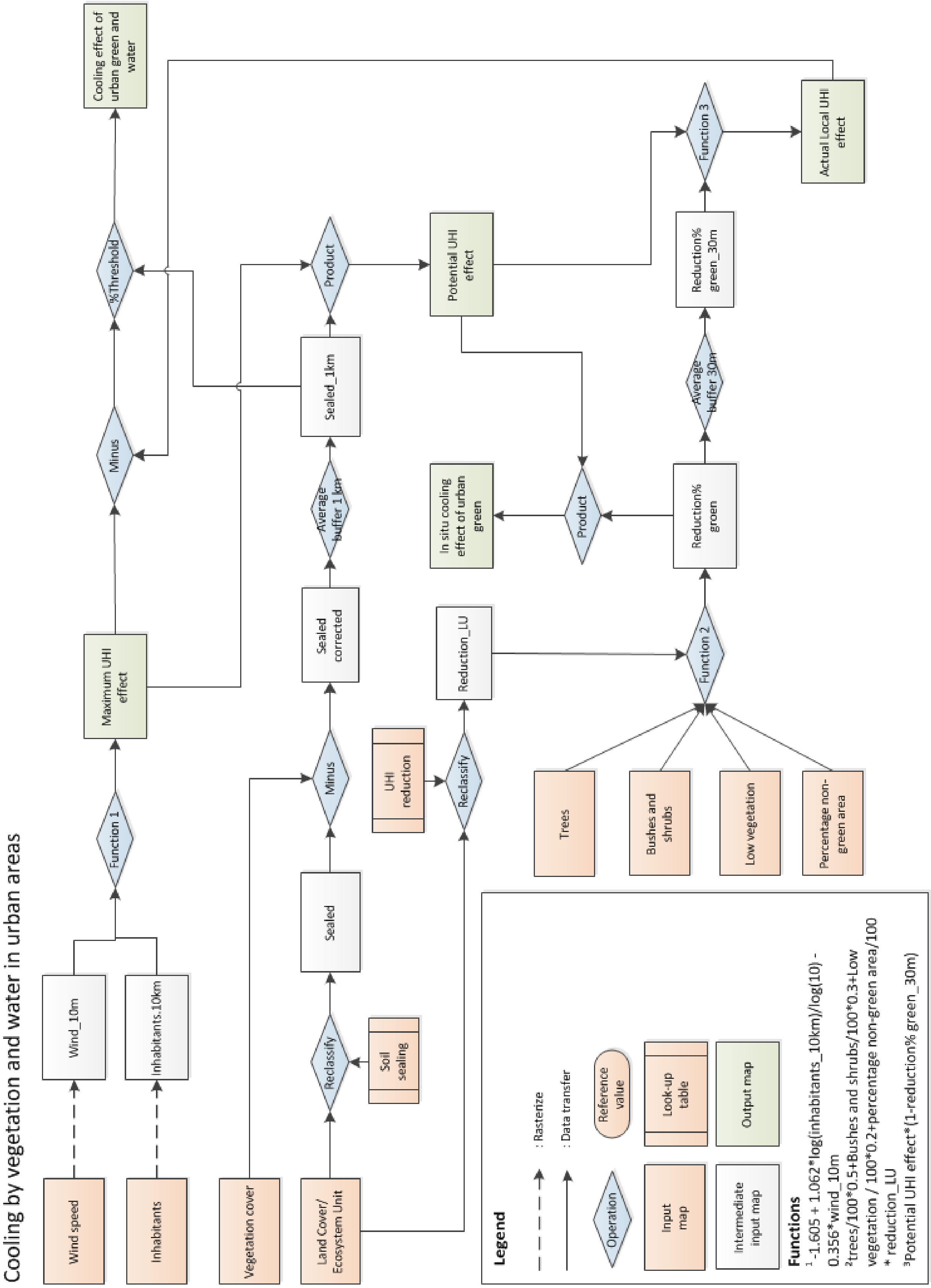

Figure 6.2. Schematic overview of 'Cooling in urban areas' model

7 Urban green and health effects

7.1 Overview

Urban green provides health benefits to people in their living environments and reduces the number of people that need to visit a doctor (Maas, 2008). Urban green has a positive effect on air quality, stress reduction, urban cooling, concentration and physical activity, among other things (e.g. Maas, 2008 and KPMG, 2012). Urban green in the surroundings of people's homes reduces the prevalence of multiple health risks and diseases, including respiratory diseases, migraine, diabetes, depression, neck and back pain, depression and coronary heart disease (KPMG, 2012). For this model, an aggregated methodology has been applied to assess the effect of urban green on nine health risks (cf. the TEEB-Stad tool, see www.teebstad.nl).

For the ecosystem service 'urban green and health effects', five output maps have been produced for the Atlas of Natural Capital based on the TEEB-Stad methodology and using the same input values as the TEEB-Stad tool. Tables 7.1 and 7.2 provide an overview of the input and output maps model for the ecosystem service 'urban green and health effects'.

Table 7.1. Output maps generated for the ecosystem service 'urban green and health effects'.

Output map	Unit	Short description
Amount of urban green in a 1 km radius	% urban green	The percentage of urban green in a 1 km radius around the cell
Reduced number of patients due to urban green surrounding homes	Reduced # patients $cell^{-1}$ yr^{-1}	The reduced number of patients per cell per year as a result of the surrounding amount of urban green.
Health effects of urban green on urban living environment	Reduced doctor's visits per ha urban green yr^{-1}	The effect a specific green area has on the reduction of doctor's visits by inhabitants in the surrounding area.
Avoided health costs due to urban green	€ ha^{-1} yr^{-1}	The reduction of public health costs as a result of urban green in the surroundings of homes.
Avoided health-related labour costs due to urban green	€ ha^{-1} yr^{-1}	The reduction of labour costs due to better health of employees as a result of urban green in the surroundings of their homes.

Table 7.2. Input maps applied to estimate the ecosystem service 'urban green and health effects'.

Input	Unit	Short description	Source
Inhabitants	# inhabitants per cell	Shows the number of inhabitants per cell	RIVM (see Appendix II)
Agricultural crop parcels	Categories for crop types	Yearly updated cadastral map of agricultural parcels with information on crop types per parcel.	RVO 2013
Vegetation cover	% cover per cell	The percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined).	RIVM (see Appendix I)
Percentage non-green area	% non-cover per cell	Percentage of a cell that is not covered by vegetation (inverse of the vegetation cover map).	VITO

7.2 Modelling the ecosystem service

The service 'urban green and heath effects' results in five output maps. The modelling of these maps is described in the following sections. Figure 7.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps. Two versions of the model have been developed. The first version includes agricultural areas surrounding cities and towns. A second version excludes agricultural areas to emphasize the impact of urban vegetation and (semi)natural vegetation surrounding urban areas. Both models use the same calculations described below.

7.2.1 Avoided health costs due to urban green

The monetary value of reduced health costs due to urban green in the surroundings of people's homes is calculated as follows:

$$€_{\boldsymbol{reduced\ health\ costs}} = \boldsymbol{HealthEffects}_{\boldsymbol{urban\ green}} \times \boldsymbol{HealthCosts}$$

Where:

- $€_{reduced\ health\ costs}$, is the monetary value of avoided health costs [€ ha^{-1} yr^{-1}];
- $HealthEffects_{urban\ green}$, is the health effects of an area of urban green [reduced doctor's visits per ha urban green yr^{-1}];
- *HealthCosts*, the annual avoided health costs per patient [€ $patient^{-1}$ yr^{-1}].

The avoided health costs per patient that were applied in the TEEB Stad tool were used (2016 € values). These values are based on KPMG (2012) and the Cijfertool Kosten van Ziekten of RIVM, which valued the average health costs for nine diseases that had a relation to urban green at €868 per patient per year.

7.2.2 *Avoided health-related labour costs due to urban green*

The monetary value of reduced health-related labour costs due to urban green in the surroundings of people's homes is calculated as follows:

$$€_{reduced\ labour\ costs} = \boldsymbol{HealthEffects_{urban\ green}} \times \boldsymbol{HealthLabourCosts} \times \boldsymbol{ParticipationFactor}$$

Where:
- $€_{reduced\ labour\ costs}$ is the monetary value of avoided health-related labour costs [€ ha^{-1} yr^{-1}];
- *HealthEffects*$_{urban\ green}$ is the health effects of an area of urban green [reduced doctor's visits per ha urban green yr^{-1}];
- *HealthLabourCosts* is the annual avoided health-related labour costs per patient [€ $patient^{-1}$ yr^{-1}].
- *ParticipationFactor* is the fraction of people that participate in the labour market [%].

The avoided health-related labour costs per patient that were applied in the TEEB Stad tool were used (2016 € values). These values are based on KPMG (2012) and Steenbeek et al. (2010). The costs consist of three components: absenteeism, reduced labour productivity and job losses. Average annual costs per patient were calculated to be €6,341 (€3,221 for absenteeism, €2,691 for reduced labour productivity and €429 for job loss). The participation factor was estimated to be 67% based on KPMG (2012).

7.2.3 *Health effects of urban green on urban living environment*

The health effects of urban green on urban areas is determined as a function of the amount of urban green in a one km radius around a given area of urban green and the population density surrounding the urban green, given the following formula:

$$\boldsymbol{HealthEffects_{urban\ green}} = \boldsymbol{PercGreenSpace_{1km}} \times \boldsymbol{PopDensity_{1km}} \times \boldsymbol{HealthImpact_{urban\ green}}$$

Where:
- *HealthEffects*$_{urban\ green}$ is the health effects of an area of urban green [reduced doctor's visits cell yr^{-1}];
- *PercGreenSpace*$_{1km}$ is the percentage of urban green within a one km radius around a cell [% urban green $cell^{-1}$].
- *PopDensity*$_{1km}$ is the number of inhabitants within a one km radius around a cell [inhabitants km^{-1}], based on the inhabitants map (Appendix II).
- *HealthImpact*$_{urban\ gree,}$ is the number of avoided doctor's visits per person as a result of the amount of urban green around a home [avoided doctor's visits per person per % urban green yr^{-1}].

The health impact of the percentage of urban green on doctor's visits per person is based on Maas (2008) and calculated to be 0.000835 avoided doctor's visits per person per percent of urban green. The map shows values for all cells that have at least 1% of urban green.

7.2.4 *Reduced number of patients due to urban green surrounding homes*

The reduced number of patients due to surrounding urban green in urban areas is determined as a function of the number of inhabitants in a given cell and the amount of urban green in a one km radius around homes, given the following formula:

$$\boldsymbol{AvoidedPatients_{urban\ green} = PercGreenSpace_{1km} \times PopDensity_{cell} \times HealthImpact_{urban\ green}}$$

Where:

- *AvoidedPatients*$_{urban\ green}$ is the health effects of an area of urban green [reduced doctor's visits cell^{-1} yr^{-1}];
- *PercGreenSpace*$_{1km}$ is the percentage of urban green within a 1 km radius around a cell [% urban green km^{-1}].
- *PopDensity*$_{cell}$ is the number of inhabitants in a given cell [inhabitants cell^{-1}] based on the inhabitants map (Appendix II).
- *HealthImpact*$_{urban\ green}$ is the number of avoided doctor's visits per person as a result of the amount of urban green around a home [avoided doctor's visits per person per % urban green yr^{-1}].

The health impact of the percentage of urban green on doctor's visits per person is based on Maas (2008) and is calculated to be 0.000835 avoided doctor's visits per person per percent of urban green in a one km radius (KPMG, 2012). The map shows values for all inhabited cells.

7.2.5 *Amount of urban green in a one km radius*

To determine the health effects of urban green on urban areas, the percentage of urban green within a one km radius around every cell needs to be calculated. This was done in two ways – one calculation includes agricultural areas surrounding cities and towns, one excludes agricultural areas. The calculation was done as follows:

$$\boldsymbol{PercGreenSpace_{1km} = \sum VegetationCover, PercNonGreen}$$

Where:

- *PercGreenSpace*$_{1km}$ is the percentage of urban green within a one km radius around a cell [% urban green km^{-1}].
- *VegetationCover* is the percentage of vegetation cover in a given cell (trees, shrubs and low vegetation combined) [% vegetation cover cell^{-1}] based on the vegetation map (Appendix I).
- *PercNonGreen* is the amount of area per cell that is covered by sealed surface based on the Ecosystem Unit map and the Agricultural Crop Parcels Map [% non-green cell^{-1}].

As agricultural areas are considered as urban green on the vegetation cover maps, in the calculations in which agricultural areas were excluded, the Agricultural Crop Parcels map was used to remove these agricultural green areas from the vegetation map.

7.3 Remarks and points for improvement

- There is a lot of new and upcoming research on the relationship between green and different health aspects. Studies focusing on specific health aspects can be incorporated into model updates.
- Maas (2008) did not find a relationship between urban green and health in highly urbanized areas, but this relationship is currently being applied in all urban areas to keep the model in line with the TEEB-Stad tool.

7.4 References

- KPMG, 2012. 'Groen, gezond en productief. The Economics of Ecosystems & Biodiversity (TEEB NL): natuur en gezondheid'
- Maas J., 2008. Vitamin G: Green environments, healthy. environments, Proefschrift ter verkrijging van de graad van docoraat Universiteit Utrecht, Utrecht, 2008.
- RIVM, 2003 onwards. Cijfertool kosten van ziekten met cijfers uit de 'kosten van ziektestudie'.
- RVO 2013. Basisregistratie Gewaspercelen (BRP), 2013. Available at http://www.nationaalgeoregister.nl/geonetwork/srv/dut/catalog.search#/metadata/%7B25943e6e-bb27-4b7a-b240-150ffeaa582e%7D
- Steenbeek R., Hooftman W., Geuskens G., Wevers C., 2010. Objectiveren van gezondheidsgerelateerde non-participatie en de vermijdbare bijdrage van de gezondheidszorg hieraan. TNO, TNO-rapport 2010.171/13738.01.01.

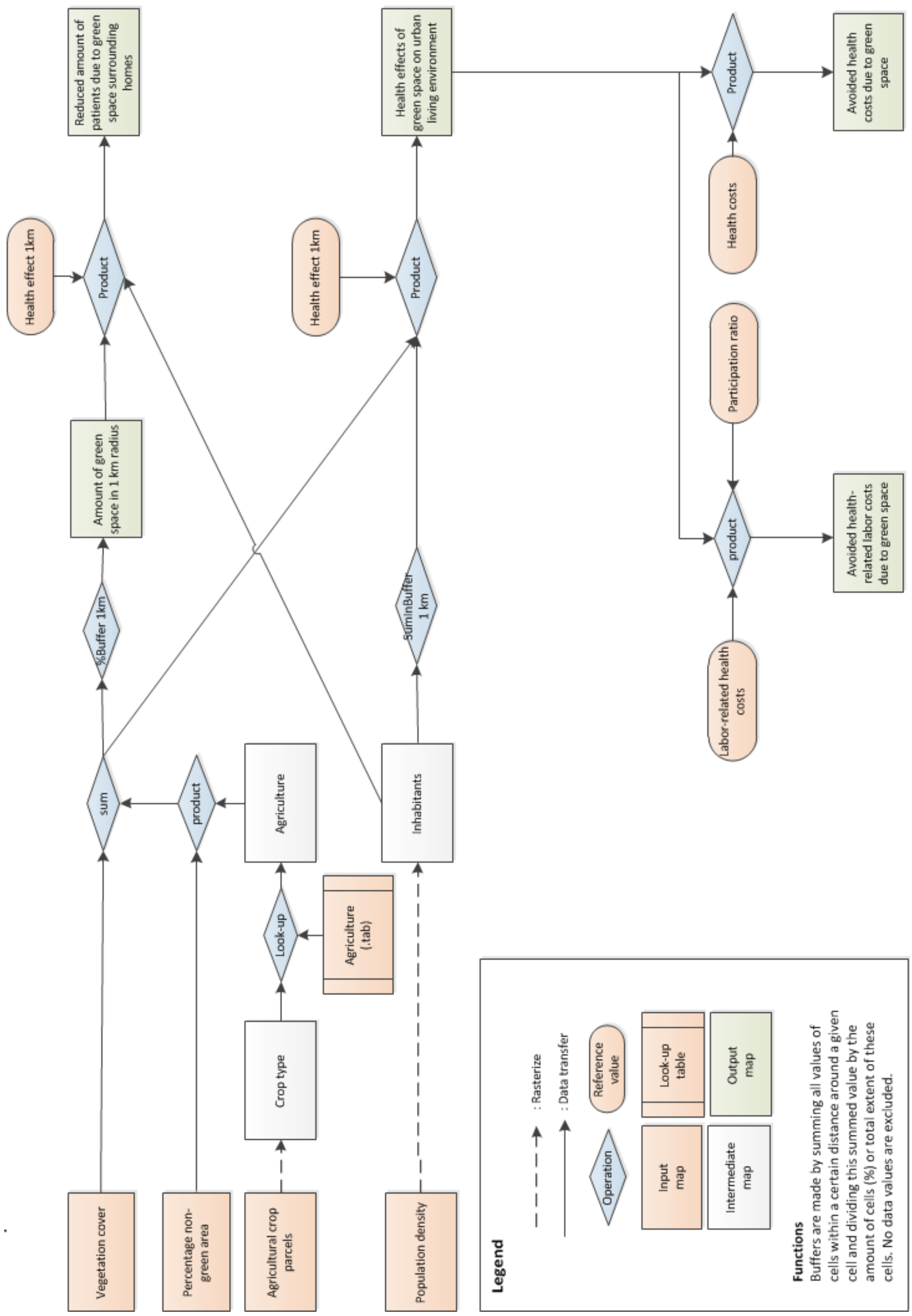

Figure 7.1. Schematic overview of 'urban green and health effects' model

8 Influence of urban green & water on residential property values

8.1 Overview

Trees, parks, gardens and water increase the amenity of residential areas, which is reflected in property values (Czembrowski & Kronenberg 2016; Franco & MacDonald, 2017). In the Netherlands, multiple studies have been done to quantify the influence of vegetation and water on property values, for example Daams et al. 2016 and for an overview Ruijgrok et al. (2006). This model uses Luttik & Zijlstra (1997) as a main data source.
The studies in the Netherlands make a distinction between two aspects, i.e. the view on green elements, parks and water, and the proximity to these elements. Currently, the increase in property value due to urban green and water in residential areas can be viewed within the Atlas of Natural Capital (see Table 8.1). The output map has been produced by combining existing spatial data for the Netherlands with maps developed by RIVM for the Natural Capital Model. Tables 8.1 and 8.2 provide an overview of the input and output maps used to model the ecosystem service 'influence of urban green and water on residential property values'.

Table 8.1. Output maps generated for the ecosystem service 'influence on residential property values'.

Output map	Unit	Short description
Influence of urban green & water on residential property value	[€]	The part of residential property values that result from surrounding green areas and water

Table 8.2. Input maps applied to estimate the ecosystem service 'influence on residential property values'.

Input	Unit	Short description	Source
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017
Inhabitants	# inhabitants per cell	Shows the number of inhabitants per cell	RIVM (Appendix II)_
Property Value	Euro	Average property value per neighbourhood 2015 (Dutch: WOZ)	CBS 2016
Vegetation	% cover per cell	Shows the percentage of a cell that is covered by vegetation (low vegetation, bushes and shrubs and trees combined).	RIVM (Appendix I)
Open Water	land use class	Selection of water classes from LCEU	RIVM

8.2 Modelling the ecosystem service

The influence of urban green and water on residential property values is estimated based on the water classes in the LCEU map and the vegetation map of the Netherlands. Figure 8.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps for this ecosystem service.

8.2.1 Influence of urban green & water on residential property value

The influence of urban green and water on residential property value is estimated according to:

$$\boldsymbol{InfluenceGreenWater = frIncrease * PropertyValue}$$

Where:

- *PropertyValue* is the property value (so-called WOZ-value in the Netherlands) available at neighbourhood level for residential areas from the CBS for 2016.
- *frIncrease* is the fraction of increase in property value for four different types: view of a tree line, view of a park or water, proximity to a park or water and open water as given in Table 8.3.

Table 8.3. Fraction of increase in property value given different amenities of urban green and water (Luttik & Zijlstra, 1997 and Ruijgrok, 2006).

Types of urban green and water	Fraction of property value increase
View of a tree line	0.05
View of a park or water	0.08
Proximity to a park or water	0.06
Open water	0.12

Currently, the presence of multiple types of green or water is not accounted for. The highest fraction increase that is available is applied: open water, view on park or water, proximity to park or water respectively.

8.2.2 Availability of open water

The availability of open water has been defined on the topographic map that shows water areas (Top10Water). Here Top10Water is used instead of the water classes from the LCEU map because the LCEU map does not distinguish between open water and small water bodies such as ditches, canals and ponds, whereas this is necessary for this model. Open water is available if the water area is larger than one ha and if it is within a 50m distance of a residential area (based on the map showing inhabitants, Appendix II).

8.2.3 Proximity to a park or water

The proximity of houses to a park or water has been derived from the vegetation map of the Netherlands that includes trees, bushes, flowers, plants and grass (Appendix I). Parks have been defined as vegetated areas larger than one ha that consist of cells with more than 60%

vegetation cover. The land cover class 'water' is based on the LCEU map and can be as small as one cell of $100m^2$. The proximity to a park or water is defined as the availability (of at least one cell) of park or water within a distance of 400m.

8.2.4 *View of a park or water*

A view of a park or water has been defined in the same way as the proximity to a park or water, with the difference that the park or water should be within a distance of 30m.

8.3 Remarks and points for improvement

- The model is currently based on the references used in the TEEB-Stad tool. A recent study conducted by Daams et al. 2016 and an ongoing follow-up project by CBS could provide a more accurate modelling approach.
- In the current version of the spatial model, a view of tree lines is not included, as the available spatial information on tree lines was not sufficient. This aspect is included in the TEEB-Stad tool methodology and could be added in a later version of the spatial model.
- Currently, all water bodies from the LCEU map have been included. Whether very small water bodies truly contribute to property values is questionable.

8.4 References

- CBS, 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- CBS, 2016. Gemeente, wijk- en buurtenkaart 2015. Available at http://www.cbsinuwbuurt.nl/#sub-buurten2015_gemiddelde_WOZwoningwaarde
- Czembrowski P. & Kronenberg J., 2016. Hedonic pricing and different urban green space types and sizes: Insights into the discussion on valuing ecosystem services. Landscape and Urban Planning 146, 11-19.
- Daams M.N., Sijtsma, F.J., van der Vlist, A.J., 2016. The effect of natural space on nearby property prices; accounting for perceived attractiveness. Land Economics 92:3 389-410.
- Franco S.F. & Macdonald J.L., 2017. Measurement and valuation of urban greenness: Remote sensing and hedonic applications to Lisbon, Portugal. Regional Science and Urban Economics, in press.
- Luttik J. & Zijlstra M., 1997. Woongenot heeft een prijs; Het waardeverhogend effect van een groene en waterrijke omgeving op huizenprijzen. Wageningen SC-DLO (Rapport 562).
- Ruijgrok E.C.M., Smale A.J., Zijlstra R., Abma R., Berkers R.F.A., Németh A.A., Asselman N., de Kluiver P.P., de Groot D., Kirchholtes U., Todd P.G., Buter E., Hellegers P.J.G.J. and Rosenberg F.A., 2006. Kentallen Waardering Natuur, Water, Bodem en Landschap, Hulpmiddel voor de MKBA. Witteveen+Bos, commissioned by Ministerie van Landbouw Natuurbeheer en Voedselkwaliteit, The Hague.

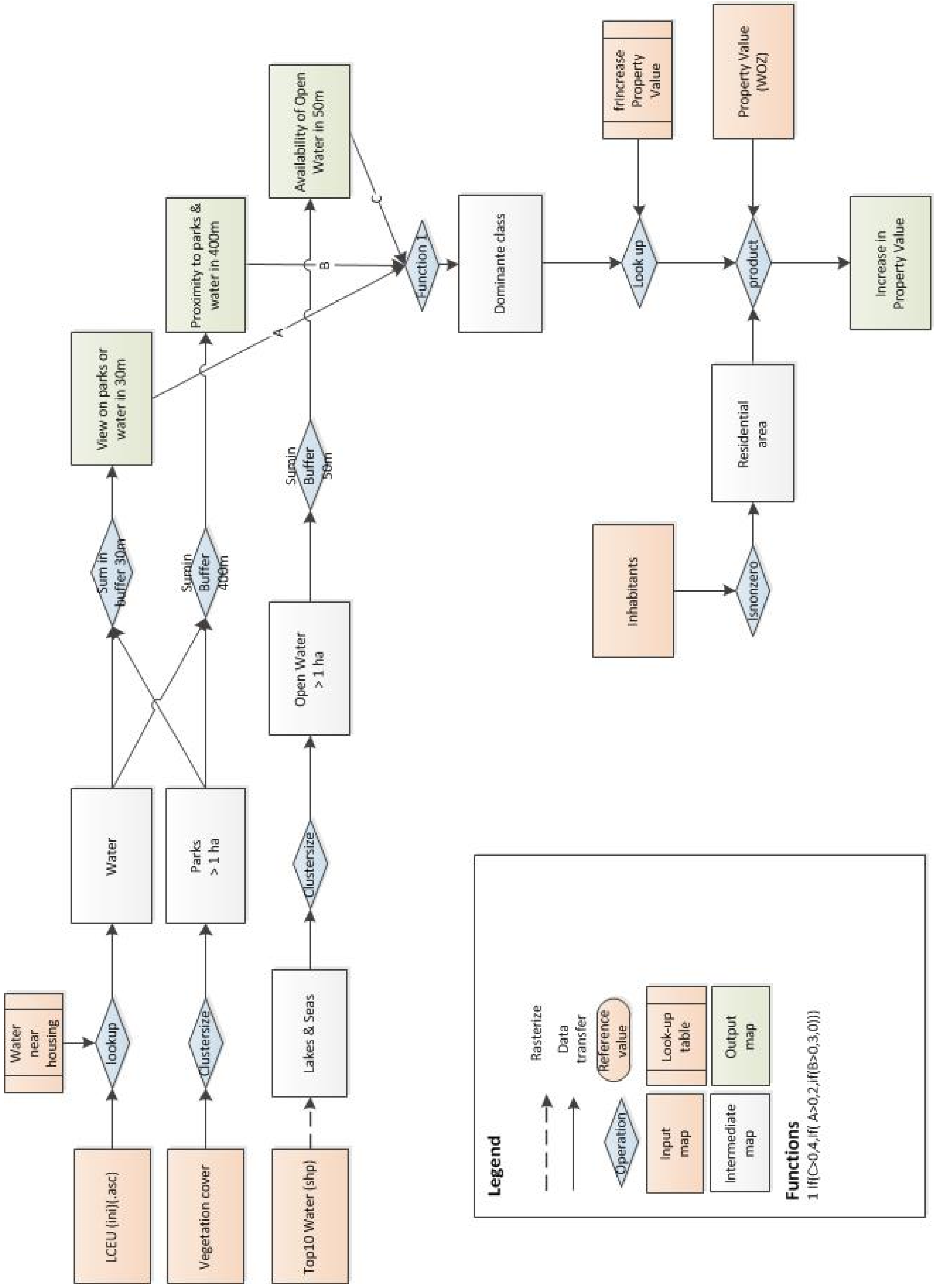

Figure 8.1 Schematic overview of the influence of urban green and water on property value.

9 Energy savings in homes due to shelter provided by trees

9.1 Overview

Trees reduce wind speed. As a result, less energy is required for the heating of houses and buildings (van Moppes & Klooster 2008; Ruijgrok et al., 2006; Swaagstra et al. 2003; Prendergast 2003). A map for energy savings in homes due to shelter provided by trees has been produced for the Atlas of Natural Capital, based on the TEEB-Stad methodology and using the same input values as the TEEB-Stad tool (see www.teebstad.nl). The output map has been produced by combining existing spatial data for the Netherlands with maps developed by RIVM for the Natural Capital Model. Tables 9.1 and 9.2 provide an overview of the input and output maps to model the ecosystem service 'energy savings in homes due to shelter provided by trees'.

Table 9.1. Output maps generated for the ecosystem service 'energy savings'.

Output map	Unit
Energy savings homes due to shelter provided by trees	[€]

Table 9.2. Input maps applied to estimate the ecosystem service 'energy savings'.

Input	Unit	Short description	Source
Ecosystem unit map	Ecosystem unit classes	Ecosystem unit classes map for the Netherlands in 2013	CBS 2017
Inhabitants	# inhabitants per cell	Shows the number of inhabitants per cell	RIVM (Appendix II)
Tree height	[m]	90 percentile of cells covered with trees	RIVM (Appendix I)

9.2 Modelling the ecosystem service

The influence of sheltering trees on the energy budget of homes is estimated based on the LCEU map, the map showing inhabitants and defining the location of residential cells and the map showing the height of the trees. Figure 9.1 provides a schematic overview of the way input data has been modelled in order to produce the output maps for this ecosystem service.

9.2.1 *Energy savings due to sheltering by trees within 50m*

The energy savings are estimated according to:

$$\begin{aligned}\boldsymbol{EnergySavings} &= \boldsymbol{AvailabilityOfTrees} \times \boldsymbol{ResidentialCell} \times \boldsymbol{frSaving} \\ &\times \boldsymbol{GasConsumption} \times \boldsymbol{Price} \times \boldsymbol{frWindDirection}\end{aligned}$$

Where:

- *AvailabilityOfTrees* is the relative availability of trees in the neighbourhood, estimated as the total sum of the trees' height (for trees taller than 10m) within a distance of 50m divided by the number of cells within that neighbourhood.
- *ResidentialCells*, the cells for which the number of inhabitants > 0 [-] based on the inhabitants map (Appendix II).
- *frSaving* is the fraction of the gas consumption saved due to sheltering by trees: 0.1 [-] (Swaagstra et al. 2003, van Moppes & Klooster, 2008)
- *GasConsumption* is the average annual gas consumption of a household: 1,600 m^3/year (van Moppes & Klooster, 2008).
- *Price* is the average gas price: €0.66/m^3 (Milieucentraal.nl, 2016)
- *frWindDirection,* the correction for wind direction, the proportion of days on which the wind blows from the direction in which trees shelter adjacent houses; 0.3 [-] (Swaagstra et al. 2003, van Moppes & Klooster, 2008)

9.3 Remarks and points for improvement

- In the current model, no distinction is made between the types of houses. Therefore, high-rise buildings that may not be affected by shelter provided by trees are currently included. Additional information on building height should be included in the model to more accurately estimate the sheltering effects.
- Dominant wind direction has not been taken into account in the model.
- Currently, a single value for average gas consumption in the Netherlands is applied. However, CBS has disaggregated data on gas consumption that could be included in an update of the model.

9.4 References

- CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map
- Milieucentraal.nl, 2016. Energieprijzen. Available at https://www.milieucentraal.nl/energie-besparen/snel-besparen/grip-op-je-energierekening/energieprijzen/
- Prendergast E., 2003. Energetische waarde van planten in de bebouwde omgeving. Energiebesparingberekeningen. ES Consulting.
- Ruijgrok E.C.M., Smale A.J., Zijlstra R., Abma R., Berkers R.F.A., Németh A.A., Asselman N., de Kluiver P.P., de Groot D., Kirchholtes U., Todd P.G., Buter E., Hellegers P.J.G.J. and Rosenberg F.A., 2006. Kentallen Waardering Natuur, Water, Bodem en Landschap, Hulpmiddel voor de MKBA. Witteveen+Bos, commissioned by Ministerie van Landbouw Natuurbeheer en Voedselkwaliteit, The Hague.
- Swaagstra A.H., Kluiver P.P., 2003. Haalbaarheidsonderzoek Energetische Stedenbouw. NEO-NOVEM, The Hague.
- van Moppes, D., Klooster, J., 2008. Groene daken Rotterdam: Maatschappelijke kosten-batenanalyse. Arcadis Nederland.

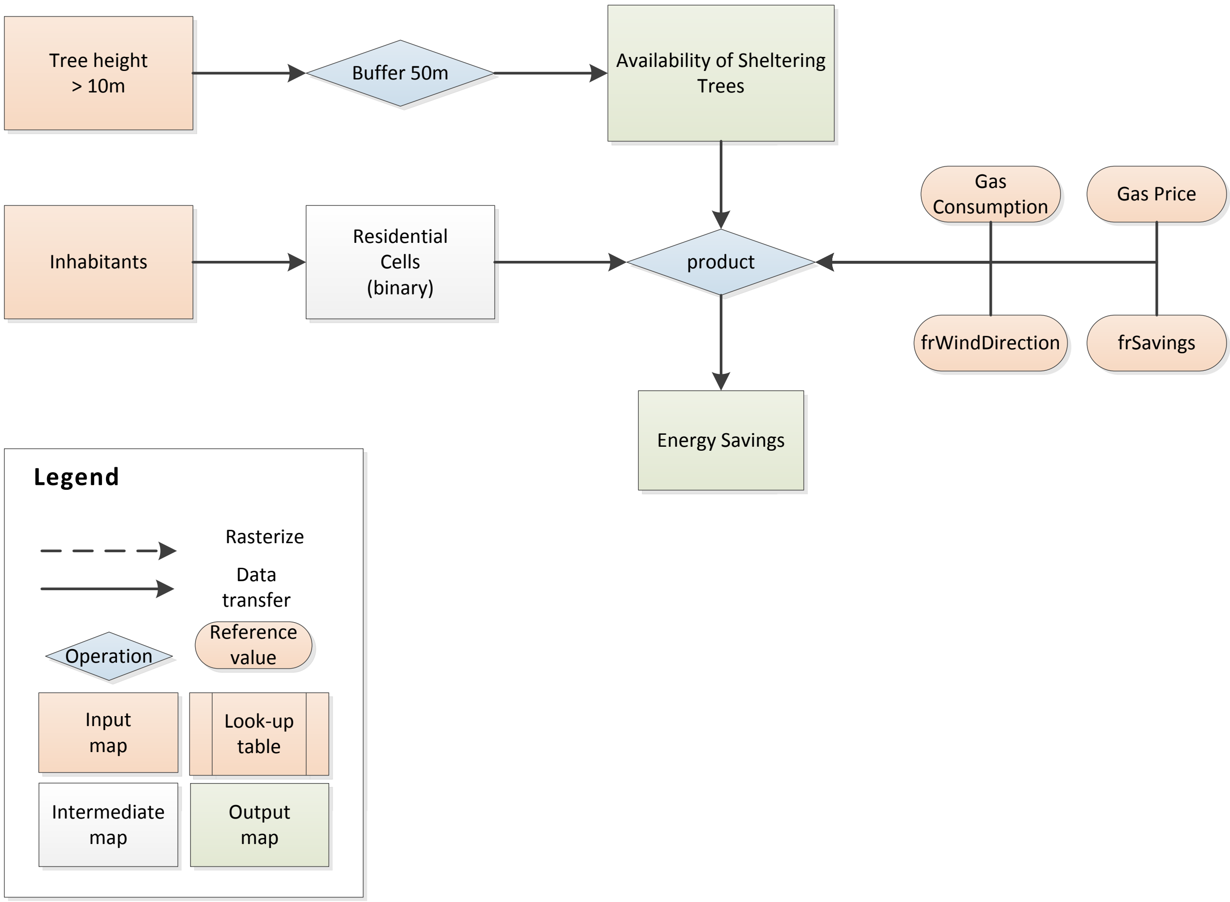

Figure 9.1 Schematic overview of the increase in property value due to urban green and water.

10 Conclusions and recommendations

This report provided the technical documentation for the first versions of the urban ecosystem service models developed in the context of the Natural Capital Model. Currently, a broad range of models for urban ecosystem services and related benefits has been developed. These models are used to produce maps on the current state of multiple urban ecosystem services in the Netherlands. This provides policy makers, businesses and citizens with an insight into the current status of natural capital in their city or neighbourhood. Maps resulting from the models will be made available on the Atlas of Natural Capital (www.atlasnaturalcapital.nl). In addition, the models allows users to calculate the effects of spatial plans and scenarios on natural capital in urban areas, which can facilitate decision-making by urban planners. The decision-support tool Green Benefit Planner will be developed for this purpose.

The presented eight sub-models embody the core of Natural Capital Model for urban natural capital. Together, these sub-models give planners a broad overview of the benefits that natural capital can provide in urban areas. The Natural Capital Model is still in the development phase and this report has described the initial set-up of eight sub-models. These models are ready to be implemented in spatial planning. Pilot projects are being carried out to apply and test the first version of the Natural Capital Model. These pilot projects will be used to further improve the sub-models and expand the set of sub-models.

The models will be further developed, together with national partners (including the Netherlands Environmental Assessment Agency (PBL), Wageningen Environmental Research (WEnR) and Statistics Netherlands (CBS)), integrating state-of-the-art national data and (inter)national scientific knowledge on the different ecosystem services. Additional partners will be approached to further improve the model. A collaborative Dutch Natural Capital Model has multiple advantages. Modelling results for different national institutes will have the same basis and therefore will not conflict. Collaboration will also enhance the speed of model development and integrate a broader knowledge base. The approach will enhance overall support and the credibility of model output.

The set of urban ecosystem service models is expected to be extended with models for recreation and use value (e.g. for walking, cycling and sports), as well as noise reduction in green areas in 2018. Additional urban ecosystem services may be added on a project basis. Not all calculations presented in the TEEB-Stad tool could be meaningfully translated into spatial models. The TEEB-Stad calculations for social cohesion and improved benefits for shop owners in green areas were not included in the spatial models because the calculations did not provide meaningful spatial results. The calculations for water retention and recreation could not be adapted to a spatial version. For these ecosystem services, different methods need to be applied.

All presented models will be subject to improvement based on newly available knowledge and data. Some models may be expanded and integrated with similar models that are available from other initiatives, such as the Natural Capital Accounts of CBS and Wageningen University. Examples of foreseen improvements are a wood production model that applies Dutch data, rather than the current data for Flanders. For air regulation, population density will be incorporated in the model, because the benefits depend on the number of people living in a given area. There is an increasing amount of interest in the relationships between health and urban green, and additional data and research outcomes are expected in 2018. All partners of the Natural Capital Model are striving to improve the current set of models and add new ecosystem service models in order to develop a comprehensive national model that is applicable to a broad range of spatial planning and policy contexts.

11 References

Haines-Young, R. & Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being. D. Rafaelli, C. Frid (Eds.), Ecosystem Ecology: A New Synthesis. Cambridge University Press, Cambridge, p. 110-139.

Potschin, M. & Burkhard, B. (2015). Glossary of Ecosystem Service mapping and assessment terminology. Deliverable D1.4, ESMERALDA project.

TEEB (2010). The Economics of Ecosystems and Biodiversity: Ecological and economic foundation. Earthscan, Cambridge.

Appendix I – Technical documentation vegetation maps ANK (trees, shrubs, low-growing vegetation)

AHN2 zip files were downloaded (as atomfeeds) from:
http://geodata.nationaalgeoregister.nl/ahn2/atom/ahn2_05m_int.xml
http://geodata.nationaalgeoregister.nl/ahn2/atom/ahn2_05m_ruw.xml

AHN2 ('Actueel Hoogtebestand Nederland') is the second version of the digital elevation model of the Netherlands. The model consists of 1,374 tif-files (raster files at 0.5 metre resolution) containing elevation information for the Netherlands (relative to Dutch Ordinance Level – NAP). Each tif-file covers an area of 5,000 x 6,250 metres. Two types of elevation information were used, each in a separate tif-file: ground level elevation and the top level elevation of all objects, relative to NAP. In total, therefore, 2,748 tif-files were downloaded, each at 0.5 metre resolution.

Height of all objects

1. The NoData values in the Ground level rasters (e.g. gaps in areas where buildings or other objects are located) were filled up by using the ArcGis tool 'Focal Statistics' (rectangle neighbourhood with 50 x 50 cell-units). The statistic was only applied in the NoData raster cells.
   Python-code: 'arcpy.gp.FocalStatistics_sa(Groundlevel raster, Groundlevel raster v2, "Rectangle 50 50 CELL", "MEAN", "DATA")'.

2. Height of all objects was calculated subsequently by subtracting the ground-level rasters from the object-rasters.
   Python-code: 'arcpy.gp.Minus_sa(object-raster, Ground-level raster v2, Object height raster)'.

3. Buildings (including a buffer of 2 metres around the building) were removed from the resulting rasters (value was set to zero) by using the BAG – buildings data layer (21 November 2016 version). The BAG vector layer was first converted to a 0.5 metre raster and the buildings were given the value = 0.
   Python-code: 'arcpy.gp.Times_sa(Object height raster, BAG buildings, Object height raster v2)'.

At this stage, there are 1,374 raster layers with a 0.5 metre resolution showing the height of all objects, but without the height of the buildings as indicated in the BAG – buildings data layer. To distinguish between vegetation and other objects, the aerial photograph of the Netherlands from 2016 in 0.25 metre resolution was used.

NDVI

4. The aerial photograph in a 0.25 metre resolution was converted to a 0.5 metre resolution and was split up into the same 1,374 areas.

5. The Normalized Difference Vegetation Index (NDVI) was calculated from the Infrared and red bands of the aerial photograph. This resulted in the conversion of the 3-band photograph into a 1-band raster layer. The NDVI is defined by: (Band 1 – Band 2) / (Band 1 + Band 2)
   All resulting values >= 0 are assumed to be vegetation.
   Python-code: 'arcpy.gp.Minus_sa(Band_1, Band_2, temp1)
   arcpy.gp.Times_sa(temp1, 10, temp2)
   arcpy.gp.Plus_sa(Band_1, Band_2, temp3)
   arcpy.gp.Divide_sa(temp2, temp3, output1)'

6. All raster cells containing vegetation were set to the value = 1. The other raster cells were set to NoData values.
   Python-code: 'arcpy.gp.Reclassify_sa(output1, "Value", "-10 0 NODATA; 0 10 1", output2, "DATA")'

7. The raster layer containing the height of all objects from step 3 was then multiplied by the raster layer from step 6.
   Python-code: 'arcpy.gp.Times_sa(output2, Object height raster v2, Object height raster v3)'

At this stage, there are 1,374 raster layers in 0.5 meter resolution showing the height of all vegetation. The high-voltage lines, however, were the only non-vegetation objects that were not completely removed from the rasters. Therefore, the high-voltage map from 2016 was used to set all raster values to zero that were within 25 metres from these high-voltage lines. The 0.5 metre resolution raster layers were then converted to a 10 metre resolution and three separate vegetation types were distinguished: trees, shrubs and low vegetation such as grass.

Three vegetation types (percentage per 10m grid cell)

8. The percentage of trees, shrubs and low vegetation per 10 metre raster cell was calculated. This was done separately for the three vegetation types. Firstly, all vegetation taller than 2.5 metres was considered as a tree. All raster cells with a value higher than 2.5 in the 0.5 metre resolution files were reclassified to the value = 1.The value of the remaining cells was set to zero. The 0.5 metre resolution raster files were subsequently aggregated to a 10 metre resolution by taking the sum of the 400 original raster cell values, divided by four. This procedure results in a 10 metre resolution raster file containing the percentage of trees per cell.
   Python-code: 'arcpy.gp.Reclassify_sa(Object height raster v3, "Value", "-1000 2.5 0; 2.500000000000001 50 1; 50.00000000000003 1000 0", temp1, "DATA")
   arcpy.gp.Aggregate_sa(temp1, temp2, "20", "SUM", "EXPAND", "DATA")
   arcpy.gp.Divide_sa(temp2, 4, output_trees)'

9. The same procedure in step 8 was repeated for shrubs and low-growing vegetation. The height of shrubs was considered to be between 1 and 2.5 metres and low-growing vegetation was considered to be between 0 and 1 metre tall.

10. The agricultural areas were set to NoData in the low vegetation raster layer by using the AAN dataset (Agricultural Areas of the Netherlands).

At this stage there are three raster layers, in 10 metre resolution, showing the percentage of vegetation per grid cell. If added up, the values range from 0 – 100% vegetation. Finally, a 10 metre resolution raster layer is calculated showing the height of the trees (in metres).

Height of the trees

11. The 0.5 metre resolution layers from step 7 were aggregated to a 10 metre resolution by calculating the 90th percentile of the 400 original raster cell values that are higher than 2.5 metres (trees). This was done in the software package RStudio 3.4.3.
    R-code:
    ```
    'f<-function(x, na.rm=TRUE)
    result<-quantile(x,probs=0.9,na.rm)
    temp <- raster("../xx.tif")
    writeRaster(temp, "tmpdata.grd",overwrite=TRUE)
    temp<-raster("tmpdata.grd")
    aggregate(temp, fact=20, fun=f, expand=TRUE,
    na.rm=TRUE, filename="tmpdata2.grd", overwrite=TRUE)
    temp2 <- raster("tmpdata2.grd")
    writeRaster(temp2, "../xx_P90.tif")'
    ```

The 1,374 resulting raster layers in 10 metre resolution were combined into one raster layer for the Netherlands.

The datasets are available through the Atlas of Natural Capital website (www.atlasnaturalcapital.nl).

Appendix II – Development of inhabitants map

Inhabitants and population density are an important component of many ecosystem service models because a service often only exists if there are users in the surroundings. To accurately model ecosystem services in an urban setting, a high-resolution inhabitants map is necessary because population density differs widely over short distances. A 10x10m-resolution inhabitants map was developed for all of the Netherlands based on the neighbourhood map of CBS (CBS Wijk- en Buurtkaart 2017) and the BAG (Basisregestratie Adressen en Gebouwen) in order to estimate the number of inhabitants per 10x10m grid cell.

First a measure for the number of domestic housing units (‘verblijfseenheden’) per square metre are established based on an POSTGIS instance of the BAG dataset: https://data.overheid.nl/data/dataset/basisregistratie-adressen-en-gebouwen--bag-

First a query is performed to select the domestic housing units that are currently in use:

Script of view “verblijfsobjectenactueelbestaand”

```
SELECT verblijfsobject.oid::character varying AS oid,
verblijfsobject.identificatie, verblijfsobject.aanduidingrecordinactief,
verblijfsobject.aanduidingrecordcorrectie, verblijfsobject.officieel,
verblijfsobject.inonderzoek, verblijfsobject.begindatumtijdvakgeldigheid,
verblijfsobject.einddatumtijdvakgeldigheid,
verblijfsobject.documentnummer, verblijfsobject.documentdatum,
verblijfsobject.hoofdadres, verblijfsobject.verblijfsobjectstatus,
verblijfsobject.oppervlakteverblijfsobject,
verblijfsobject.verblijfsobjectgeometrie, verblijfsobject.begindatum,
verblijfsobject.einddatum, verblijfsobject.geometrie

FROM bag.verblijfsobject

 JOIN bag.verblijfsobjectgebruiksdoel ON verblijfsobject.identificatie::text
= verblijfsobjectgebruiksdoel.identificatie::text

WHERE verblijfsobjectgebruiksdoel.gebruiksdoelverblijfsobject::text =
'woonfunctie'::text AND verblijfsobject.begindatum <= 'now'::text::date
AND verblijfsobject.einddatum >= 'now'::text::date AND
verblijfsobject.aanduidingrecordinactief::text = 'N'::text AND
verblijfsobject.verblijfsobjectstatus::text <> 'Niet gerealiseerd
verblijfsobject'::text AND verblijfsobject.verblijfsobjectstatus::text <>
'Verblijfsobject ingetrokken'::text AND verblijfsobject.geometrie &&
st_makeenvelope(10400::double precision, 546000::double precision,
279000::double precision, 620000::double precision, 28992);
```

The following query retrieves the number of domestic housing units per square metre:

Script of view "pandscores"

```
SELECT pandscore.pand, pandscore.score,
st_area(pandactueelbestaand.geometrie) AS opp,
pandscore.score::double precision /
st_area(pandactueelbestaand.geometrie) AS finalscore,
pandactueelbestaand.geometrie

FROM ( SELECT vop.gerelateerdpand AS pand, count(*) AS score

FROM ( SELECT DISTINCT vo.identificatie, vp.gerelateerdpand

FROM emi.verblijfsobjectactueelbestaandquadranta vo

JOIN bag.verblijfsobjectpand vp ON vo.identificatie::text =
vp.identificatie::text) vop

GROUP BY vop.gerelateerdpand) pandscore

JOIN bag.pandactueelbestaand ON pandscore.pand::text =
pandactueelbestaand.identificatie::text;
```

The resulting feature class contains all residential buildings in the Netherlands, along with an attribute that expresses the number of domestic housing units per square metre. The feature layer is imported into a personal geodatabase for further processing.

Next, a feature class is imported containing Dutch neighbourhood statistics. The data are provided by CBS: https://www.cbs.nl/nl-nl/dossier/nederland-regionaal/geografische%20data/wijk-en-buurtkaart-2017.

A spatial join between both feature classes is performed, resulting in a new layer in which the summed attributes of the buildings are calculated for each neighbourhood.

Another spatial join is performed between the new layer and the layer containing the residential buildings. This results in a new feature class in which each residential object contains the statistics on the neighbourhoods.

In the next step, a new field of the data type 'double' is added to the new layer. Using the Arcmap field calculator, a 'proxy' value for the number of residents per 100m^2 pixel is calculated for each building feature:

((score/sum_score)*aant_inw)/(opp/100)

In which:

score number of domestic housing units per square metre
sum_score number of domestic housing units per neighbourhood (obtained from spatial join)
aant_inw number of residents in the neighbourhood
opp area of the building

A new 10m raster layer is created using SAGA rasterized in QGIS based on the newly calculated attribute.
The reason for using this particular module for rasterizing is the relatively wide perimeter that is applied when assigning pixels to features, whereas other rasterized modules tend to lead to losses of pixels, e.g. when less than half a pixel cell is filled by an overlapping feature.
Consequentially, the resulting raster will overestimate the total population number. To correct for this, a factor is applied to each pixel cell:

Factor = (sum of inhabitants in raster/number of inhabitants in the Netherlands in 2017)

RIVM

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