Natural Capital Model

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This document contributes to the body of knowledge which will be incorporated in more policy-oriented publications such as the National Nature Outlook and the Assessment of the Human Environment reports, and thematic assessments.

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Natural Capital Model

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Abstract

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As part of the expertise development within the WOT, and in collaboration with a number of other knowledge institutes, we worked in recent years on the Natural Capital Model. This model consists of a set of ecosystem service models and is designed to determining the biophysical state of the natural capital in the Netherlands (mapping), as well as estimating the effects of existing and new policy and future developments on this natural capital (modelling). The model determines the potential societal demand for goods and services and to what extent ecosystems in the Netherlands meet this demand. The aim of this report is to present the technical underpinning of the latest version of the Natural Capital Model, including model assumptions, data requirements and data outputs. With the right input, the model can generate figures and spatial maps for the thirteen ecosystem services provided by urban, rural and natural areas: drinking water production, wood production, biomass for energy production, pollination, soil fertility, water retention, urban cooling, water purification, pest control, carbon sequestration, air quality regulation, outdoor recreation and natural heritage. This report is written following the Status A quality criteria of the WUR. Status A quality is about model quality, describing the model, assumptions, and assessing validation, calibration and uncertainty analysis. Actually obtaining Status A, applying the model and improving the individual ecosystem service models will be a priority for the coming years.

Keywords: ecosystem services, natural capital, supply, demand, models

Als onderdeel van de Kennisontwikkeling binnen de WOT is er in samenwerking met een aantal andere kennisinstituten de afgelopen jaren gewerkt aan het Natural Capital Model. Dit model bestaat uit een set van ecosysteemdienstmodellen en is ontworpen om zowel de biofysische toestand (mapping) van het natuurlijk kapitaal in Nederland te kunnen bepalen, als het effect in te kunnen schatten van bestaand en nieuw beleid en van toekomstige ontwikkelingen van dit natuurlijk kapitaal (modellering). Het model bepaalt de potentiële maatschappelijke vraag aan goederen en diensten en de mate waarin ecosystemen in Nederland aan deze vraag kunnen voldoen. Het doel van dit rapport is om de technische onderbouwing van de meest recente versie van het Natural Capital Model te presenteren, inclusief model-aannamen, benodigde gegevens en resultaten. Met de juiste input kan het model cijfers en ruimtelijke kaarten voor dertien ecosysteemdiensten genereren voor stedelijke, landelijke en natuurlijke gebieden: drinkwaterproductie, houtproductie, biomassa voor energieproductie, bestuiving, bodemvruchtbaarheid, waterberging, verkoeling in de stad, waterzuivering, plaagonderdrukking, koolstofvastlegging, luchtzuivering, groene recreatie en natuurlijk erfgoed. Dit rapport is geschreven conform het Status A-kwaliteitssysteem van de WUR. Status A-kwaliteit gaat over modelkwaliteit en beschrijft de modellen, aannames, validatie, kalibratie en onzekerheden. Het daadwerkelijk verkrijgen van deze A-status, het toepassen van het model en het verbeteren van de afzonderlijke ecosysteemdienstmodellen heeft prioriteit voor de komende jaren.

Trefwoorden: ecosysteemdiensten, natuurlijk kapitaal, aanbod, vraag, modellen

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Preface

With the technical description of the Natural Capital Model in this report, we hope to take a step in quantifying the useful goods and services that nature can provide and thereby support the inclusion of ecosystem services in Dutch decision-making. The model is being used for more and more applications, so we will continue to work in collaboration with others on increasing its scientific quality and applicability for practice and policy in the future.

We thank Dirk-Jan van der Hoek (PBL), Wim Nieuwenhuizen (WENR) and Clara Veerkamp (PBL) for their supervision and review of the report. In addition, we would like to thank Ton de Nijs (RIVM), Martina Paulin (RIVM), Rixt de Jong (CBS), Patrick Bogaart (CBS) and Joop van Bodegraven (LNV) for discussions on natural capital in our regular meetings.

Bart de Knegt

Contents

Summary

The societal debate about nature has expanded from biodiversity conservation to the recognition of the various contributions that nature makes to society via ecosystem services. Consequently, there is a need for instruments to evaluate the effect of future developments and interventions on these services and to identify options for action in order to achieve a more sustainable future and realise sectoral policy targets.

The Natural Capital Model (NC-Model) is being developed to help meet this need. Wageningen Environmental Research (WENR) and the Netherlands Environmental Assessment Agency (PBL) have been working on this model in collaboration with other institutes (for instance RIVM, Statistics Netherlands, Wageningen University) as part of the expertise development within the Statutory Research Tasks Unit (WOt). These institutions also have their own data and work on different applications where they also use a range of other methods. The NC-Model provides insight into the biophysical contribution Dutch nature makes to human wellbeing by spatial calculation of ecosystem services. The ecosystem services included in the model are drinking water production, wood production, biomass for energy production, pollination, soil fertility, water retention, urban cooling, water purification, pest control, carbon sequestration, air quality regulation, outdoor recreation and natural heritage. The model is designed for use at the national and regional levels, but could possibly be applied at lower levels as well. The model is still under development and is expected be improved in scope and quality in the coming years.

The NC-Model consists of a set of ecosystem service models and is aimed at determining the biophysical state of natural capital in the Netherlands. The model provides insights into the current situation and state of ecosystem services (mapping) and calculates potential consequences of future spatial plans, policy interventions, autonomous developments and other changes (modelling). The model quantifies the potential demand for goods and services and the potential supply of ecosystems in the Netherlands to meet this demand (supply). As the NC-Model aims to support planners and policymakers in making more balanced decisions when assessing the sustainability and implications of (spatial) plans and policy, it provides location-based spatial calculations of the ecosystem services in the Netherlands. The model can also be used to identify the contribution nature can make towards achieving certain societal challenges (nature-based solutions). Examples include assessing the impact of more flower-rich field margins to increase pest control in agricultural areas and reduce pesticide use in order to enhance food security, as well as other co-benefits (e.g. landscape attractiveness, biodiversity).

The NC-Model is largely automated, which means that the correct input data will generate a standard set of indicators. This makes the model accessible to a larger group of stakeholders. Work has also been done on WUR's Status A quality system. Status A quality concerns model quality, describing the models, assumptions, validation, calibration and uncertainty analysis. This report describes the progress of all Status A components per ecosystem service. Some models are further in their development than others and not all ecosystem services currently meet all the quality requirements for Status A. Obtaining Status A, applying the model to specific cases and improving the individual ecosystem service models will be a priority for the coming years.

The aim of this report is to present the technical underpinning of the NC-Model. Although other reports have been published on ecosystems services in the Netherlands (Van Berkel et al., 2021) and earlier versions of the NC-Model (Remme et al., 2017), this is the first time the complete set of models are described in one document. As the models used are continuously under development, future reports will probably be published online only. This report consists of 21 chapters. The first chapter introduces the conceptual framework, applications, model quality aspects and collaborating institutes. This chapter will be used to further align separate ecosystem services models. Chapter 2 describes how the NC-Model is technically implemented. Chapter 3 describes the input maps that are needed to run the NC-Model. Chapters 4 to 18 describe the separate ecosystem service models that comprise the NC-Model. These chapters have a fixed format. First, the theoretical rationale is described, then the technical implementation, the input, output, parameters and variables, followed by an evaluation of the model's functioning. The chapters finish with a summary of the model quality and wishes for the future. Chapter 19 covers model development, model

organisation and user documentation. Chapter 20 is the summary of the Status A self-assessment and Chapter 21 is about other benefits of ecosystem services that can be calculated. This report does not include results from model applications.

Samenvatting

Het maatschappelijk debat over natuur verbreedt zich van biodiversiteitsbehoud naar het erkennen van de bijdrage die natuur heeft voor de samenleving (ecosysteemdiensten). Hierdoor ontstaat de behoefte aan instrumenten waarmee het effect van toekomstige ontwikkelingen en interventies op deze bijdrage van de natuur kan worden geëvalueerd en waarmee handelingsopties in beeld worden gebracht om een meer duurzame toekomst te bewerkstelligen en beleidsdoelen te realiseren.

In dit kader is het Natuurlijk Kapitaal Model (NK-Model) ontwikkeld. Via de Kennisontwikkeling van de WOT is er door WENR en PBL de afgelopen jaren in samenwerking met andere instituten (zoals RIVM, CBS, WUR) aan dit model gewerkt. Deze instituten hebben ook hun eigen data en werken aan verschillende toepassingen waarvoor ze ook verschillende andere methodes gebruiken. Het NK-Model geeft inzicht in de biofysische bijdrage van de Nederlandse natuur via de (ruimtelijke) berekening van ecosysteemdiensten. De ecosysteemdiensten die met het NK-Model berekend kunnen worden zijn: drinkwaterproductie, houtproductie, biomassa voor energieproductie, bestuiving, bodemvruchtbaarheid, waterberging, verkoeling in de stad, waterzuivering, plaagonderdrukking, koolstofvastlegging, luchtzuivering, groene recreatie en natuurlijk erfgoed. Het model is ontwikkeld om toe te passen op landelijk en regionaal niveau, maar zou mogelijk op lagere schaalniveaus toegepast kunnen worden. Het model is nog in ontwikkeling. Er wordt verwacht dat het domein zich zal verbreden en de modelkwaliteit zal verbeteren in de komende jaren.

Het model integreert een set van ecosysteemdienstmodellen. Het is erop gericht zowel de biofysische toestand (mapping) van het natuurlijk kapitaal in Nederland te kunnen bepalen, als het effect in te kunnen schatten van bestaand en nieuw beleid en van toekomstige ontwikkelingen van dit natuurlijk kapitaal (modellering). Het model kwantificeert de potentiële vraag naar ecosysteemdiensten en het potentiële aanbod van ecosystemen in Nederland om in deze vraag te voorzien. Het NK-Model is gericht op het ondersteunen van planners en beleidsmakers om meer gebalanceerde keuzes te maken als het gaat om duurzaamheid en implicaties van (ruimtelijke) plannen en beleid. Daarom is dit model ontwikkeld om locatie specifieke berekeningen van ecosysteemdiensten in Nederland te maken. Het model geeft inzicht in de consequenties van toekomstplannen, beleidsinterventies, autonome ontwikkelingen of andere veranderingen (door het veranderen van model-input) op het leveren van meerdere ecosysteemdiensten. Het model kan ook worden gebruikt om de bijdrage van natuur voor verschillende maatschappelijke uitdagingen te kwantificeren (nature-based solutions). Bijvoorbeeld: het evalueren van de impact van meer bloemrijke akkerranden op plaagonderdrukking om voedselveiligheid te vergroten, pesticidegebruik te reduceren en andere voordelen te vergroten (bijvoorbeeld aantrekkelijkheid van het landschap, biodiversiteit).

Het NK-Model is voor een groot deel geautomatiseerd, waardoor met de juiste invoerdata voor alle ecosysteemdiensten een standaardset indicatoren genereerd wordt. Hiermee wordt het mogelijk voor een grotere groep mensen alle onderliggende ecosysteemdienstmodellen door te kunnen rekenen. Er is tevens gewerkt aan het Status A-kwaliteitssysteem van de WUR (evaluatie, ontwikkeling en organisatie van het model en interpretatie en gebruik van de modeluitkomsten). Status A-kwaliteit gaat over modelkwaliteit en beschrijft de modellen, aannames, validatie, kalibratie en onzekerheden. In dit rapport wordt de voortgang van alle onderdelen van status A per ecosysteemdienst beschreven. Sommige modellen zijn verder in hun ontwikkeling dan andere. Nog niet alle ecosysteemdiensten voldoen aan alle gestelde kwaliteitseisen van status A. Het daadwerkelijk verkrijgen van deze A-status, het toepassen van het model in casussen en het verbeteren van de afzonderlijke ecosysteemdienstmodellen heeft prioriteit voor de komende jaren.

Doel van deze rapportage is om de technische onderbouwing van het NK-Model te presenteren. Ondanks dat er eerder rapportages zijn verschenen over ecosysteemdiensten in Nederland (van Berkel et al. 2021) en eerdere versies van het NK-Model (Remme et al., 2017), is dit de eerste keer dat de complete set van modellen zijn beschreven in een document. Omdat de gebruikte modellen continu verbeterd worden, zullen toekomstige updates van het model waarschijnlijk online gepubliceerd worden. Dit rapport bevat 21 hoofdstukken. Het eerste hoofdstuk introduceert het conceptuele raamwerk, toepassingen, modelkwaliteitsaspecten en instituten waarmee is samengewerkt. Dit hoofdstuk zal gebruikt worden om de

afzonderlijke modellen uit te lijnen. Hoofdstuk 2 beschrijft hoe het NK-Model technisch is geïmplementeerd. Hoofdstuk 3 beschrijft de input-kaarten die nodig zijn om het NK-Model te draaien. Hoofdstuk 4 tot en met 18 beschrijven de afzonderlijke ecosysteemdienstmodellen die onderdeel zijn van het NK-Model. Deze hoofdstukken hebben een vast format. Eerst wordt het theoretische kader beschreven, dan de technische implementatie, gevolgd door een beschrijving van de input, output-parameters en variabelen. Dan word het modelfunctioneren besproken. Elk hoofdstuk eindigt met een samenvatting van de modelkwaliteit en wensen voor de toekomst. Hoofdstuk 19 gaat over modelontwikkeling, modelorganisatie en gebruikershandleiding. Hoofdstuk 20 is de samenvatting van de Status A self-assessment en hoofdstuk 21 gaat over andere voordelen dan ecosysteemdiensten die kunnen worden berekend. Dit rapport bevat geen resultaten van modeltoepassingen.

1 Introduction

Bart de Knegt (WENR)

1.1 Conceptual framework

1.1.1 What are Ecosystem services?

There is an increasing awareness that biodiversity and ecosystems not only exist, but are also essential for human survival and for a good quality of life. Biotic natural capital or ecosystem capital consists of ecosystems, which deliver a wide range of services that are beneficial for human well-being. Examples of such benefits are the pollination of agricultural crops by wild pollinators (such as bees) so food is produced, the purification of soil, air and water so people have clean drinking water, the retention and sequestration of carbon (e.g. in peatlands or forests) to mitigate the effects of climate change and the positive effects on human health. We can experience and appreciate these benefits – financial, material or intangible – individually or as a group, directly or indirectly (Pascual et al., 2022). Whether we live in the countryside or in the middle of the city, whether we are passionate nature lovers or have no eye for it at all, ecosystems are factories of economic prosperity and a source of human well-being. The goods and services that natural capital or ecosystems provide to people are called ecosystem services (Figure 1.1). The recent scientific literature on this topic also refers to Nature's Contribution to People (NCP), which is roughly the same concept but has a broader definition than ecosystem services (Diaz et al., 2018). Ecosystem services can consist of tangible or intangible goods and services and are often divided into three groups (see also Section 1.1.3). Provisioning ecosystem services take the form of material, physical products, such as woody biomass, animal feed or food. Regulating ecosystem services are physical processes, such as water purification or regulation of the urban climate. Cultural ecosystem services have an intangible form, such as opportunities for recreation, relaxation, scientific research, education, and preserving our natural heritage for current and future generations (Figure 1.1).

Figure 1.1 *shows examples of ecosystem services provided by the landscape. The use of ecosystem services yields societal benefits. Ecosystems and their services are the basis of our individual and collective well-being and our economic prosperity.*

Interventions in the landscape influence the delivery of ecosystem services and therefore also affect prosperity and well-being of humans in the Netherlands. However, information about the effects of interventions on ecosystem services is often missing in policy decisions. PBL aims for this reason to improve the visibility of current and future ecosystem services in order to improve support for decision-making by government and business. Therefore the NC-Model is developed. This model assesses the benefits of our natural capital hence the name NC-Model.

1.1.2 Ecosystem services as conceptual framework for the NC-Model

Aim of the model

The NC-Model aims to support planners and policy makers on making more balanced decisions when assessing the sustainability of implications of (spatial) plans and policy. Therefore, the NC-Model (NC-Model) was developed to provide location-based spatial calculations of ecosystem services in the Netherlands. The model provides insights into the current situation/state of ecosystem services at the national and provincial level, as well as calculates potential consequences of future spatial plans, policy interventions, autonomous developments or other changes (by changing the model input) on the delivery of multiple ecosystem services. The model can also be used to identify the contribution of nature to certain societal challenges (nature-based solutions). For instance, assessing the impact of increasing the amount of flower field margins on pest control services to agricultural areas to enhance food security, as well as other co-benefits (e.g., landscape attractivity, biodiversity).

Key model elements: supply & demand of ecosystem services
To assess the ecosystem services as the benefits to people, the NC-Model works with the supply-demand-framework (Figure 1.2), referring to the notion that ecosystem services are realized only if the societal demand for these services is met by the ecosystem's capacity to deliver that service (Burkhard et al. 2012, 2014). The capacity of an ecosystem to deliver a service depends on the structure, processes and functions of an ecosystem (Figure 1.2). Ecosystems are dynamic complexes of communities of animals, plants and micro-organisms and their not living, abiotic environment that form a functional entity (https://www.biologyonline.com/dictionary/ecosystem). Ecosystems vary depending on abiotic characteristics like soil type, acidity of the soil, trophy degree, moisture conditions, temperature, and altitude. Examples of ecosystems are for example a forest ecosystem or an agricultural ecosystem with landscape elements like hedges and wooded banks. Different types of ecosystems affect the bundle of ecosystem services that are supplied. The type, size, quality, location and interactions with other ecosystems are determinants of the ecosystem services that are supplied. On the other side there is the demand for goods and services (possibly supplied by ecosystems as ecosystem services) required or desired by society (Villamagna et a., 2013). There are different approaches used to operationalize demand, but generally classified into two demand categories: desires and consumption/direct use of ecosystem services (Wolff et al., 2014, table 1.1). Desires including the need for risk reduction or prevention (e.g., need for protection) as well as people's preferences and values, commonly used to quantify demand for regulating services and cultural services respectively. The direct use and consumption of ecosystem services (e.g. wood consumption) is predominantly used to identify the demands for provisioning services, as well as cultural services (e.g., direct use of recreational or cultural sites) (Wolff et al., 2015).

To conceptualize the demand within the NC-Model, the demand categories as described by Wolff et al., 2014 were used. On the one hand there are services that are wanted by society but have no corresponding policy goals. For instance the demand for pollination is determined by the dependency of agricultural crops on pollination to be able to set seed or produce fruit. On the other hand there are services that are wanted by society and are also translated into (quantitative) policy goals. For instance people want to breath clean air, and also quantitative targets (norms, see table 1.1) set by the EU and WHO on the maximum concentration of fine dust air particles allowed in the air to insure a good air quality. Vegetation is able to capture these fine dust particles and in that way contributes to meet the desired condition. For carbon sequestration there are also quantitative policy goals (or norms) on the sequestration of carbon in time. For instance to reduce the carbon emissions by 49% in 2030 and by 100% in 2050 following the Paris Climate Agreement. Sometimes there are more policy targets for an desired service. For instance there are multiple policy targets for the conservation and restoration of biodiversity. There are goals defined by the Convention of Biological Diversity on the global level (Aichi targets), goals concerning the Birds and Habitats Directives on the European level, and goals on the national and sub-national level.

The NC-Model calculates the (mis)match between supply and demand from ecosystems for these services. Ecosystem services are only actually used if supply and demand match. Society only benefits from services if the supply of these services is also used. For instance a marsh area that is fed by nutrient rich water from an arable field generates an ecosystem service by purifying the water. The same marsh area that is not fed by nutrient rich water does not deliver the service of water purification. In the last instance there is no demand or use for a the service of water purification. Another example is an accessible forest near a city with a high population delivers a bigger ecosystem service compared to the same forest in an area with no or limited demand for recreation. Many regulating and cultural ecosystem services need to be supplied where the demand is located (e.g. pest control, outdoor recreation), while the goods from production services are transportable (e.g. drinking water, wood) and can be produced anywhere. How the supply, demand and use is derived per ecosystem services is described in this reports chapters per ecosystem service.

We do know the demand for goods and services as reflected by societal needs and preferences. This demand could be supplies by ecosystems. In this case we call these services ecosystem services. But it is also possible to import these goods and services, produce them by technical means or leave them unsupplied. The NC-Model calculates the contribution of ecosystems to supply these goods and services as ecosystem services.

Explicitly distinguishing between supply, demand and use of ecosystem services has some important consequences for applying the concept of ecosystem services in policy. In the first place, this means that the societal value of ecosystem services does not depend solely on the characteristics of that ecosystem itself, but also on the societal context in which that ecosystem and the services it generates are situated. Changes in that context can make the services that the ecosystem provides valuable to various degrees, even if the ecosystem itself does not change. This view of 'value' differs from estimates of the biological value of ecosystems that are traditionally used in nature conservation and that mainly focus on the attributes of those ecosystems themselves (attributes such as rarity, structural diversity, surface area and substitutability).

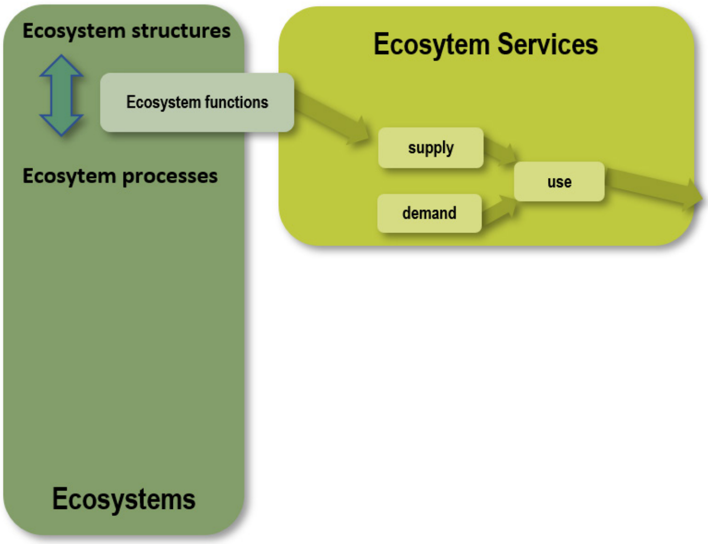


Figure 1.2 *The NC-Model's core consists of the relation between the capacity of ecosystems to deliver a service (supply), the societal demand for this service and their combination/match what delivers ecosystem services (based on Van Reeth et al., 2014).*

Broader conceptual context of the NC-Model

The NC-Model essentially works with the supply, demand and use to determine which and how many ecosystem services are provided. Supply and demand are influenced by direct drivers (such as changes in land use, climate change and pollution) and indirect drivers (such as demographics, economics, culture and religion) (Fig. 1.3). These drivers are not directly modelled in the NC-Model, but are accounted for through the use of various input maps (e.g., desiccation, fragmentation, change in temperature etc. Figure 1.3 (from Van Reeth et al. 2014) shows these other components of the larger conceptual framework. This framework was inspired by the conceptual frameworks of previous ecosystem assessments and subsequent interdisciplinary research (De Groot et al., 2010; Haines-Young et al., 2006; Haines-Young et al., 2010; MA, 2005; Mace et al., 2011; Maes et al., 2013).

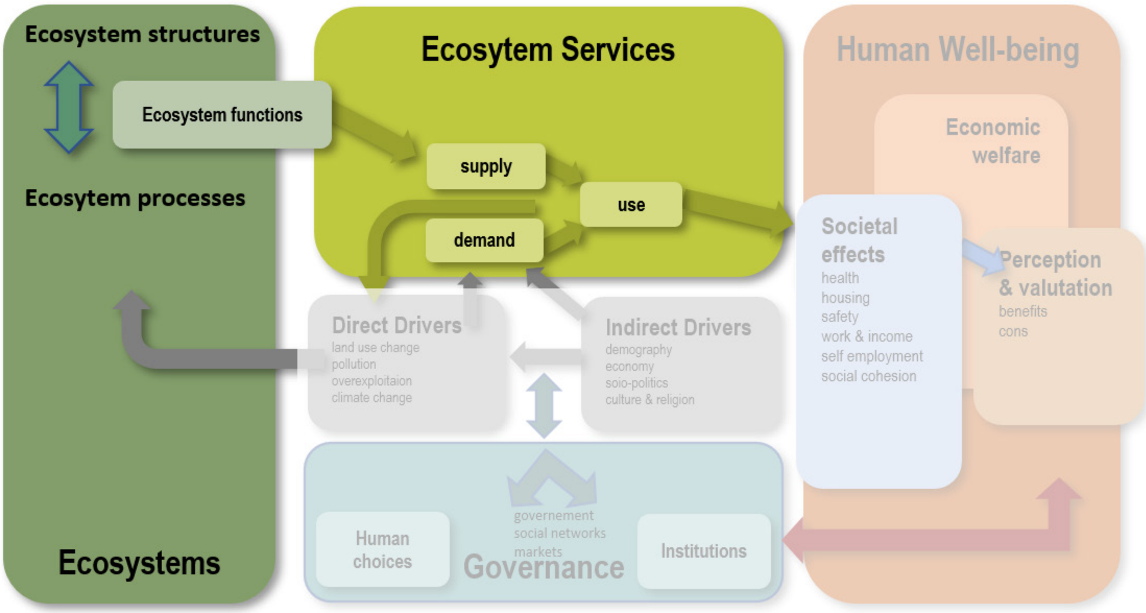


Figure 1.3 *The model's context (bleached out parts) consists of parts that are not part of the model itself. The effects of interventions via governance on (in)direct drivers on the delivery of ecosystem services can be calculated via scenario input. Effects on human well-being indicators is calculates in other modules. Based on Van Reeth et al., 2014*

Direct and indirect drivers can have undesirable effects on ecosystems or people, and they are often presented as 'pressures', as part of an environmental disturbance chain (driver, pressure, state, impact, response or DPSIR framework) (Van Reeth & Vanongeval, 2005; Verbruggen, 1998). Direct and indirect drivers influence the supply and demand of ecosystem services. For example, under changing climate conditions a fragmented, desiccated, fertilised and acidified ecosystem will contain less biodiversity than an ecosystem without these pressures. Due to this decline in biodiversity, the ecosystem will be less able to provide ecosystem services (Harrison et al., 2014). The NC-Model does not model these drivers directly, but links have been made to calculate the effects of a number of the most important pressure factors such as desiccation, fertilisation and climate change on the supply of ecosystem services. The model does allow adjustment of the demand for ecosystem services via the input maps. This can be done, for example, by increasing the number of people or increasing the load of substances that ecosystem services can remove from systems. Annex 13 contains a list of the most important pressure factors on the supply and demand of ecosystem services and the influence of these factors on the services.

The effects of ecosystem services on human well-being (such as health effects, social cohesion and economic valuation) are also not determined by the model. Ecosystem services do have an effect on human well-being. This can be expressed in various ways. This also includes the monetary valuation of ecosystem services. However, this value is determined (CBS/WUR) in other processes, such as the natural capital accounts (United Nations, 2021).

The effects of policy and practice (governance) that influence the direct and indirect drivers are also not included directly in the model. Government agencies and public bodies, social networks and markets all influence the supply of and demand for ecosystem services via direct and indirect drivers. However, the effects of human choices and actions to protect and restore ecosystems can be calculated with the NC-Model if they are supplied as input data for the model.

Design of the NC-Model

The NC-Model relates the supply of ecosystem services and the demand in separate sub-models per ecosystem services. The input consists of a harmonized set of data on land use, environmental variables and the management of nature areas. Then separate ecosystem services models calculate the (mis)match of supply and demand for ecosystem services. Taken together, the sub-models comprise the full model. These models per ecosystem services provide output maps with the supply, demand and use of ecosystem services spatially and in graphs. The full model will be capable of spatially modelling ecosystem services form both urban, rural and natural ecosystems, depending on the wishes of the user (fig 1.4).

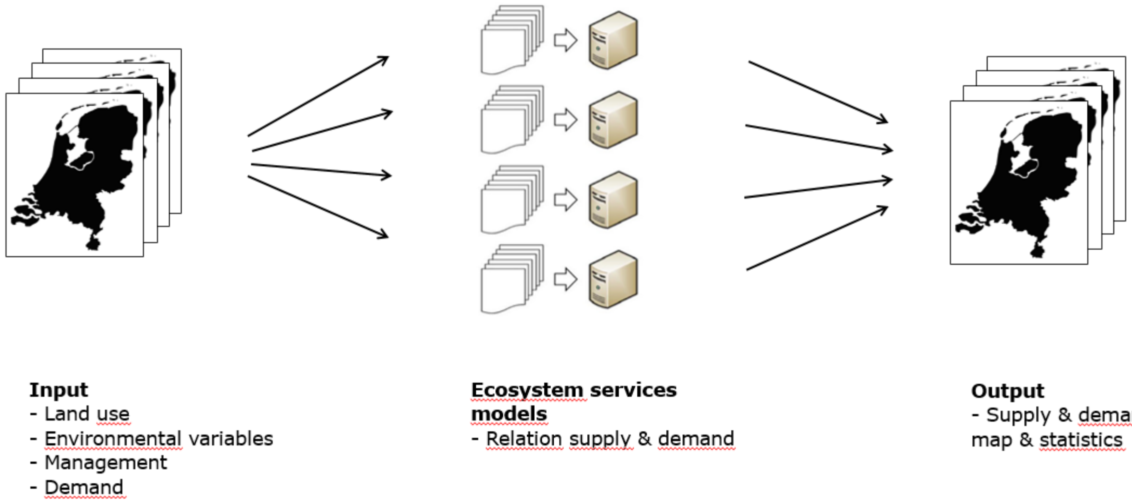


Figure 1.4 *Design of the NC-Model with sub-models per ecosystem service.*

This report describes the first versions of these sub-models per ecosystem service. As the NC-Model develops, the sub-models will be improved as new data and knowledge becomes available and additional sub-models may be added.

1.1.3 Definition and selection of ecosystem services and indicators

There are various way to classify ecosystem services and define associated indicators. We based our classification on the definition of ecosystem services as presented by CICES (Common International Classification of Ecosystem Services), version 5.1. (ref, 2018) (https://cices.eu/resources). CICES describes ecosystem services by using a five-level hierarchical structure including section (e.g., provisioning), division (e.g., biomass, water), group (e.g., cultivated plants),class (e.g., cultivated plants for nutrition) and class type (e.g., cereals). For each level examples of common indicators are provided. The classification used in this report is based on the level of groups. Some adjustments were made to make the classification more relevant for the Dutch situation. For instance labour from animals is not very relevant for the Netherlands, so this service was not assessed. There are broad equivalences between CICES and other commonly used ecosystem services classification systems such as MA, TEEB, IPBES, NCP (Diaz et al., 2018) and SEAA (UN, 2021). These lists are fairly similar and there are also tables to convert between the various classifications. For this model we chose to use the classification of CICES at the level of groups since CICES was used previously (De Knegt et al., 2014), is compatible with the Dutch context and also provides a logical and intelligible classification of ecosystem services.

However, we were not able to model all relevant ecosystem services for the Netherlands. For some ecosystem services, models are being developed at the moment. The figure below (Figure 1.5) shows the services for which a model is available and those for which this is not yet available.

Source: PBL, WUR, CICES 2014

Figure 1.5 *Overview of ecosystem services that are included (coloured) and not included (grey).*

Indicators and units

Selected ecosystem services indicators and units for all ecosystem services differ (Table 1.1). To make the outcomes comparable and to do justice to the holistic assessment of ecosystem services, model outcomes of all ecosystem services are presented in biophysical terms (i.e., supply) as well as a percentage of supply compared to the actual demand (i.e., (mis)match, Burkhard 2012, 2012). In the case of policy targets, results are also presented in terms of percentage achievement of policy targets.

Table 1.1 *Sources of norms for demand, supply and their combination.*

ES category	ES	Demand category	Demand	norm	Supply	Use	Unit
Provisioning services	Drinking Water Production	desires/direct use	demand for sustainable land use in 100-years water infiltration area around water extraction point	sustainable drinking water production	supply of sustainable land use in 100-years water infiltration area around water extraction point	% surface area of 100 years zone around water extration point with sustainable land use (hectare)	ha
	Wood Prodution	desires/direct use & policy	demand for wood products	self sufficience of wood production	supply of wood from forest	% wood production versus demand (m3 woodequivalents without bark/yr)	1000 m3
	Biomass for Energy Production	desires/direct use & policy	demand for energy	National Energy Agreement 16% sustainable energy production in 2023. 100% of energy production from sustainable sources	supply of energy from woody biomass from forest	% energy prodution compared to energy use from forest (PJ/yr)	PJ
Regulating services	Soil fertility	desires/direct use	demand for fertile soils for agricultural crops (eg. good hydrology)	no yield loss because of insufficient soil fertility	supply of fertile soils for crop production (eg. good hydrology)	% avoided harvest loss of crops by fertile soils defined by their hydrology (kg/ha/yr)	tons/pieces
	Urban Cooling	desires/direct use	demand for cooling during heatweaves in cities as a consequence of the Urban Heat Island effect	Reduce the Urban Heat Island effect	supply of cooling by vegetation in cities	% avoided temperature rise of the UHI during a heat wave by vegetation (degree Celcius/capita)	oC
	Water purification	desires/direct use & policy	demand for good chemical conditions for waterbodies (Nitrate & Phosfor)	Fysical-chemical waterquality norms for nitrate and phosphorus for water bodies according to the EU Water Framework	supply of retention of chemicals (nitrate & phosfor) by vegetation	% surface aree of waterbodies with good chemical conditions (nitrate & phosfor) (hectare)	tons NO3, P
	Pest Control	desires/direct use & policy	demand for pest control of agricultural crops that are susceptible to pests	no yield loss because of pests/to reduce by 50% the use and risk of chemical pesticides by 2030.	supply of natural enemies of pests in agricultural crops	Average density of natural enemies in agricultural crops that are susceptible to pests (0-100)	density natural enemies (dimensionless)
	Pollination	desires/direct use	demand for pollinations for all pollinator dependent crops	no yield loss because of pollination deficits	supply of natural pollinators in agricultural crops	% avoided production loss of pollination dependent crops by natural pollinators (kg/ha)	ton/ha ((avoided)loss per total area)
	Carbon Sequestration (forest)	desires/direct use & policy	demand for sequestration of emitted carbon	Paris Climate Agreement 2030 49% reduction, 2050 no net emissions	supply of carbon sequestration by woody biomass of forest	% sequestration of CO2 by forest compared to total emission or policy targets (Mton CO2 eq/yr)	kg CO2
	Carbon Sequestration (peat soils)	desires/direct use & policy	demand for sequestration of emitted carbon	Paris Climate Agreement 2030 49% reduction, 2050 no net emissions	supply of carbon sequestration by peat soils	% sequestration of CO2 by peat soils compared to total emission or policy targets (Mton CO2 eq/yr)	kg CO2
	Air Quality Regulation	desires/direct use & policy	demand for good air quality	concentration of fine dust particles PM2.5 below 10ug/m3 WHO norm	supply of absoroption of fine dust particles from the air by vegetation	% people under the WHO norm for PM 2.5 fine dust (ug/m3)	tons PM2.5
	Water Retention	desires/direct use	demand for soils with enough infiltration capacity so there will be no flooding	infiltration capacity greater than 6 mm/hour	supply of infiltration capacity by vegetation and soils	% people living at places with a water retention capacity greater than 6mm/hour of saturated soils (mm/hour)	mln ltr in 1 hour
Cultural services	Outdoor Recreation	desires/direct use	demand for enough green space for recreation from where people live	no shortages of green where people live	supply of attractive and accessible green space	% people with enough green space in their living environment (number of places for recreation for walking and bicycling)	number of places for recreation
	Natural Heritage	desires/direct use & policy	demand for good enough environmental and spatial conditions for species so they don't go extinct	1) halt biodiversity loss by 2030 and achieve recovery by 2050 & no threatened species, 2) no BHD species and Habitats threatened	supply of habitat in good condition (environmental and spatial)	% species wich have good environmental and spatial conditions to guarantee their sustainable occurence (# species that could occur	number of species with good conditions

1.2 Applications

The model a has been applied to quantify ecosystem services for the following situations:
1. Determining the current state of ecosystem services in the Netherlands
2. Determining the effects of future changes (scenario analysis),
3. Determining where interventions help to implement social tasks via ecosystem services (nature as a solution).
4. Other uses/applications

1.2.1 Current state

The NC-Model supports various WOt products that require knowledge about the current state of ecosystem services:
1. The state of ecosystem services at the moment is the issue, based on the *Nature Balance* and the *Environmental Data Compendium*. This also concerns the development of ecosystem services in the past.
2. The product *Nature Outlook* starts with defining the problem with an outline of the current social challenges. A picture of the current state of ecosystem services trends from the past is also important for this. The spatial component of how the supply and demand of ecosystem services relate to each other also plays a role as a starting point for considering possible solutions with a view to the future.
3. One of the three objectives of national and provincial nature policy addressed in the product *Learning Evaluation of the Nature Pact* (Lerende Evaluatie van het Natuurpact – LEN) concerns enhancing nature and the economy. This requires knowledge about ecosystem services, what they are, what the current situation is, how the situation has developed and what can be done to enhance these services at the national and provincial level.

The application is then to provide a picture for the Netherlands as a whole about how the supply of ecosystem services relates to the demand for useful goods and services. An example of a study for which the NC-Model was used to determine the current state of supply and demand is the Nature Services Indicator (De Knegt et al., 2020), see Figure 1.7. The information about supply and demand can also be spatially represented (see Figure 1.8). The NC-Model is used for the services of pollination, soil fertility, water storage, cooling in the city, water purification, pest suppression, air quality regulation and green recreation.

Measurements are used in the indicator for the services of drinking water, wood production, carbon sequestration, biomass for energy and natural heritage. For the other ecosystem services the models from the NC-Model are used. No analysis has been performed on the differences and similarities in results between the measured and modelled values or how these values differ from what other institutes report.

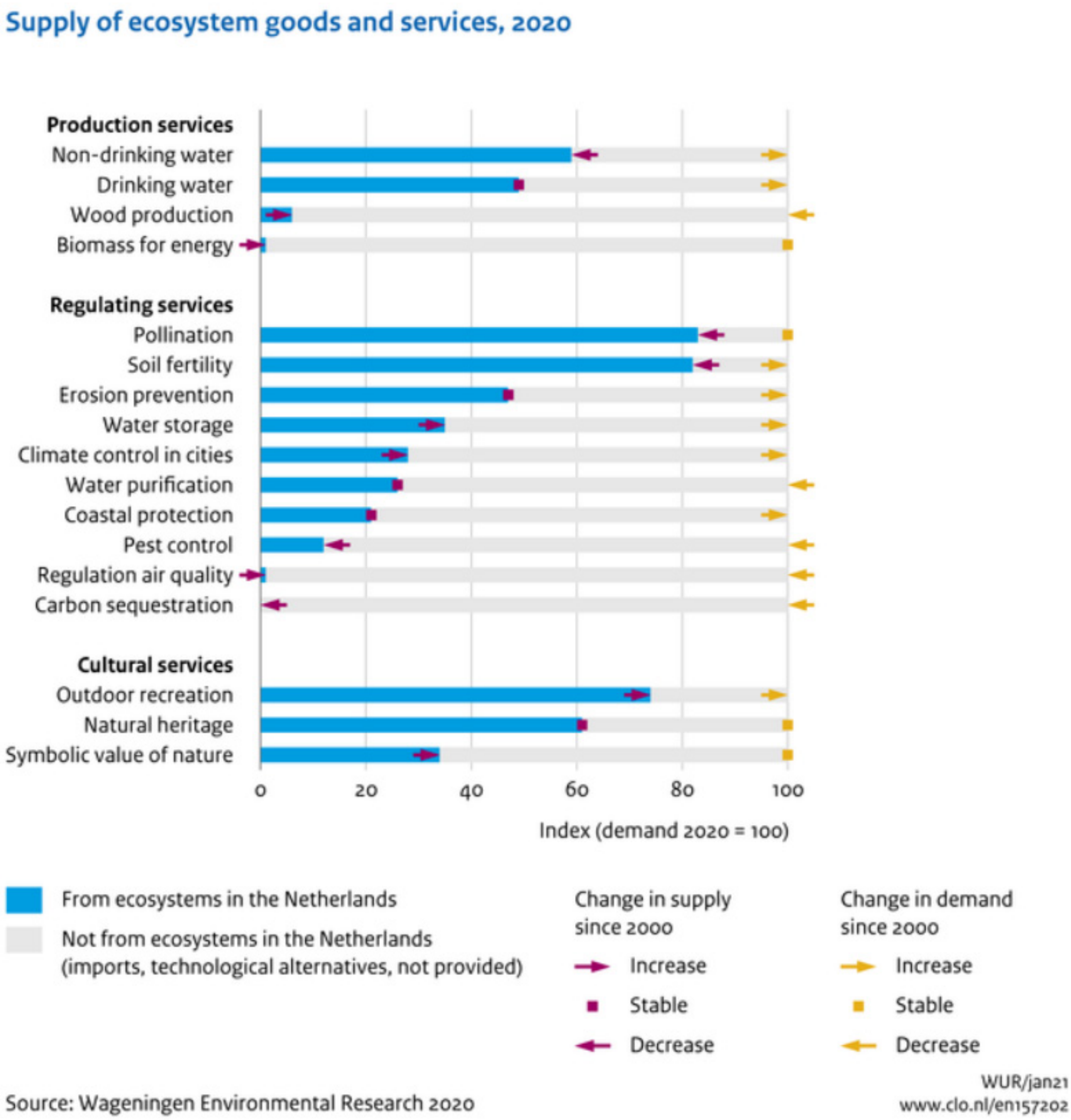


Figure 1.7 *Using the NC-Model to quantify the current state of ecosystem services in the Netherlands (Nature Services Indicator). For some ecosystem services, the match or mismatch in supply and demand is determined by using the NC-Model.*

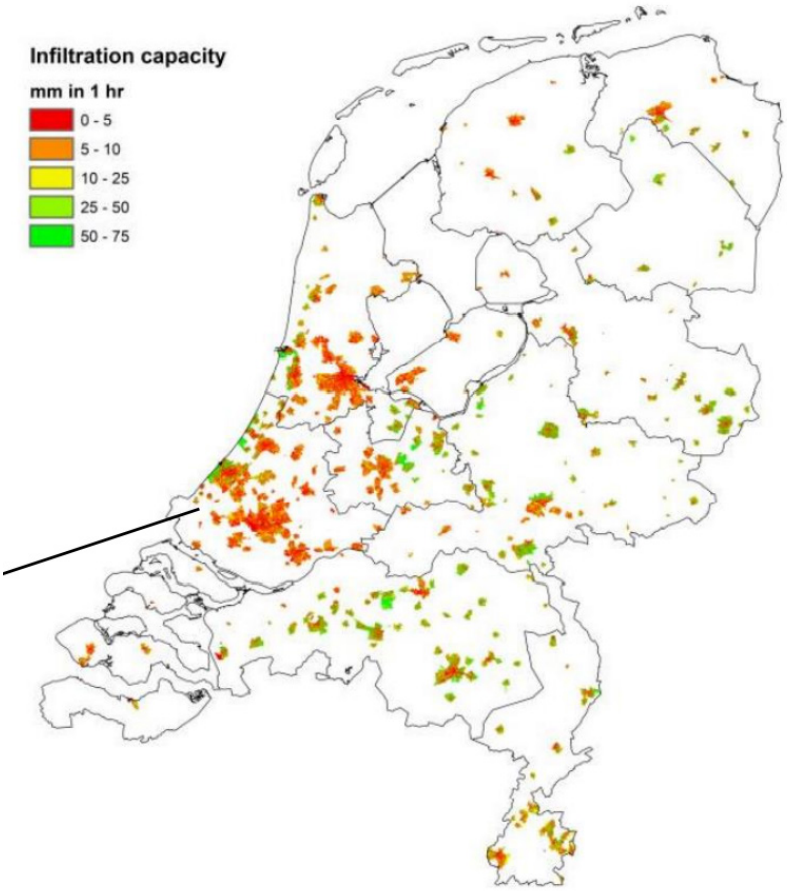


Figure 1.8 *The relationship between supply and demand of goods and services can also be represented spatially. See, for example, the map of water storage in the Netherlands.*

1.2.2 Effects of scenarios

The NC-Model has also been used to determine the effects of for example for the Nature Inclusive Scenario of the Nature Outlook (Breman et al., 2022) or for calculating the effects of election programmes of political parties (PBL, 2021). In the *Scenario Natuurinclusief* (Netherlands Nature Inclusive Scenario), the cities have been designed to be greener, the rural area has been planned with nature-inclusive agriculture, including strip cultivation, field margins and nature-friendly watercourse banks. Nature reserves and peat bogs are designated to reduce carbon emissions, sequester more carbon and mitigate the effects of climate change by giving more space to river and stream systems. These ideas have been made concrete by implementing them in the input maps of the NC-Model. Then the NC-Model was run with this set of input maps. The results for rural areas as part of the total set of ecosystem services of this study are summarised in Figure 1.9 below.

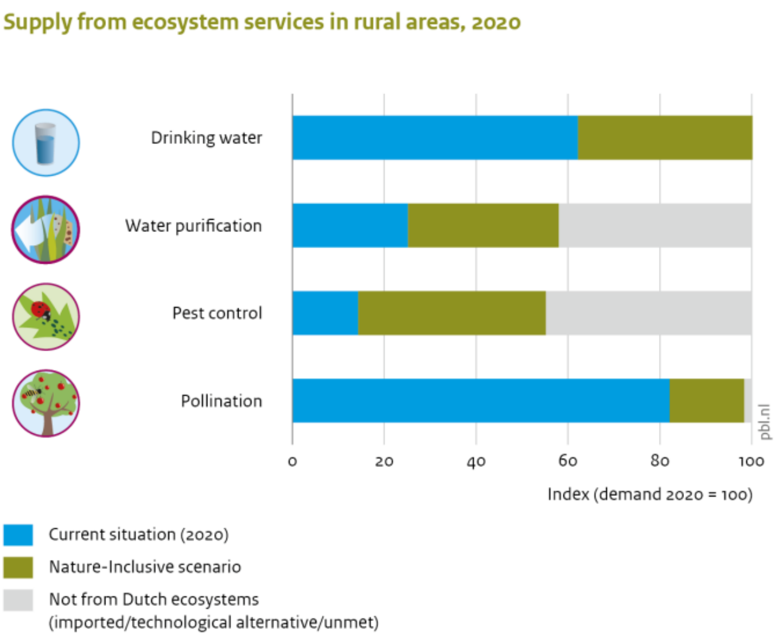


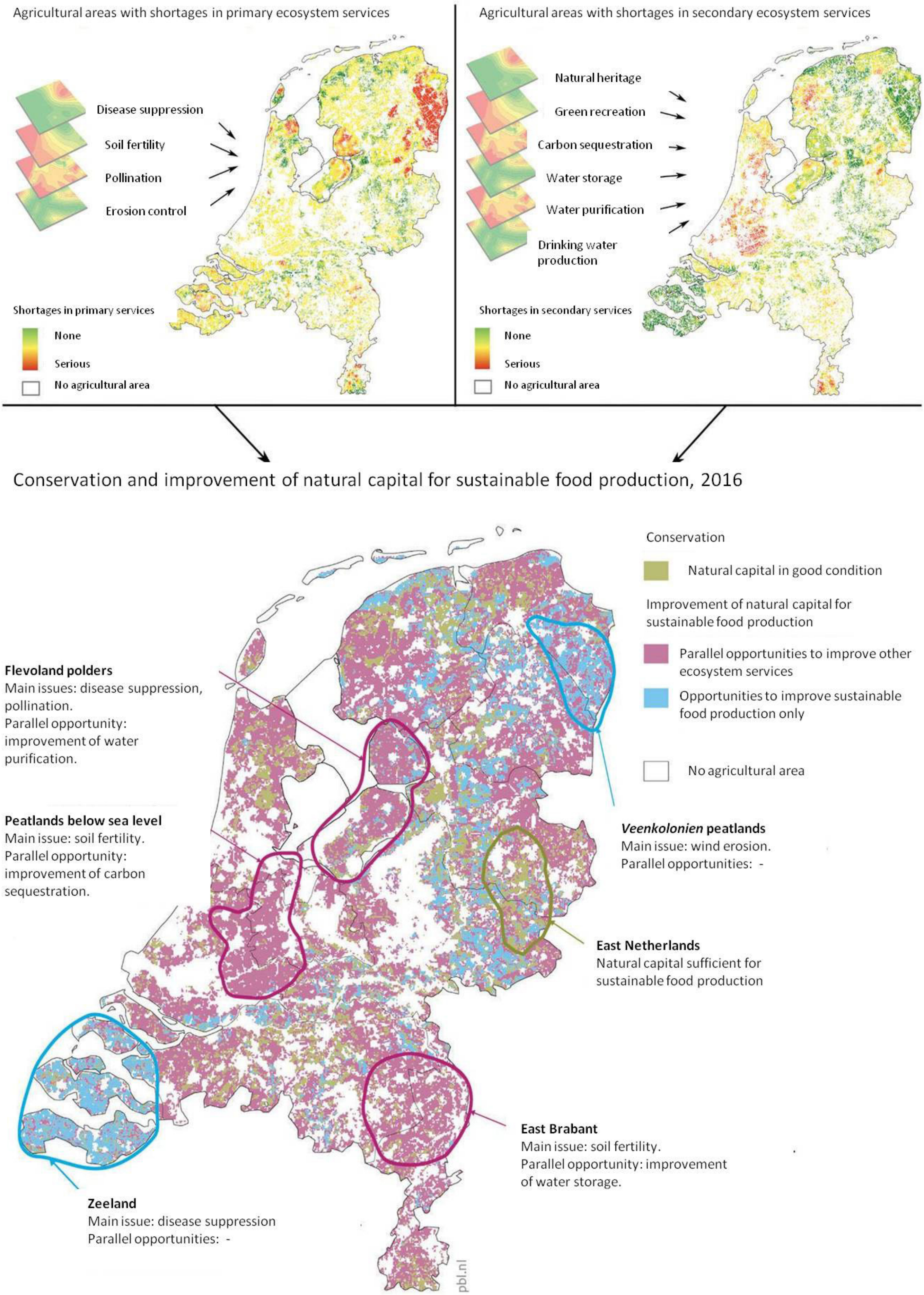
Figure 1.9 *Effects of the Nature Outlook Nature Inclusive Scenario on 4 ecosystem services in rural areas in the Netherlands.*

1.2.3 Ecosystem services to address societal challenges

Finally, the NC-Model can also be used to identify locations where nature-based solutions enhance the delivery of ecosystem services to address societal challenges like climate change is more effective compared to other locations (Figure 1.10).

Figure 1.10 *Relationship between ecosystem services and societal challenges.*

For example, the application below (Figure 1.11) looks at how to enhance ecosystem services for sustainable agriculture. A number of ecosystem services have been selected that can help with this process. For example, focusing on natural pest control services can help to reduce the need for pesticide. Relying more on the soil's ability to provide nutrients and moisture can help reduce the amount of fertiliser and irrigation required. We refer to these as primary ecosystem services. In this way a number of other ecosystem services have been selected that can help to reduce the negative externalities of current agriculture. Maps of all these ecosystem services have been made of the Netherlands where there is a shortage of the service depending on whether a choice is made for nature-inclusive agriculture. This produces a map of the Netherlands for each ecosystem service, with green spots (no shortage) and red spots (shortage). These shortages can then be stacked to see where in the Netherlands there is the greatest and least need to enhance ecosystem services with more nature-inclusive agriculture. Subsequently, we also looked at which other ecosystem services are deficient that nature-inclusive agriculture could make a contribution to. The use of field margins, hedges and hedgerows to stimulate the pest-suppressing effect of ecosystems can have a positive effect on the natural heritage (increase in biodiversity) and make the agricultural area more attractive for recreational use (ecosystem service green recreation). We refer to these as secondary ecosystem services. The result of this study is shown in Figure 1.11 (De Knegt et al., 2019).



Source: WUR, PBL

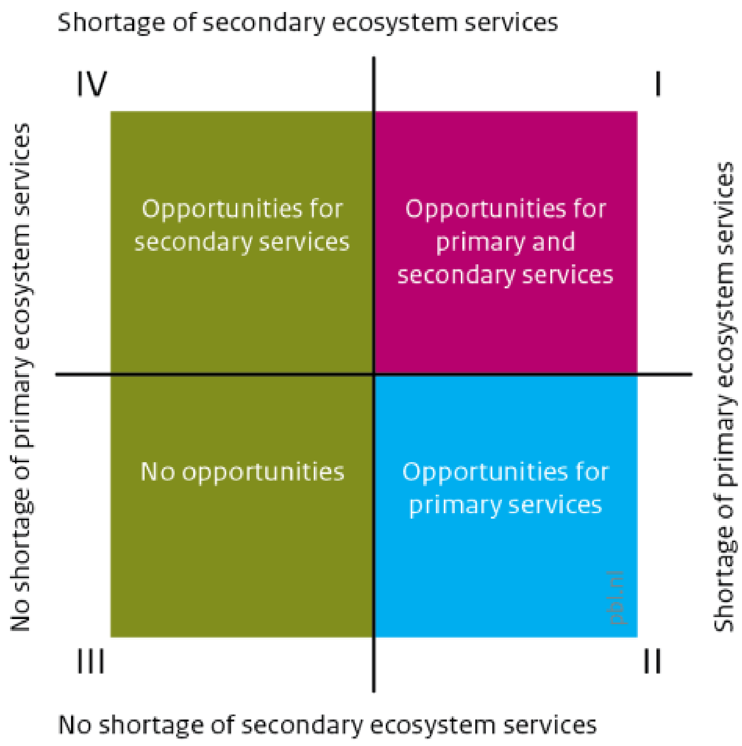


Figure 1.11 *Spatial opportunity map to make agriculture more sustainable by using ecosystem services.*

1.2.4 Other applications

The NC-Model can also be used for other applications, to perform more customised analyses. Examples whereby for instance the tool of QuickScan (https://www.quickscan.pro) can be used include:

1. Analysing demand and supply maps and the match between the two.
2. Adjusting the limits/norms in cases of surplus or shortage.
3. Stacking maps to assess bundles of ecosystem services (synergies and trade-offs).
4. Creating difference maps.

In addition, the QuickScan toolkit is suitable for processing the results:

a. Making cut-outs, for example nationally, per province or per soil type.
b. Generating maps, figures and tables.
c. Tracing the final results back to the source.
d. Working out a case interactively with stakeholders.

1.3 Quality Assurance Status A

Quality Assurance
Models and data sets that are used as part of WOt for PBL and other products must meet the status A quality requirements (Houweling and Voorn, 2015). This includes the description of the model and its technical implementation, the evaluation of the model (sensitivities, uncertainties and validation), the development and organisation of the model and the interpretation and use of the model's results (Table 1.3). This report describes the key components of status A for each ecosystem service model (Chapters 4-18). The components 'Development & Organisation' and 'Interpretation & Use' apply to the NC-Model as a whole and are described in Chapter 19.

The model has been developed for use at the national and regional levels. The further you zoom in, the more uncertain the results become. Status A is therefore granted for the specific statement that applies and for which the parameter estimates and validation apply. If the model is used at a lower scale level, for example at the level of land parcels, the user must take into account that these statements are only indicative and that the uncertainties at that level are unknown. Moreover, the uncertainties strongly depend on the quality of the input data. In general, soil and groundwater maps have the coarsest resolution. The coarsest input map then determines the finest scale level at which statements are still reliable.

Communicatie, reliability, Completeness and Status-A progress
Ideally, the reliability is communicated directly as part of the results. Status A does not yet provide for this. In advance of this provision, the following aspects are therefore briefly summarised: the reliability of the results for each ecosystem service (5-part scale), the completeness of the indicator used (3-part scale) and the progress on Status A (scored for all 14 components). Chapter 20 provides an overview of the quality status of the components of the NC-Model.

Reliability
The reliability of the numerical data is presented according to the system used in the *Environmental Data Compendium*. This concerns how well we are able to model the ecosystem service. On the one hand, this has to do with how much we know about an ecosystem service, how well we understand the control variables that determine the delivery of the service and, on the other hand, how good the data is to be able to make a reliable estimate of the ecosystem service. The reliability of the models is determined on the basis of expert judgement:
- Category A (very high)
- Category B (high)
- Category C (sufficient)
- Category D (moderate)
- Category E (low)

Completeness
CICES (Common International Classification of Ecosystem Services) provides definitions of ecosystem services. The CICES version 4.3 classification at the level of groups has been used previously (De Knegt et al., 2014). It is very compatible with the Dutch context and also provides a logical and intelligible classification of ecosystem services. In 2018 this CICES classification was updated as version 5.1 (https://cices.eu/resources). Broadly speaking, this does not differ much from version 4.3, so the previous classification and nomenclature can still be used. The classification used in this report is based on the level of groups.

The choice of which aspects are included often depends on the availability of data. For example, water pollution consists of many different pollutants. For individual substances it is impossible to indicate the extent to which ecosystem services can filter them from the environment. It was therefore decided to look at the most important pollutants for water, in this case phosphates and nitrates. During the purification of water by ecosystems, many other pollutants will also be filtered from the water. So indirectly, those substances are included in the ecosystem service. However, it is not known exactly how these processes work. For this reason, for each ecosystem service it is indicated – on the basis of expert judgement – how completely the chosen model covers the definition compared to the CICES 4.3 definition. Components that are missing in the model are indicated per model in the fifth section under the heading “Wishes for the future”.

- Category A (complete)
- Category B (contains the most important aspects)
- Category C (contains some aspects)

Status-A progress

The progress for each model is scored on the basis of expert judgement for all relevant components as identified in the status A process. See Table 1.3 below. A three-part scale was used for this:

- complete
- partly complete
- missing

Table 1.3 *Status A quality assurance components.*

Criterium	Part	Aspects	Reference in this report
Science & Technology			
ST.1	The model/dataset is described		
1	There is a general description of the model/dataset	purpose * area of application * theoretical framework * paradigms	per ecosystem service
1	The conceptual and formal model are documented	explicitly documented * assumptions * simplifications * embedded in literature	per ecosystem service
ST.2	The technical implementation of the model/dataset is documented		
2	The implementation is documented	Basic structure * flow diagram	per ecosystem service
2	The technical environment is documented	Language * IDE * settings * limitations	per ecosystem service
2	The model/dataset is tested	Tests documented * protocol * untested components named	per ecosystem service
ST.3	The parameters, variables, inputs to and output of the model/dataset are described		
3	The parameters and variables of the model/dataset are documented	Quantities * units * default values * default source * description	per ecosystem service
3	Calibration of parameters is described	Procedure * results discussed	per ecosystem service
3	The input and output is described	Structure * format * quantities * units * precision * description * link variables & parameters * version echo	per ecosystem service
3	The origin of input data is described	Data preparation pipeline * source * scripts tested	per ecosystem service
ST.4	The functioning of the model/dataset is evaluated		
4	A sensitivity analysis is performed	Tailored to model/dataset type * documented * discussed	per ecosystem service
4	An uncertainty analysis is performed	Qualitative discussion	per ecosystem service
4	The model/dataset is validated	Discussed * non-validated components named	per ecosystem service
4	The use of the model/dataset is monitored	Example studies listed	per ecosystem service
5	There is a general assessment of model/dataset quality	Relate goal to: test * sensitivity * uncertainty * validation * use	per ecosystem service
Development & Organisation			
DO.5	The development of the model/dataset is planned		
5	There is a development plan	List of plans * progress reported * based on evaluation	Chapter 19.1
5	A version control system is in place	Documented * acceptance criteria * (WUR) central archiving	Chapter 19.1
DO.6	The organisation around the model/dataset is planned		
6	The metadata of the model/dataset is available	Domain appropriate format	Chapter 19.2
6	There is a management plan	Responsiblities: content * technical * next-in-line * ownership * financial cover	Chapter 19.2
6	Dependencies are discussed	Datasources * (third-party) use	Chapter 19.2
6	External use is formalised	Conditions for use * User support	Chapter 19.2
Interpretation & Use			
IU.7	User documentation is provided		
7	Interpretation guidance is provided	Goal * area of application * theoretic framework * summary of evaluations * general public	Chapter 19.3
7	There is a user manual	Operation instructions * installation guide * summary of technical documentation * minimal system requirement * format of input & output * contact information	Chapter 19.3

1.4 Collaboration with other institutes

More and more organisations, institutes and universities in the Netherlands are assessing natural capital. For example, RIVM keeps the *Atlas of Natural Capital* up to date (https://www.atlasnatuurlijkkapitaal.nl/) and use the Natural Capital Model and the Groene Batenplanner for assessments (Remme et al., 2017). Statistics Netherlands and WU work together in the *Natural Capital Accounts* (https://www.cbs.nl/nl-nl/maatschappij/natuur-en-milieu/natuurlijk-kapitaal). They also do monetary valuation of natural capital. WENR-Wot mainly work with the biophysical part of the NC-Model for calculating effects of future scenarios. RIVM, CBS, PBL, WU, LNV and WENR have therefore started a consortium to work jointly on a harmonised dataset and a set of mapping tools/models. This prevents duplication of work and also ensures consistent results and communication. CBS and WU also make use of the basic nature and landscape database (Sanders and Meeuwsen, 2019) within the natural capital accounting project. This data is also used by WENR-WOT as a basis for the current situation and future scenarios. In addition, work is being done on harmonising the models used. The process of harmonising data and models is an ongoing activity. CBS, WUR, RIVM and other parties report separately on the data and models used. Since all institutions do specific applications, data, models and methods vary. Consequently, there could still be differences in the data and models between the different institutions presented in this report. The intention is that this, as far as relevant, will be increasingly harmonised over time.

1.5 Literature

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2 Technical implementation ESD-Shell

Rene Jochem (WENR), Levi Biersteker (WENR)

The NC-Model is a framework of individual ecosystem service models that are technically accommodated in one shell: the ecosystem servicesDShell. The idea behind the ESDShell is to provide the underlying models with an explicit Graphical User Interface (GUI) that controls the implementation of the models and their operation (in the Azure cloud). This allows anyone with GIS skills to run all underlying ecosystem service models. The ESDShell is still under development. This documentation provides insight into the desired structure and use. In addition, a start has been made on generating technical documentation on the fly from the model code as part of the source package. This makes it possible to create a new technical document every time the NC-Model is changed (2.7).

2.1 Graphical User interface (GUI)

The user interface consists of a list called 'blackboard', which contains all the information needed to run the model, such as paths to input maps, metadata, paths to tables, output folders and parameters. The user can see from the columns which information is requested in order to operate one or more models in the rows. For example, if column 'section' has the value 'map', the user knows that it is an input map. Under ‘key’ it says exactly which map is requested, e.g. ‘pestcontrol_bloemarm’; referring to the map of flower-poor ecosystems that is input to the pest suppression model. For information and clarification, the 'meaning' column states what is meant by the field and the '?' column contains a hyperlink to documentation about the map or model.

Running a new or different scenario can be done by entering other scenario files and using input files. If you want to run a new or different scenario, first go to 'Scenario File' in the upper left corner and press 'New'. First you are asked where to put the result file, after which you can indicate which modules to run for the scenario (see Figure 2.1). After pressing "ok", you are presented with an empty list on which you can enter the paths and settings (Figure 2.2).

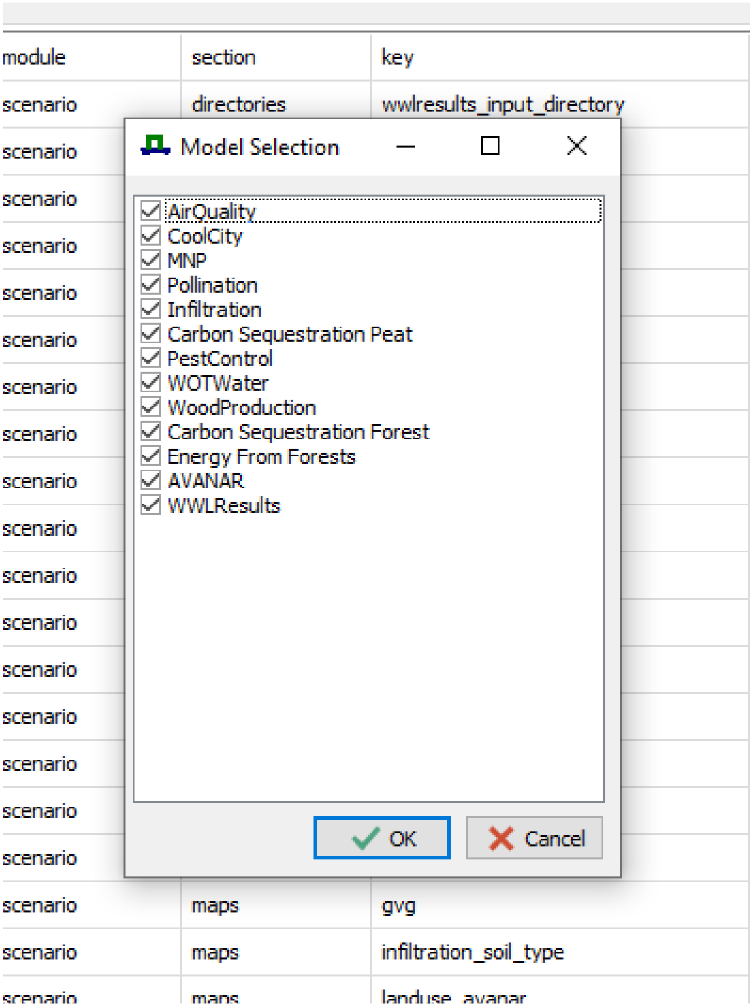
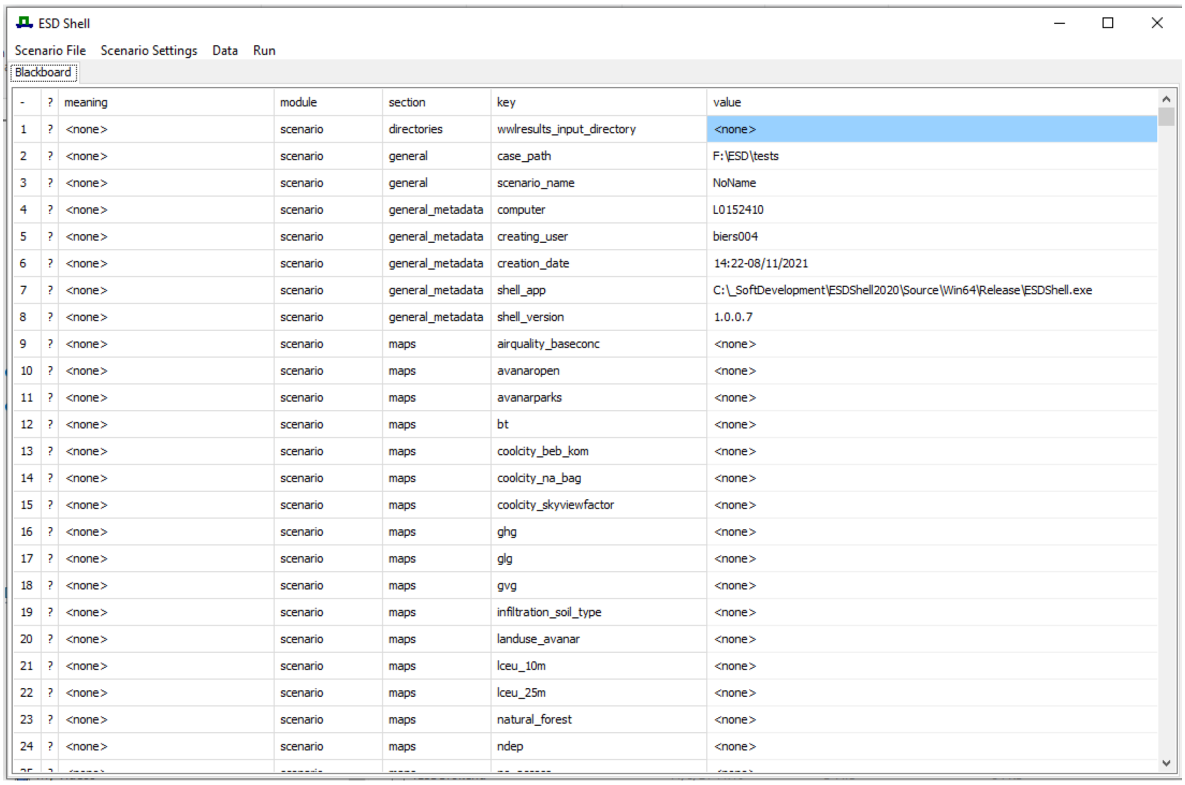


Figure 2.1 *On the user interface you can specify which of the ecosystem service models to run.*

Once all fields are filled in, go to 'Run' and then 'Scenario', or press F9 to start running the model immediately. The drop down ‘Run’ menu also contains the test function. This checks that all modules are functioning correctly. At the time of publication, this has not yet been fully implemented.


ESD Shell

Scenario File Scenario Settings Data Run

Blackboard

-	?	meaning	module	section	key	value
1	?	<none>	scenario	directories	wwlresults_input_directory	<none>
2	?	<none>	scenario	general	case_path	F:\ESD\tests
3	?	<none>	scenario	general	scenario_name	NoName
4	?	<none>	scenario	general_metadata	computer	L0152410
5	?	<none>	scenario	general_metadata	creating_user	biers004
6	?	<none>	scenario	general_metadata	creation_date	14:22-08/11/2021
7	?	<none>	scenario	general_metadata	shell_app	C:_SoftDevelopment\ESDShell2020\Source\Win64\Release\ESDShell.exe
8	?	<none>	scenario	general_metadata	shell_version	1.0.0.7
9	?	<none>	scenario	maps	airquality_baseconc	<none>
10	?	<none>	scenario	maps	avanaropen	<none>
11	?	<none>	scenario	maps	avanarparks	<none>
12	?	<none>	scenario	maps	bt	<none>
13	?	<none>	scenario	maps	coolcity_beb_kom	<none>
14	?	<none>	scenario	maps	coolcity_na_bag	<none>
15	?	<none>	scenario	maps	coolcity_skyviewfactor	<none>
16	?	<none>	scenario	maps	ghg	<none>
17	?	<none>	scenario	maps	glg	<none>
18	?	<none>	scenario	maps	gvg	<none>
19	?	<none>	scenario	maps	infiltration_soil_type	<none>
20	?	<none>	scenario	maps	landuse_avanar	<none>
21	?	<none>	scenario	maps	lceu_10m	<none>
22	?	<none>	scenario	maps	lceu_25m	<none>
23	?	<none>	scenario	maps	natural_forest	<none>
24	?	<none>	scenario	maps	ndep	<none>

Figure 2.2 *With the user interface you can specify where the input data is located and where the output data should be saved.*

The 'ecosystem servicesDSettings' contain the paths to the various modules and to the software required, such as GDAL and Python. The 'ecosystem servicesDSettings' can be saved to an '.ecosystem servicesDSettings' file: go to 'Scenario Settings' at the top and choose 'save settings'.

2.2 Overview

The software development life cycle (SDLC) was used to create the application. This involves iterating through the steps of Analysis, Design, Implementation, Testing, Release and Maintenance. In the extended documentation, these steps are used as the structure of the automatically generated technical documentation. The following is a summary based on the analysis and design.

The individual ecosystem service models all have a unified interface so that they can be addressed in the same way in the ecosystem servicesDShell, even though the various ecosystem services are programmed in different languages (Figure 2.3). For some models, spatial data needs to be converted to the standard geoTif. As a result, users always work with geoTif files, regardless of whether the models use PCRaster or ecosystem servicesRI-Binaries. The control also differs per model; there are Python scripts that are given as an argument for a Python executable while other models use R or are compiled into a binary application. This adaptation layer, which provides the unified interface, is called the adapter. The adapters for the different models must be addressed at the right time for convert, run and result extraction. This task has been assigned to the broker, which is controlled from the Graphical User Interface (GUI) (see 2.1).

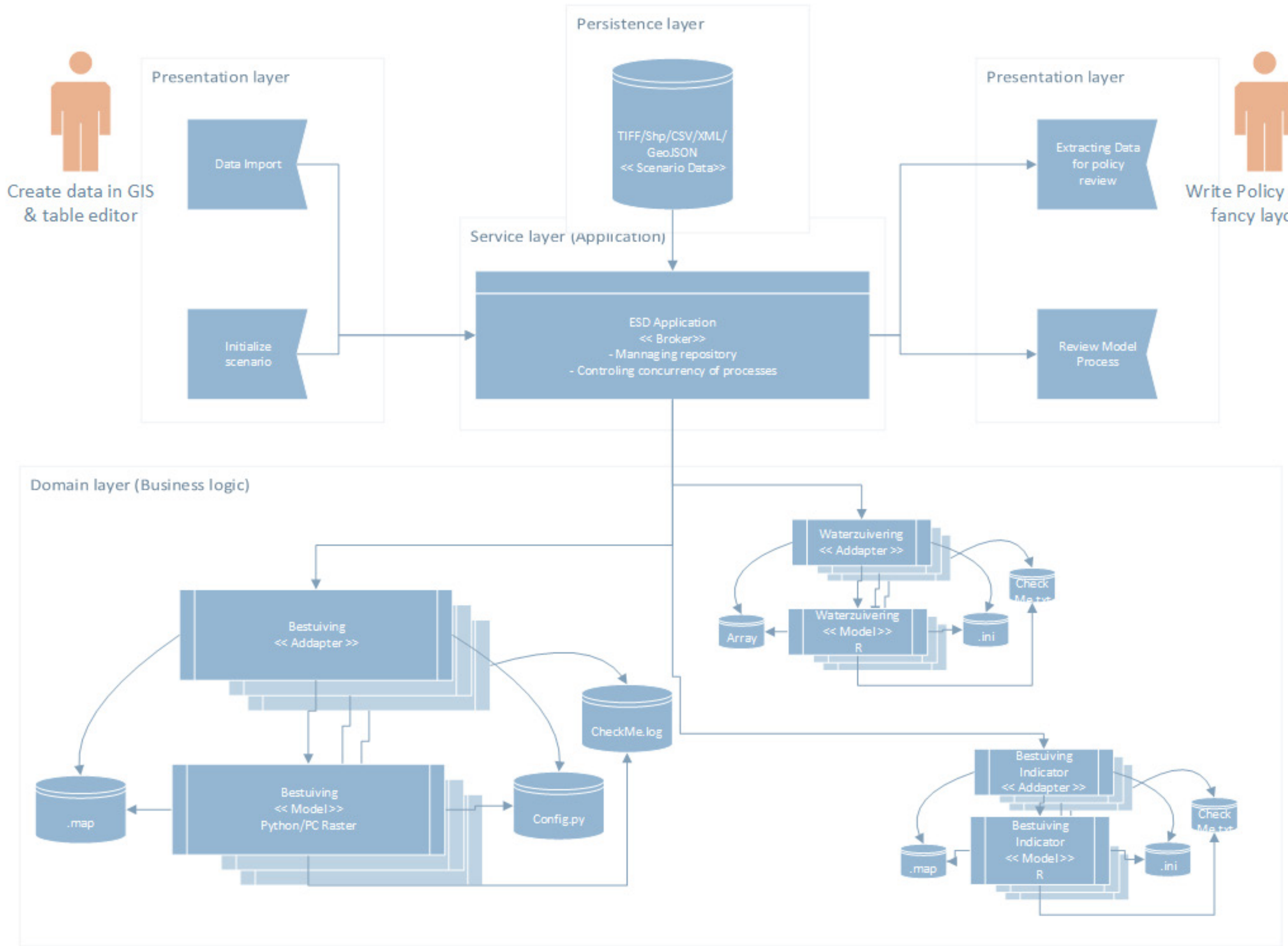


Figure 2.3 *The ESDShell user interface consists of a 'broker' which allows settings to be made that run the individual ecosystem service models. The 'adapter' controls the individual ecosystem service models.*

2.3 Overview of technical implementation

The core of ESDShell is the 'broker', which makes settings and controls the process through a list of '*adapter instances*': ecosystem service models chosen by the user. The adapter contains a number of standard functions that are set by the module-specific '*factories*'.

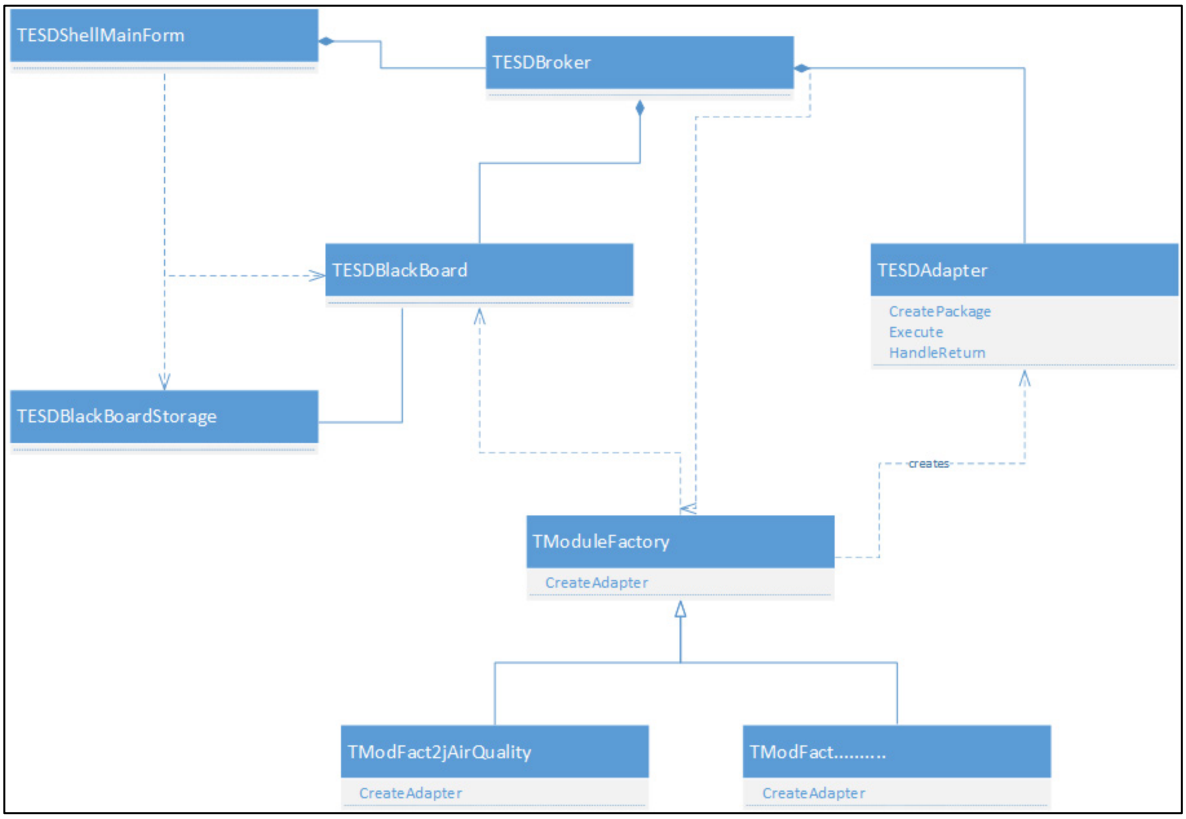


Figure 2.4 *The architecture (or object-oriented design) of ecosystem servicesDShell. The user interacts with the GUI (Tecosystem servicesDShellMainForm), which in turn controls the Broker. The Broker reads the user's input from the input list on the GUI (Tecosystem servicesDBlackBoard), and uses it to call the ModuleFactories (TModuleFactory). Each module in ESDShell has its own factory. In this figure, air quality is given as an example (TModFact2jAirQuality). The factories then set up the Adapters (Tecosystem servicesDAdapter) after which they are added to a list of adapters. When a user issues the command to run the model, the 'Execute' function of each adapter is called up, after which the module is run.*

Each module has its own *'factory'* class which creates and sets up the adapter. When the model is run, each module is put into a *module package* and set up according to the adapter settings. *Module packages* contain the code, parameters, the input maps and tables to run the model, and a folder to which the output is written.

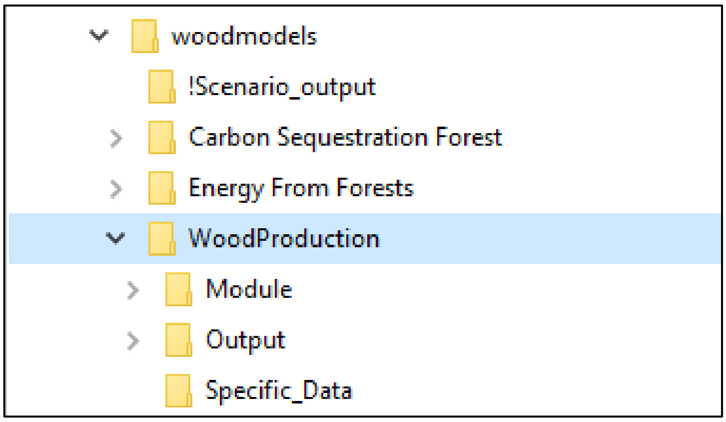


Figure 2.5 *The structure of a scenario folder, containing various module packages. The example of the WoodProduction ecosystem service is expanded for illustration purposes.*

The broker contains two lists of adapters. The first is the basic list of ecosystem services that are independent of other ecosystem services. The second is the list of adapters for ecosystem services that are in some way dependent on the output of another module. For example, this is the case with the carbon sequestration from the forest module, for which the wood production module must be run first.
Currently the broker is controlled by a GUI, but it could easily be controlled by a console interface. This is desirable when, for example, a very large number of runs are needed in the Cloud for a sensitivity or uncertainty analysis.

When the user issues the command to run the modules, the GUI directs the broker to take the following sequential steps:
1. Create a folder with all the input and output data of the scenario in question
2. Create the module adapters for the selection of ecosystem service models
3. Create the module packages for the various ecosystem service models
4. Run the packages
5. Create the packages that depend on output from others
6. Implement the packages that depend on output from others
7. Remove the input maps and tables from the module package (folders).
8. Remove the adapters

2.4 Requirements for individual ecosystem service models

The ESDShell can incorporate ecosystem service models developed in C++, Python, or R, which fulfil/meet certain requirements. This is necessary for optimal communication between the ecosystem service models and the ESDShell. The following components should be available for each ecosystem service model:

Command line interface
ESDShell will try to call a model using a batch (.bat) file, which is a text file containing a series of DOS/command line commands. The file locations of the maps used by the model will be passed as arguments to the command invoking the model, thus you will have to get filenames from these passed arguments.

An example of a functional batch file (.bat)
ESDShell calls models through batch files. A batch file is a text file containing a set of DOS commands—which the command prompt can interpret. The batch file should at least contain a command which calls the model, maps and parameters it requires.

Implement the creation of onpackagereturn inifile
Implement result onpackagereturn inifile. This Inifile will be used to check if the model ran without complications or errors. An inifile consists of sections subdivided by keys and has the following layout:

```
[SOMESECTION]somekey=somevalueanotherkey=anothervalue
```

As the file will be used to check if the model ran OK, the file must contain a section named MODELRESULT with a set of keys named: modelversion, resultstring, resultmessage.

- modelversion=current version of your model
- resultstring=single string with one of three values; OK, warning or error
- message=exitmessage of your model (i.e. "Finished without errors" or "exception: list index out of bounds").

The model should verify the input maps and data. If the provided data is incorrect, the resultstring should give an error and a message should provide info as to why the model can't run. If the model can run on the provided maps or data, but the values are outside of a realistic range or is most likely wrong, the resultstring should read warning, again with a useful message. A similar approach should be taken when running functions that may produce exceptions. To catch an error use a try block and pass the exception to the log file.
The result inifile should also contain the most important statistic or result from the model run, so that ESDShell can add this to *summary.txt.*

Provide a test set of input maps
To verify the correct operation of your model under ESDShell, provide a set of input maps and a description of the results the model will produce when using them. The maps should cover a small area, to keep down computation time. It is also a good idea to pick an area with NaN/nodata values, so it can be checked if the model deals with it correctly.

2.5 Future developments

Azure batch is a form of distributed computing (https://en.wikipedia.org/wiki/Distributed_computing), in which a group of virtual computers collectively perform a set of independent tasks. This makes it ideally suited for doing uncertainty or sensitivity analyses of the ESDShell modules, because these analyses require running each module repeatedly with different parameter values. The idea is to create an Azure batch protocol for ESDshell. In this case, ESDShell is placed in a *batch node*, the necessary software (such as Python modules) is installed, and the input and modules are copied. Because the parameters of the code are decoupled from the modules, we can use various parameter sets in sensitivity and uncertainty analyses. However, ESDShell *itself* contains no uncertainties or sensitivities.
ESDShell is prepared for distributed operation in the sense that it can be called up from the command line with an ‘ESDScenario’ file as an argument to run immediately.

2.5.1 Testing

ESDShell contains a test function that calls the module's test function, or runs the module on the supplied test set. After this an outcome, whose correct value in the test set is known, is read from the 'result ini' and compared to the value it should be. If they match, the module is considered to be operating correctly. This feature has not yet been fully implemented.

2.6 Development environment

The standalone application of the ESDShell is written in C++ and is developed in C++ Builder 10.4 (Embarcadero Technologies); it uses Embarcadero's vcl library. It runs on Windows 10 locally and Windows Server 2019 on the VM. All code and technical documentation is under version control, using TortoiseSVN. For developers with access to QMAR, this can be found under file://wurnet.nl/dfs-root/PROJECTS/QMAR/SVNRepro2010/ESDShell.

2.7 Dynamic documentation

The technical documentation will be automatically generated by Doxygen (https://www.doxygen.nl/index.html). This is the standard program for creating technical documentation from C++ code. The program "reads" the comments that the developer of the code included on html pages, which are put into an existing wiki.
Doxygen also works on Python code and the modules will also be documented with Doxygen. An example has been prepared of how modellers should comment on their code so that Doxygen can recognise and read their comments. The functions and classes that modellers define are automatically made intelligible in a standard way by this means.
This dynamic documentation ensures that the documentation always keeps pace with the code of ESDShell.

3 Input maps

Hans Roelofsen (WENR)

A key input map for each ecosystem services model is one or more land use map(s) (see also section 3.2.1 for the development of the land use map). This map is built made by making use of the basic file nature and landscape (Sanders and Meeuwsen, 2019). This is a map and the source for generating input maps of all other ecosystem service models. This enables scenarios to be created on just one map, after which the input files for all ecosystem services can be generated easily and consistently. This chapter describes how this land-use map can be created for current or future situations.

3.1 Input and output

Table 3.1 lists all the inputs needed to run the ecosystem service models. Section 3.5.5 provides an overview of all input maps with more information on their requirements.

Table 3.1 *Input variables needed to run all ecosystem services models. 'Section' refers to variables (scenario) or pathname (setting). 'Key' refers to the type of data: directory, general, maps, models, parameters, tables or other. 'Value' describes the name of the input data. 'Description' (in dutch)*

Section	Key	Value	Description
scenario	directories	wwlresults_input_directory	Folder met WWL resultaten
scenario	general	case_path	Pad naar scenario folder
scenario	general	scenario_name	Scenarionaam
scenario	general_metadata	computer	Computernaam
scenario	general_metadata	creating_user	Gebruikersnaam
scenario	general_metadata	creation_date	Datum
scenario	general_metadata	shell_app	
scenario	general_metadata	shell_version	Versie applicatie
scenario	maps	airquality_baseconc	Luchtzuivering basisconcentratie (10m)
scenario	maps	avanaropen	Avanar openeheidskaart (10m)
scenario	maps	avanarparks	Parkenkaart voor groene recreatie (10m)
scenario	maps	bt	Beheertypekaart voor MNP (25m)
scenario	maps	coolcity_beb_kom	Verkoeling in de stad bebouwde kom (10m)
scenario	maps	coolcity_na_bag	Verkoeling in de stad (10m)
scenario	maps	coolcity_skyviewfactor	Verkoeling in de stad luchtzichtbaarheidskaart (10m)
scenario	maps	ghg	Hoogste grondwaterstandskaart (25m)

Section	Key	Value	Description
scenario	maps	glg	Laagste grondwaterstandskaart (25m)
scenario	maps	gvg	Gemiddelde voorjaars grondwaterstandskaart (25m)
scenario	maps	infiltration_soil_type	Infiltratie bodemtype (10m)
scenario	maps	landuse_avanar	Groene recreatie landgebruik (25m)
scenario	maps	lceu_10m	LCEU 10m resolutie
scenario	maps	lceu_25m	LCEU 25m resolutie
scenario	maps	natural_forest	Boskaart natuurlijk bos (25m)
scenario	maps	ndep	N Depositiekaart (25m)
scenario	maps	no_access	Groene recreatie geen toegangskaart (25m)
scenario	maps	ontsluitingagr	Groene recreatie agrarische ontsluiting (25m)
scenario	maps	pestcontrol_akkers	Plaagonderdrukking akkerkaart (10m)
scenario	maps	pestcontrol_bloemarm	Plaagonderdrukking bloemarm kaart (10m)
scenario	maps	pestcontrol_bloemrijk	Plaagonderdrukking kaart bloemrijk (10m)
scenario	maps	pestcontrol_boomrij	Plaagonderdrukking bomenrij kaart (10m)
scenario	maps	pestcontrol_bosjes	Plaagonderdrukking kaart met bosjes en struiken (10m)
scenario	maps	ph	MNP pH kaart (25m)
scenario	maps	pollination_percelen	Bestuiving percelenkaart (10m)
scenario	maps	population_10m	Bevolkingskaart 10m resolutie
scenario	maps	production_forest	Boskaart productie (25m)
scenario	maps	rbomen	Bomenkaart (10m)
scenario	maps	rgras	Graskaart (10m)
scenario	maps	rstruiken	Struikenkaart (10m)
scenario	maps	soil_physics	Bodemfysica (25m)
scenario	maps	woodproduction_crop_parcels	Houtproductie akkerkaart (25m)
scenario	maps	woodproduction_groundwaterlevel	Houtproductie grondwaterkaart (25m)
scenario	maps	woodproduction_land_cover	Houtproductie landgebruikskaart (25m)
scenario	maps	wotwater_provinciegrenzen	WOT-waterzuivering provinciegrenzen (shape)
scenario	maps	wotwater_stroomgebieden	WOT-waterzuivering (shape)
scenario	models	airquality	Draai luchtzuivering (on/off)

Section	Key	Value	Description
scenario	models	avanar	Draai groene recreatie (on/off)
scenario	models	carbon sequestration forest	Draai koolstofvastlegging door bos (on/off)
scenario	models	carbon sequestration peat	Draai koolstofvastlegging door veen (on/off)
scenario	models	coolcity	Draai verkoeling in de stad (on/off)
scenario	models	energy from forests	Draai energie uit bossen (on/off)
scenario	models	infiltration	Draai infiltratie (on/off)
scenario	models	mnp	Draai MNP (on/off)
scenario	models	pestcontrol	Draai plaagonderdrukking (on/off)
scenario	models	pollination	Draai bestuiving (on/off)
scenario	models	woodproduction	Draai houtproductie (on/off)
scenario	models	wotwater	Draai WOT-waterzuivering (on/off)
scenario	models	wwlresults	Draai WWL-resultaten (on/off)
scenario	parameters	airquality_parameters	Parametersectie voor luchtzuivering
scenario	parameters	coolcity_parameters	Parameterfile voor verkoeling in de stad (xlsx)
scenario	parameters	infiltration_parameters	Parameterfile voor infiltratie (xlsx)
scenario	parameters	pestcontrol_parameters	Parameterfile voor plaagonderdrukking (xlsx)
scenario	parameters	pollination_parameters	Parameterfile voor bestuiving (xlsx)
scenario	parameters	wotwater_parameters	Folder met parameters voor WOT-waterzuivering
scenario	parameters	wotwater_period	Seizoen om door te rekenen met WOT-waterzuivering
scenario	parameters	wwlresults_parameters	WWL-resultaten parameterfile (xlsx)
scenario	tables	avanar_table_directory	Folder met tabellen voor groene recreatie
scenario	tables	cseqforest_table_directory	Folder met tabellen voor koolstofvastlegging door bos
scenario	tables	energyforest_table_directory	Folder met tabellen voor energie uit bossen
scenario	tables	woodproduction_table_directory	Folder met tabellen voor houtproductie
settings	airquality	source_path	Bronpad voor module luchtzuivering
settings	avanar	source_path	Bronpad voor module Groene recreatie
settings	carbon sequestration peat	source_path	Bronpad voor module Koolstofvastlegging door veen

Section	Key	Value	Description
settings	coolcity	source_path	Bronpad voor module verkoeling in de stad
settings	infiltration	source_path	Bronpad voor module infiltratie
settings	mnp	source_path	Bronpad voor module MNP
settings	pestcontrol	source_path	Bronpad voor module plaagonderdrukking
settings	pollination	source_path	Bronpad voor module bestuiving
settings	tools	anaconda_path	Pad naar miniconda of anaconda
settings	tools	gdal_path	Pad naar gdal
settings	woodproduction	source_path	Bronpad voor module houtproductie
settings	wotwater	source_path	Bronpad voor module WOT-waterzuivering
settings	wwlresults	source_path	Bronpad voor module WWL-resultaten

3.2 Theoretical rationale for the development of the land use map

3.2.1 General description

All ecosystem service models use one or more land use maps of the Netherlands, distinguishing between different land use categories (e.g., wet heathland or fauna-rich field margin). All the land-use categories in a map together (what is normally in the map legend) are called a categorisation. The categorisations of two or more land-use maps may partially overlap or be mutually exclusive; this is called ‘union’, ‘intersection’, or ‘difference’. For example, the union of categorisation A with categories {x, y, and z} and categorisation B with categories {z, q, w, s} is {x, y, z, q, w, s}, the intersection is {q} and the difference of A versus B is {x, y}.

Within a land-use map, land-use categories are mutually exclusive; a place is category x or category y, but not both. However, differences between two or more land-use maps are possible; for example, the same location is category x on map 1 and category p on map 2. The differences may be due to different categorisations, or if the same categorisation A and B is used, it may be due to different time the snapshot was taken between map 1 and map 2.

Translating from one categorisation to another is possible. This can be done 1 to 1 or with the n:1 relationship, see table 3.2.

Table 3.2 *Example of translation of categorisations to multiple other categorizations.*

Categorisation	Categorisation
A	B
x	a
y	b
z	c
q	d

Categorisation	Categorisation
A	B
x	a

y	a
z	b
q	b

The translation key between categorisation A and categorisation B can be applied to two maps in those categorisations. The maps are then harmonised in terms of categorisation, but may still differ in the spatial domain. Consider land use in 1950, 2021 and 2050: the categories are identical, but the spatial distribution is not.

Each ecosystem service model views land use from a different perspective; for example, for wood production models, the distinction between deciduous/coniferous/mixed forest is important, while this distinction is irrelevant for the recreation model. Habitat for pollinators is described along different lines than habitat for birds, butterflies and plants in the MNP model. This means that a relevant categorisation exists for each model. Thus, most models were developed based on a specific land-use map, i.e. a map with a categorisation relevant to that model. Within an ecosystem service model, parameters are usually associated with each category of the overall categorisation; such a parameter would be the delivery capacity of a service for each land-use category.
However, a multiplicity of land-use maps with a multiplicity of categorisations is undesirable for three reasons. First, because it hinders unambiguous reporting on land use; on which categorisation is the reporting based? Second, because of possible discrepancies between the maps; depending on publication date, a location may still be agricultural on one map and built-up on another. Third, because it complicates scenario studies that involve changes to land use; any change must be made on each map according to the corresponding categorisation for that map.

An obvious solution is to create a *single* base map, from which the desired categorisations of the ecosystem service models can be identified with translation keys. A forest remains a forest, but becomes 'mixed forest' in Model X and 'N16.03 dry forest with production' in Model Z depending on the ecosystem service. To do this, however, the base map categorisation must be sufficiently fine-grained to encompass the requested categories of each ecosystem service model. After all, translation of categorisations means that no information can be added; at most the information can be simplified (1:n translation). In other words, the base map categorization is the ‘union’ of all ecosystem services (ecosystem services) map categorisations. The spatial development on the base map could be shown by combining the ecosystem services maps hierarchically, i.e. stacking them.

3.2.2 Conceptual model and formal model

To apply the above theoretical framework in practice, the Multi-Reclass Tool (MRT) was developed at WEnR during 2019/2020. The first idea for the MRT came from Henk Meeuwsen, as a logical sequel to the *Basisbestand Natuur en Landschap* (Nature and Landscape Master File), which he helped to develop. In mid-2020, the MRT development was taken over by Hans Roelofsen. The MRT has since been accessible through the WUR gitlab system https://git.wur.nl/roelo008/mrt/

The MRT has two parts:
1. Creating a new categorisation and corresponding map by combining various source maps and their categorisations. This is done by formulating and applying decision rules and results in a base map. This first part of the MRT is referred to as ‘upstream’.
2. Translating the base map into other categorisations, for example as requested by ecosystem service models, using translation keys between the base map categorisation and the ESD categorisations. This second part of the MRT is referred to as ‘downstream’.

The concept of ‘decision rules’ is illustrated in the table below (table 3.3). Here, the MRT is applied to three maps, each with its own categorisation: the Top10 surface map, the Management Types map, and a map of Business Parks (the Nature & Landscape Database provides these maps). Decision rules are used to create a new categorisation.

Table 3.3 *Example of decision rules.*

newval	description	Top10	Management Types	Business Park
10	mixed dry forest with production	142	1603	n
11	dry deciduous forest with production	143	1603	n
12	building on business estate	90	n	1
13	building	90	n	n

The new categorisation is in the 'description' column. Each category consists of certain combinations of the source maps: 'mixed dry forest with production' occurs where the Top10 map has mixed forest category (pixel value 142) *and* where the Management Type Map has N16.03 Dry Forest with production category (pixel value 1603). The third decision rule combines buildings from Top10 with the map layer of business parks to create 'building on business park'. These decision rules are in the 'upstream' domain of the MRT. The column 'newval' specifies the numerical value of the new category on the digital land use map.

A translation key between the base map categorisation and, for example, ecosystem services categorisations can look like this (table 3.4):

Table 3.4 *Example of a translation key between base map categories and ecosystem services categorisations.*

newval	description	general land use	forest type
10	mixed dry forest with production	Public Relations Department M. Bos	Mixed
11	dry deciduous forest with production	Public Relations Department M. Bos	Dry
12	building on business estate	Building	None
13	building	Building	None

The two new categorisations 'general land use' and 'forest type' translate the base map categories into new categories relevant to a particular Ecosystem Service Model. Such translations are in the 'downstream' domain of the MRT.

The MRT asks for an Excel file in which the decision rules (reclassrules) are formulated. In addition, the Excel may optionally include a downstream tab that contains downstream translations. The MRT also requires a 'combined raster' in which all source rasters are merged. See the documentation for the ArcGIS Pro 'Combine' tool https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/combine.htm. The MRT is explained in more detail in the Gitlab repository https://git.wur.nl/roelo008/mrt/-/blob/master/README.md

See also Annexes 10, 11 and 12 for a translation of Top10NL visualisation codes to BNL codes and for BNL_codes derived from Top10NL and for BNL_codes derived from Top10NL.

3.3 Technical implementation

3.3.1 Implementation model

The general workflow of the MRT is shown in the figure below (Figure 3.1).

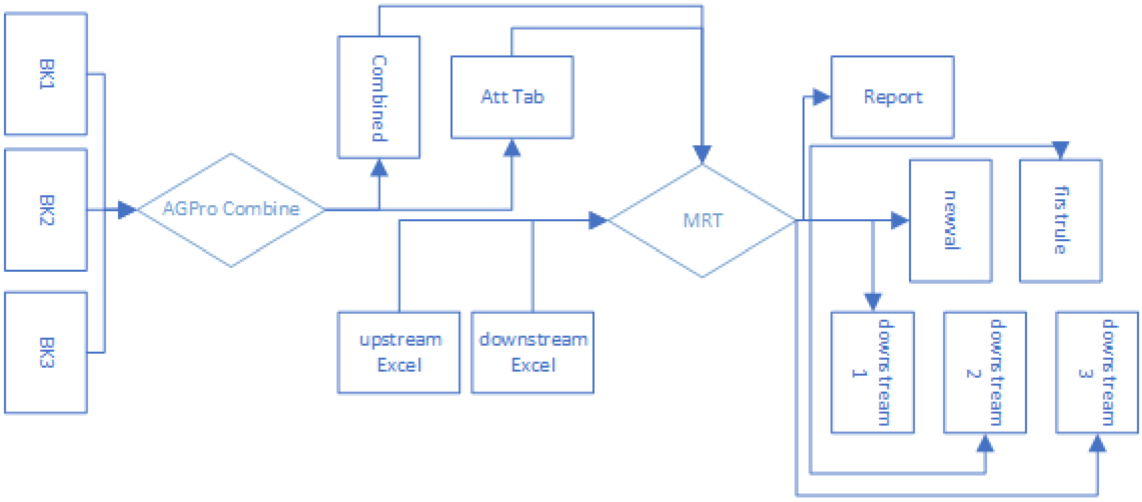


Figure 3.1 *General workflow of the Multi Reclass Table. BK=source map, Att Tab=Attribute Table.*

MRT requires the following elements? as input:
1. A Combined raster plus its Attribute Table
2. Upstream reclass rules from an Excel file
3. (optional) Downstream translations

The MRT can generate various products:
1. A report giving the gross and net land areas of the upstream decision rules
2. A geospatial raster of the outcome of the decision rules ('newval')
3. A geospatial raster showing per pixel which decision rule was applicable ('firstrule')
4. A geospatial raster with downstream categorisation.

The MRT itself consists of three Python files that interact with each other. Two files from another Python repository are also called (from the *benb_utils* repository). See Figure 3.2 below.

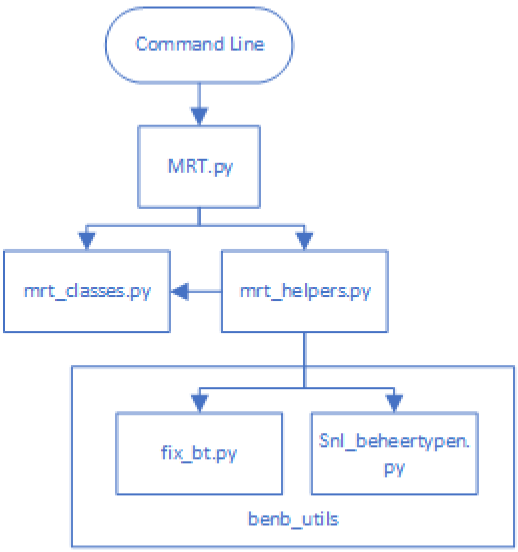


Figure 3.2 *The Multi Reclass Tool consist of multiple Python scripts that interact with each other.*

MRT.py
The three python files are described in more detail below.

This is the python file that is called by the user. The input provided by the user is processed and checked. The base class (ReClass, see below) of the MRT is digitised and the methods of the base class are called to generate the requested output.

mrt_helpers.py
This file contains 18 functions that are called one or more times from other parts of the MRT. Each function has a docstring describing its input and output.

mrt_classes.py
This file defines the four python classes that connect to the provided input and have methods to define all possible output. These four classes are ReClass, Model, CombinedRaster and SourceRaster and are related as follows:

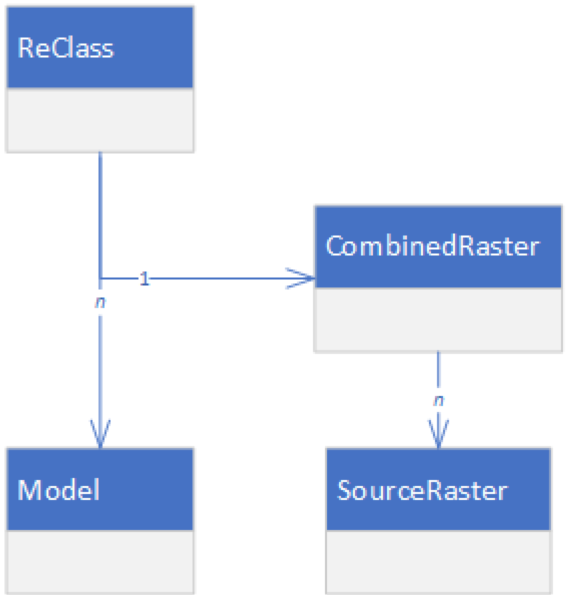


Figure 3.3 *The four Python classes that convert the input to needed outputs.*

The arrows mean *class association*, not *class inheritance*. This means that an instance of the ReClass class contains one instance of the CombinedRaster class and *n* instances of the Model class. The instance of the CombinedRaster class contains *n* instances of the SourceRaster class.

The class methods are described below.

ReClass

__init__
- Parse all arguments.
- create placeholders for all class fields
- create diverse timestamps and project name
- read and parse upstream Excel sheet
- identify and store the source rasters
- if provided, read and parse downstream Excel sheet
- if provided, create Model class instances for each downstream model
- create CombinedRaster class instance and append to self
- verify integrity between source rasters in CombinedRaster instance and source rasters according to upstream sheet
- verify that reclass-rule values are congruent with the combined grid attribute table

parse_rules
- creates a python-style query for each reclassrule

look_upstream
- applies the query of each rule to the attribute table of the combined-raster. Calculates gross and net match in hectares and difference.
- create *newval* and *firstrule* instances of Model class and append to self

look_downstream
- update the combined raster attribute table with two columns for each downstream model:
  - downstream model raster value
  - downstream model category

write_raster
- write a geospatial raster for one of the models of self.

mnp_table
- write an MNP styled CSV table to file with the legend and a description of downscaled management types.

write_report
- write an Excell file to disk with metadata on the MRT run, results of the reclass etc

test
- write summary of the MRT input and output options of StdOut

xtab
- Add an additional sheet to the report carrying a cross-tabulation between two models.

Model

__init__
- create placeholders for all Model class fields

report
- print summary of Model class instance properties to StdOut

CombinedRaster

__init__
- parse and check arguments
- open connection to the combined raster file on disk
- read combined raster file attribute table to memory
- Identify source rasters of the combined rasters
- create SourceRaster class instance for each source raster and append to self
- determine pixel area of combined raster
- check for negative values in the attribute table Count field and correct if needed

SourceRaster

__init__
- store source raster name and values

3.3.2 Technical environment

The MRT was developed in the Python (version 3.9) programming language and uses the following non-standard Python modules:

- Pandas v. 1.1.5 (for table-data analysis)
- Geopandas v. 0.8.1 (for reading and writing DBF files)
- Rasterio v.1.1.8 (for reading and writing geospatial rasters)
- Numpy v. 1.19.4 (for n-dimensional array calculations)

- Openpyxl v.3.0.5 (for reading and writing Excel files)

The MRT is administered using the GIT version control system. All files surrounding the MRT are online as gitlab repository in the WUR gitlab environment https://git.wur.nl/roelo008/mrt.

The MRT is called in the Command Prompt. The MRT runs on Windows 10, but has not been tested for use in a UNIX environment.

3.3.3 Testing

A concise testing protocol was developed for two of the 18 helper functions where the function is queried for a variation of inputs and the output is compared to a predetermined desired output. Calling these tests is not part of the overarching MRT functionality and must be done manually.
A test dataset of limited size was also created to which the MRT could be applied. This allows the user to quickly determine if the decision rules do in fact lead to the desired output.
All products made using the MRT to date have been manually checked before further use. This consistently showed that the MRT applied the decision rules consistently and without error. This is apparent, for example, when all the source rasters, the combination raster, and the MRT output are superimposed in a GIS environment.
An underexplored aspect of the MRT is the handling of geospatial rasters of resolutions other than 2.5 m. The response of the MRT to this would need to be tested if needed.

3.4 Parameters and variables

3.4.1 Parameters and variables

The MRT has three compulsory and 11 optional parameters.

Compulsory
- xls full address to the Excel sheet containing the reclass rules (e.g., `c:\docs scenario1.xlsx`)
- rast complete address to the combined raster (e.g. `c:\gether_combiraster_v1.tif`)
- us name of the Excel tab that contains the reclass-rules

Optional:
- --help: shows help and closes the program
- --ds: name of tab with downstream rules
- --test: verify that all inputs are OK, does nothing else
- --report: create report (Excel sheet) with all information about the outcomes of the multi-Reclass. Reports on gross and net land area of each decision rule, among other things.
- --write: write the new land-use categories and/or one or more downstream categories as a geospatial raster. Multiple values are possible.
- --xtnt: spatial extent of the output raster. Choice of :BNL: (0, 300,000, 280,000, 625,000), :LCEU: (10,000, 300,000, 280,000, 620,000) or :src: (equal to the extent of :rast:). Default :BNL:. This option is currently not implemented correctly, it is better not to use it!
- --or: output file type. Choice of :geotiff:, :flt: or :map:. :geotiff: is default and is currently the only supported format.
- --verbose: :True:/:False:, give more feedback while running the tool. Default :False:.
- --base_out: directory where the output is created.
- --nodata: specify which value in the output grid should be tagged as :nodata:. By default, none of the output pixel values are tagged as :nodata:.
- --mnp: write MNP style CSV table for Management Type Map. This is necessary to link the card to MNP. This requires the [benb_utils](https://git.wur.nl/roelo008/benb_utils) module.
- --xtab A B: write cross-table in report between columns A and B in upstream or downstream sheet
- --ovr: create overviews when writing new rasters. Default False

3.4.2 Calibration

Calibration does not apply to the MRT.

3.4.3 Input and output

The input consists of a 'combined raster' and an Excel sheet. The 'combined raster' is a geospatial raster file that is the output of the ArcGIS Pro Combine tool. It has the following specifications:
- geo-tif or esri file raster data format
- data type: signed integer
- single band
- preferably in standard BNL extent (0, 300,000, 280,000, 625,000) and 2.5 m resolution.

In addition, the Attribute Table of the combined raster must be present; it is generated by default by the Combine Tool. Attribute table can be *.dbf or *.csv.

The Excel sheet contains at least upstream decision rules; downstream information is optional. See the MRT ReadMe for details for formatting the Excel file.

The MRT can generate various products:
1. A report giving the gross and net land areas of the upstream decision rules
2. A geospatial raster of the outcome of the decision rules ('newval')
3. A geospatial raster showing per pixel which decision rule was applicable ('firstrule')
4. A geospatial raster with downstream categorisation.

3.5 Evaluation of model functioning

3.5.1 Sensitivity analysis

Not applicable.

3.5.2 Uncertainty analysis

Not applicable.

3.5.3 Validation

No validation has yet taken place.

3.5.4 Overall assessment

Manual comparison of the MRT output maps with the original source maps shows that the decision rules are consistently and correctly applied. For the current situation, a land-use map was created using the MRT from which other land use maps were derived that link up with the Ecosystem Service Models. The base map of the current situation, plus the resulting ESDmaps, are described in more detail in this report because they will also be used within this project.

In addition to the technical infrastructure in the form of the MRT, this also involved a creative process:
1. identifying the source maps
2. establishing the categories in the base map
3. defining the reclass-rules that result in the base map categorisation
4. translating base map categorisation into model-specific categorisations

The reclass-rules and translations are recorded in an Excel document (<TEAMS>\Wageningen University & Research\Natuurverkenning breder doelbereik - General\LUKaart\huidig\nvk_huidig.xlsx). The categorisation of the base map should be sufficiently fine-grained to provide the information needed for each Ecosystem Service Model. In very general terms, this meant the following:

1. Downscaled management types for the MNP.
2. Distinction between coniferous, deciduous and mixed forest to benefit wood models taken from the Top10 surface.
3. Tree rows, watercourses and linear infrastructure from Top10 NL/BNL, as well as agricultural woodland and field margins from the ANLB packages as habitat for pest suppressors.
4. Agricultural crops organised by dependence on pollination, susceptibility to pests, and monetary yield. For pest suppression and pollination model. Derived from BRP table.
5. Distinction between business park/no business park.
6. Distinction between urban/non-urban to benefit the cooling model, based on the BNL-OAD layer
7. All Top10 surface categories to make the entire map comprehensive, to benefit all models that also require a comprehensive map.

Ten source maps were used. In principle these are all external maps (i.e. from outside the institute). However, each source map has been extensively pre-processed to make it suitable for use in the MRT (i.e., the MRT accepts only geospatial rasters of identical pixel size and extent). Five of the 10 source maps are from the Nature & Landscape Database, see Sanders & Meeuwsen (2019).

1. Top10 surface from BNL
2. Top10 ditch from BNL
3. Top10 trees from BNL
4. Downscaled management type map dd 20190730t111601 (previously made by Meeuwsen & Sanders for the *Environmental Balance*)
5. ANLB map, taken from the GeoDesk, in which the management codes have been translated {agricultural nature, agricultural nature woodland, agricultural nature perennial flower-poor, agricultural nature perennial flower-rich}.
6. Basic Registration of land parcel map from 2017 (taken from the NC-Model project), in which the crop codes were translated into a *Nature Outlook*-relevant category. This means that crop codes that are identical with respect to pest susceptibility, pollination dependence, and monetary yield were grouped together: 300 crop codes were simplified to 34 categories.
7. Business parks, from BNL
8. Density of addresses, from BNL
9. BBG 2015. As rastered version of the BBG (land-use database – CBS 2015) where each land-use category is set to 1. Serves as a spatial "template" for the MRT output so that the total acreage of the base map is comparable to the BBG land area (approximately 4,154,000 hectares)
10. Tree base file, (boomregister).

For these 10 source files, 167 reclass rules were defined that together come to 167 new categories in the base map (in principle, the MRT can have multiple reclass rules that result in the same category, but that was not the case here).

The base map is: "nvk_current-20201126-100144_newval.tif" (581Mb, 7 December 2020 1003h). It is important that when the base map is used and distributed, the associated files are included:

- nvk_current-20201126-100144_newval.qml QGIS legend file
- nvk_current-20201126-100144_newval.tif.vat.dbf DBF file with the legend, is automatically recognised by ArcGIS Pro and can be read separately in QGIS
- nvk_current-20201126-100144_report.xlsx Excel with details of the MRT, including the land areas in each category.

Additional metadata is stored in the TIF file that can be read with GIS software.

Just as the base map categorisation should contain fine-grained information for all Ecosystem Service Models, the spatial resolution (pixel size) should be no greater than finest requested resolution for the Ecosystem Service Models. This was 2.5 m. The MNP management types map must be supplied at 2.5 m resolution. This means that the base map also has 2.5 m resolution.

The 167 categories in the base map have been re-translated into 16 new categorisations focused on one or more Ecosystem Service Models. See the Excel file for translation keys (Downstream tab).

1. BBG2015. Categorisation to the BBG (CBS, 2015). Intended to allow land areas in the same category to be compared between the base map and the BBG2015 file. 11 categories
2. LCEU. Categorisation to the LCEU map from CBS. Intended for all Ecosystem Service Models parameterised on the 25 LCEU categories.
3. 1BLandUse. Categorisation for the Drinking Water Production Model (1B). 5 categories
4. 1DBostype. Distinguishes between coniferous, deciduous and mixed forest or no forest. Intended for wood production models
5. 1DNatuurbos. Distinction: natural forest yes/no. Intended for wood production models
6. 1DProductiebos. Distinction: production forest yes/no. Intended for wood production models
7. 2FAkkers. Distinction: arable field yes/no. Intended for pest control model.
8. 2FBomenrij. Distinction: row of trees yes/no. Intended for pest control model.
9. 2FBosjes. Distinction: small woodland areas yes/no. Intended for pest control model.
10. 2FMeerjarigBloemarm. Distinction: perennial flower-poor habitat yes/no. Intended for pest control model.
11. 2FMeerjarigBloemrijk. Distinction: perennial flower-rich habitat yes/no. Intended for pest control model.
12. 2FPercelen. Distinguishes 34 categories of agricultural crops. Intended for pest control model.
13. AVANARLandUse. 7 categories relevant to AVANAR (Outdoor recreation)
14. NeergeschaaldeBeheertypen. 60 downscaled management types. Relevant to MNP
15. GewastypeWWL. 19 categories of agricultural crops for the *Waterwijzer Landbouw (*Tool for predicting yield loss as a function of crop type, climate, weather, soil and hydrological conditions*)*.

In addition to the category translation from the base map categorisations to Ecosystem Service Model categorizations, the ecosystem services maps also had to match the requested resolution and extent of the Ecosystem Service Models. The MRT produced the above maps at 2.5 m resolution, equal to the base map. The ESDmaps were scaled up to the requested resolution (usually 10 m, sometimes 25 m) and extent in separate operations. When scaling from 2.5 to larger resolution, the 'majority' rule was used, i.e., the most-frequently occurring category in each block of 4X4 2.5 m pixels (for 10 m) was assigned to the new 10 m pixel.

Note that in addition to the above land-use maps, the Ecosystem Service Models often use other maps (such as the tree, grass and shrub maps). These are known as 'condition maps'. These are not produced by the MRT. Moreover, for calculations of the current situation, the standard condition maps of the models could be used.

All geodata related to the Current Situation map can be found in the NVK project share: w:PROJECTS_bdb_geodata_current.

3.5.5 Overview of input maps for each ecosystem service model

The Table 3.5 below lists the maps that are inputs to the different ecosystem services models. The multitude of input maps remains a point of concern, as this makes it difficult to construct a scenario quickly. It is therefore recommended to reduce the number of maps in the further development of the model. A whole series of maps are now used that are all about land use. Thus, it could be explored/investigated whether it would be better to interleave them in a hierarchical manner. For example, the land-use maps, crop maps, nature type maps, management type maps, shrub and tree maps could potentially be interleaved.

To address this concern, initial approaches have been taken in the *Basisbestand Natuur en Landschap* project (Nature and Landscape Master File – Sanders et al., 2019). in 2022, the 2018 version of the *Basisbestand Natuur en Landschap* was used as much as possible for the calculation of the current situation. This enables ecosystem services to be stacked later on because the same master file was used.

Table 3.5 *Input maps for the ecosystem services sub-models (in Dutch). In columns the different ecosystem services models are listed. Green squares are the input maps that are needed as input maps to run the different sub-models.*

Condtion	Land use	nr	name	opmerking	resolution (m)	extent	type	Drinking water production 1B	Wood production 1D	Energy from forests 1E	Cooling in cities 2D	Water purification 2E	Soil fertility 2A	PestControl 2F	Pollinatin 2G	Carbon sequestration forest 2H1	Carbon sequestration peat 2H4	Air purification 2J	Water infiltration 2L	Outdoor recreation 3A	Biodiversity (protected areas) 3B
	x	1	LCEU	LCEU-achtige kaart	25	.map	categorisch			x						x					
	x	2	LCEU	LCEU-achtige kaart	10	.tif	categorisch				x			x	x			x	x		
	x	3	1BLandUse	Simpele LU klasses	2.5	.tif	categorisch	x													
	x	4	1DBostype		25	.map	categorisch		x	x											
	x	5	1DProductieBos	area fraction natural forest	25	.map	continue, float 32		x							x					
	x	6	1DNatuurBos	area fraction production forest	25	.map	continue, float 32		x							x					
	x	7	GewastypeWWL	WWL gewascodes (10 gewassen)	10	.tif	categorisch														
	x	8	2FPercelen	Landgebruik met gewassen	10	.tif	categorisch								x						
	x	9	2FMeerjarigBloemrijk	aan/afwezigheidskaart	10	.tif	oppervlakte (int)							x							
	x	10	2FMeerjarigBloemarm	aan/afwezigheidskaart	10	.tif	oppervlakte (int)							x							
	x	11	2FBosjes	aan/afwezigheidskaart	10	.tif	oppervlakte (int)							x							
	x	12	2FBomenrij	aan/afwezigheidskaart	10	.tif	oppervlakte (int)							x							
	x	13	2FAkkers	aan/afwezigheidskaart	10	.tif	oppervlakte (int)							x							
	x	14	AVANARLandUse	Landgebruik met downstream AVANAR info	10	.map	categorisch													x	
	x	15	Beheertypen	neergeschaalde beheertypen	2.5	.tif	categorisch														x
	x	16	Gewastypen WWL		10	.tif	categorisch						x								
	x	17	AVANARsupply	wandel-draagkracht. Worden gemaakt door Micl	25	.tif	continue													x	
	x	18	AVANARsupply	fiets-draagkracht. Wordt gemaakt door Michiel \	25	.tif	continue													x	
x		19	GLG	low groundwater level	25	.map	continue		x				x				x				
x		20	GHG	high groundwater level	25	.map	continue		x				x				x				
x		21	grondwatertrap	grondwatertrap	25	.map	categorisch		x												
x		22	GLG	low groundwater level tov mv	250	.asc	continue														
x		23	GHG	high groundwater level tov mv	250	.asc	continue														
x		24	GVG	voorjaarsgrondwater	25	.tif	continue														x
x		25	N	stikstofkaart	25	.tif	continue		0/1												x
x		26	pH	bodem pH	25	.tif	continue														x
x		27	temp	temperatuur	25	.tif	continue		0/1												0/1
x		28	CBS inwoners Nederland	aantal mensen totaal (vraag)	25	.tif	continue													x	
x		29	CBS inwoners Nederland	aantal mensen totaal (vraag)	10	.tif	continue				x							x	x		
x		30	CBS inwoners Nederland allochtoo	aantal mensen allochtoon (vraag)	25	.tif	continue													x	
x		31	CBS inwoners Nederland autochto	aantal mensen autochtoon (vraag)	25	.tif	continue													x	
x		32	rbomen	bomenkaart	10	.tif	continue				x								x		
x		33	rstruiken	struikenkaart	10	.tif	continue				x								x		
x		34	rgras	graskaart	10	.tif	continue				x								x		
x		35	SkyViewFactor	SVF	10	.tif	continue				x										
x		36	na_bag	m2 buildings per cell in SVF map	10	.tif	continue				x										
x		37	beb_kom	urbanisation level	10	.tif	categorisch				x										
x		38	Stroomgebieden met maatregelen	maatregelen (%): moerasbuffer, nat. vriendelijk nvt		.shp	nvt					x									
		39	rpm25	conc fijnstof 2.5 um	10	.tif	continue											x			
		40	BOFEK	Bodemkaart, bofek 2012	25	.map	categorisch		x								x				
		41	BOFEK	Bodemkaart, bofek 2012	10	.tif	categorisch												x		
		42	Drinkwaterinzijggebieden	mask ligging inzijggebieden	2.5	.tif	binair	x													
tussenres		43	actuele houtproductie	output 1D	25	.map	continue			x						x					

3.6 Literature

Sanders, M.E., H.A.M. Meeuwsen, 2019. Basisbestand Natuur en Landschap, WOT Natuur & Milieu, WOT-04-010-036.95, Wageningen University & Research, Wageningen, november 2019.

4 Wood production

Nanny Heidema (WENR), Bart de Knegt (WENR)

The wood production model produce a standalone output (i.e. word production) but is also a necessary input for two other models: biomass production for energy and carbon sequestration.

4.1 Theoretical rationale

4.1.1 General description of the model

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 harvestable wood in m^3/yr. Variables that determine the actual wood production are soil type, water table, forest type and forest management.

The model was originally developed by the Flemish Institute for Technological Research (VITO) and the National Institute for Public Health and the Environment of the Netherlands (Remme et al., 2017). RIVM and WUR have worked together and added the models to a Python package of Ecosystem Services Models. In 2018, WENR made some adaptations to improve the VITO and RIVM models with Dutch harvest and growth data based on literature- and expert knowledge (Schelhaas et al., 2014). Therefore the effect of forest management (natural forest versus production forest) is added to the Wood production model and this has also an effect on the Carbon sequestration model and Biomass production for energy model.

In general, output maps can be produced by making use of functions and look-up tables to model data from input maps and reference values. Three types of input data are used to model each output map:

1. Input maps: Spatial datasets with environmental and geographical information.
2. Look-up tables: Literature- and expert-based tables to reassign and reclassify units between maps.
3. Reference values: Values from scientific literature that are used in calculations in the model.

4.1.2 Conceptual and formal model

Actual wood production

The actual wood production depends on the annual increment and the fraction of wood that is harvested per year and the annual increment factor and the area fraction per forest management type. The actual wood production (*w*) depends on the summarized Annual increment (Vito) (*m*), the increment factor, the Area fraction of the raster cell covered by forest (a), Increment factor (*g*); fraction of wood increment and the Harvest factor (*h*); fraction of wood harvested. The fractions are per year, per forest management type (*i*) (Table 4).

Function 1 Actual wood production

actual wood production =
*∑ annual increment (Vito) * increment factor * area fraction * harvest factor*

$$w = \sum_{i=1}^{n} m_i * g_i * a_i * h_i$$

(Function 1a, b and c in the flowchart, Annex 1).

Harvest factor

The fraction harvested is based on the 6th National Forest Inventory (Schelhaas et al., 2014) depending on forest type en forest management type (Table 5).

Table 4.1. *Harvest factors per forest and management type (LU 2).*

forest type (id)	harvest factor	management type	forest type (description)
1	0.466	production forest	mixed wood
2	0.373	production forest	deciduous
3	0.531	production forest	coniferous
1	0.233	natural forest	mixed wood
2	0.181	natural forest	deciduous
3	0.265	natural forest	coniferous

Area fraction

The area fractions rasters per forest management contains the fraction (percentage(%)/100) of the raster cell covered by forest and with that type of forest management.

Raster cells that are classified as forest but have no forest management, according to the area fraction rasters, are completely (100%) assigned to forest with management type production forest.

Increment factor

The annual increment factor per forest type and forest management based on the 6th National Forest Inventory (Schelhaas et al., 2014).

Table 4.2 *The annual increment factor per forest type and forest management.*

forest type (id)	increment factor	management type	forest type (description)
1	1.07	production forest	mixed wood
2	1.1	production forest	deciduous
3	1.08	production forest	coniferous
1	0.93	natural forest	mixed wood
2	0.9	natural forest	deciduous
3	0.92	natural forest	coniferous

Annual increment

The annual increment map (Vito) (*m*) and increment factor (*g*) maps are derived from all the input maps, except crop parcels, in Table 2 and several reclassification steps, see next paragraph (Annual increment (derivation)).

Annual increment (Vito)

The annual increment (Vito) map is calculated using:

- Forest type (intermediate map)
- Soil texture group (intermediate map)
- Drainage group (intermediate map)

Forest type
The forest type and the land covered by forest is derived from a Land cover map (Annex 1; LU 1).

Soil texture and soil drainage
The input raster is the (classified) Soil Physics Units map and look up table to reclassify the map into four soil texture groups. The same map with a second look up table is also one of the four input maps for the drainage group map.
The drainage group is derived from:

- Drainage class (groundwater) derived from:
  - GHG class derived from:
    - GHG (input raster map)
  - GLG class derived from:
    - GLG (input raster map)
  - Soil texture type (intermediate map)
    - Soil Physics Unit (input raster map)
- Drainage class (soil) derived from:
  - Soil texture type (intermediate map)
    - Soil Physics Unit (input raster map)
  - First groundwater layer (input raster map)

Soil texture
According Remme et al. 2018: 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.

RIVM report 2017-0040 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[1]. RIVM report 2017-0040 Table 2.5 shows the reclassification of these 8 texture classes into 4 texture groups and two texture types[2].

In Annex 3 are combined the two above mentioned tables. It shows all combinations for look up table(s) to reclass BOFEK unit to texture class, texture group and texture type.

Soil drainage
The soil drainage is derived from the reclassified input maps first groundwater level, Mean highest & mean lowest groundwater and the intermediate map soil texture type classes (from previous paragraph). Below the description of the reclassification of the groundwater input maps.

GHG and GLG
The input maps 'Mean Highest Groundwater levels' (GHG in Annex 1) and 'Mean Lowest Groundwater levels' (GLG in Annex 1) are reclassified to 13 classes (Annex 4).

Reclassification of the mean groundwater level classes and the two texture type classes leads to nine drainage classes (LU 8 in Annex 1). Annex 5 Drainage class (groundwater) shows the complete look up table.

First Gt
The so called first Gt or groundwater table input map is derived by rasterizing the vector map (Bodemkaart van Nederland 1:50 000, Alterra, 2006) by the groundwater table id's. Reclassification of the first groundwater level class and the two soil texture type classes into seven drainage classes (soil) (LU 5 in Annex 1) (Annex 6).

---

[1] This is data and input preparation, done outside the model. But it can also be done in the model. If the BOFEK is the input map, then look up tables (LU3 and LU4) must be changed (Annex 3).
[2] In the RIVM report 2017-0040. Remme (2017), table 2.5 is the Texture type code mixed up. The correct Texture codes of Texture type "Heavy" is Code 1 and of Texture type "Light" is Code 2.

The drainage class map (soil and groundwater) are combined to one Composted drainage class map with a function (4 in Annex 1):
Per raster map cell, the value of drainage class (groundwater) is selected but if the cell value is Null (NoData) then the cell value of drainage class (soil) selected. Because the GHG and GLG maps for the current situation do not have omissions this step is redundant.

Soil drainage group
The combined drainage class map is reclassified with a look up table (LU8 in Annex 1) to a drainage group map (Table 7).

Table 4.3 *Description of drainage classes and groups and the reclassification of drainage class id's to drainage group ids (LU 9).*

Drainage class id	Drainage class code (RIVM figures and tables)	Description drainage class	Description drainage group	Drainage group id
1	A	excessively drained soils (very dry)	Very dry	1
2	B	well-drained soils (dry)	Dry	2
3	C	moderately well drained soils (medium dry)	Dry	2
4	D	insufficiently drained soils (moderately wet)	Moist-wet	3
5	E	rather poorly drained soils with groundwater permanently (wet)	Moist-wet	3
6	F	poorly drained soils with groundwater permanently (very wet)	Wet	4
7	G	extremely poorly drained soils (very wet)	Wet	4
8	H	poorly drained soils with backwater (temporary groundwater) (very wet)	Moist-wet	3
9	I	rather poorly drained soils with backwater (temporary groundwater) (wet)	Wet	4

Annual increment (Vito)
The combination and reclassification ((LU 10 in Annex 1)) of the soil texture group and the drainage group maps (from the previous paragraphs) and the forest type map results in the Annual increment (Vito) map (Annex 8).

Demand
The demand was derived from statistics by Probos: https://www.clo.nl/indicatoren/nl007015-balans-voor-hout-en-houtproducten-voor-nederland.

4.2 Technical implementation

4.2.1 Implementation model

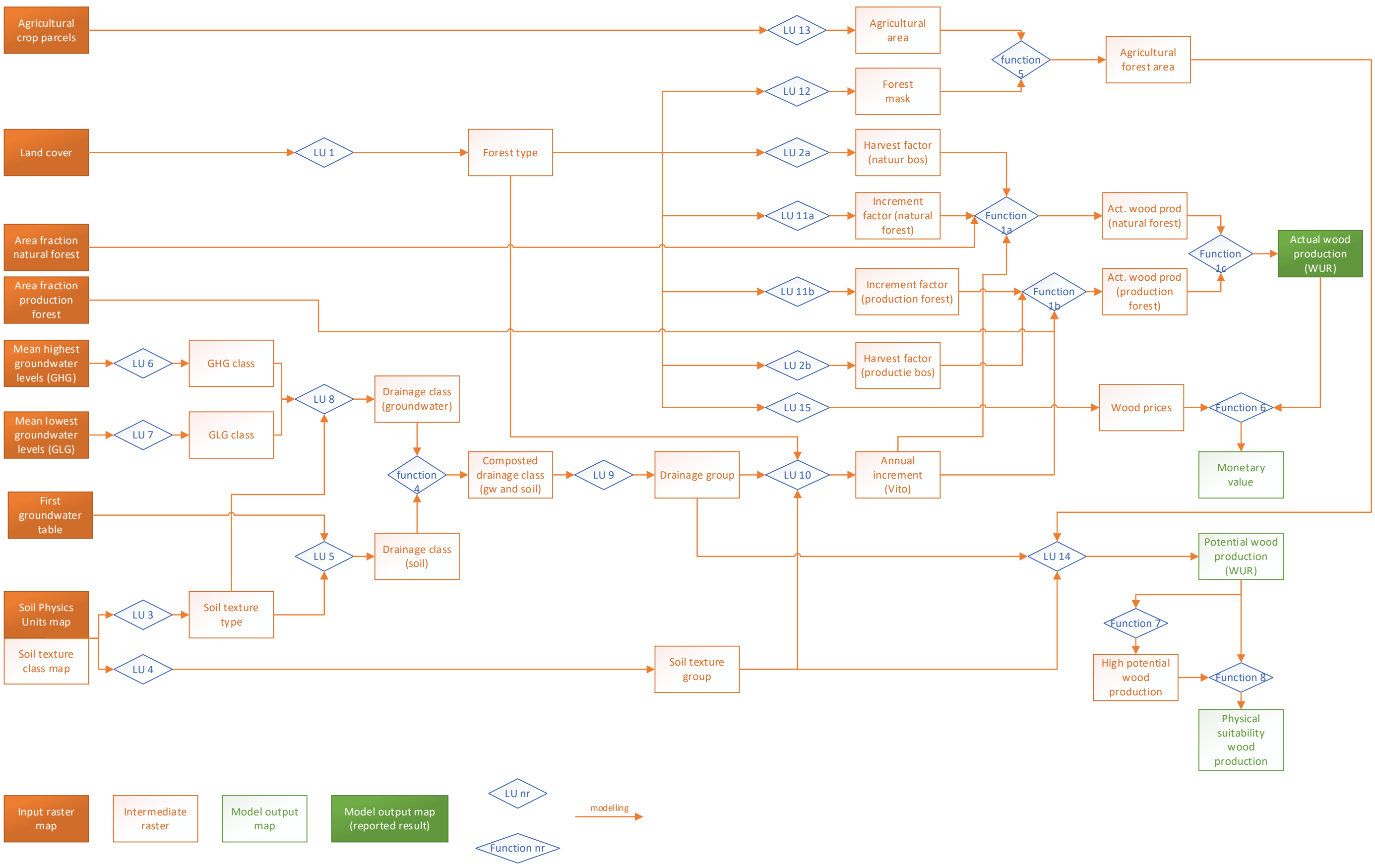


Figure 4.1 *Flowchart of the wood production model.*

4.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9) and PCRaster version 4.2.0-rc.1 built on 24.01.2018. An environment.yml file is available in git (https://git.wur.nl/roelo008/NC-Model_bossen) that can be used to reproduce the exact environment used in the simulations.

4.2.3 Testing

No tests have been performed. A test area was defined (all of the Netherlands). The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

4.3 Input and output, Parameters and variables

4.3.1 Parameters and variables

Table 4.3 *Parameters applied to estimate the ecosystem service 'wood production'.*

Input	Unit	Short description	Source
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	BIJ12, 2020
Area of natural forest	Boolean map (0 or 1)	The maps show which parts of the map are natural forest	BIJ12, 2020
Area of production forest	Boolean map (0 or 1)	The maps show which parts of the map are production forest	BIJ12, 2020

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

4.3.2 Calibration

No calibration has been performed. We did look if the results were in agreement with statistics from Probos. This was the case. The results differed only a couple precents of this indicator: https://www.clo.nl/indicatoren/nl007015-balans-voor-hout-en-houtproducten-voor-nederland.

4.3.3 Input and output

Input
The input is described in table 4.4.

Table 4.4 *Input maps applied to estimate the ecosystem service 'wood production' (Remme, 2018).*

Input	Unit	Short description
First groundwater level (Soil map)	First groundwater levels (id)	Spatial information on groundwater level and soil structure to roughly 1 meter depth
Land cover/ ecosystem unit map	LCEU land use classes (id)	Land cover classes map (LCEU or Top10)
Area fraction natural & production forest	Fraction between 0 and 1	Forest management: the area fractions (percentage cover per cell (%)/100) of the grid cell covered by natural forest and covered by production forest.
Soil Physics units map	Soil biophysical units (id)	Defines areas with similar soil characteristics and hydrological activity (BOFEK, 2012)
Mean highest & mean lowest groundwater levels	Groundwater level in cm (minus surface)	Defines maximum and minimum average groundwater levels

Forest types and management
Given the available information on forest cover and forest management in the Netherlands (Land cover/ ecosystem unit map), the wood production model distinguish three forest types (table 4.4) and two forest management types (table 4.6).

Table 4.5 *Forest types.*

forest type (id)	forest type (description)
1	mixed wood
2	deciduous
3	coniferous

Table 4.6 *Forest management types.*

management type (id)	management type (description)
1	natural forest
2	production forest

Where the land cover is of type forest and which type of forest can be derived from land cover maps like LCEU or Top10. By using a look-up table (LU) and classify the every land cover class to non-forest or one of the three forest types (Annex and LU 1).

Output
Output is a map with 10m resolution and statistics of the actual wood production (harvestable wood production) in m3/yr for the total of the Netherlands.

4.3.4 Standard indicators

Supply
Supply of wood from Dutch forests.

Demand
Total wood consumption in the Netherlands.

Combination of supply and demand
% wood production versus demand (m^3 wood equivalents without bark/yr).

See also Table 1.1. N742 ZB

4.4 Evaluation of model functioning

4.4.1 Sensitivity analysis

A sensitivity analysis has not been performed. Although a scenario has been run with more forest and the results indicate the differences are plausible (Breman et al., 2022).

4.4.2 Uncertainty analysis

An uncertainty analysis has not been performed.

4.4.3 Validation

No rigorous validation of the present model has taken place. However, an attempt has been made to reconstruct historical wood stocks on the basis of known harvest, growth and environmental variables on the one hand and actual measurements of the wood stocks on the other.

Methods

The basic assumption for the calculations is that the stock of wood at a given time can be determined by adding the previous year's stock to the change in stock in that year:

1. V2 = V1 + deltaV1

Where V is the stock per hectare (m^3/ha) and deltaV is the change in stock (m^3 ha^{-1} yr^{-1}).
Note: This calculation can also be performed back in time.
Stock change consists of growth minus harvest and mortality:

2. deltaV = Growth - Harvest – Mortality

Growth, harvest and mortality are expressed in m^3 ha^{-1} yr^{-1}. Growth, harvest and mortality vary over time. The assumption here is that growth, harvest and mortality in a given year can be calculated as the level in a reference year multiplied by a correction factor F:

3. Growth = Reference growth * F_growth
4. Harvest = Reference harvest * F_harvest
5. Mortality = Reference mortality * F_mortality

Growth varies over time as a function of climate (= temperature), atmospheric CO_2 levels, nitrogen deposition, and changing forest composition in terms of tree age and species. We assume that all these factors act multiplicatively:

6. F_growth = F_t * F_CO_2 * F_N * F_forest

Where F_t is the correction factor for temperature, F_CO_2 is the correction factor for CO_2, F_N is the correction factor for nitrogen deposition, and F_forest is the correction factor for changes in forest composition. These factors are dimensionless.

The carbon stock per ha (VC) at a given time can be calculated as:

7. VC = V * D * BEF *CC

Where D is the wood density (kg dry weight/m^3 fresh volume), BEF is the biomass expansion factor (dimensionless) and CC is the carbon content (kg C/ kg dry weight).
The annual change in carbon stock can be determined from the difference in carbon stock of successive years:

8. deltaVC = VC2 - VC1

The amount of C that is taken out of the forest annually through harvesting can be determined as:

9. C_harvest = Harvest * D * CC

A quantity of carbon can be converted into CO_2 equivalents using:

10. CO2eq = C *44 / 12

Where 44 is the atomic weight of CO_2 and 12 is the atomic weight of C.
The totals for the entire forest area in the Netherlands for wood stock, carbon stock, growth, harvest, etc. can be determined by multiplying the value per ha by the forest area in the respective year.

Method for reconstructing the period 1950-2013

First, we tested the method by reconstructing the development of the forest over the period 1950-2013. This takes the standing stock as estimated in NBI6 for the year 2013 as the starting point and attempts to calculate back to 1950.

Growth

The reference growth rate is taken as estimated in the NBI6, representative of the period 2003-2013, where this value is assigned to 2013. Here we assume a gross growth rate of 8 m^3 ha^{-1} $year^{-1}$. This is growth as determined at the permanent monitoring points, including correction for growth of trees harvested between inventories. This value is thus slightly higher than stated in the NBI6 report.

For F_t, F_CO2, and F_N, the response curves from de Vries et al. (ref) are used, with the level of response determined every 10 years, starting in 1950. In between, the response was linearly interpolated. Three different methods were tested for the determination of F_forest:

Reconstruction of F_forest from historical inventory data

F_forest is a function of the species composition and age structure of the forest. The area of forest by species and age is known from historical forest surveys. Combined with the expected growth per ha of these species per age class, the expected growth of the forest can thus be calculated, and by comparing the expected growth at different times the F_forest can be determined. For expected growth, two methods are available: the yield tables of Janssen et al. (1996) and data from the NBI6 (Schelhaas et al., 2014). The yield tables are based on measurements from experimental fields in the years 1950-1990, while the NBI6 is based on measurements at sample points in the period 2001-2013. In general, according to the NBI6 data, by-growth peaks about 10 years earlier than the yield tables, and growth is higher in older forest (Figure 1). From the data of the first to the sixth forest statistics and the HOSP, the areas by age class for the species Scots pine, other conifer species, oak, poplar and other deciduous species were determined for the respective years on record. The tables of Scots pine growth class 8, Douglas-fir class 12, oak class 6, poplar quality II, and beech class 8 were used to determine F_forest using the yield tables (Method 1A), respectively. For the determination of F_forest using the NBI6 data (method 1B), the curves were determined based on the estimated by-growth per sample point, averaged over all plots with the respective species as the main tree species, per 10-year age interval. For other coniferous wood, all plots with a dominant coniferous species other than Scots pine were used, and for other deciduous wood, all plots with a dominant deciduous species other than oak or poplar were used.

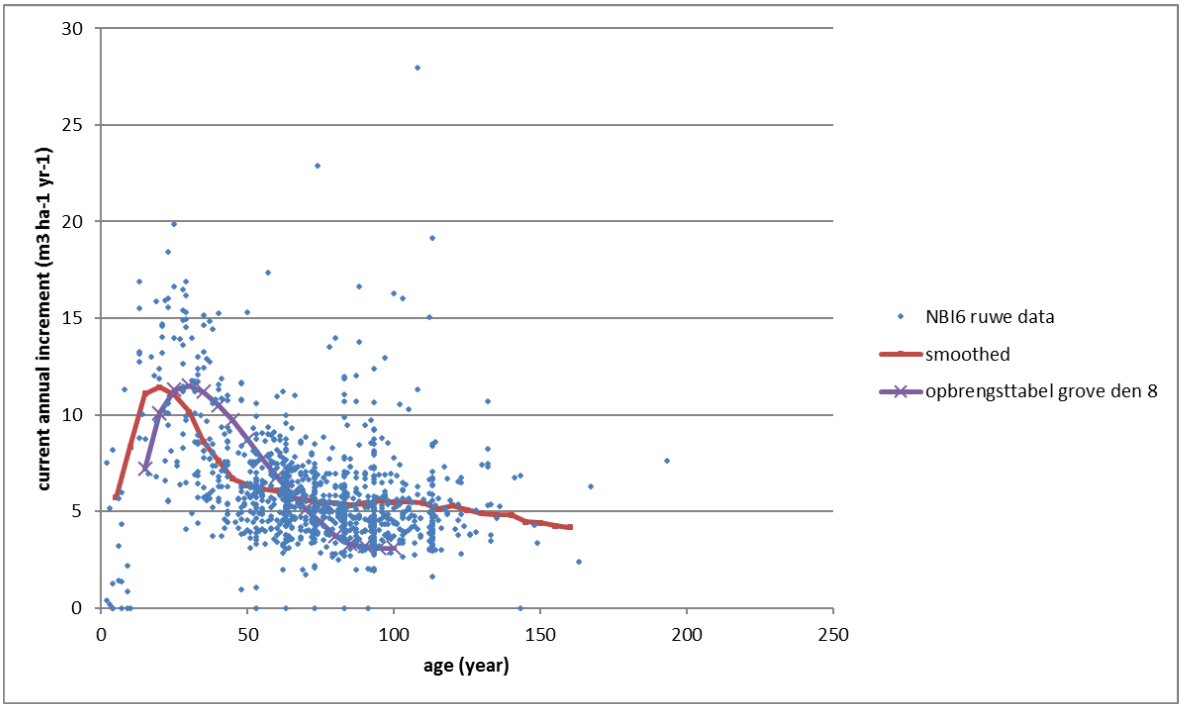


Figure 4.2 *Comparison of the growth of Scots pine as measured in the NBI6 and according to the yield table growth class 8. Translation: NBI6 ruwe data = National Forest Inventory raw data, opbrengsttabel grove den 8 = yieldtable scotch pine 8.*

Direct estimation F_forest from historical by-growth

Based on the measured by-growth in a survey, the level of F_forest needed for that by-growth can be determined based on the correction factors mentioned earlier and the reference growth. The measured by-growth in the various surveys was interpolated, and the F_forest_direct was determined for each year.

Harvest

From the permanent sample points measured in both the MFV (2001-2005) and NBI6 (2012-2013), we can infer how many m^3 wood are felled annually. This is estimated to be 4.3 m^3 ha^{-1} yr^{-1}. The FAO provides statistics on annual wood harvests since 1960, but these are the totals for the whole of the Netherlands, and are the net volumes that actually leave the forest, therefore after harvest losses. We interpolated the area estimates from the various forest surveys to get a continuous area series. We then determined the wood harvest per ha by dividing the annual FAO figures for total harvest by the area of forest. We took the average harvest in the period 2003-2013 as the reference level and determined the F_harvest for each year. For the period 1950-1960, we have no wood harvest data and have assumed that the F_harvest is the same as for 1960.

Mortality
No historical data are available for tree mortality. We therefore assume a linearly increasing mortality from 0.5 m^3 ha^{-1} yr^{-1} in 1950 to the estimated NBI6 value of 1.2 m^3 ha^{-1} yr^{-1} in 2013.

Results of the reconstruction for 1950-2013
Both methods based on the historical age structure yield a fairly similar F_forest, while the F_forest determined by direct means results in a very different pattern (Figure 2). The other correction factors range from 0.8 to 1. As might be expected, the F_forest_direct yields a good reconstruction of the measured by-growth in the past (Figure 3). Methods based on the historical age structure overestimate by-growth in the first half of reconstruction and underestimate it in the second half. None of the three methods can reconstruct the measured stock during the period 1950-1970 (Figure 4). The direct method follows the trend in measured values reasonably well after 1980, while the age-dependent methods deviate considerably up to 1995 and follow the measured values closely thereafter.

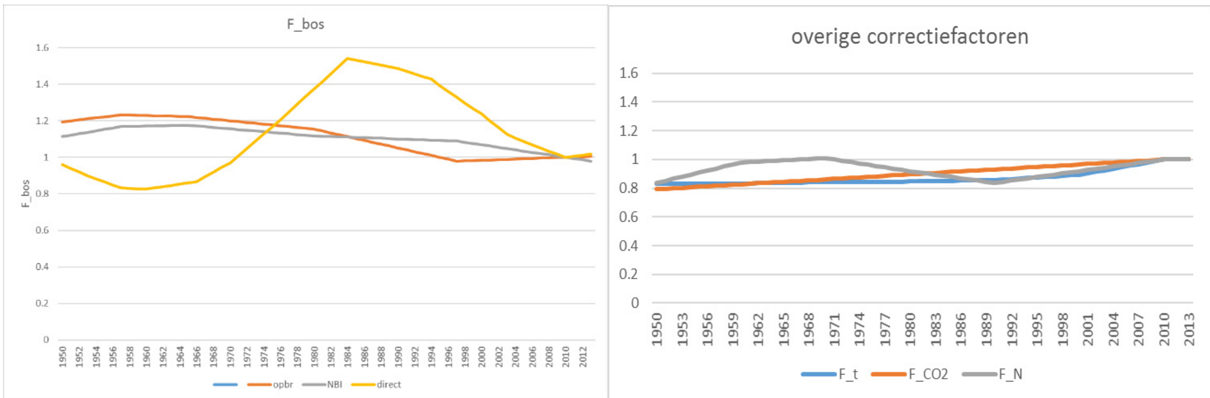


Figure 4.3 *Links: Correction factor F_bos as determined by the three methods. Right: Other correction factors affecting F_growth. Translation: F_bos = F_forest, overige correctiefactoren = other correction factors.*

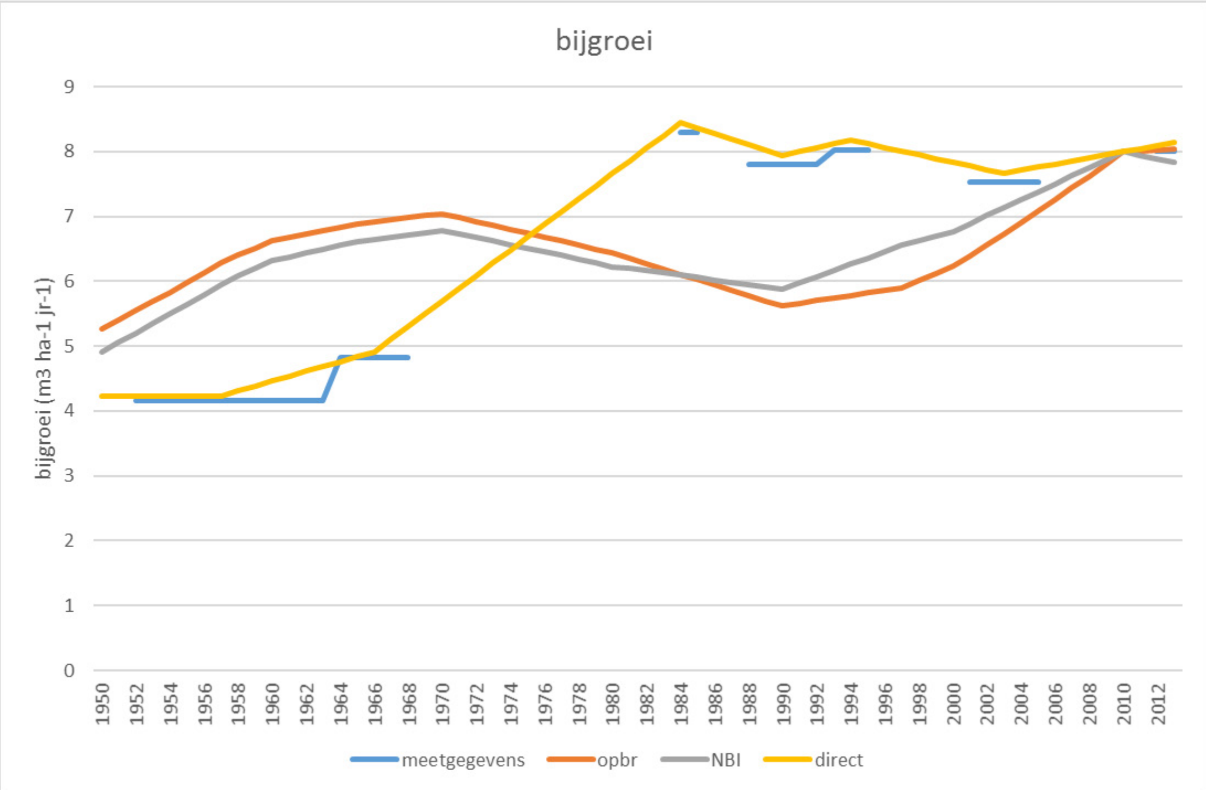


Figure 4.4 *Reconstruction of the by-growth according to the three methods, compared with the measurement data. Translation bijgroei = increment.*

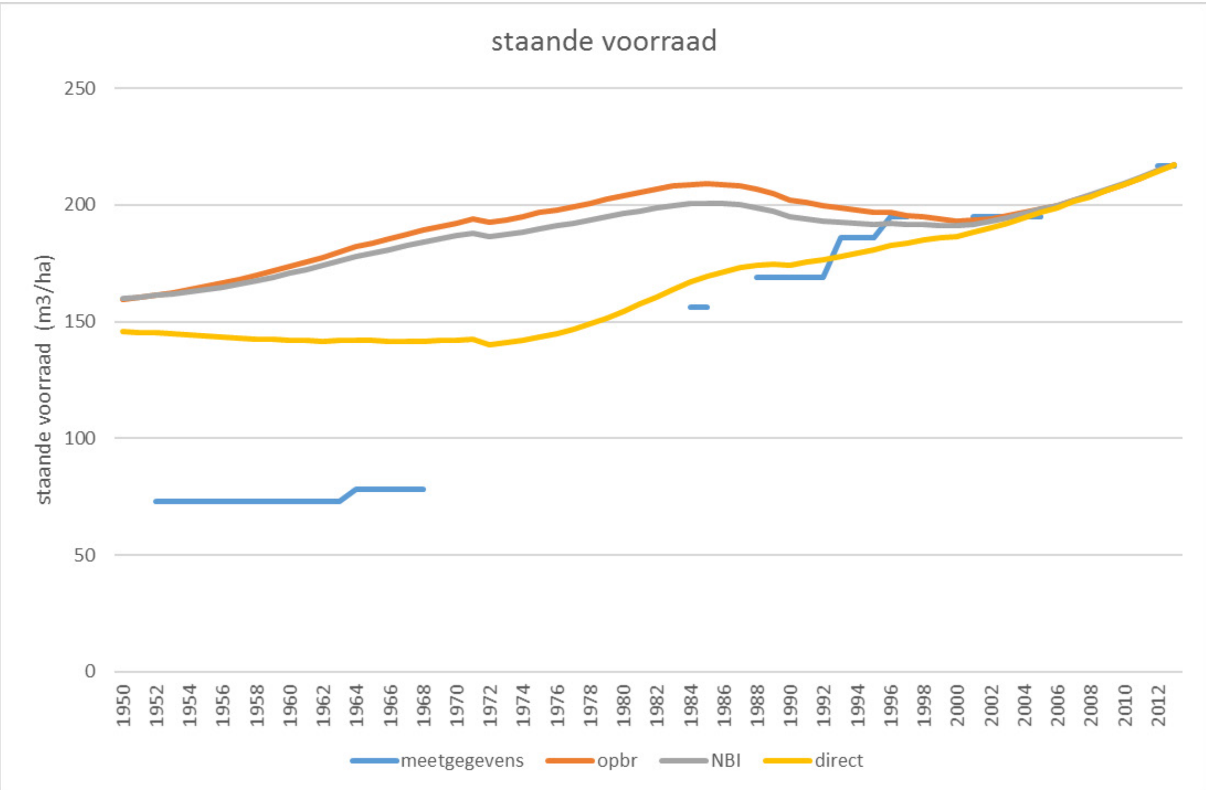


Figure 4.5 *Reconstruction of the standing stock (back from 2013) according to the three methods, compared with the measurement data. Translation: staande voorraad = standing stock.*

Discussion of the reconstruction

An independent determination of the four correction factors for growth does not provide a good reconstruction of by-growth relative to measurements, but does result in a good match with fairly recent stock measurements. A direct derivation of the F_forest from the measurements provides a reasonable match with the measured stock over a longer period, but in the period 1950-1970 it shows a stock that is twice as high as reported in the surveys. Major reasons for this discrepancy are the unreliability of old data, and the absence of harvest data before 1960. The older surveys usually worked with standard tables instead of measurements. It was not until the fourth period of forest statistics (1981-1984) that actual measurements were made. Based on this reconstruction, it is not possible to make a good assessment about how well the method works. However, it does appear that a larger effect on growth is predicted for the last few years relative to the measured change.

Scenarios

In the first scenario, we calculated stock accumulation through 2080 with the assumption that temperature, CO_2 and nitrogen deposition are constant. Harvest and mortality were also assumed to remain constant at 2013 levels. F_forest is derived from the simulated by-growth per 5-year period from an EFISCEN simulation for the NEV. This simulation does not take changing environmental factors into account and assumes constant harvest. Growth and mortality are dynamic outputs due to changes in forest composition. By-growth in 2080 decreases to about 80% of current levels due to forest ageing. By 2080, the stock has increased to 315 m^3/ha. This is close to the value simulated by EFISCEN (306 m^3/ha). Anomalies arise because mortality in EFISCEN is dynamic, and the by-growth level in 2013 is slightly different.

In the second scenario, we assumed a further increase in temperature and CO_2, while nitrogen deposition continues to decline. Other factors remain constant. In this case, the stock increases to 381 m^3/ha due to higher by-growth than in Scenario 1, as higher temperature and CO_2 offset the effects of reduced nitrogen deposition.

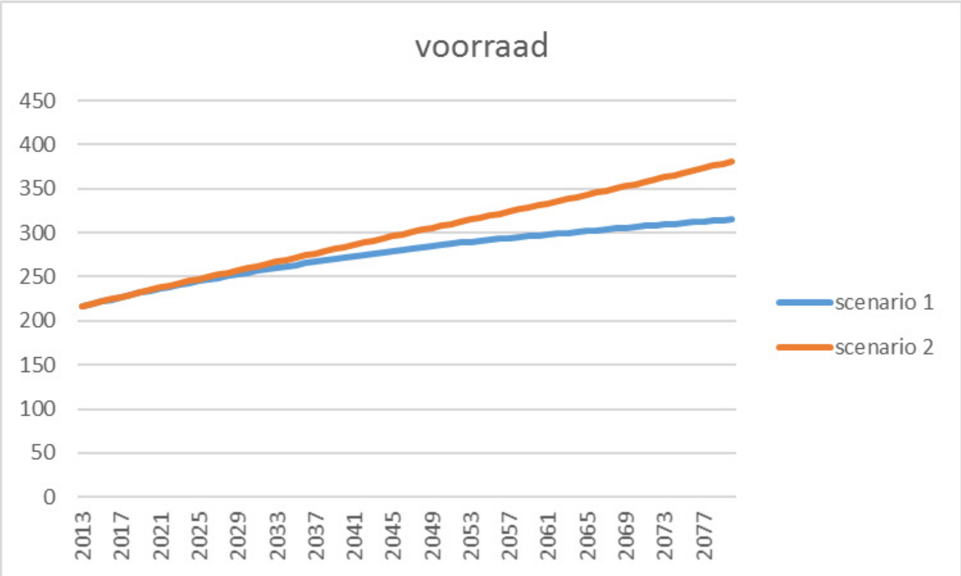


Figure 4.6 *Stock development to 2080 for Scenario 1 (unchanged environmental conditions and harvest) and Scenario 2 (Scenario 1 with changing environment). Translation: voorraad = stock.*

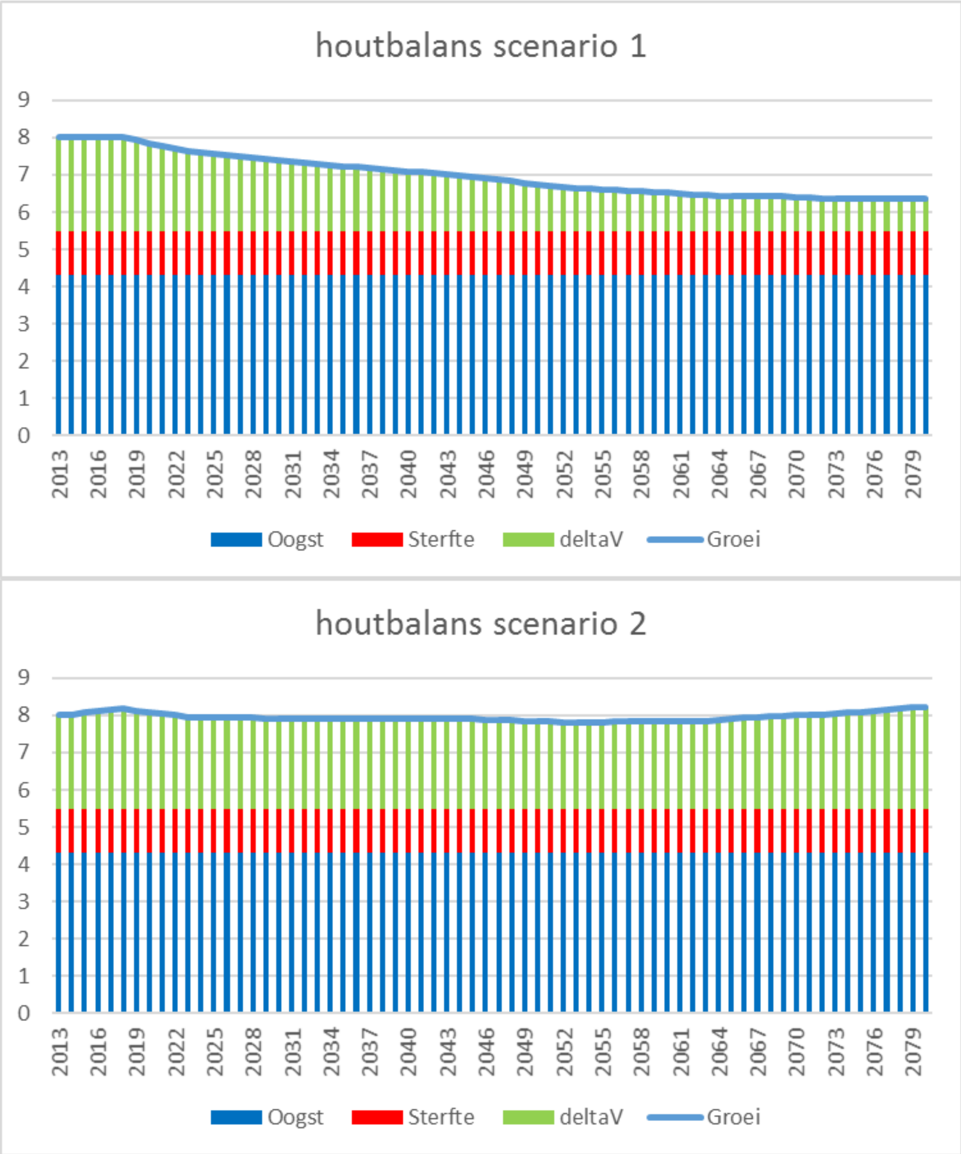


Figure 4.7 *Wood balance in both scenarios. Translation: houtbalans scenario = woodbalance scenario.*

4.4.4 General assessment of model quality

An overall assessment has not yet taken place.

4.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

4.5.1 Reliability

A Very high, B. high, **C. sufficient,** D. moderate, E. low

4.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

4.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- Testing

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- Calibration
- **Input and output**
- **Origin Input data**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- **Validation**
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

4.5.4 Future model development options

- Investigate how the model can fit more closely (by improving model parameters or adding variables) to the measured values with validation data.
- Make more explicit attribution of how the wood from the forest is used. This concerns the distinction, for example, between wood for construction, biomass for energy generation and/or carbon sequestration. If wood is used for housing then it stays in the chain longer and at the same time contributes to carbon sequestration. Also, the different parts of a tree can be allocated separately. For example, the roundwood is used for construction and thus carbon sequestration, and only the branches, roots and stumps are used for energy generation.
- Data on vegetation cover (10-metre grid cell maps of the percentage of grass, shrubs and trees or the tree registry) can be combined with current land-use data from the nature and landscape master file to achieve even better spatial coverage of the model, especially in the city where the input files that are used poorly estimate the amount of forest.
- The completeness of the ecosystem service can be improved. Within production services, CICES (Haines-Young and Potschin, 2013) distinguished 'biomass', which consists of three components. First, there are fibres and other materials from plants, algae and animals for direct use. These include wood, fibres, flowers, hides, cotton, rubber, oil, wax, soap and paint. Second, there is biomass for agricultural use, e.g., animal feed and manure. Third, there is genetic material, e.g., for medicines, fermentation processes, or wild animals in breeding programs. With wood production, the ecosystem service is quite narrow in scope, although it is one of nature's most important products.

4.6 Literature

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5 Drinking water production

Bart de Knegt (WENR), Inez Woltjer (WENR)

5.1 Theoretical rationale

5.1.1 General description of model

To produce drinking water of sufficiently good quality, groundwater protection areas have been designated. These are zones from which it takes water 100 years to reach the extraction point from the edge (i.e. catchment areas). These areas have been mapped. In the Netherlands, groundwater protection areas are covering approximately 1,450 km^2i.e. almost 4% of the Dutch (land) territory. In a groundwater protection area, there are restrictions on certain? human activities to reduct the risk? of groundwater contamination. These restrictions are included in regulations associated with groundwater protection plans.

Extraction areas for the public water supply are areas from which surface water or groundwater is extracted. Sources of recharging the groundwater-saturated zone may include precipitation infiltrating from the land surface and water infiltrating from ditches, lakes, canals and rivers.

The model used here is simple in design and determines the extent to which the current land use allows the soil to perform its purifying function sufficiently well (drinking water quality). In land use where manure or chemical fertiliser, pesticides or other harmful substances enter the groundwater, there is no sustainable use and natural soil processes cannot provide enough clean drinking water. The demand is defined as 100% sustainable land use of the catchment area.

5.1.2 Conceptual model and formal model

The model determines what proportion (%) of the 100-year catchment areas is compatible with drinking water production. Sustainable land use now includes:
- Nature reserves of the NNN
- Stricter agricultural nature management (where no fertiliser may be applied).
- Organic farming
- Buildings
- Open waters

Customary agriculture or industry does not fall into any of these categories and as such is not considered compatible with sustainable drinking water production.

The model used here is simple in design and contains a number of simplifications. Water extracted at the extraction point is often not quite drinking water quality, and simple purification steps may still be needed (e.g. aeration and sand filtration). But these simple steps are very different from the radical purification (e.g. UV/peroxide treatment, membrane filtration, activated carbon) that must take place if pollutants such as pesticides, manure, drug residues or other contaminants are present in the water. In addition, the model looks mainly at the quality of the water and not at whether the normal quantity is sufficient. It is recommended that the model be improved in the future (see Section 4.5.4).

5.2 Technical implementation

5.2.1 Implementation model

Below is the flowchart from input to result (Figure 5.1). Table 5.1 shows the area and percentage of the catchment areas with the various land-use classes.

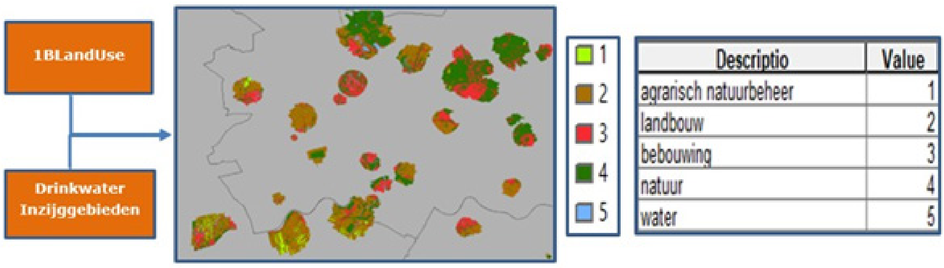

Figure 5.1 *Flow diagram from input to result.*

Table 5.1 *Current distribution of land-use classes in the catchment areas around drinking water extraction points.*

Value	Descriptio	DUURZAAM	OPP_ha	perc
1	agrarisch natuurbeheer	ja	1501	1
2	landbouw	nee	29942	17
3	bebouwing	ja	28938	16
4	natuur	ja	115774	66
		totaal	176156	100
		percentage NIET duurzaam		17
		percentage duurzaam		**83**

5.2.2 Technical environment

The Drinking Water model has been programmed in Python (Python 3.9.1) and uses Rasterio (version 1.1.8) and Numpy. To work with big raster data (2.5 m resolution covering all of the Netherlands), Dask and Xarray was used. An environment_drinkwater_1.yml file is available in git (z`, that can be used to reproduce the exact conda-environment used in the simulations.

5.2.3 Testing

The model has not yet been tested. However, the results for the current situation were assessed for plausibility. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

5.3 Input and output, parameters and variables

5.3.1 Parameters and variables

The following parameters are in the model:
- Area of land use within the 100-year catchment areas
- Distribution of land use distinguished as sustainable:
  - Nature (sustainable land use)
  - Organic farming (sustainable land use)
  - Strict agricultural nature management (sustainable land use)

- Open waters (sustainable land use)
- Regular agriculture (unsustainable land use)

5.3.2 Calibration

No calibration has been performed.

5.3.3 Input and output

Input
Maps showing the following land uses:
- Nature (sustainable land use)
  - SNL (nature and landscape grant scheme) management type map
- Organic farming (sustainable land use)
  - WUR GEODESK data file (Smidt internal memo)
- Strict agricultural nature management (sustainable land use)
  - Land use map (see Chapter 3)
- Open waters (sustainable land use)
  - Land use map (see Chapter 3)
- Regular agriculture (unsustainable land use)
  - Land use map (see Chapter 3)

Output
Outputs are maps and tables showing the amount (ha/%) of the above land uses in the 100-year catchment areas around water extraction points.

5.3.4 Standard indicators

Supply
Ecosystems that have a purifying effect on the water (to drinking water quality).

Demand
Entire area of the 100-year catchment zones for drinking water extraction with sustainable land use (nature, organic farming, water, buildings or strict agricultural nature management).

Combination of supply and demand
% surface area of 100-year catchment zones around water extraction point with sustainable land use (hectares).

See also Table 1.1.

5.4 Evaluation of model functioning

5.4.1 Sensitivity analysis

A sensitivity analysis has not yet taken place.

5.4.2 Uncertainty analysis

An uncertainty analysis has not yet taken place.

5.4.3 Validation

A validation has not yet taken place.

5.4.4 General assessment of model quality

An overall assessment of model quality has not yet taken place.

5.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **<u>complete</u>**, <u>partly (in)complete</u>, incomplete.

5.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate, E. low**

5.5.2 Completeness

Completeness: A. (almost) complete, B. contains most important aspects, **C. contains some aspects.**

5.5.3 Status A progress

ST.1: Model description
- **<u>General description</u>**
- **<u>Description conceptual and formal model</u>**

ST.2: Technical implementation
- **<u>Implementation</u>**
- **<u>Technical environment</u>**
- Testing

ST.3: Description parameters, variables, input and output
- **<u>Parameters and variables</u>**
- Calibration
- **<u>Input and output</u>**
- **<u>Origin Input data</u>**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

5.5.4 Future model development options

- At present, the ecosystem service of drinking water is framed in terms of the sustainability of the land use of catchment areas. A recommendation is also to look at whether the quantity of drinking water is sufficient to meet our future needs (see also CICES definition). A study by Wuijts et al. 2014 showed that a bottleneck could potentially occur in the future and as a result of climate change.

- More consideration could be given to the magnitude of the ecosystem's (land use categories) contribution in purifying drinking water.

- Additional consideration could be given to how the level of land use is related to the treatment measures required to achieve drinking water quality. This would provide a more accurate estimate of the actual ecosystem contribution to purification up to drinking water quality. Other factors such as water type (riparian groundwater, groundwater, surface water), soil type, and groundwater currents could also be included in estimating the ecosystem's contribution to water purification.

5.6 Literature

Wuijts, S. RIVM E. van der Grinten, RIVM E. Meijers, Deltares C.I. Bak-Eijsberg, Deltares J.J.G. Zwolsman, KWR (2014). Impact klimaat op oppervlaktewater als bron voor drinkwater Van knelpunten naar maatregelen. RIVM Rapport 609716007/2013.

6 Biomass for energy (forest)

Nanny Heidema (WENR) and Bart de Knegt (WENR)

6.1 Theoretical rationale

6.1.1 General description of model

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). In this model we look at biomass produced by wood from forests in the Netherlands. 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.

The original Vito model is adjusted and results in two output maps: actual production from forests, potential energy production from forest.

6.1.2 Conceptual and formal model

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).

Actual energy from forest
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:

Actual energy from forest =
*Actual wood production * (average biomass expansion factor – 1) * wood energy content factor * (1 – yield loss factor)*

- *Actual wood production* is the actual wood production in m^3/ha.year.
- *Wood energy content* is the wood energy content of 9 GJ/m^3
- Average Biomass expansion factior –1 =
  - *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))
  - x *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.
- *Yield 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.

Land cover and forest type

Like in the previous wood production chapter the land cover type map is reclassified to the three forest types (Annex 2, LU1), (CBS, 2017; BIJ12, 2020).

Biomass expansion factor (BEF)

The forest type map is reclassified twice into an average biomass expansion factor map (and a biomass expansion factor map).

Table 6.1 *Biomass expansion factors.*

Forest type id	Forest type description	Biomass expansion factor	Average biomass expansion factor
1	mixed wood	1.545	1.315
2	deciduous	1.52	1.32
3	coniferous	1.57	1.31
0	Other land use	0	0

6.2 Technical implementation

6.2.1 Implementation model

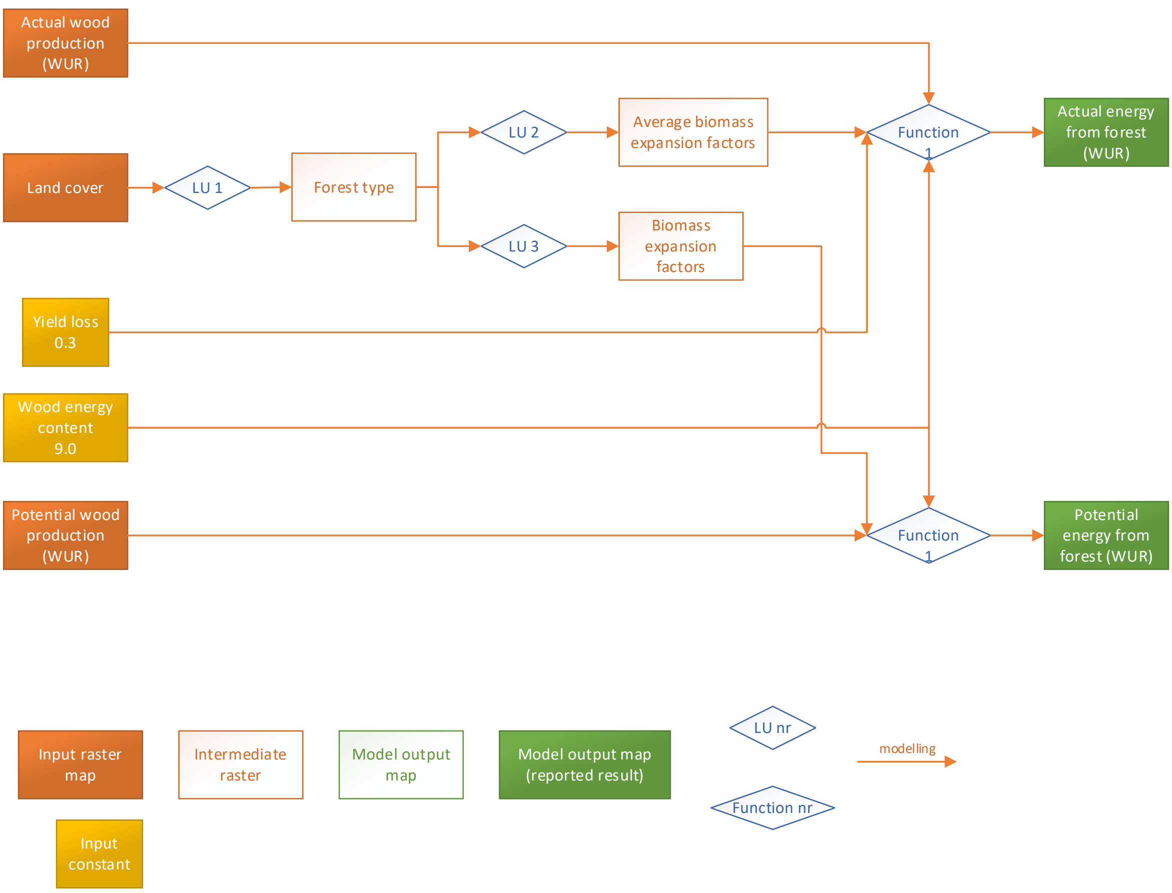

Figure 6.1 *Flowchart of the biomass from forest model.*

6.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9) and PCRaster version 4.2.0-rc.1 built on 24.01.2018. An environment.yml file is available in git (https://git.wur.nl/roelo008/NC-Model_bossen) that can be used to reproduce the exact environment used in the simulations.

6.2.3 Testing

No tests have been performed. A test area was defined (all of the Netherlands). The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

6.3 Input and output, Parameters and variables

6.3.1 Parameters and variables

This model uses the results from the wood production model as input en has the same parameters, see chapter 5. The extra parameter that is used is the Biomass Expansion Factor. That is the ration of the total above ground tree biomass.

6.3.2 Calibration

No calibration has been performed.

6.3.3 Input and output

Input

Table 6.2 *Input maps applied to estimate the ecosystem service 'energy from fores' (Remme et al., 2017).*

Input	Unit	Short description
Actual wood production	m^3 wood ha^{-1} yr^{-1}	Actual wood production in currently forested area's.
Land cover/ ecosystem unit map	Basisbestand Natuur en Landschap classes (id)	Land cover classes map, see chapter 3.

Output

Table 6.3 *Output maps (2) of the ecosystem service model 'energy from forest' (Remme et al., 2017).*

Output map	Unit	Short description
Actual energy from forest	GJ ha^{-1} yr^{-1}	Actual energy production from forests.

6.3.4 Standard indicators

Supply
Supply of energy from woody biomass from Dutch forest (PJ/jaar).

Demand
Demand is the current consumption of energy on a national level (PJ/jaar).

Combination of supply and demand
% energy production compared to energy use from forest (PJ/yr).

See also Table 1.1.

6.4 Evaluation model functioning

6.4.1 Sensitivity analysis

A sensitivity analysis has not been performed. Although a scenario has been run with more forest and the results indicate the differences are plausible (Breman et al., 2022).

6.4.2 Uncertainty analysis

An uncertainty analysis has not been performed yet.

6.4.3 Validation

A validation have not been performed yet. See also paragraph 4.4.3.

6.4.4 General assessment of model quality

No general assessment of the model have been performed.

6.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **<u>complete</u>**, <u>partly (in)complete</u>, incomplete.

6.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low

6.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects, C. contains some aspects.**

6.5.3 Status A progress

ST.1: Model description
- **<u>General description</u>**
- **<u>Description conceptual and formal model</u>**

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ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation

- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

6.5.4 Future model development options

- Make more explicit attribution of how the wood from the forest is used. This concerns the distinction, for example, between wood for construction, biomass for energy generation and/or carbon sequestration. If wood is used for housing then it stays in the chain longer and at the same time contributes to carbon sequestration. Also, the different parts of a tree can be allocated separately. For example, the roundwood is used for construction and thus carbon sequestration, and only the branches, roots and stumps are used for energy generation.
- Other land-use types (such as agriculture, other natural areas, wetlands, etc.) also produce biomass that can be used for energy generation (see CICES definition). We would like to add these types of nature to the model over time.

6.6 Literature

BIJ12 (2020). Landelijke beheertypenkaart.

Breman B.C., W. Nieuwenhuizen, G.H.P. Dirkx, R. Pouwels, B. de Knegt, E. de Wit, H.D. Roelofsen, A. van Hinsberg, P.M. van Egmond, G.J. Maas (2022). Natuurverkenning 2050 – Scenario Natuurinclusief. Wettelijke Onderzoekstaken Natuur & Milieu, WOt-rapport 136. 155 blz.; 29 fig.; 17 tab.; 109 ref; 7 bijlagen.

CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map

Remme, R., 2017. Netherlands NC-Model – Technical Documentation. Food Production. Atlas of Natural Capital (www.atlasnatuurlijkkapitaal.nl/en).RVO 2013.

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.

7 Carbon sequestration (forest)

Nanny Heidema (WENR) and Bart de Knegt (WENR)

This chapter, together with carbon sequestration in peat, can be seen as the carbon sequestration ecosystem service. Because forest and peat involve different domains with different actor mechanisms, two separate chapters are devoted to this ecosystem service.

7.1 Theoretical rationale

7.1.1 General description of model

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 actual carbon sequestration in forests.

7.1.2 Conceptual and formal model

Actual carbon sequestration in biomass
The actual carbon sequestration in biomass is the amount of carbon that is actually sequestered by trees on an annual basis. For this calculation forested areas from the landmap (chapter 3) isare used. Three forest types are used for the model: coniferous forests, deciduous forests, and mixed forests. To determine the actual carbon sequestration in trees, information is needed on the annual increment of biomass in the trees of a certain location, the carbon density of trees and the ratio of the total biomass of a tree type (including branches, roots, etc.) compared with the stem. The annual actual carbon sequestration is calculated as follows:

$$\boldsymbol{Actual\ carbon\ sequestration} = \boldsymbol{Actual\ wood\ production} \times \boldsymbol{Storage\ change} \times \boldsymbol{BEF} \times \boldsymbol{C_{density}} \times \boldsymbol{C\_to\_CO2}$$

Where
- 'Actual carbon sequestration' is the amount of carbon stored annually by woody vegetation [ton C dam^{-2} yr^{-1}].
- '*Actual wood production* is an output map of the wood production model (see chapter 5 for the model description). This map shows the annual actual wood production by woody vegetation [m^3 dam^{-2} yr^{-1}].
- 'Storage change' is a factor that describes the change in standing stock of the trees [-].
- '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).
- '$C\_to\_CO_2$' is the conversion factor between the amount of CO_2 that is taken up and the amount of C that is stored.

Actual wood production
See chapter 5.

Storage_change
Storage change natural forest see Annex 3, LU2.
Storage change production forest see Annex 3, LU3.

Table 7.1 *Storage change natural and production forest.*

forest type	Storage change natural forest	Storage change production forest
1	2.17	1.48
2	2.1	1.62
3	1.73	1.3
0	0	0

BEF
Biomass expansion factors (BEF) see Annex 3, LU4.

Table 7.2 *Biomass expansion factors per forest type.*

Forest type id	Forest type description	Biomass expansion factor
1	mixed wood	1.545
2	deciduous	1.52
3	coniferous	1.57
0	Other land use	0

wood_density
See Annex 3, LU5.

Table 7.3 *Wood density per forest type.*

forest type	wood density
1	550
2	650
3	450
0	0

C to CO_2
See Annex 3, LU6.

Table 7.4 *Converion factor C to CO2 per forest type.*

forest type	C to CO2
1	1.833333
2	1.833333
3	1.833333
0	0

7.2 Technical implementation

7.2.1 Implementation model

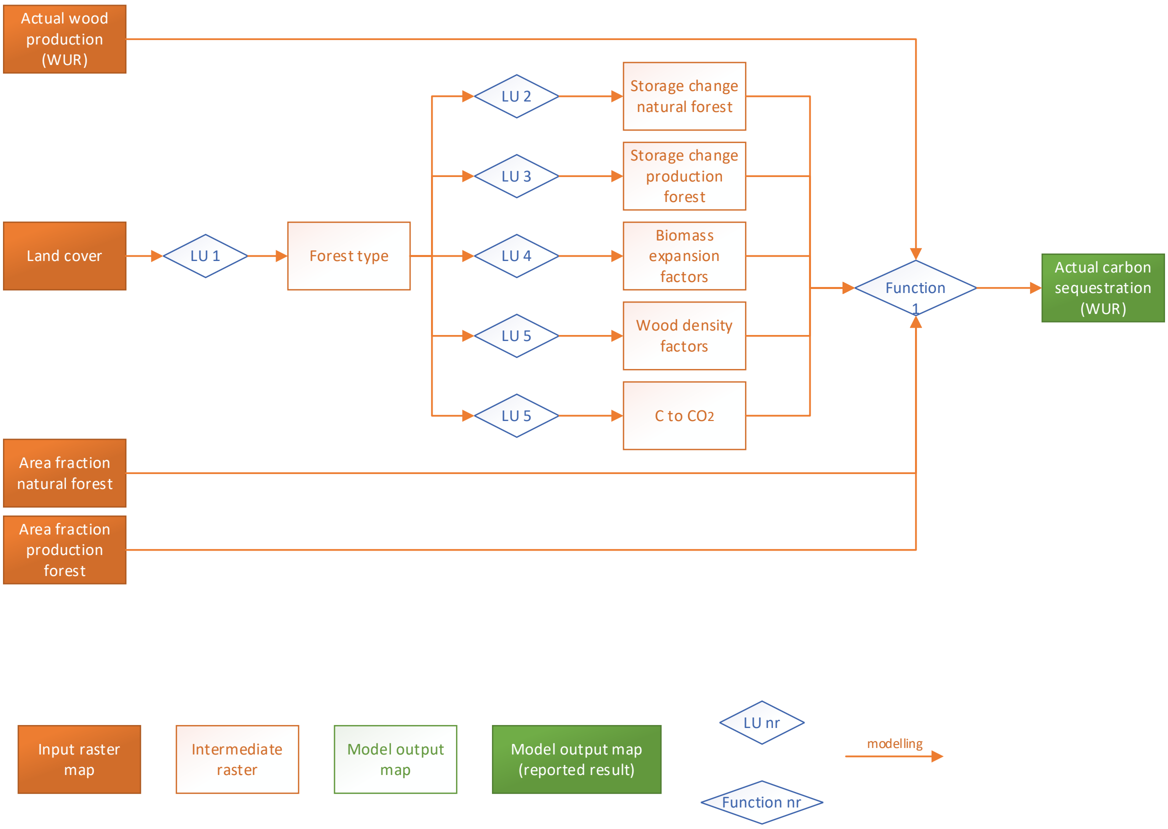

Figure 7.1 *Workflow for carbon sequestration by wood from forest.*

7.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9) and PCRaster version 4.2.0-rc.1 built on 24.01.2018. An environment.yml file is available in git (https://git.wur.nl/roelo008/NC-Model_bossen) that can be used to reproduce the exact environment used in the simulations.

7.2.3 Testing

Er zijn nog geen tests uitgevoerd, wel is een testgebied geselecteerd (heel Nederland) en zijn de resultaten op plausibiliteit beoordeeld. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

7.3 Input and output, Parameters and variables

7.3.1 Parameters and variables

- 'Actual carbon sequestration', is the amount of carbon stored annually by woody vegetation [ton C dam^{-2} yr^{-1}].
- '*Actual wood production* is an output map of the wood production model (see chapter 5 for the model description). This map shows the annual actual wood production by woody vegetation [m^3 dam^{-2} yr^{-1}].
- 'Storage change', is a factor that describes the change in standing stock of the trees [-].
- '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).
- '$C\_to\_CO_2$', is the conversion factor between the amount of CO_2 that is taken up and the amount of C that is stored.

7.3.2 Calibration

A calibration has not yet been performed.

7.3.3 Input and output

Input

Table 7.5 *Input maps applied to estimate the ecosystem service 'energy from forest' (Remme et al., 2017).*

Input	Unit	Short description
Actual wood production	m^3 wood ha^{-1} yr^{-1}	Actual wood production in currently forested areas.
Land cover/ ecosystem unit map	LCEU land use classes (id)	Land cover classes map (LCEU or Top10)
Area fraction natural & production forest	Fraction between 0 and 1	Forest management: the area fractions (percentage cover per cell (%)/100) of the grid cell covered by natural forest and covered by production forest.
Potential wood production	m^3 wood ha^{-1} yr^{-1}	Potential wood production given soil texture, drainage and current (agricultural) land use.

Output

Table 7.6 *Output maps (2) of the ecosystem service model 'energy from forest' (Remme et al., 2017).*

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

7.3.4 Standard indicators

Supply
Carbon sequestration by forest (Mt/yr).

Demand
The demand for the service carbon sequestration by forest can be approached in several ways:
- Relative to total emissions of CO_2 (equivalents) in the Netherlands
- Relative to the total emissions of CO_2 (equivalents) from forest.
- Relative to the 2030 climate agreement target for forest (=0.4-0.8 Mt/yr)

Combination of supply and demand
% sequestration of CO_2 by forest compared to total emission or policy targets (Mt CO_2 eq/yr).

See also Table 1.1.

7.4 Evaluation of model functioning

7.4.1 Sensitivity analysis

A sensitivity analysis has not been performed. Although a scenario has been run with more forest and the results indicate the differences are plausible (Breman et al., 2022).

7.4.2 Uncertainty analysis

An uncertainty analysis has not been performed yet.

7.4.3 Validation

A validation have not been performed yet. See also paragraph 4.4.3.

7.4.4 General assessment of model quality

No general assessment of the model have been performed.

7.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

7.5.1 Reliability

A Very high, B. high, **C. sufficient**, D. moderate, E. low

7.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects, C. contains some aspects.**

7.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

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ST.3: Description parameters, variables, input and output
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- **Input and output**
- **Origin Input data**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

7.5.4 Future model development options

- Make more explicit attribution of how the wood from the forest is used. This concerns the distinction, for example, between wood for construction, biomass for energy generation and/or carbon sequestration. If wood is used for housing then it stays in the chain longer and at the same time contributes to carbon sequestration. Also, the different parts of a tree can be allocated separately. For example, the roundwood is used for construction and thus carbon sequestration, and only the branches, roots and stumps are used for energy generation.
- Other types of nature (such as heaths, wetlands, grasslands, agriculture and urban green space) can also sequester carbon (see also CICES definition). We would like to add these types to the model over time. In 2022, a project to improve on the carbon sequestration ecosystem service from nature will begin. These include adding other types of nature, joining LULUCF, and improving the modelling of the effect of measures (such as different forest management or using infiltration systems on peatland).
- https://chloris.earth/ has developed a method for mapping carbon sequestration from satellite images. Satellite imagery is suitable for mapping past and present carbon in aboveground biomass. A problem with land-use maps is the definitions used for different types of nature. Satellite imagery can be used to estimate the height and area of vegetation much more precisely, without depending on definitions of underlying types of nature. The model is suitable for making predictions about carbon sequestration based on future changes. Whether model predictions could be made that also use the NDVI vegetation maps could be investigated.

7.6 Literature

Breman B.C., W. Nieuwenhuizen, G.H.P. Dirkx, R. Pouwels, B. de Knegt, E. de Wit, H.D. Roelofsen, A. van Hinsberg, P.M. van Egmond, G.J. Maas (2022). Natuurverkenning 2050 – Scenario Natuurinclusief. Wettelijke Onderzoekstaken Natuur & Milieu, WOt-rapport 136. 155 blz.; 29 fig.; 17 tab.; 109 ref; 7 bijlagen.

CBS 2017. Ecosystem Unit map, 2013. Available at https://www.cbs.nl/en-gb/background/2017/12/ecosystem-unit-map

8 Carbon sequestration (peat soils)

Michiel van Eupen (WENR)

This chapter, together with carbon sequestration in forest, can be seen as the carbon sequestration ecosystem service. Because forest and peat involve different domains with different actor mechanisms, two separate chapters are devoted to this ecosystem service.

8.1 Theoretical rationale

8.1.1 General description of model

In their natural state, vegetation in peatlands capture carbon dioxide (CO_2) which is retained in the ecosystem because of a slow breakdown of organic matter. Natural peat lands, however, also emit methane (CH_4) as a result of the waterlogged (anaerobic) conditions that lead to methanogenesis. In natural peatlands, the total balance between CO_2 uptake and CH_4 release mostly results in net carbon sequestration. The rate and balance of sequestration versus emissions depends, among other factors, on moisture conditions and temperature. Whilst natural peat lands thus act as carbon sinks, agriculturally used peat lands commonly act as sources for carbon. This is related to drainage, which is required for agricultural activities. In the Netherlands, most peatlands (about 235,000 ha, 7% of the land surface) are subject to various sorts of agricultural practices associated with drainage, resulting in oxidation of peat and release of CO_2 to the atmosphere. Since the industrial period a large proportion of these peat soils were heavily drained and fertilized. As a result, peat subsidence rates in the Netherlands are up to 18 mm yr^{-1} . Between 1970 and 2003, 67,000 ha of peat soils oxidized and these areas are now classified as mineral soil (Kuikman et al., 2005).

Kuikman et al. (2005) used the definition of the IPCC Good Practise guidelines for Histosols to quantify carbon emission from organic soils. A Histosol is a profile with more than 40 cm organic soil in the top 80 cm of the soil (FAO, 1998). Peaty soils contain less than 40 cm organic soil and are therefore not included in this definition of organic soils by the IPCC. In 2014 the soil map was updated for peat and peaty soils in the Northern part of the Netherlands; and changes from peat to peaty and from peaty to mineral soils have been updated (De Vries et al., 2014).

The demand for the ecosystem service "Carbon sequestration" can be set from three different perspectives:
- Firstly, the contribution can be determined in relation to the total emission of carbon by the Dutch economy.
- Secondly, the emissions can be determined on the basis of land use in the Netherlands. This can include the whole of the Netherlands (peat, including forest, other nature, city, agricultural area and water) or concern only the peat areas.
- Thirdly, the policy objective can be taken as starting point. The Climate Agreement sets goals for reducing emissions from peat soils. This target has been set at 1 Mton yr^{-1} (Klimaatakkoord, 2019).

8.1.2 Conceptual and formal model

Van den Akker et al. (2007) calculated CO_2 emissions from subsidence of peat soils in the Netherlands. They found a relationship between subsidence, Lowest yearly ground water levels and ditch water levels. Furthermore, they found that peat soils with a clay cover had lower subsidence rates (see Figure 8.1). Van den Akker et al. (2010) found an average CO_2 emission of 2.259 ton CO_2 ha^{-1} yr^{-1} per mm subsidence, or 0.706 ton C ha^{-1} yr^{-1} per mm subsidence (see also Figure 8.2)

We used the reported relationships for subsidence equation 5 and 8 in Van den Akker et. al. (2007):

- Peat soil without clayey topsoil:

$$Soil\ subsidence = 23.537\ GLG - 6{,}68 \quad (equation\ nr.5, (van\ den\ Akker\ et\ \ al., 2007)$$

- Peat soil with clayey topsoil:

$$Soil\ subsidence = 23.537\ GLG - 10{,}47 \quad (equation\ nr.8\ , (van\ den\ Akker\ et\ \ al., 2007))$$

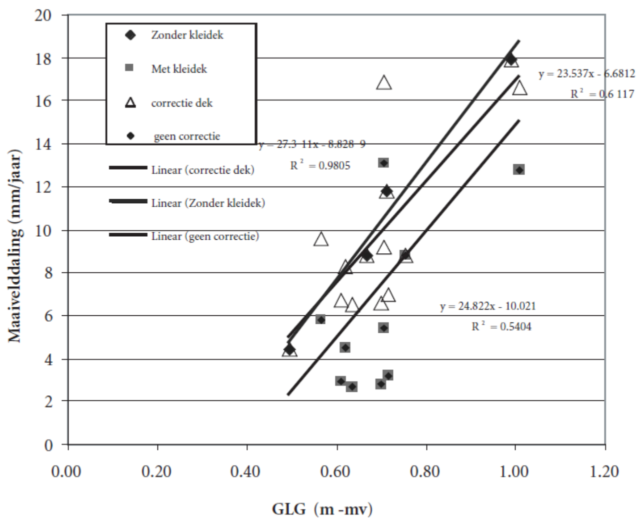


Figure 8.1 *Relation between Lowest ground water level (GLG) and soil subsidence for peat soil with and without peat soils with a and without clay cover ("kleidek") (van den Akker et al., 2007).*

Discussion

There are different methods available to calculate the final subsidence and the the GHG-emissions involved. See eg. tables Figure 7.2 from Motelica-Wagenaar & Beemster (2020), which used and compared four methods in a local case study in the Netherlands:

No.	Method	GHG emission $[t\,CO_2\text{-eq}\,ha^{-1}\,yr^{-1}] =$	Input data needed besides area of peat	Background	GHG estimated
1	Waternet (Stoffels, 2009)	-0.212 $[t\,CO_2\,ha^{-1}\,yr^{-1}\,cm^{-1}]$ · mean lowest groundwaterlevel [cm] + 1.677 $[t\,CO_2\,ha^{-1}\,yr^{-1}]$	mean lowest groundwater table	This method is developed based on a literature study of GHG emissions in Dutch peat meadows in grass land (Stoffels, 2009), see Fig. 2.	CO_2, N_2O and CH_4
2	Jurasinski et al. (2016)	-0.408* (mean groundwater level [cm − mv] − clay cover [cm]) + emission N_2O $[t\,CO_2\text{-eq}\,ha^{-1}\,yr^{-1}]$ + emission CH_4 $[t\,CO_2\text{-eq}\,ha^{-1}\,yr^{-1}]$ (see Table 2)	mean groundwater level clay cover	This method is used by GDNK (2018). This method is developed based on a literature study by Jurasinski et al. (2016), see Fig. 3.	CO_2, N_2O and CH_4
3	Van den Akker et al. (2008)	2.3 $[CO_2\,ha^{-1}\,mm^{-1}]$ · soil subsidence $[mm\,yr^{-1}]$	subsidence rates	This method is used by PBL (van den Born et al., 2016).	CO_2
4	Arets et al. (2016)	19 $t\,CO_2\,ha^{-1}\,yr^{-1}$	–	This method was used for the national CO_2 counting by RIVM (RIVM, 2016).	CO_2

Figure 8.2 *Methods to estimate soil subsicence and GHG-emissions from preat soils in the Netherlands Motelica-Wagenaar & Beemster (2020).*

Their conclusions were:

"Different methods were compared to estimate GHG emissions in agricultural peat land areas, which lead to comparable current GHG emission estimations. However, not all methods can be used to analyze effects of different policies on GHG emissions. It is recommended to update these methods regularly when new insights become available on GHG emissions in agricultural peat land areas" (Motelica-Wagenaar & BeeMaster, 2020)

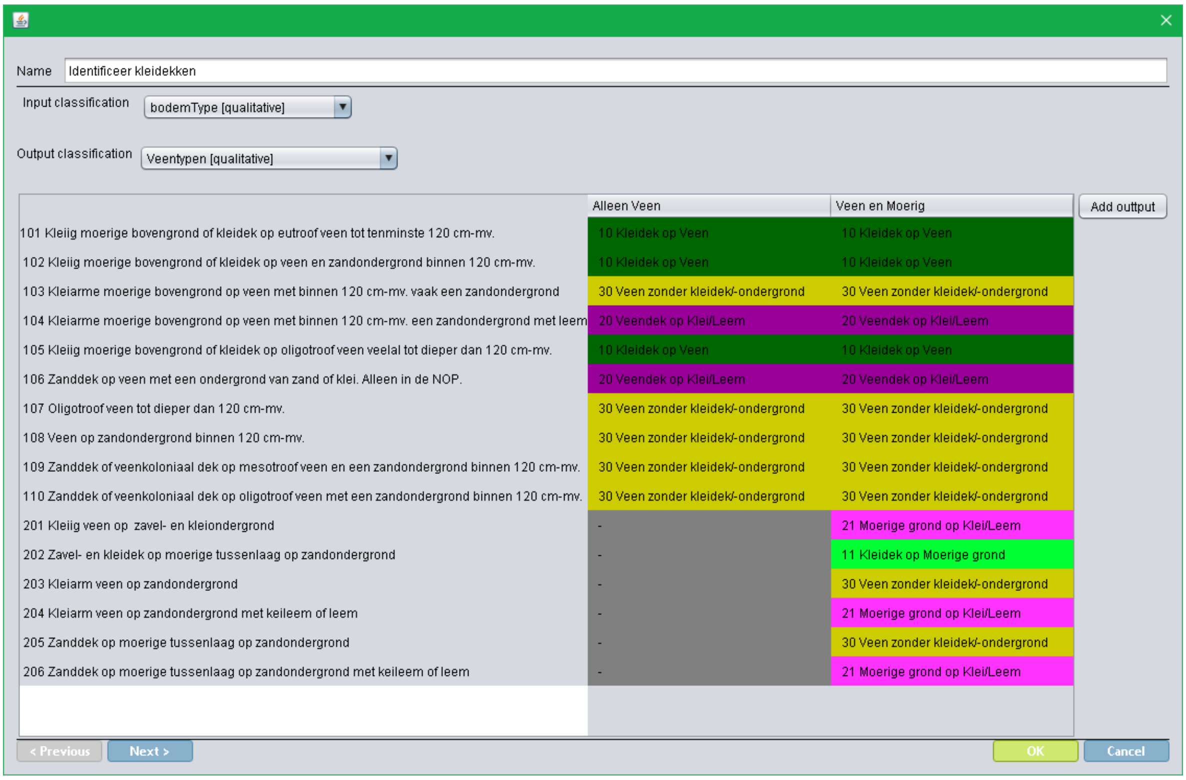
Besides the presented methods shown in Motelica-Wagenaar & Beemster (2020) also other methods exist to calculate GHG emissions from agricultural peat lands, for example measurements of CO2 emissions in Dutch agricultural peatlands (Couwenberg, 2011; Couwenberg et al., 2011; Fritz et al., 2017 all using annual mean groundwater levels for the estimation of CO_2 emissions). The basic model principles are very similar to the method of Jurasinski et al. (2016), but parameterised based on Dutch measurements (Motelica-Wagenaar & Beemster, 2020). The method of Fritz et al. (2017) is also applied in the method of the Green Deal Nationale Koolstofmarkt (GDNK) to valorize CO_2 emissions reductions in peat (GDNK, 2018). A key figure of 0.45 tons of CO_2 ha-1 yr-1 per 10 mm extra draining is used in the GDNK. In general, the amount of CO_2 emissions is mainly determined by the summer groundwater level and the average lowest groundwater level. It is exactly in summer period that the deepest groundwater levels coincide with the highest soil temperatures, causing the oxidation of the peat to be the strongest. Therefore, according to Van den Akker et al. (2018), methodologies using annual mean groundwater levels should be applied in local situations where multi-year measurement series are available.

Based on the above literature, it seems undesirable to generate nationally (extrapolated) figures for the estimation of CO_2 emissions which are just based mean annual groundwater levels as method. Especially since there methods available which can take into account the effects of different specific water management policies in the field of lowering greenhouse gas emissions (Motelica-Wagenaar & Beemster, 2020).

8.2 Technical implementation

8.2.1 Implementation of the model

First step in the workflow is to extract the peat soils from the Dutch soil map (BOFEK, 2012, most actual data can be found at: https://www.wur.nl/nl/show/bodemfysische-eenhedenkaart-bofek2020.htm) extracting types 101-110 in These types includes the possible presence and location of a clay layer in the sub-soil (See Figure 7.3).



	Alleen Veen	Veen en Moerig
101 Kleiig moerige bovengrond of kleidek op eutroof veen tot tenminste 120 cm-mv.	10 Kleidek op Veen	10 Kleidek op Veen
102 Kleiig moerige bovengrond of kleidek op veen en zandondergrond binnen 120 cm-mv.	10 Kleidek op Veen	10 Kleidek op Veen
103 Kleiarme moerige bovengrond op veen met binnen 120 cm-mv. vaak een zandondergrond	30 Veen zonder kleidek/-ondergrond	30 Veen zonder kleidek/-ondergrond
104 Kleiarme moerige bovengrond op veen met binnen 120 cm-mv. een zandondergrond met leem	20 Veendek op Klei/Leem	20 Veendek op Klei/Leem
105 Kleiig moerige bovengrond of kleidek op oligotroof veen veelal tot dieper dan 120 cm-mv.	10 Kleidek op Veen	10 Kleidek op Veen
106 Zanddek op veen met een ondergrond van zand of klei. Alleen in de NOP.	20 Veendek op Klei/Leem	20 Veendek op Klei/Leem
107 Oligotroof veen tot dieper dan 120 cm-mv.	30 Veen zonder kleidek/-ondergrond	30 Veen zonder kleidek/-ondergrond
108 Veen op zandondergrond binnen 120 cm-mv.	30 Veen zonder kleidek/-ondergrond	30 Veen zonder kleidek/-ondergrond
109 Zanddek of veenkoloniaal dek op mesotroof veen en een zandondergrond binnen 120 cm-mv.	30 Veen zonder kleidek/-ondergrond	30 Veen zonder kleidek/-ondergrond
110 Zanddek of veenkoloniaal dek op oligotroof veen met een zandondergrond binnen 120 cm-mv.	30 Veen zonder kleidek/-ondergrond	30 Veen zonder kleidek/-ondergrond
201 Kleiig veen op zavel- en kleiondergrond	-	21 Moerige grond op Klei/Leem
202 Zavel- en kleidek op moerige tussenlaag op zandondergrond	-	11 Kleidek op Moerige grond
203 Kleiarm veen op zandondergrond	-	30 Veen zonder kleidek/-ondergrond
204 Kleiarm veen op zandondergrond met keileem of leem	-	21 Moerige grond op Klei/Leem
205 Zanddek op moerige tussenlaag op zandondergrond	-	30 Veen zonder kleidek/-ondergrond
206 Zanddek op moerige tussenlaag op zandondergrond met keileem of leem	-	21 Moerige grond op Klei/Leem

Figure 8.3 *BOFEK Soil classification for peat- ("veen") and other organic peaty soils ("Veen en moerig") (BOFEK, 2012).*

This is resulting in the following peat soil map used for CO2 emission, see *Figure 8.4.*

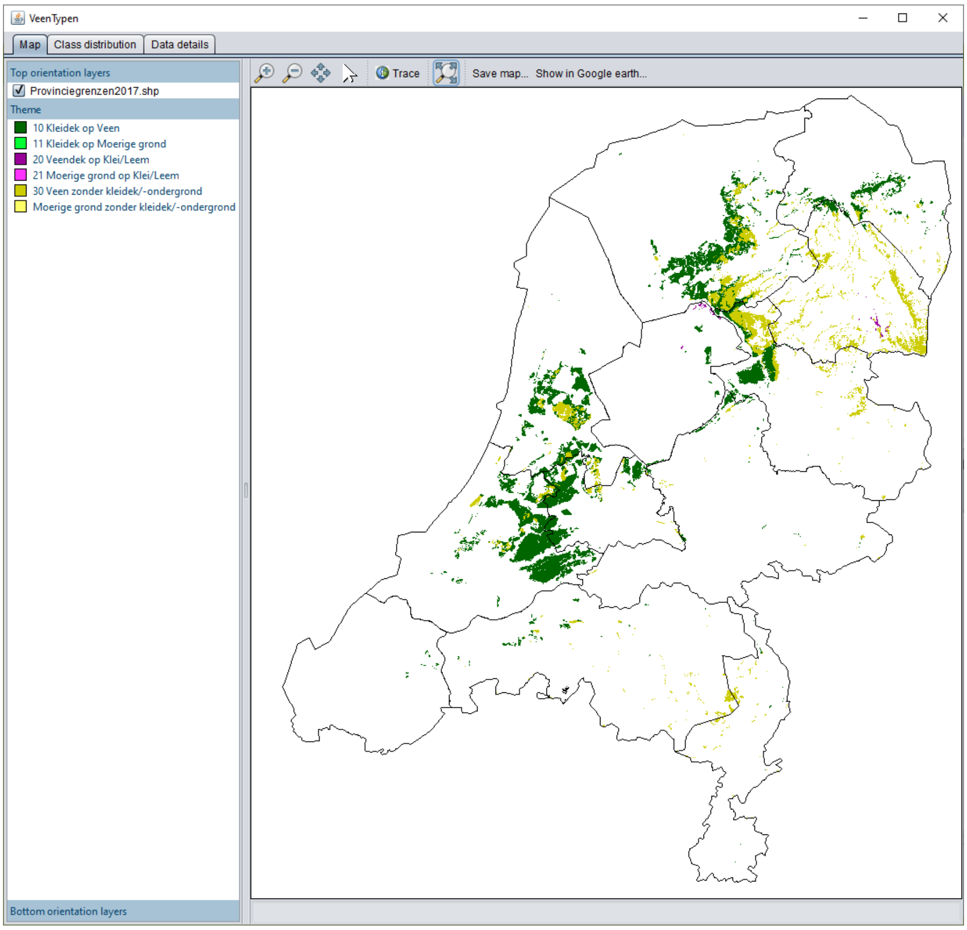


Figure 8.4 *from BOFEK (BOFEK, 2012) extracted peat soil map as used for CO_2 emission.*

The most recent available maps of lowest ground water table (GLG) of the eastern and western part of the Netherland was combined to make a national map of GLG. This map was produced in 2018 for the Basis Registratie Ondergrond (BRO).

CO_2 uit Veen Procedure beschrijving QUICKScan
Calculation steps:
A number of reclassification tables is used in combination with a function derived from Van den Akker et al. (2007) (see figure 8.5). All steps finally are put into one summarizing PC-raster phyton script which can be run outside the QUICKScan tool/GUI

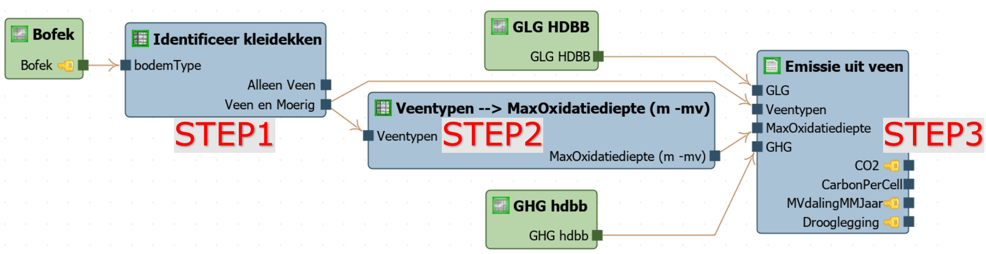


Figure 8.5 *Schematisation of the model.*

Step 1: Identify clay decks (“identificeer kleidekken”).
The type of peat is identified on the basis of the peat (“veen”) and other organic peaty soils (“moerig”) from the BOFEK map (types 201 to 206). This allows the maximum oxidation depths (step B) and emissions (step

C) to be derived. The user has the choice to include only peat soils, or also all other organic peaty soils in the calculation. In the current calculation only "real" peat soils are included for the emission calculations:

- Select peat ("veen") and possibly other organic peaty soils ("moerig") in the BOFEK soil map
- Reclassification by the model to peat types based on the clay/loam cover and subsoil
- Result maps of the reclassification according to peat types.

Left Peat and organic soils; right only peatlands

Step 2: Determine maximum oxidation depth based on Van den Akker et al. (2007), the following maximum oxidation depths are used for each peat type (figure 8.6). Below these depths (GLG), no oxidation takes place and therefore no emission of Carbon: maximum oxidation depths (m-mv). These maximum depth are corrected in Step C by taking the minimum dewatering depth as given by the average highest annual groundwater level as starting point for maximum oxidation.

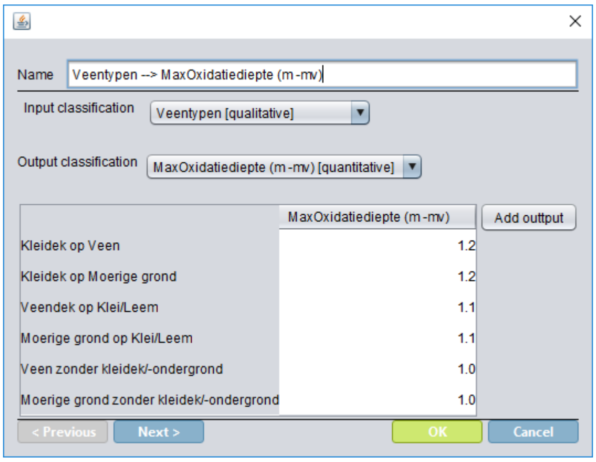


Figure 8.6 *Maximum oxidation depth (meters minus surface).*

Step 3: Determine emission from peat. This part of the PC-Raster Phyton script determines the oxidation of CO_2 per grid cell. By summing all grid cells over the Netherlands, the total emission in tons of CO_2 per year can be calculated. Using the current data it sums up to a total of 4.4 million tons.

8.2.2 Technical environment

Used Software:

- QUICKScan version 4.0 (see www.quickscan.pro)
- PCRaster version 4.2.0-rc.1 built on 24.01.2018 automatically installed and integrated into the QUICKScan software.

All steps are put into one summarizing PC-raster phyton script which can be run outside the QUICKScan tool/GUI.

8.2.3 Tests

The model has not been tested with e.g. field observation data. The technical implementation of the formulas was tested and checked, independently of the developer, when the PC-Raster software code was transferred to be placed in the generic software environment.
A visual check has taken place of emissions in the Netherlands for the current situation. Those results seems to be logical in terms of spatial extent and quantities, based on the used data and formulas. The results for the current situation and of a future scenario (Breman et al., 2022) have also been judged on their plausibility.

8.3 Input and output, parameters and variables

8.3.1 Parameters and variables

1. *"gemiddeld laagste grondwaterstand (GLG)":* average lowest annual groundwater level in cm min mv
2. *"de gemiddeld hoogste grondwaterstand (GHG)":* the minimum dewatering depth as given by the average highest annual groundwater level. De-watering depths see 7.2, figure 7.6
3. 2. BOFEK soiltypes: Peat(y) soils:
   - with(out) clay cover (BOFEK codes)

See also 7.2 for in-depth decription of the variables.

8.3.2 Calibration

Calibration of the models is based on Van den Akker et al. (2007):
- Peat soils without clay cover: Ground level decline per year = 23.537 MLG – 6.68
- Peat soils with clay cover: Ground level decline per year 23.537 MLG – 10.47

And optional input dataset GVG (average spring groundwater level) was used to see if these levels better reflected the actual most wet conditions (compared to the now used GHG-levels) for the calculation of the maximum oxidation depths. However after discussion with Jan van den Akker (pers. Comm) this test and results were rejected.

No further calibration was performed other than explained in the method (7.2).

8.3.3 In- and output

Processing uses three input files
1. *GLG (average lowest groundwater level) in cm minus surface: 25m resolution; .map format*
2. *GHG (average highest groundwater level) in cm minus surface: 25m resolution; .map format*
3. *BOFEK* soil types

Since PC-raster is raster based, all files need to be in a .map file format if diretly used in the pcraster environment. If used in the QUICKScan environment the .tif format can be used and the conversion from tif-map is done on the fly by the software.
Currently calculation is done with a spatial resolution of 25m , but the script can technically handle all resolutions.

8.3.4 Standard indicators

Supply
Carbon sequestration by peatlands (Mt/yr).

Demand
The demand for the carbon sequestration service in peat can be approached in several ways:
- Relative to total emissions of CO_2 (equivalents) in the Netherlands
- Relative to total emissions of CO_2 (equivalents) from peatlands.
- Relative to the 2030 climate agreement target for peat (=-1 Mt/yr)

Combination of supply and demand
% sequestration of CO_2 by peat soils compared to total emission or policy targets (Mt CO_2 eq/yr).

See also Table 1.1.

8.4 Evaluation of model functioning

8.4.1 Sensitivity analysis

A sensitivity analysis of the model has not yet been carried out. One run has been made for the Nature Outlook 2021 with increased groundwater levels (Breman et al., 2022). This shows that rewetting part of the peat soils leads to an emission reduction of 1.5 Mton/yr. Settings see Breman et al. (2022). Which seems a plausible result.

8.4.2 Uncertainty analysis

An uncertainty analysis has not yet been carried out other than described in van de Akker et al. (2007).

8.4.3 Validation

No real validation has been done using field observation data. A comparison has been made with the national figures (2.8Mton) from the Natural Capital project (CBS, WU 2017) (=2.6Mton) and the National Inventory report (Coenen et al., 2016) (=2.6Mton). The figures for the current situation were very similar.

8.4.4 General assessment of model quality

No overall assessment of model quality has been made. See Motelica-Wagenaar & Beemster (2020) for an evaluation of multiple methods to estimate soil subsidence and GHG-emissions from peat soils in the Netherlands.

Indicators
The indicator used is the total emission/sequestration of CO_2 equivalents in Mt per year. This figure can be compared to total carbon emissions from the Dutch economy, carbon emissions from land use, or the objectives in the climate agreement (see Section 7.1.1).

8.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: complete, partly (in)complete, lacking.

8.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low.

8.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

8.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- **Testing**

ST.3: Description parameters, variables, input and output

- **Parameters and variables**
- Calibration
- **Input and output**
- **Origin Input data**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

8.5.4 Future model development options

- Uncertainties about emission factors should be reduced by actual field measurements.
- In addition, we would also like to understand the effects of different forms of infiltration systems (such as pressure drainage) on groundwater levels and emissions.
- We would also like to know more about the possibilities of restoring peatlands and the effects of various forms of alternative agriculture (paludiculture – crop production on wet soils). Experiments are currently being conducted into this approach.
- We would also like to include the effects of seepage on groundwater levels in the future.
- Since scenarios aim at water levels below -20 centimeter below ground, this means we use an extrapolation of regressions (presented in figure 8.1). Maybe the model should be restricted to the range of the regression lines.
- Other types of nature (such as heaths, wetlands, grasslands, agriculture and urban green space) can also sequester carbon (see also CICES definition). We would like to add these types to the model over time. In 2022, a project to improve on the carbon sequestration ecosystem service from nature will begin. These include adding other types of nature, joining LULUCF, and improving the modelling of the effect of measures (such as different forest management or using infiltration systems on peatland).

8.6 Literature

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9 Pollination

Marjolein Lof (WU)

About 75% of the food crops worldwide depend on pollination by animals, primarily by insects like honey bees, wild bees, bumble bees and hoverflies. The production and quality of these crops would be considerable less without their presence.

9.1 Theoretical rationale

9.1.1 General description

Crop pollination is a regulating service defined as the fertilization of crops by pollinators that increase crop production. The purpose of the pollination ecosystem service model is to estimate the contribution of wild pollinators to the production of food crops of which the production depends on a greater or lesser extent on pollination by insect pollinators. The pollination model is developed for the Netherlands, but the extent is flexible as it depends on the input land use map. Therefore, it can also be used for regions or other countries. The current parameterization is valid for temperate biomes.
The ecosystem service (ecosystem services) pollination is defined as the avoided production loss of pollinator dependent food crops due to pollination by wild pollinators (e.g. wild bees, wild bumble bees and hoverflies). Wild pollinators require sufficient resources in the agricultural landscape. These resources include suitable nesting habitats (e.g. tree cavities, or suitable soil substrate) as well as sufficient floral resources (i.e. pollen and nectar). Ecosystems provide nesting habitats and floral resources for wild pollinators to varying degrees. The model assumes that pollinators are indeed present in habitats that are suitable for them (actual observation data of wild bees and other pollinators are not available), and that they all contribute to the pollination of nearby planted crops. Managed honey bees do not depend on ecosystems for nesting and were therefore excluded. For the pollination service, the contribution of the local landscape to the production of pollination-dependent crops was determined. The contribution depends on the distance to the cultivated crop. Crop pollination is primarily provided by the ecosystems in the landscape surrounding the crop fields and not by the cropland itself.

9.1.2 Conceptual and formal model

The conceptual schedule of the pollination ecosystem services model is presented in figure 9.1.

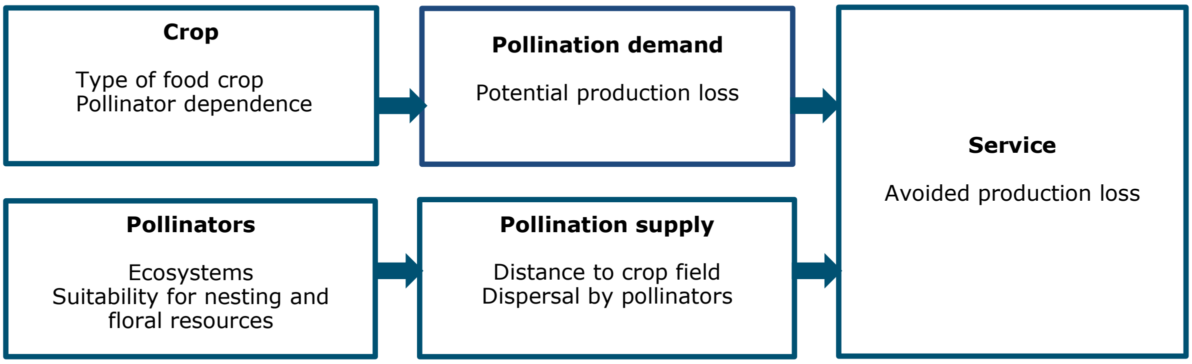

Figure 9.1 *The conceptual schedule of the pollination ecosystem services model. From one side there is demand for pollination by food crops of which the production depends for a certain extent on insect pollination, on the other side there is supply of pollination by ecosystems that vary in their suitability to provide nesting habitats and food sources for pollinators. The supply and the demand are compared to assess the percentage of the potential production loss that is avoided by pollinators nesting in the local landscape.*

Pollination demand

To assess pollination demand, data on the spatial location of crops is needed in combination with what percentage of the potential crop production depends on insect pollination (table 9.1). For the spatial location of crops the basic registration of crop fields (BRP, "basis registratie gewaspercelen") can be used. Or a land use map that distinguishes several crop types based on their dependence on pollination. The BRP contains the location of each crop field and the type of crop that is cultivated. In the model, a raster containing different crop types is combined with the pollination need of these crop types to determine the potential production loss in absence of insect pollinators. The used measure for pollination dependence per crop is based on a review article by Klein et al. (2007) on the positive impact by animal pollination on crop production per crop type. This impact (or dependence) is divided in five classes for the need of animal pollination, essential (> 90% of the production is lost without animal pollination), great (40 – 90% production loss), modest (10 – 40% production), little (>0 – 10% production loss), no increase (0 % production loss). For the pollination ecosystem services model the mean value of each class is taken: essential 95%, great 65%, modest 25%, little 5% and 0% for crops that do not depend on pollination. The model assumes that all varieties of a certain crop depend similar on animal pollination (e.g. that there is no variance in how varieties of a crop depend on pollination).

Table 9.1 *Look-up table for pollination demand of pollination dependent crops classes in the basic registration of crops in the Netherlands (Basisregistratie Gewaspercelen). Based on the classification used for the pollination requirements for the Atlas Natuurlijk Kapitaal (ANK) and the classification of Klein et al. (2007).*

BRP crop code	BRP crop name	Decription	Pollination demand (%)	Cropgroup
241	Kapucijners (en grauwe erwten)	Capuchins (gray peas)	5	sperziebonen
242	Bruine bonen	Beans	5	sperziebonen
244	Erwten, groene/gele (groen te oogsten)	Peas	5	sperziebonen
308	Erwten (droog te oogsten)	Peas	5	sperziebonen
853	Tuinbonen (droog te oogsten)	Broad beans	5	sperziebonen
854	Tuinbonen (groen te oogsten)	Broad beans	5	sperziebonen
2747/2748	Peulen (productie/zaden)		5	sperziebonen
2751/2752	Pronkbonen (productie/zaden)	Runner beans	5	sperziebonen
2779/2780	Stem green bean	Stem green bean	5	sperziebonen

BRP crop code	BRP crop name	Decription	Pollination demand (%)	Cropgroup
2781/1782	String bean	String bean	5	sperziebonen
311	Field beans	Field beans	25	sperziebonen (veldbonen)
258	Luzerne	Alfalfa	5	overige gewassen (luzerne_soja)
663	Lupinen, niet bittere	Lupine	5	overige gewassen (luzerne_soja)
665	Sojabonen	Soybeans	5	overige gewassen (luzerne_soja)
515	Zonnebloemen	Sunflower	25	overige gewassen (aardbei_koolzaad)
1922	Koolzaad, winter (incl. boterzaad)	Oilseed rape, winter	25	overige gewassen (aardbei_koolzaad)
1923	Koolzaad, zomer (incl. boterzaad)	Oilseed rape, summer	25	overige gewassen (aardbei_koolzaad)
2700-2703	Aardbeien open grond	Strawberries	25	overige gewassen (aardbei_koolzaad)
2704-2707	Aardbeien op stellingen	Strawberries	25	overige gewassen (aardbei_koolzaad)
428	Gele mosterd	Yellow mustard	65	overige gewassen (raapzaad_komkommer)
655	Zwarte mosterd	Black mustard	65	overige gewassen (raapzaad_komkommer)
664	Rapeseed	Rapeseed	65	overige gewassen (raapzaad_komkommer)
2729/2730	Komkommer (productie/zaden)	Cucumber	65	overige gewassen (raapzaad_komkommer)
2731/1732	Augurk (productie/zaden)	Gherkin	65	overige gewassen (raapzaad_komkommer)
666	Vlas, olie-. Lijnzaad niet van vezelvlas	Linseed	5	zomergerst
1095-1096	Appelen. Aangeplant voorafgaande aan lopende/lopende seizoen.	Apple	65	appel peer fruit
1097-1098	Peren. Aangeplant voorafgaande aan lopende/lopende seizoen.	Pear	65	appel peer fruit
1099	Wijndruiven	Grapes	65	appel peer fruit
1100	Overige pit- en steenvruchten (zoals perziken, tafeldruiven)	Stone fruits	65	appel peer fruit
1869	Bessen, blauwe	Blueberry	65	appel peer fruit
1870	Pruimen	Plum	65	appel peer fruit
1872	Kersen, zuur (opbrengst bestemd voor verwerkende industrie)	Sour cherry	65	appel peer fruit
2326	Frambozen	Raspberries	65	appel peer fruit
2327	Bramen	Blackberries	65	appel peer fruit
2328	Kersen, zoet	Sweet cherry	65	appel peer fruit
1873	Bessen, zwarte (opbrengst verwerkt voor verwerkende industrie)	Blackberry	25	Rubus-bessen
1874	Overig kleinfruit (zoals kruisbessen, kiwi's)	Other small fruits	25	Rubus-bessen
2325	Bessen, rode	Red berry	25	Rubus-bessen
2723/2724	Courgette (productie/zaden)	Courgette	95	overige gewassen (courgette_pompoen)
2733/2734	Meloen (productie/zaden)	Melon	95	overige gewassen (courgette_pompoen)
2735/2736	Pompoen (productie/zaden)	Pumpkin	95	overige gewassen (courgette_pompoen)

Pollinators

Ideally pollinator distribution is based on spatial maps on pollinator density. However, these maps are currently not available. Therefore, it is assumed that suitability of habitats for pollinators, assessed by the presence of floral resources and nesting availability, can be used as a proxy for pollinator distribution. Kennedy et al. (2013) showed that the proxy for pollinator distribution based on the suitability of the surrounding land cover for nesting and floral resources and assuming that nearby resources contribute more than distant resources, is a good predictor for pollinator density in crop fields.

To asses pollination supply, the following data is needed, a land use/land cover map with the spatial delineation of ecosystem types and information on the suitability of these ecosystems for pollinators based on the quality of the ecosystem for nesting and the availability of floral resources (table 9.2). The suitability of the ecosystems for pollinators is based on the qualitive assessment of habitat types by Kennedy et al. (2013).

Table 9.2 *Look-up table for an indicator of combined nesting suitability and floral resource availability for ecosystem types in the Netherlands, on a 0 - 100 scale, with 100 indicating most suitable, and 0 unsuitable (based on Kennedy et al., 2013). *total nesting and floral suitability for regular cultivation of economic crops were not used in the model (assumed value = 0), because these are considered to be the recipients of the pollination service and not suitable year-round for pollinators.*

Description ecosystem types	Total nesting and floral suitability
Heath	100
Forest; deciduous	89
Natural grassland, bushes and hedges bordering fields, dunes with permanent vegetation	80
Forest; mixed	66
River flood basin, fresh water wetlands	48
Tree lines	45
Forest; coniferous	44
Public green space, other unpaved terrain	41
Salt marsh	36
Meadows (grazing)	26
Beach, coastal dunes, inland dunes	26
Built-up, infrastructure	0
Water	0

Pollinator supply

Different species of pollinators move at different length scales. Large pollinators such as bumble bees forage over long distance (up to 1750 m; Walther-Hellwig and Frankl, 2000), while small pollinators such as solitary bees, forage over shorter distances (up to several hundred meter). Ricketts et al. (2006) found in their meta-analysis on 13 studies in temperate biomes that visitation rates of pollinators declined to half its maximum at 1308 m distance between the nesting sites and the crop. The optimal model for visitation rate (scaled 0 – 1, with 1 the maximum visitation rate) in temperate biomes is exp(-0.00053d). Where d, is distance between the nesting sites and the crop in meters. This model includes both species that forage over long distances and species that remain close to their nesting site. We assume that pollinators from all suitable habitats in the local landscape contribute to pollination. To obtain the relative visitation rate (scaled 0 -100) in a crop in map unit c (Lonsdorf et al., 2009) we calculate,

$$v_c = \sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{hc}}}{\sum e^{-0.00053 d}}$$

where *Sh* represents the relative pollinator abundance (scaled 0 – 100, where 100 marks maximum suitability) in map unit *h* (based on the suitability for nesting and foraging for pollinators of the habitat in map unit *h*), *dhc* is the distance between map unit *h* and the crop in map unit *c*. This is implemented by taking the convolution of the pollinator distribution (based on habitat suitability) and the negative exponential, with decay rate 0.00053.

Pollination
Rader et al. (2016) find a relationship between visitation variation and fruit set variation, based on 39 studies. Variation in fruit set was measured in 14 crops. They found that both bees (not including honey bees) and non-bee pollinators had a positive relationship between fruit set and pollination. Furthermore, studies show that often more pollen are deposited than needed for successful fruit set, 10 to 40 times more pollen have been reported in Sáez et al. (2014) and Pfister et al. (2017). Therefore, we model the function of pollination based on visitation rate as Pc = 5vc, vc between 0 and 20 and 100 for vc ≥ 20. This is a starting assumption, there can be differences between crops, but we do not take that into account here.

Avoided production loss
The avoided production loss (APL) in presence of pollinators can be calculated as,
APL = "PPL" * ("pollination")/100
Where PPL is the potential production loss, which is equal to the dependence on pollination.
The avoided production reduction represents the use of the pollination service by the crops.
In the model output two values are calculated based on the avoided production loss;
"perc_APL" is the mean value for APL in all crop fields.
"perc_PPLA" is the mean potential production loss that is avoided due to pollination, calculated as the sum of the avoided production loss (APL) in the crop fields divided by the sum of the potential production loss (PPL) in the crop fields multiplied by 100. In essence, "perc_PPLA" is a value for of the weighted mean pollination, where the avoided production loss in crops with a higher potential production loss have a higher weight than crops with a lower potential production loss.

Contribution of the ecosystems
The contribution (supply) of the ecosystems to the avoided production reduction, APRh, is calculated by,

$$APR_h = \sum_{c=1}^{C} APR_c \frac{\sum_{h=1}^{H} S_h \frac{e^{-0.00053 d_{ch}}}{\sum e^{-0.00053 d}}}{\sum_{h=1}^{H} S_h}$$

Where *APRc* is the avoided production loss in the crop in map unit *c*, *dch* is the distance between the crop in map unit *c* and the ecosystem in map unit *h*. The relative contribution of all ecosystems in a 10 km radius around the crop is weighted by the sum of the relative pollinator abundances, *Sh*. Contribution to avoided production loss in crop fields by the ecosystem in map unit *h* is based on all crop fields that require pollination in a 10 km square around map unit *h*. This is calculated for all map units that contain an ecosystem that is suitable for pollinators.

9.2 Technical implementation

9.2.1 Implementation model

Main model
The pollination model is written in python and together with a yml file containing the environment needed to run the model stored in a repository online (https://git.wur.nl/roelo008/bestuiving). The model calculates the avoided production loss due to insect pollination. The calculation can be divided in two main branches.

In the top branch (Figure 9.2) the pollination demand is calculated by first reading in a raster with crop classification data as an spatial array. Followed by combining that spatial array with information on crop fields with a lookup table on crop dependence on animal pollination. This results in a spatial array with values for the dependence of crop production on insect pollination.

In the lower branch (Figure 9.2) the pollination supply is calculated in 3 steps:
1. First the land use raster is read in as a spatial array and combined with a lookup table containing values for habitat suitability for the supply of pollinators (ranging from 0 – 100). This results in a spatial array with habitat suitability.

2. Then habitat suitability is used as a proxy for pollinator supply by the ecosystem types. In the function calculate dispersal, the distribution of pollinator visitation is calculated by taking a convolution between the pollinator supply (e.g. habitat suitability array) and a kernel describing the redistribution of the pollinators based on observed visitation rates for pollinators (Ricketts et al., 2008). Based on the analysis of Ricketts et al. (2008) the redistribution kernel is a negative exponential with decay rate α. To calculate the redistribution kernel the function calculate dispersal furthermore needs the pixel size of the raster (in m). For efficient calculation the function calculate dispersal divides the area (i.e. the Netherlands or a province) is divided in smaller areas when it is bigger than a pre-set number of cells. To also include the visitation by pollinators from outside the smaller area, a parameter for the width of the buffer (in m) around the smaller area that needs to be included is input for the function calculate dispersal. This calculation results in an visitation array.
3. Next, in function 1, the percentage pollination is calculated for all the cells with crops that depend on pollination (i.e. dependence >0) based on percentage visitation.
   Subsequently, in function 2, the pollination service in the crop fields is calculated. This service is defined as the avoided production loss (APL) and is calculated based on what percentage of the crop production depends on pollination and the percentage pollination received.

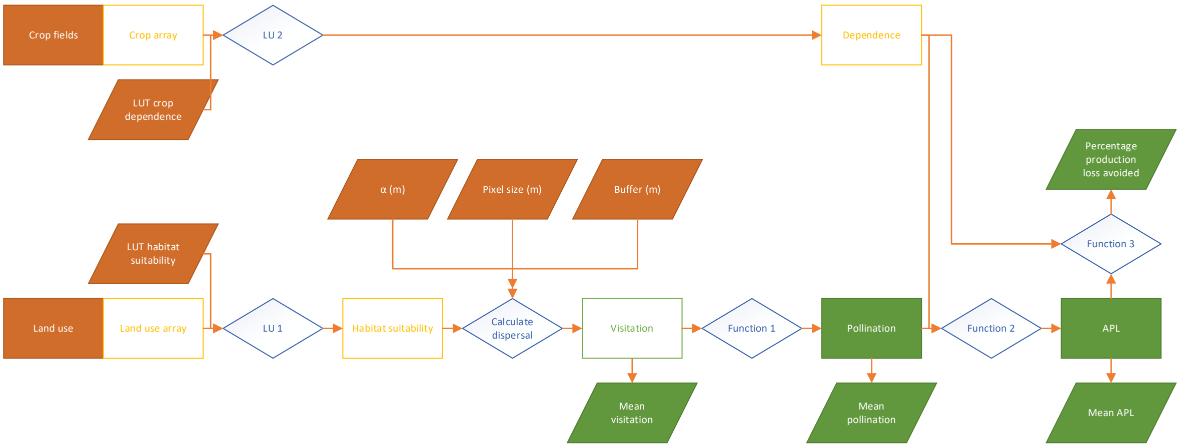

Figure 9.2 *Flow diagram of the pollination model. The filled orange boxes are input raster files. The filled orange parallelograms are input variables or lookup tables, these are stored in one excel file (https://git.wur.nl/roelo008/bestuiving/-/blob/master/tests/dat/params_pollination.xlsx). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/rasters from the model. The filled green parallelograms are output values, these are written to an output file: model_result.ini, which also stores the paths of all input files. The green/white boxes are output arrays that are not written to an output raster. LU1 (bottom) combines the land use array with the lookup table with habitat suitability of the land use class for pollinators, based on the flower resources and the nesting suitability. LU2 (top) combines the crop array with the lookup table with dependence of the crop production on pollination. "Calculate dispersal" is a function that performs a convolution of the habitat suitability array and the dispersal kernel of the wild bees. This dispersal kernel is a 2D negative exponential kernel with decay rate α in meter. Function 1 calculates pollination in each 10x10m cell with a crop that depends on pollination (i.e. dependence array >0) based on the visitation array. pollination = MIN(100, 5*visitation). Function 2 calculates the avoided production loss (APL) in percentage in each 10x10m cell with a crop that depends on pollination (i.e. dependence array >0). APL = dependence*(pollination/100). Function 3 calculates the percentage of production loss avoided (PPLA) over all cells with pollinator dependent crops. PPLA = (sum(APL)/sum(dependence))*100.*

Optional module

There is an optional module where the contribution of the ecosystems to the avoided production loss is calculated (Figure 9.3).

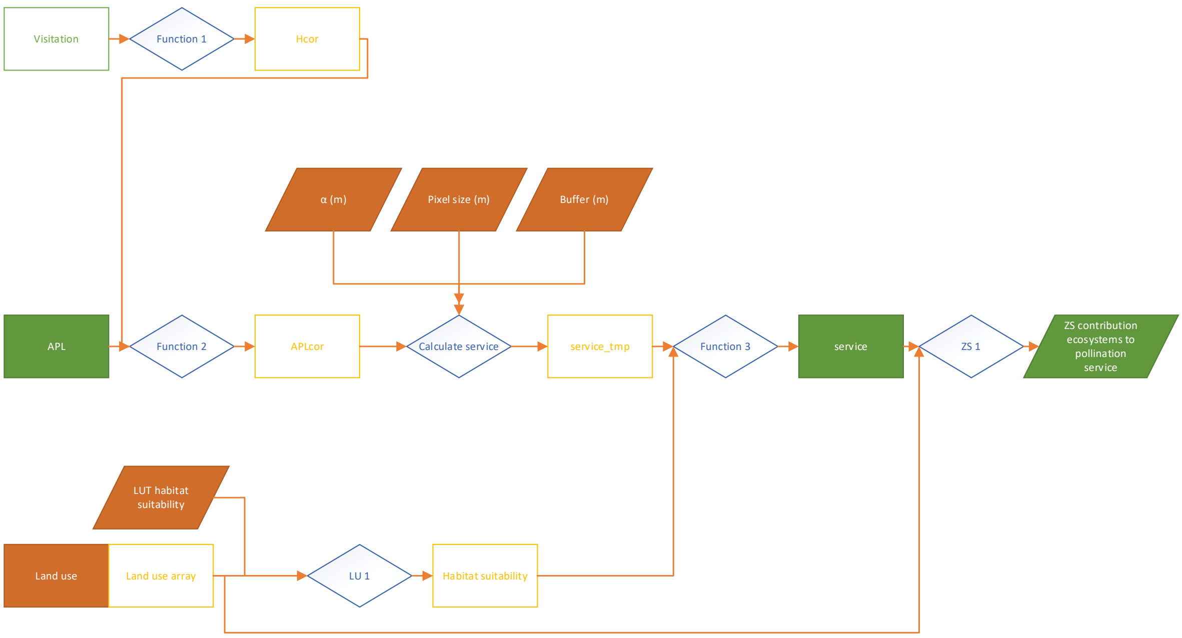

Figure 9.3 *Flow diagram optional module of pollination model that calculates the contribution of the ecosystems to the avoided production loss. The filled orange box is an input raster file. The orange/white boxes are intermediate arrays. The filled orange parallelograms are input variables or lookup tables, these are stored in one excel file (https://git.wur.nl/roelo008/bestuiving/-/blob/master/tests/dat/params_pollination.xlsx). In general, the green filled boxes are output arrays/rasters from the model. The green filled box "APL" is an output array from the main model and an input array for this module. The green/white box "visitation" is an output array from the main model that is not written to an output raster and is used as an input for this module. The filled green parallelograms contains an output table, this is written to an output csv file. Function 1 calculates Hcor = 100/visitation, a transformation factor for the contribution of ecosystems. In this function cells with visitation = 0 or NA are set to Hcor=1 (e.g. in these cells no transformation is needed). Function 2 transforms the value APL to correct for loss to unsuitable habitats during the next calculation step and for differences in suitability of habitats for pollinators: APLcor = APL*Hcor. "Calculate service" is a function that performs a convolution of APLcor array and the dispersal kernel of the wild bees. This dispersal kernel is a 2D negative exponential kernel with decay rate α in meter. Function 3 transforms the output from calculate service back to the original scaling by multiplying with the suitability: service = service_tmp*habitat suitability.*

This is calculated in three main steps. First the value of the avoided production loss is corrected, by taking into account the suitability of the local landscape. If a crop field cell would be situated in a landscape consisting of the most suitable habitat for pollinators only (habitat suitability = 100), visitation in the cell would be 100. Then all the whole landscape would contribute to the APL and no adjustment is needed. If a crop field cell is situated in a landscape with only small patches with suitable habitat for pollinators, visitation is low (for example visitation = 5). If there would not be a correction, during the calculations of the contribution of ecosystems to the APL, most of the avoided production loss would be attributed to unsuitable ecosystem types that did not contribute to the APL. By adjusting the avoided production loss by APLcor = APL*(100/visitation) (function 2), the value in the crop field is increased to perfectly balance the loss in unsuitable habitats (in the example above, APLcor = APL*100/5 = 20*APL. Then the values of the avoided production loss are redistributed over the landscape using the dispersal kernel of the wild pollinators. In the final step (function 3) the results are corrected by multiplying the result with the habitat suitability, this way a habitat that is very suitable contributes more (as it also contributed more to visitation) and an unsuitable habitat does not contribute to the avoided production loss (e.g. habitat suitability = 0).

9.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9). An environment.yml file is available in git (https://git.wur.nl/roelo008/bestuiving/-/blob/master/environment.yml) that can be used to reproduce the exact environment used in the simulations. The model has be run on a computer with an Intel Xeon W-2133 3.6 GHz processor and 16.0 GB RAM. Due to memory limitations the variables are stored as float32.

9.2.3 Testing

There is a test data set that can be used to verify whether the model works as expected. This is a dataset from a small part of the Netherlands so that the test can be done in only a few minutes. This area, the municipality of Borsele, was chosen because the pollination service in this area is much lower than the demand, making it very sensitive to variation. More comprehensive testing, like testing for extreme input values or verification with field measurements has not been done. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

9.3 Input and output, Parameters and variables

9.3.1 Parameters and variables

The parameters are stored in an excel file which can be found at:
https://git.wur.nl/roelo008/bestuiving/-/blob/master/tests/dat/params_pollination.xlsx

Parameters:
- The dependence on pollination per crop type/group, this is a value between 0-100 indication how much the production is reduced in absence of insect pollinators, see 'afh' sheet in the parameter excel file.
- The suitability of the habitat for pollinators, this is a value between 0-100 indicating the relative suitability of the habitat for pollinators based on floral resources and nesting availability (Kennedy et al., 2013), see 'habsuit' sheet in the parameter excel file.
- The decay rate of the negative exponential function used to calculate pollinator visitation ('alpha_m') given in meter, see 'params sheet in the parameter excel file.
- The width of the buffer for calculation of pollination visitation in meter ('buffer_m'), see 'params' sheet in the parameter excel file. This is linked to the decay rate, for strong decay a smaller buffer can be used.
- The pollination efficiency ('eff_poll'), unitless, see 'params' sheet in the parameter excel file. This is a value that calculates the expected percentage pollination (range 0-100) based on the relative visitation (range 0-100).
- Pixel size of the input rasters ('px') in meter, constant, see 'params' sheet in the parameter excel file.

The excel file with the parameters is an input variable of the simulation. It is therefore possible to use a copy of the excel file with alternative parameter values as an input file.

Input variables
The model consists of four mandatory and seven optional variables
Mandatory variables:
1. land_use: Geospatial raster showing land use following LCEU categories
2. nvk_scen: Geospatial raster (.tif) with crop fields, following NVK categories for crop fields. The same folder should also contain a .tif.vat.dbf file with the same name as the .tif file. Containing the Description of the NVK categories.
3. params: Excel sheet with lookup tables and model parameters and constants
4. scenario: Name of the scenario calculated, is used in the names of the output files

Optional variables:
1. --out_dir: output directory
2. --write_rasters: write geospatial ouput rasters to output directory
3. --reporting: write a text file with key outcomes
4. --test_input: verify model initialization, do nothing else
5. --test: verify model with test set, do nothing else
6. --service: Calculate contribution of ecosystems to avoided production loss
7. --env_proj_path Path of proj folder in python environment

9.3.2 Calibration

The model has not been calibrated yet.

9.3.3 Input and output

Output

Output values:

1. perc_APL: mean percentage avoided production loss (APL) in pollination dependent crops
2. perc_poll: mean pollination percentage in pollination dependent crops
3. perc_PPLA: percentage of potential production loss that is prevented by received pollination
4. perc_visit: mean visitation by pollinators in pollination dependent crops

These output values are written in model_result.ini in the output directory

Optional output

1. pollination.tif Geospatial raster showing percentage pollination in pollination dependent crops (optional, --write_rasters)
2. avoided_production_loss.tif Geospatial raster showing percentage avoided production loss in pollination dependent crops (optional, --write_rasters)
3. poldienst.tif Geospatial raster showing the contribution of ecosystems to the avoided production loss (optional, --service)
4. zs_poll_eu.csv CSV file with a table with per ecosystem type, the area in m^2, the mean and standard deviation of the service and the sum of the contribution. Currently this is in percentage APL, but it is possible to link this to ton/ha or euro/ha.

9.3.4 Standard indicators

Supply

Supply of natural pollinators by ecosystems.

Demand

Pollination of (all) pollination dependent agricultural crops.

Combination of demand and supply

% avoided production loss of pollination dependent crops by natural pollinators (kg/ha).

Also see Table 1.1.

9.4 Evaluatie modelfunctioneren

9.4.1 Sensitivity analysis

A sensitivity analysis has not been performed.

9.4.2 Uncertainty analysis

An uncertainty analysis has not been conducted yet.

9.4.3 Validation

The model is based on a validated model that calculates visitation of pollinators based on habitat suitability (Ricketts et al., 2008), but the current model has not been validated.

9.4.4 General assessment of model quality

A general assessment of the model according to its goals (test * sensitivity * uncertainty * validation * use) has not been done yet.

9.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **<u>complete</u>**, <u>partly (in)complete</u>, incomplete.

9.5.1 Reliability

A Very high, B. high, **C. sufficient, D. moderate**, E. low

9.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

9.5.3 Status A progress

ST.1: Model description
- **<u>General description</u>**
- **<u>Description conceptual and formal model</u>**

ST.2: Technical implementation
- **<u>Implementation</u>**
- **<u>Technical environment</u>**
- Testing

ST.3: Description parameters, variables, input and output
- **<u>Parameters and variables</u>**
- Calibration
- **<u>Input and output</u>**
- **<u>Origin Input data</u>**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

9.5.4 Future model development options

- Research on the importance of different habitat for pollinators like protected areas and natural elements in the agricultural landscape.
- Research on the actual dispersion and foraging distances of different insect species from source habitats to pollinate agricultural crops.
- Research on the demand of the crops on pollination. What is the actual loss of harvest of quality of the crops if pollination is absent or insufficient?
- Following the CICES systematic beside pollination of agricultural crops also the pollination of non-agricultural species is important. Also seed dispersal is mentioned in the CICES classification. This is not included. Furthermore CICES mentions this services is also about maintenance of source populations and habitat to protect their genetic diversity. This part is covered by the ecosystem services of natural heritage (see chapter 16).

9.6 Literature

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10 Water purification

Bart de Knegt (WENR), (earlier with the cooperation of Luuk van Gerven)

10.1 Theoretical rationale

10.1.1 General description of model

Introduction
The Netherlands faces the challenge of meeting the objectives of the Water Framework Directive (WFD) (Kaika, 2003), which stipulate that the surface water is sufficiently clean and healthy by 2027. Specifically, this means that the 'Ecological situation' must be in order. This means that in addition to the biological aspects (algae, aquatic plants, macrofauna and fish), the general physical chemistry must also be in order. Since the surface water concentrations of nitrogen (N) and phosphorus (P) are part of the general physical chemistry, compliance with the WFD standards for N and P is important.

Nutrient status in the Netherlands has improved substantially since the 1980s, although this improvement has stalled in most surface waters since 2009 (Van Gaalen et al. 2015). This means that additional effort is needed to comply with the WFD standards for N and P, as the standards are not yet met in 55% of WFD water bodies (WFD Fact Sheets, reporting year 2018). The question is to what extent purification measures in and around surface water can address this challenge.

The 'purification tool' described here calculates the effect of a number of purification measures on the nutrient status of surface water in the Netherlands. These measures include helophyte filters, marsh buffer strips, nature-friendly banks and unfertilised zones. The specific question is whether the purification capacity of these measures is sufficient to meet the WFD standards for N and P? And if so, where and to what extent should these measures be implemented? The development of the purification tool is part of a WOT project on ecosystem services.

General approach
Figure 10.1 illustrates the input, calculation algorithm and output of the purification tool. The input and calculation algorithm are discussed in detail in the following sections, while the output is described in the next section (results). A number of features of the purification tool are described below:

- **Objective:** Quantifying the effect of four treatment measures on surface water quality (N and P). What measures are needed, where are they needed, and to what extent must they be used to meet the WFD targets for N and P?
- **Spatial scale:** The Netherlands is divided into 538 catchments. The location and characteristics of these catchments were taken from the study *Landbouw en de KRW-opgave voor nutriënten* (Agriculture and the WFD nutrient challenge – Groenendijk et al., 2016). For each of the catchments, we looked at whether the WFD water body in the catchment meets the WFD standards for N or P, and if not to what extent the WFD goal can be achieved by taking treatment measures. Some catchments have multiple WFD water bodies. In this case, we looked at the most challenging WFD water body.
- **Temporal scale:** For each catchment area, the purification tool calculates the annual average natural purification and the additional annual average purification by treatment measures. The additional treatment is projected to the summer half-year average N and P concentrations of the WFD water bodies as reported for the WFD.
- **Time horizon:** The purification tool compares the current WFD status for N and P (reporting year 2018) with the calculated future WFD status after taking treatment measures. The tool assumes that the purification measures have equivalent effect and that their effect continues into perpetuity, whereas in reality the purification effect often diminishes as the measure ages. Also, the tool assumes that the area characteristics (see Figure 2.1) remain the same and thus do not change due to, for example, human

actions or different weather/climate. Thus, given these assumptions, there is no clear envisioned year in terms of results. Thus, the envisioned year could just as easily be 2027 (the year by which the WFD goals must be met) as 2050.

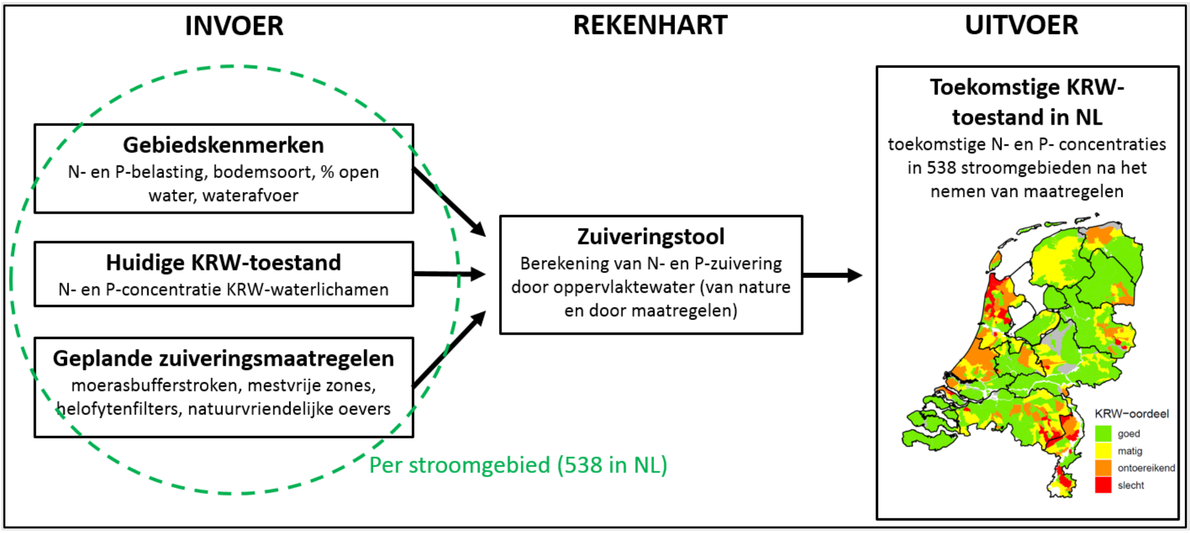

Figure 10.1 *Schematic overview of input, calculation algorithm and output of the purification tool.*

10.1.2 Conceptual model and formal model

Calculation algorithm

Based on the given input, the purification tool calculates per catchment the future nutrient concentration (c_{2050}) of the WFD water body in the catchment according to:

$$C_{2050} = \left(\frac{1 - r_{2050}}{1 - r_{current}}\right)\left(\frac{L_{2050}}{L_{current}}\right) C_{current}$$

where:

$c_{current}$	the current nutrient concentration of the WFD water body (as reported for the 2018 WFD). If a catchment has multiple WFD water bodies, the worst-scoring WFD water body (the most challenging) is considered.
$r_{current}$	current purification capacity of the surface water system, expressed as a retention fraction with a value between 0 (no purification) and 1 (full purification)
r_{2050}	future purification capacity of the surface water system after taking additional treatment measures, expressed as a retention fraction with a value between 0 (no treatment) and 1 (full treatment)
$L_{current}$	current nutrient load of the catchment (based on Groenendijk et al. 2016)
L_{2050}	future nutrient load of the catchment

In this first version of the purification tool, the future nutrient load (L_{2050}) is the same as the current load ($L_{current}$), so the future concentration is only affected by differences in treatment capacity (r_{2050} versus $r_{current}$) and not by differences in load. Any expansion of the purification tool to include measures at the source (such as reduced fertilisation) would, however, change future nutrient loads and have an effect on future water quality.

The current purification capacity of the water system($r_{current}$) was calculated based on area characteristics, based on the methodology used in Groenendijk et al. (2016). Table 10.1 shows how the purification capacity was calculated according to the type of area (artificial drainage (polder), natural drainage or a combination of both), the type of nutrient (nitrogen or phosphorus) and the type of nutrient source: leaching or runoff (diffuse load) or other sources (point load).

The future purification capacity of the water system (r_{2050}) is equal to the current purification capacity ($r_{current}$) plus the additional purification due to measures. This additional purification from helophyte filters, marsh buffer strips and nature-friendly banks is derived from key figures in a recent literature study on the effects of such measures (Groenendijk et al., in prep.) (see Table 10.2). Annex 8 describes the results of the literature study in detail. For unfertilised zones, the purification capacity was derived from land parcel calculations, described in detail in Annex 8.

As a final step, the purification tool determines whether the calculated future concentration C_{2050} meets the WFD standard, as reported and used by the water boards.

Table 10.1 *Method used to calculate current retention by area type, broken down by nitrogen (N, left) and phosphorus (P, right), for different types of sources. Further details on the retention methodology can be found in Van Boekel et al., 2012.*

Area type	**Nitrogen (N)**		**Phosphorus (P)**	
	Leaching and runoff	**Other sources**	**Leaching and runoff**	**Other sources**
Polder with peat and clay soil	Retention based on open water surface area	Retention based on open water surface area	50%	20%
Polder with sandy soil	50%	20%	50%	20%
Transition area	50%	20%	50%	20%
Naturally drained area	Retention based on discharge and retention times	20%	Retention based on discharge and retention times	20%

Table 10.2 *Purification efficiencies of marsh buffer strips, nature-friendly banks and helophyte filters (from a literature study – Groenendijk et al., in prep.). Also indicated is how the measures are entered in the purification tool.*

Measure	**N (kg N/ha)**	**P (kg P/ha)**	**To be entered as**
Marsh buffer strip	180	12	% of watercourses^ with a marsh buffer strip, in combination with their average width
Nature-friendly bank (NFB)	90*	6*	% of watercourses^ with NFB, in combination with their average width
Helophyte filter (flow field)	145	10	% of land area

* The purification capacity of nature-friendly banks (NFBs) is relatively unknown. It has been assumed that their purification capacity is 50% of that of marsh buffer strips, because marsh buffer strips are constructed for the purpose of nutrient removal and NFBs are not. For NFBs, the nature function is paramount and nutrient removal is seen as a positive side effect.

^ The watercourse length per catchment was determined using the TOP10 vector file. This does not include ditches and dry-falling watercourses. The secondary watercourses (<6 m wide) and primary watercourses (>6 m wide) are included. In terms of length, 32% of the Dutch watercourses consist of ditches or dry-falling watercourses, 54% of secondary watercourses, and 14% of primary watercourses.

The following are some key assumptions of the purification tool:

- WFD task: if a catchment has several WFD water bodies, then the water body with the greatest WFD challenge was considered. It is possible that this is a different water body for excess N than for excess P.
- Retention: the maximum purification yield is 90%. Yields higher than the maximum are truncated to 90%. Some catchments already have more than 90% retention in the current situation. Measures in such a catchment then do not lead to an improvement because their effect is truncated.
- Annual average: the calculation tool calculates the annual average purification capacity and how it increases due to measures. To arrive at a future water quality, this treatment increase is projected onto the current summer half-year average N and P concentrations of the WFD water bodies. Purification measures taken in the past are not included, but are implicit in the calculated current purification capacity. Through an input option, it is possible for the purification tool to calculate the purification capacity for the summer half-year average instead of yearly average.

- Effect of measures: The purification tool assumes that measures have an instantaneous effect and that their effect continues for ever. In reality, the purification capacity of a measure often decreases as the facility associated with the measure ages. In addition, the purification tool assumes that helophyte filters, nature-friendly banks and marsh buffer strips have the same purification efficiency everywhere in the Netherlands. For unfertilised zones, the yield does vary by catchment depending on area characteristics such as soil type and slope of the land parcel (see Annex 8).

10.2 Technical implementation

10.2.1 Implementation model

A flow chart showing the program's main modules is not yet available.

10.2.2 Technical environment

The purification tool is programmed in R, a freely downloadable programming platform. The input is in the form of a number of text files (.txt and .csv) that can be modified using Excel. Running the purification tool R script takes several minutes, after which calculation results are stored in text files (.txt or .csv) and are visualised in figures (.pdf).

10.2.3 Testing

No test protocol has yet been implemented. However, a test area has been chosen: the whole of the Netherlands for N and P. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

10.3 Input and output, parameters and variables

10.3.1 Parameters and variables

Parameters
- Catchment areas (id, name)
- Area characteristics
  - Area type (cat.)
    - Naturally drained, polder, transition area
  - Soil type (cat.)
    - Sand, clay, peat
  - Area of open water (%)
  - Drainage (m^3)
  - Catchment area (ha)
  - Watercourse length (metres)
- Retention capacity according to area characteristics N and P summer and winter (kg/ha/yr) for runoff and
- Retention capacity measures N and P summer and winter (kg/ha/yr)
- Limit values N and P for WFD target attainment (cat.)
  - Good, moderate, insufficient, poor

Variables
- Current nutrient load N and P
  - Measures (kg/ha/yr)
- Measures
  - Marsh buffer strip (%)
  - marsh buffer strip_width_(metres)
  - nature_friendly_bank_(%)

- nature_friendly_bank_width_(metres)
- helophyte filter_(%)
- unfertilised zone_(%)

10.3.2 Calibration

The model has not yet been calibrated.

10.3.3 Input and output

Input

- current nutrient load (N & P averaged over 2010-2013) on surface water for each catchment, in accordance with 'KRW-opgave en landbouw' (WFD challenge and agriculture – Groenendijk et al., 2016)
- area characteristics of the catchment (soil type, % open water, polder or natural drainage, area-specific drainage)
- measures to be taken per catchment (marsh zones, helophyte filters, nature-friendly banks, unfertilised zones)
- information on water bodies (catchment, current N&P concentration and N&P standard, as reported in 2018)
- catchments_with_their_water_bodies.txt (assignment of water bodies to the 538 catchments used)

Catchments

For each of the 538 catchments, the purification tool requires data on area characteristics, current WFD status and planned purification measures. The area characteristics and current WFD status are already filled in for the current situation, so the user only needs to fill in the Implementation degree of the purification measures.

Area characteristics

The purification tool requires data for each catchment on area characteristics that affect self-purification capacity (natural purification). These area characteristics are taken from Groenendijk et al. (2016):

- Current nutrient load on surface water (N,P): this is an average load over the period 2010-2013, determined through a combination of model results (STONE; Wolf et al., 2003) and measurement data (Emissions Registration www.emissieregistratie.nl). To calculate the self-purifying capacity, the nutrient load was divided into the diffuse load from the land (leaching and runoff from agriculture and natural areas) and the load from other nutrient sources (often point sources such as water intake from upstream catchments or from surrounding rivers and discharges from industry, sewage treatment plants or overflows).
- Type of area: is the catchment area a polder, a naturally drained area or a combination of both (transition area)?
- Soil type: does the soil of the catchment consist mainly of sand, peat, clay or loess?
- Open water surface: distinguishing between winter and summer, assuming that some watercourses run dry in summer and therefore do not contribute to the total summer open water surface in the catchment.
- Water discharge: summer and half-year average discharge of area water as calculated by STONE during 2010-2013.
- Area: total area of the catchment (land and water).

Current WFD status

The purification tool needs information on the current water quality (N and P concentrations as reported for the WFD in 2018) and the WFD standards of N and P for all WFD water bodies in the Netherlands, as well as the catchment in which the WFD water body is located.

Planned purification measures

The purification tool can estimate the effect of four purification measures in and near surface water. A detailed description of these measures and their purification capacity can be found in Annex 8 (marsh buffer strips, helophyte filters and nature-friendly banks, unfertilised zones). As input, the purification tool needs information on the total area in which these measures are possible and what part of this area (%) is used:

- Marsh buffer strips & nature-friendly banks: potential area is derived from length of watercourses in the catchment (excluding dry-falling watercourses) (source: TOP10 watercourses) in combination with the width of the purification measure to be specified. In addition, the user provides the proportion (%) of this area where the purification measure is taken.
- Helophyte filter: potential area consists of the land area of the catchment (specified as an area characteristic). The user only needs to specify what proportion (%) of the land area will used as a marsh buffer/helophyte filter.
- Unfertilised zones (dry buffer strips): potential acreage of unfertilised zones was taken from a recent study of the purifying effect of unfertilised zones (Groenendijk et al., in prep.). This study looked at agricultural parcels suitable for the creation of unfertilised zones (parcels adjacent to watercourses and not provided with pipe drainage), with the width of the unfertilised zone varying between 2 and 5 metres depending on how much space there is within the parcel (see Annex 8). The resulting parcel acreage of unfertilised zones was scaled up to the 538 catchments of the purification tool. The user only needs to indicate what proportion (%) of this potential area will be established as unfertilised zone.

Output

- Current and future purification percentage of surface water, for each catchment, for N & P
- Future nutrient loads (N & P) on surface waters, for each catchment
- The expected future nutrient concentration (N & P) in surface water in 2050 (based on current concentration, purification percentage (now and in 2050) and nutrient load (now and in 2050)
- Target attainment for each catchment: are the WFD standards for N & P met after taking measures?

NOTE: Some catchments have multiple WFD water bodies. For such a catchment, we look at WFD water body with the largest WFD challenge (where the current concentration deviates most from the standard)

water quality

The main output of the purification tool is the future water quality: after taking purification measures in and near the surface water, the extent to which the catchments meet the WFD targets for N and P (see Figure 10.2). In addition, the purification tool visualises the calculated purification capacity, for the current situation and the situation after taking measures (see Figure 10.3). The purification tool also generates data files with the underlying values for Figures 10.2 and 10.3 (N and P concentrations, WFD assessment and treatment capacity per catchment for the current situation and the situation after measures are taken).

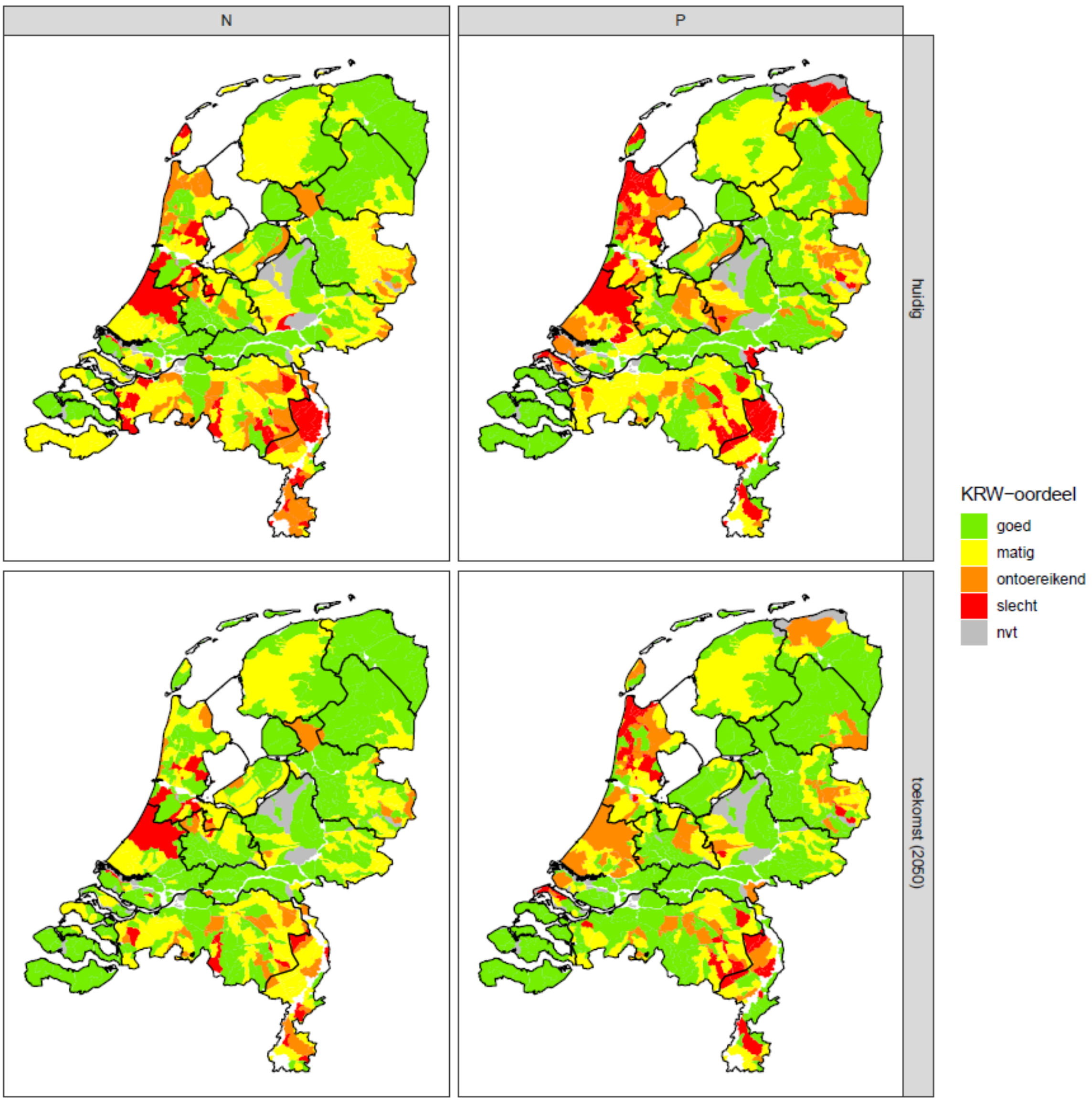

Figure 10.2 *Surface water quality for nitrogen (N, left) and phosphorus (P, right) in the current situation ($c_{current}$: WFD reporting year 2018) (top) and in the future (c_{2050}) after taking fictive measures as calculated by the purification tool (bottom).*

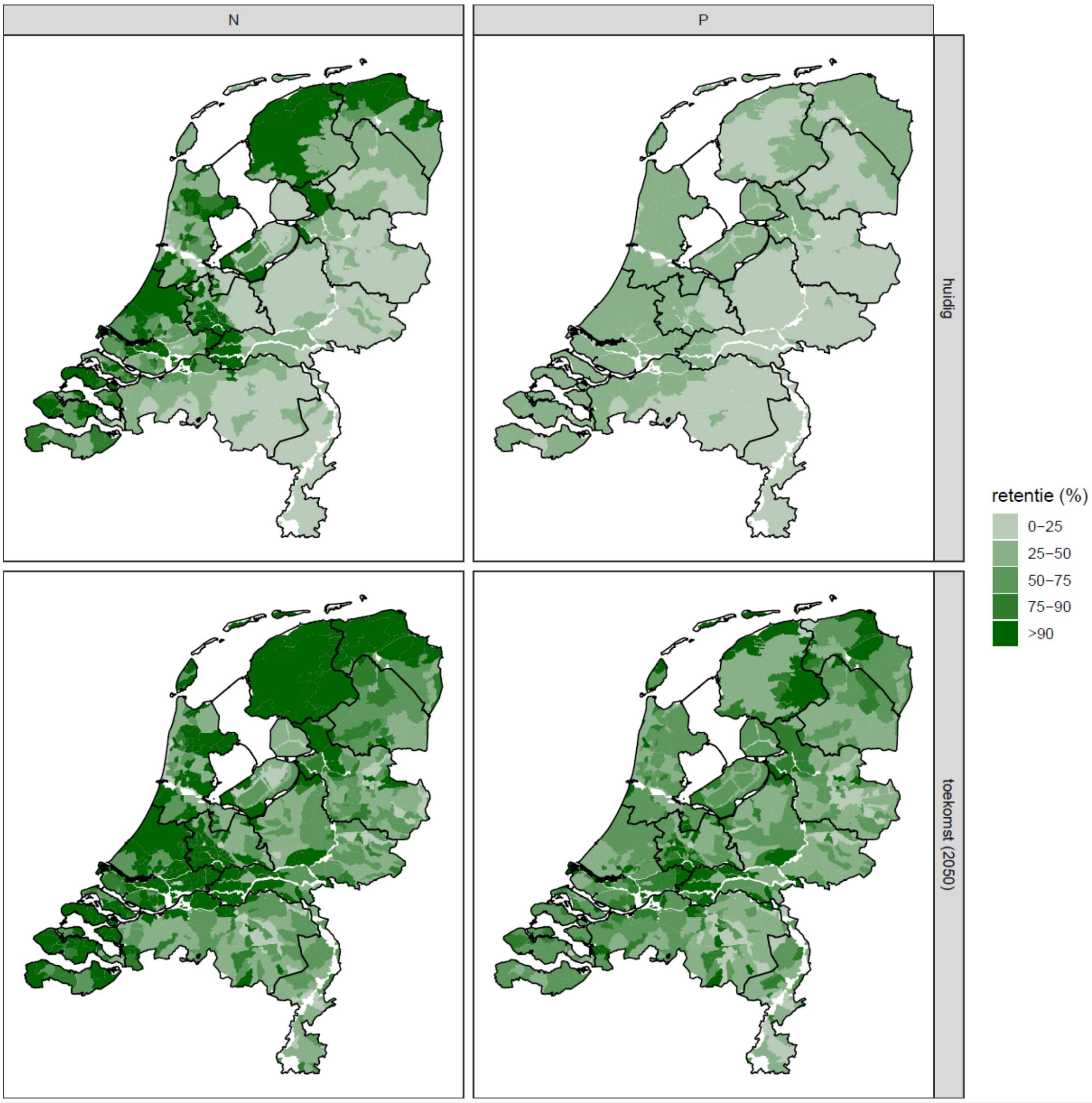

Figure 10.3 *Water retentions for nitrogen (N, left) and phosphorus (P, right) calculated by the purification tool in the current situation (r_{huidig}: top) and in the future after taking fictive measures (r_{2050}: bottom).*

Purifying capacity as an ecosystem service

It is also possible to determine what the fictive N and P concentrations of the WFD water bodies would be if the natural purifying capacity of the water system ($r_{current}$) were to disappear. This concentration ($C_{current,\ without\ purification}$) was calculated as follows:

$$C_{current,without\ purification} = \left(\frac{1}{1 - r_{current}}\right) C_{current}$$

The results are shown schematically in Figure 10.4. This figure illustrates the ecosystem service that water systems provide through their natural self-purifying capacity.

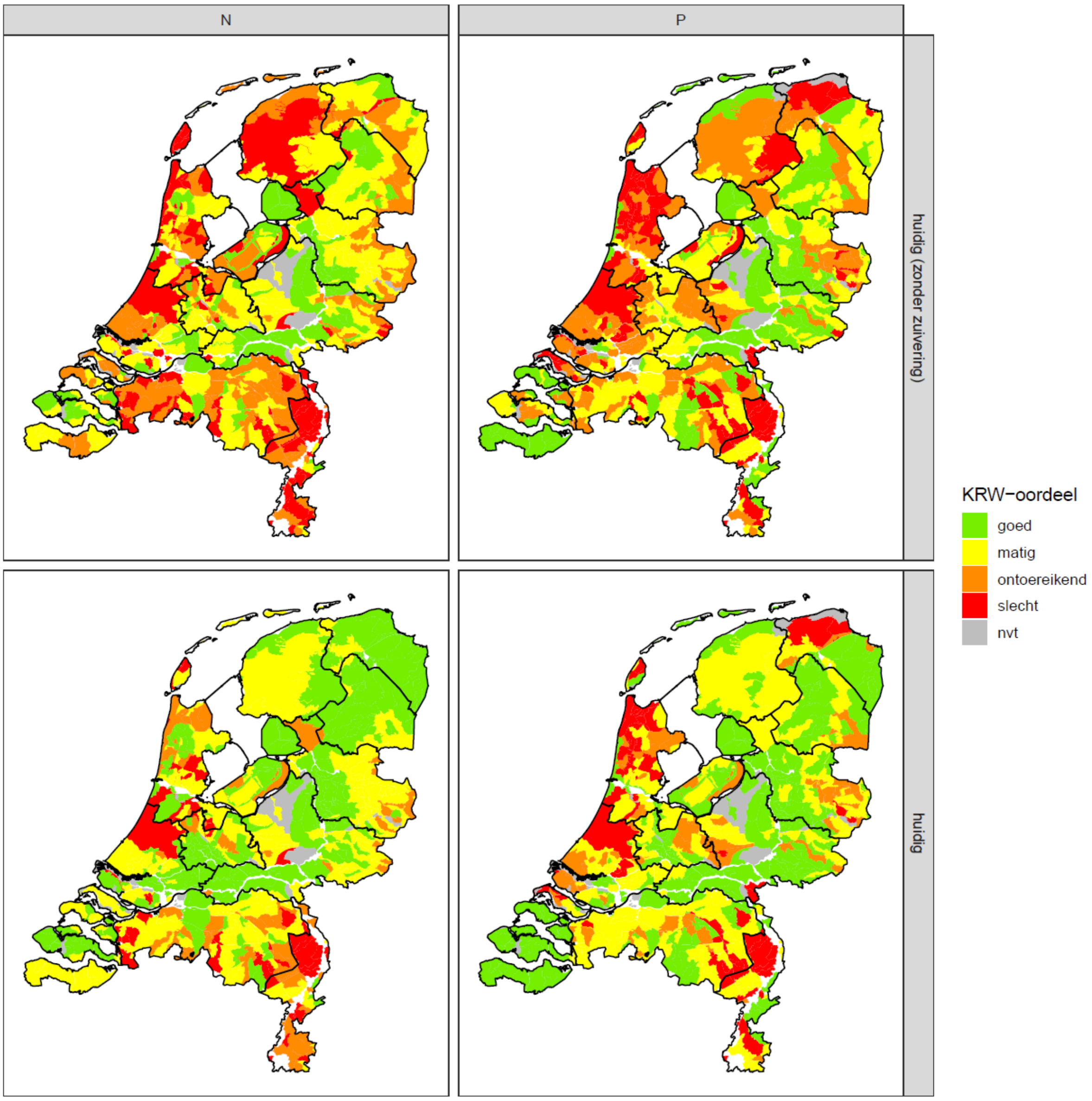

Figure 10.4 *The fictive water quality calculated by the purification tool if the purification capacity of the water system were to disappear (top) compared to the current situation (bottom), for nitrogen (N, left) and phosphorus (P, right).*

10.3.4 Standard indicators

Supply
Supply of water-purifying (N and P) vegetation in and around water bodies.

Demand
Area of the WFD catchments with excessive concentrations of N and P according to the WFD standard.

Combination of supply and demand
% surface area of water bodies with good chemical conditions (nitrate & phosphorous) (hectare).

See also Table 1.1.

For calculating the final result (natural purification as an ecosystem service), we assume the percentage of catchments (averaged over N and P) where the WFD rating is 'good' due to natural purification. The percentage of water bodies (surface area) that already have a 'good' rating without natural purification at current surface water loads are not counted as an ecosystem service (see dark green section in Figure 10.5).

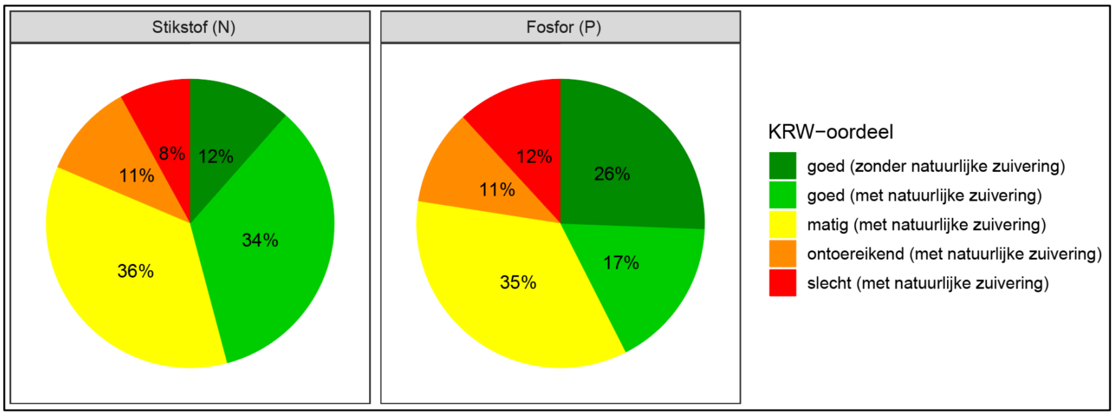

Figure 10.5 *Current surface water quality (WFD rating) for nitrogen (left) and phosphorus (right) for all 538 catchments in the Netherlands (weighted by their surface area) that the purification tool uses in its calculations. For catchments that meet the WFD standard, we also look at which part would still meet the standard in the absence of natural purification (dark green) and which part would not (light green).*

10.4 Evaluation of model functioning

10.4.1 Sensitivity analysis

As a final step, a sensitivity analysis is performed on the effect of the four purification measures that the purification tool can calculate. For each measure, the degree of implementation was incrementally increased and the extent to which it achieved the WFD standards was examined (Figure 10.6). It can be seen that the construction of helophyte filters has the greatest effect. At an implementation rate of 20%, the N and P standards would be met for almost every catchment. This means that 20% of the land area should be set up as a helophyte filter. For the other measures, the effect is lower, but they also cover less area because their implementation rate relates to the percentage of watercourse length along which the measure is possible, and thus not to the total percentage of land area as with the helophyte filters.

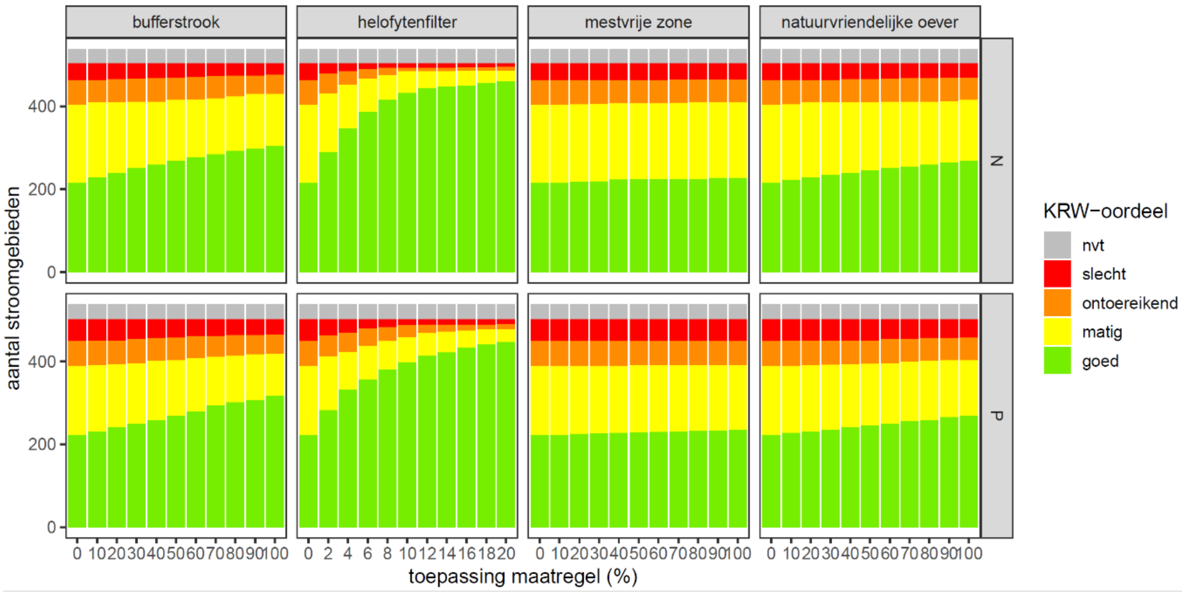

Figure 10.6 *The effect of measures for achieving the WFD standards in surface water for N (top) and P (bottom). The x-axis shows the implementation rate of the measure; 0% is the current situation and 100% is full application of measures (where this is possible). The y-axis shows the number of catchments. For marsh buffer strips and nature-friendly banks, a width of 5 metres was assumed.*

10.4.2 Uncertainty analysis

A quantitative uncertainty analysis has not yet been performed.

10.4.3 Validation

No validation has yet taken place.

10.4.4 General assessment of model quality

An overall assessment of the model has not yet been conducted that benchmarks the objective with testing, sensitivity analysis, uncertainty analysis, validation, and use. However, a number of general, qualitative conclusions can drawn:

- The purification tool provides an exploratory picture of the effects of four purification measures in and near surface water (marsh buffer strips, helophyte filters, nature-friendly banks and unfertilised zones) on surface water quality (N and P) in the Netherlands. The tool provides insight into where and to what extent these measures can best be implemented to meet WFD standards for nutrients.
- The purification tool predicts that creating helophyte filters is a promising measure to meet WFD standards, although it comes at a price: arable land must often be sacrificed to provide the needed space. Measures such as unfertilised zones, nature-friendly banks and marsh buffer strips take up less space, but partly because of this they have a smaller effect on surface water quality.
- Given the sometimes rather crude assumptions of the purification tool, the results should be interpreted with some caution. For example, the tool assumes that the purification capacity of the measures is independent of area characteristics and that it does not decrease over time, while it is known that purification capacity depends heavily on area characteristics such as soil type and hydrology, but also on the construction method, management and age of the purification measure. Only for unfertilised zones does the tool take into account that the purification capacity varies locally, according to area characteristics such as the slope of the adjacent parcel, the groundwater level and the soil type.

10.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

10.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low

10.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

10.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- Testing

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- **Calibration**
- **Input and output**
- Origin Input data

ST.4Model functioning
- **Sensitivity analysis**
- Uncertainty analysis
- Validation
- Monitoring of use
- **General assessment**

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

10.5.4 Future model development options

- Measures Expanding the tool to include water quality measures. This could include additional purification measures (such as drain pipe enclosures to treat drain pipe effluent) as well as source or route measures in agriculture. These measures could be linked to the agricultural measures considered in the National Water Quality Analysis (Groenendijk et al., in prep.).
- Changing conditions: Incorporating future developments. Take account of changes in natural purification capacity due to climate change (higher temperature, different discharge dynamics), and changes in fertiliser policy and land use.
- Synchronisation Accounting for synchronisation of catchments. To what extent does an action affect the water quality of a downstream catchment? This is interesting if more measures are taken locally than elsewhere. It can also be used to explore where within the larger catchment the deployment of measures will have the most effect, more upstream, more downstream or evenly distributed?
- Calculation algorithm Tightening the rules that are used to determine the current natural purification of a catchment. For P in particular, these rules are sometimes short of the mark For example, the influence of the water body on P retention could be specified in more detail.
- Purification key figures: Spatially differentiate the purification capacity of helophyte filters, nature-friendly banks and marsh buffer strips, as is already done for unfertilised zones. This could be done by looking

more closely at where these measures are actually possible, to what extent they are possible and whether local area characteristics affect the purification capacity.

- Spatial scale: Expand the number of catchments so that each catchment contains no more than one WFD water body. This is currently not the case and some catchments contain multiple WFD water bodies.
- Improve access: develop a user-friendly app or web viewer to run the purification tool and view the results.
- CICES includes both fresh and salt water. In this chapter, only freshwater was considered. Chemical water quality involves nitrogen and phosphate. In addition to these substances, the WFD specifies a total of 33 priority substances, not all of which are considered individually. Finally, the WFD sometimes adjusts targets downward if a natural reference is not achievable. A lower target can be set for each water body: the good ecological potential (GEP). For artificial bodies of water, a natural reference was not been established. Instead, a maximum ecological potential (MEP) is used, where the target is the GEP. Artificial bodies of water can also have a lower GEP established for each body. In the analyses, the assessment as established by the WFD is used.

10.6 Literature

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11 Air quality regulation

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11.1 Theoretical rationale

11.1.1 General description of model

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).

Particulate pollution covers a broad spectrum of pollutant types that permeate the atmosphere. Particulate matter is commonly referred to by size groupings: coarse and fine. PM_{10} includes particles up to < 10 µm in aerodynamic diameter, whereas PM2.5 only represents the smallest particles (<2.5 µm) . In recent years it has become clear that PM2.5 particles pose a higher health risk because these smaller particles penetrate deeper into the lungs. Data from epidemiological studies indicates that long term exposure to PM2.5 can increase both human morbidity and human mortality risks (Kunzli et al., 2000). Therefore, we focus on the smaller particles, PM2.5. Trees and other vegetation play an important role in the reduction of air pollution (Jeanjean et al., 2016; Powe and Willis, 2004).
The model parameterization is explicitly designed for the Netherlands, for example the length of the growing season.

Mitigating fine dust particle 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 PM10 (e.g. Beckett et al. 1998, Powe & Willis, 2004, Tiwary et al., 2008).

11.1.2 Conceptual and formal model

Main assumptions
The model uses yearly average $PM_{2.5}$ concentration data. Hence an underlying assumption of the model is that $PM_{2.5}$ concentrations are normally distributed over a year. Timing of foliage as well as precipitation are accounted for in the model. Furthermore, as $PM_{2.5}$ is a fraction of PM_{10}, capture of $PM_{2.5}$ by vegetation (e.g. forests, natural grasslands, cropland, heath) is modelled using the equations for PM10 capture by Powe and Willis (2004) (see Remme et al., 2018).

Scientific literature shows inconclusive evidence for the influence of vegetation on the reduction of PM10, 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.

Method description
Particulate matter is captured through deposition on leaf and bark surfaces. The process of deposition depends on tree type and meteorological conditions (Powe and Willis, 2004). Deposition varies depending on density of the foliage and leaf form (the leaf area index, LAI).

For the calculation of $PM_{2.5}$ capture by vegetated ecosystems (e.g. forests, natural grasslands, cropland, heath) we combined the Ecosystem Type map with a 10m spatial grain with a map of yearly average PM_{10} in µg m^3 (based on 24 hour daily averages) for 2015 on a 1000 m spatial grain (RIVM, 2015). $PM_{2.5}$ capture was estimated using the following equation (corresponding to capture of PM_{10} as calculated in Powe and Willis, 2004):
X1
ABSORPTION = SURFACE * PERIOD * FLUX

where:
ABSORBTION = dry pollution deposition on vegetation cover ($PM_{2.5}$ *capture* in µg m^{-2})

SURFACE = area of land considered (A in m^2) * surface area index (S in m^2 per m^2 of ground area)

PERIOD = period of analysis (t in s (i.e. 31536000 s)) * proportion of dry days per year (p_{dry})* proportion of in-leaf days per year ($p_{on\text{-}leaf}$)

FLUX = deposition velocity (v_d in m s^{-1}) * ambient $PM_{2.5}$ concentration ($C_{PM2.5}$ in µg m^{-3})
Or,
$PM_{2.5}\ capture_{on\text{-}leaf}$ (in kg ha^{-1}) = $A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4}) * C_{PM2.5}$
$PM_{2.5}\ capture_{off\text{-}leaf}$ (in kg ha^{-1}) = $A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4}) * C_{PM2.5}$

We take,
$M_{on\text{-}leaf} = A * S_{on\text{-}leaf} * t * p_{dry} * p_{on\text{-}leaf} * v_d * (10^{-9}/10^{-4})*0.5$
And,

$M_{off\text{-}leaf} = A * S_{off\text{-}leaf} * t * p_{dry} * (1 - p_{on\text{-}leaf}) * v_d * (10^{-9}/10^{-4})*0.5$.

where the factor 0.5 denotes the resuspension rate of particles for all land cover types except water (0,0) coming back to the atmosphere (Zinke, 1967, De Nocker et al. 2016).

For each vegetated ecosystem type we add these multiplication factors $M_{year} = M_{on\text{-}leaf} + M_{off\text{-}leaf}$ to calculate $PM_{2.5}$ *capture* in kg ha^{-1} based on ambient $PM_{2.5}$ concentration, $C_{PM2.5}$ in µg m^{-3}. The deposition velocities, the surface area index and multiplication factors per ecosystem type with vegetation cover are summarized in table 11.1. Values for deposition velocity are based on Powe and Willis (2004), however, for coniferous forest, we used a similar LAI as for in-leaf deciduous forest based on a meta-analysis by Asner et al. (2003).

Table 11.1 *Deposition velocities (m s^{-1}), the surface area index (m^2 m^{-2}) and yearly multiplication factors for forest types and other vegetation types.*

	Deposition velocity		**Surface area**		
Ecosystem type	**On-leaf**	**Off-leaf**	**On-leaf**	**Off-leaf**	M_{year}
Deciduous forest	0.0050	0.0014	6	1.7	1.87
Coniferous forest	0.0050	0.0050	6	6	3.03
Mixed forest					2.45
Other vegetation	0.0010	0.0010	2	1.5	0.18

The above model calculates PM2.5 capture in kg per hectare per year. However, the effect of particulate matter on health is mostly derived from epidemiological studies where frequency of the health outcome is related to the level of exposure in µg/m3. Therefore, the capture in kg PM2.5 per hectare per year needs to be converted to a reduction in annual mean concentration PM2.5 in µg/m^3. Assuming a boundary layer of 2000 m with mixing during the day, and converting capture per year to capture per day, results in a conversion factor θ of 0.137 from kg/hectare/year capture to a reduction of the daily mean ambient PM2.5 concentration in µg/m^3.

The presence of vegetation affects the observed $PM_{2.5}$ concentration, $CPM2.5_{obs}$. To calculate the service of $PM_{2.5}$ concentration reduction by vegetation, $CPM2.5_{red}$, the observed concentration needs to be corrected for the presence of vegetation in the reference situation, M_{year_ref}. Thus,

$CPM2.5_{red} = \theta * Myear\_ref * (CPM2.5_{obs} + CPM2.5_{red})$

This results in,

$$C_{PM2.5_{red}} = \frac{\theta * M_{year\_ref} * C_{PM2.5_{obs}}}{1 - (\theta * M_{year\_ref})}$$

The reference concentration without vegetation, $CPM2.5_{no\_veg}$, is equal to $CPM2.5\_obs + CPM2.5\_red$, or

$$C_{PM2.5_{no\_veg}} = C_{PM2.5_{obs}} * \left(1 + \frac{\theta * M_{year\_ref}}{1 - (\theta * M_{year\_ref})}\right)$$

In above equations, θ is the conversion factor from kg $PM_{2.5}$ per hectare to $PM_{2.5}$ concentration in $\mu g/m^3$, M_{year_ref} is the ecosystem dependent $PM_{2.5}$ capture factor (Table 11.1) for the vegetation in the reference situation (i.e. the year of the observed $PM_{2.5}$ concentration) and $CPM2.5_{obs}$, $CPM2.5_{red}$ and $CPM2.5_{no\_veg}$ are respectively the observed $PM_{2.5}$ concentration, the reduction in $PM_{2.5}$ concentration due to vegetation, and the $PM_{2.5}$ concentration if no vegetation would be present.

The reference concentration without vegetation, $CPM2.5_{no\_veg}$, can subsequently be used to calculate the $PM_{2.5}$ concentration in the current situation or a scenario,

$$C_{PM2.5_{scenario}} = (1 - \theta * M_{year\_scen}) * C_{PM2.5_{no\_veg}}$$

by using the ecosystem dependent $PM_{2.5}$ capture factor, M_{year_scen} (Table 11.1) for the vegetation in the scenario (or current situation). The difference between the $PM_{2.5}$ concentration without vegetation and the concentration in the scenario is the air filtration service.

$$C_{PM2.5_{reduction\_scenario}} = C_{PM2.5_{no\_veg}} - C_{PM2.5_{scenario}}$$

Norms
The World Health Organisation (WHO) states exposure to $PM_{2,5}$ is more harmful that exposure to PM_{10}. The smaller particles of $PM_{2,5}$ penetrate deeper in the lungs (Brunekreef en Forsberg, 2005). Therefore norms are formulated by the European Directive of air quality since 2008 on $PM_{2,5}$.
For $PM_{2,5}$ the norm is 25 $\mu g/m^3$ for the yearly average. The WHO considers these norms as mid-term targets on the way to values of 10 $\mu g/m^3$ (WHO, 2006). In the mean time the target is adjusted to 5 $\mu g/m^3$. This is not yet incorporated in the model code.

11.2 Technical implementation

11.2.1 Implementation model

The flow diagram consists of two main parts. At the top, input maps from the reference situation (i.e. the year of the observed PM2.5 concentration maps) are used to calculate the PM2.5 concentration if there would be no vegetation present. At the bottom, input maps about the scenario are used to calculate the reduction in the PM2.5 concentration due to the vegetation. Going from left to right, the function "verify groenkaarten" function generates an array with the fraction of trees "boom_huidig" and an array with the total fraction of shrubs and low vegetation "grasstruik_huidig". Next, "Functie 1" and "Functie 2" calculate the PM2.5 capture by trees, respectively shrubs and low vegetation, in paved ecosystem types, based on the reference land use array "lceu_orig_array" and a vector with paved ecosystem types. If it is paved, it uses the fraction of tree, respectively shrub and low vegetation cover, combined with the capture by trees ("Myear boom"), respectively other vegetation ("Myear grasstruik") to calculate the capture by trees, respectively shrubs and low vegetation in paved areas. In the middle, the function "LU1" combine the land use array of the reference situation ("lceu orig array") with the lookup table with the PM2.5 capture factors, producing arrays with the capture factors by vegetation in unpaved ecosystem types, Myear_blanco. In "Functie 3" the array with capture factors in the unpaved land uses is updated to include the capture factors in the paved land uses: "Myear_blanco" = "Myear_blanco" + "boom_afvang" + "grasstruik_afvang". At the bottom the same set of functions, but now based on the scenario maps, are used to calculate the PM2.5 capture factors for the paved and the unpaved ecosystem types, resulting in an updated Myear_scen. In "Functie 4" the PM2.5 concentration without vegetation is calculated, using

$$C_{PM2.5_{no\_veg}} = C_{PM2.5_{obs}} * \left(1 + \frac{\theta * M_{year\_ref}}{1 - (\theta * M_{year\_ref})}\right)$$

Where "base_conc_arr" is $C_{PM2.5obs}$ is "Myear_blanco" is M_{year_ref} and θ is the factor 0.137 ("mul_factor"), this results in the array "conc_blanco" ($C_{PM2.5no\_veg}$). This concentration without vegetation is then used in "Functie 8" to calculate the concentration in the scenario "conc_scen" ($C_{PM2.5scenario}$),

$$C_{PM2.5_{scenario}} = \left(1 - \theta * M_{year\_scen}\right) * C_{PM2.5_{no\_veg}}$$

using the capture factors of the scenario "Myear_scen" and the same factor 0.137 ("mul_factor"). Both the reference concentration without vegetation and the concentration in the scenario are compared to the WHO threshold for $PM_{2.5}$ in "Functie 9" respectively "Functie 10" and pixels with a concentration ≤ the threshold get value 1 and the remaining pixels get value 0. The resulting arrays "eval_blanco" and "eval_scen" are combined with the population count array (not shown) to evaluate the percentage of the population that lives in an area below the threshold concentration in the reference situation or due to the presence of vegetation.

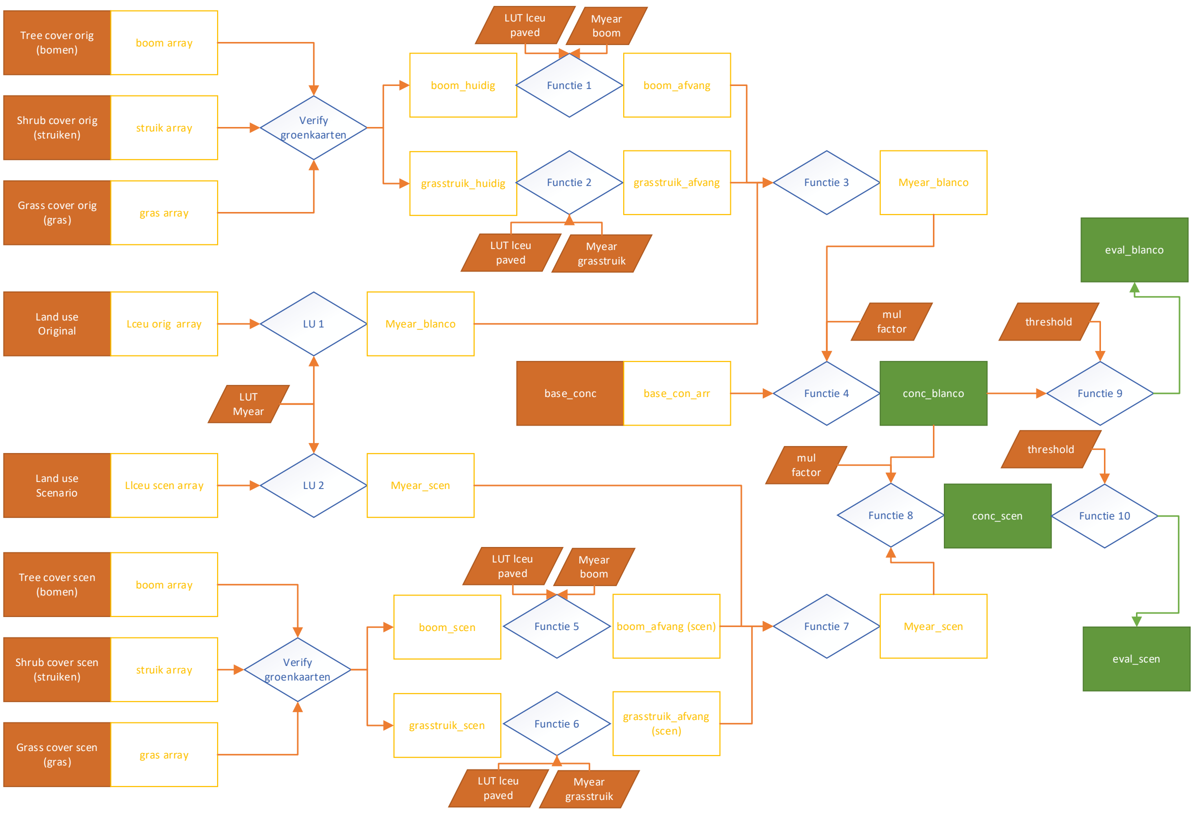

Figure 11.1 *Flow diagram of the air filtration model. The filled orange boxes are input raster files.*

The filled orange parallelograms (see figure 11.1) are input variables or lookup tables, these are stored in a yml file (https://git.wur.nl/roelo008/2j_airquality/-/blob/master/resources/params.yml). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/raster files from the model. From the output arrays output values are calculated (not shown), these are written to an output file: model_result.ini, which also stores the paths of all input files. The flow diagram consists of two main parts, at the top, input maps about the reference situation (i.e. the year of the observed $PM_{2.5}$ concentration maps) are used to calculate the $PM_{2.5}$ concentration if there was no vegetation present, at the bottom input maps on the scenario are used to calculate the reduction in the $PM_{2.5}$ concentration due to the vegetation. At the top and the bottom of the flow diagram, the "verify groenkaarten" function generates a map with the fraction of trees (i.e boom_array/100) and a map with the total fraction of shrubs and low vegetation "grasstruik" (i.e. (struik_array + gras_array)/100). It furthermore checks the total cover of the boom, struik and gras array, and corrects the "grasstruik" if the maximum is higher than 100. "Functie 1"/"Functie 5" and "Functie 2"/"Functie 6" specifically calculate the $PM_{2.5}$ capture by trees, respectively shrubs and low vegetation, in paved ecosystem types. It checks if a land use is in a vector with paved land uses. If it is paved, it uses the fraction of tree, respectively shrub and low vegetation cover, combined with the capture by trees ("Myear boom"), respectively other vegetation ("Myear grasstruik") to calculate the capture by trees, respectively shrubs and low vegetation in paved areas. In the middle, LU1 and LU2 combine the land use array of the reference situation (land use original) respectively the land use array of the scenario with the lookup table with the $PM_{2.5}$ capture factors, producing arrays with the capture factors by vegetation in unpaved ecosystem types, Myear_blanco, respectvely Myear_scen. In "Functie 3" the array with capture factors in the unpaved land uses is updated to include the capture factors in the paved land uses: "Myear_blanco" = "Myear_blanco" + "boom_afvang" + "grasstruik_afvang". For the scenario, the same calculation is done in "Functie 7", resulting in an updated Myear_scen containing the capture factors of vegetation in unpaved and paved land use types. In "Functie 4" the $PM_{2.5}$ concentration without vegetation is calculated, using

$$C_{PM2.5_{no\_veg}} = C_{PM2.5_{obs}} * \left(1 + \frac{\theta * M_{year\_ref}}{1 - \left(\theta * M_{year\_ref}\right)}\right)$$

Where "base_conc_arr" is $C_{PM2.5obs}$ is "Myear_blanco" is M_{year_ref} and θ is the factor 0.137 ("mul_factor"), this results in the array "conc_blanco" ($C_{PM2.5no\_veg}$). This concentration without vegetation is then used in "Functie 8" to calculate the concentration in the scenario "conc_scen" ($C_{PM2.5scenario}$),

$$C_{PM2.5_{scenario}} = \left(1 - \theta * M_{year\_scen}\right) * C_{PM2.5_{no\_veg}}$$

using the capture factors of the scenario "Myear_scen" and the same factor 0.137 ("mul_factor"). Both the reference concentration without vegetation and the concentration in the scenario are compared to the WHO threshold for $PM_{2.5}$ in "Functie 9" respectively "Functie 10" and pixels with a concentration ≤ the threshold get value 1 and the remaining pixels get value 0. The resulting arrays "eval_blanco" and "eval_scen" are combined with the population count array (not shown) to evaluate the percentage of the population that lives in an area below the threshold concentration in the reference situation or due to the presence of vegetation.

11.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9). An environment.yml file is available in git (https://git.wur.nl/roelo008/2j_airquality/-/tree/master/) that can be used to reproduce the exact environment used in the simulations. The model has be run on a computer with an Intel Xeon W-2133 3.6 GHz processor and 16.0 GB RAM. Due to memory limitations the variables are stored as float32.

11.2.3 Testing

There is a test dataset to verify the model. This testset is a small part of the Netherlands. Extensive test with for example extreme input data have not been performed. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

11.3 Input and output, parameters and variables

11.3.1 Parameters and variables

Parameters:

- Retention capacity per land use type (‘*Myear*’), zie: https://git.wur.nl/roelo008/2j_airquality/-/blob/master/resources/params.yml#L7
- Multiplication factor (constant) to convert kg/ha to mg/m^3. See: https://git.wur.nl/roelo008/2j_airquality/-/blob/master/resources/params.yml#L5
- Area of the Netherlands in km^2 (constant): 33893 km^2. See: https://git.wur.nl/roelo008/2j_airquality/-/blob/master/resources/params.yml#L4
- Treshold exceedane air quality: 10 µg/m^3 pm 2.5 (WHO, 2005). Zie: https://git.wur.nl/roelo008/2j_airquality/-/blob/master/resources/params.yml#L3 en http://apps.who.int/iris/bitstream/handle/10665/69477/WHO_SDE_PHE_OEH_06.02_eng.pdf;jsessionid=36090F4AA3D01A638215C220CD6E0D6B?sequence=1

All parameters are documented in a yml file, which is read by the model. Within the yml it is possible to add sections with alternative parameter values to calculate with these values. THe model works with 11 obligatory and 4 optional variables.

Obligated

1. base_conc: Raster reference concentration of 2.5µm particles.
2. lceu_orig: Land use raster in LCEU categories in reference year.
3. lceu_scen: Land use raster in LCEU categories in scenario.
4. inw: Raster population count per pixel.
5. bomen_orig: Raster tree cover (%) per pixel, reference.
6. struiken_orig: Raster shrub cover (%) per pixel, reference.
7. gras_orig: Raster low vegetation cover (%) per pixel, reference.
8. bomen_scen: Raster tree cover (%) per pixel in scenario
9. struiken_scen: Raster shrub cover (%) per pixel in scenario.
10. gras_scen: Raster low vegetation cover (%) per pixel in scenario.
11. scenario_name: Naam van het scenario dat doorgerekend wordt

Optional

1. --params_sections (default: “default”). name of parameterselection if the user want to use other values for the default settings.
2. --out_dir: directory waar de output geschreven wordt
3. --rasters: creeer geospatials als output
4. --report: schrijf een rapport als output

11.3.2 Calibration

No calibration have been performed.

11.3.3 Input and output

Input

Base Concentration: this is the base concentration map of 2.5µm fine dust particles. This map is the startingpoint for which the effects of vegetation are being projected. This map is the concentration of the current situation. Source: RIVM Grootschalige Concentratiekaarten voor Fijn Stof $PM_{2.5}$ https://www.rivm.nl/gcn-gdn-kaarten/concentratiekaarten/cijfers-achter-concentratiekaarten/gcn-concentratiekaartbestanden-achterliggende-jaren.

LCEU original: this is the land use map of the Netherlands for the current situation following LCEU categorisation (https://www.cbs.nl/-/media/_pdf/2017/12/2017ep14-ecosystem-unit-map.pdf), resolution 10 m.

LCEU scenario: this is the land use map for the Netherlands for the scenario.

population: this is a raster with the number of people per pixel in the scenario. Bron: CBS statistische gegevens per vierkant en postcode.
Trees/Grass/Shrubs: these are the NDVI 'green maps' from PDOK, with the percentage between 0-100% for the cover of the vegetation. The model needs tree/gras/shrub maps for the current as the scenario (*_orig en *_scen).

Output
"getal01": "populatie onder threshold blanco",
"getal02": "populatie boven threshold blanco",
"getal03": "populatie onder threshold blanco percentage",
"getal04": "populatie boven threshold blanco percentage",
"getal05": "populatie onder threshold scenario",
"getal06": "populatie boven threshold scenario",
"getal07": "populatie onder threshold scenario percentage",
"getal08": "populatie boven threshold scenario percentage",
"getal09": "oppervlakte Nederland onder threshold blanco sq km",
"getal10": "oppervlakte Nederland onder threshold blanco percentage",
"getal11": "oppervlakte Nederland onder threshold scenario sq km",
"getal12": "oppervlakte Nederland onder threshold scenario percentage",
"getal13": "capita gewogen gemiddelde concentratie fijnstof blanco",
"getal14": "capita gewogen gemiddelde concentratie fijnstof scenario",
"getal15": "per capita gemiddelde reductie fijnstof concentratie",
"getal16": "procentuele reductie per capita van fijnstof concentratie door groen",
"getal17": "totale populatie"

These output values are written in model_result.ini in the output directory

Optional output
The optional output consists of 3 sets of geospatial raster files:
One set containing the calculated $PM_{2.5}$ concentration respectively with and without vegetation named, 'conc.tif', 'conc_wo_veg.tif'
One set containing the geospatial raster files with the number of people below or above the WHO concentration threshold for the scenario or the reference situation (blanco) named, 'scenario_pop_below_thresh.tif', 'scenario_pop_above_thresh.tif', 'blanco_pop_below_threshold.tif', 'blanco_pop_above_threshold.tif'
One geospatial raster file showing were the PM2.5 concentration is below (value 1) or above the threshold named,
'below_thresh.tif'

11.3.4 Standard indicators

Supply
Supply of air-purifying vegetation.

Demand
The demand for clean air (no one should be exposed annually to more than an average of 10 μg/m^3 $PM_{2.5}$ (= WHO standard)). The WHO standard has recently been lowered to 5 μg/m^3. This change has not yet been incorporated into the model.

Combination of supply and demand
% of people whose are exposed to particulate matter below the WHO guidelines for PM 2.5 (ug/m^3).

See also Table 1.1.

The indicator is calculated as the percentage of people whose exposure is below the WHO guideline of 10 μg/m^3 due to the presence of vegetation. For this purpose, a run was first done without vegetation. This is the reference. A run was then made with the current amount and location of green vegetation. The difference between the run without and with vegetation in the number of people falling below the guideline is the indicator that is used.

11.4 Evaluation of model functioning

11.4.1 Sensitivity analysis

A sensitivity analysis has not been performed. Although a scenario has been run with more vegetation in cities, and the results indicate the differences are plausible (Breman et al., 2022).

11.4.2 Uncertainty analysis

No uncertainty analysis has been done yet.

11.4.3 Validation

No validation has been performed yet.

11.4.4 General assessment of model quality

No overall assessment has yet taken place.

11.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: <u>**complete**</u>, <u>partly (in)complete</u>, incomplete.

11.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low

11.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

11.5.3 Status A progress

ST.1: Model description
- <u>**General description**</u>
- <u>**Description conceptual and formal model**</u>

ST.2: Technical implementation
- <u>**Implementation**</u>
- <u>**Technical environment**</u>
- Testing

ST.3: Description parameters, variables, input and output
- <u>**Parameters and variables**</u>
- Calibration
- <u>**Input and output**</u>
- <u>**Origin Input data**</u>

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

11.5.4 Future model development options

- Forests affect the airflow, which in turn affects the possible retention of PM2.5 by vegetation. In the current model, a linear relation between the retention of PM2.5 and the extent of (a group of) trees is assumed, and a single tree also has a (small) positive effect on PM2.5 retention. Whether this is actually the case depends on the exact location and local circumstances. Street trees can also locally increase the PM2.5 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.
- WHO norms for good air quality are recently changed from 10 μg/m³ to 5 μg/m³. This needs to be incorporated in the next version of the model.
- Now the indicator is calculated per capita. This is because people stay most of the time in and around where they live. Because in cities and villages is less vegetation compared to rural places the effect of this service is rather low. You could argue people also stay at other places than where they live and this should be taken into account.
- Besides the threshold for the concentration of fine dust particles to be good or insufficient one could argue all decrease of the concentration below or above the threshold is beneficial for human health. This could be an additive indicator besides the standard one that is used now.

11.6 Literature

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12 Prevention of heat islands

Marjolein Lof (WENR), Bart de Knegt (WENR), (earlier with the cooperation of Sytske Koopmans)

12.1 Theoretical rationale

12.1.1 General description of model

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. Here we have defined the local climate regulation service as the contribution of vegetation located within a radius of 250m to the cooling capacity of urban areas during a heat wave. The urban cooling model is developed for the Netherlands, furthermore the ecosystem service is only supplied in urban areas, where urban areas are distinguished by the 'urbanization class' (stedelijkheidsklasse) as defined by Statistics Netherlands per neighbourhood.

There is also a model on prevention of heat island by RIVM which differ in results of this model.

12.1.2 Conceptual and formal model

Theewes et al. (2016) showed that vegetation cover and the sky-view factor (e.g. the fraction of open air that can be seen in a 360 degree radius (Dirksen et al., 2019)) can be used to estimate the increase in temperature (UHI_{max}) in the urban areas as compared to rural areas, where vegetation cover and open view reduce the UHI_{max}. Direct measures for the availability of water for vegetation (which influences the evaporation capacity of the vegetation) are not taken into account, nor is the shading effect explicitly taken into account. When water shortage occurs during a heat wave, the effect of vegetation might be overestimated.

The increase in temperature in urban areas is calculated with (Theewes et al., 2016):

$$UHI_{max} = \left(2 - SVF - f_{veg}\right)\left(2 - SVF - f_{veg}\right) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

Where, UHI_{max} (estimation) is the maximum difference between the urban and the rural temperature. SVF is the sky-view-factor a value between 0 and 1 that describes the fraction of open air that can be seen in a 360 degree radius, with 0 complete cover and 1 completely open. This is calculated as a spatial mean within a 250 radius. Furthermore, f_{veg} is the fraction vegetation cover within a 500m radius, S is the daily mean of the shortwave incoming radiation (based on hourly data), U is the daily average wind speed (based on hourly data) and DTR (Diurnal Temperature Range) is the difference between the minimum and maximum temperature in the rural area. U and DTR are the average values from 8AM to 7AM the next day, while S is the average from 1AM to 0AM next day (table 12.1).

Table 12.1 *Times for which the variables were derived.*

Variable	Time (local time)	Description
UHI_{max}	Day 0, 0800–day 1, 0700	max($T_{urban} - T_{rural}$) from 1-h average data
$S^{\downarrow}$	Day 0, 0100–day 1, 0000	Sum of the shortwave incoming radiation from 1-h maxima in rural area divided by 24 h
U	Day 0, 0800–day 1, 0700	Average wind speed at 10 m from 1-h averages in rural area
D_{avg}	Day 0, 0800–day 1, 0700	Average wind direction at 10 m from 1-h averages in rural area
DTR	Day 0, 0800–day 1, 0700	Difference between the maximum and minimum temperature in rural area

The difference between the UHI_max with and without vegetation is the contribution of vegetation to the lowering of the UHI. To calculate the effect of vegetation on the local climate (reduction of UHI),

the increase in temperature without vegetation present is calculated by,

$$UHI_{max,\ no\,veg} = (2 - SVF - 0) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

The effect of vegetation is thus equal to,

$$\Delta UHI_{max} = f_{veg} * \sqrt[4]{\frac{S * DTR^3}{U}}$$

We derived the sky-view factor from KNMI on a 1x1 meter basis (based on AHN2 height dataset). Climatological data from 32 weather stations spread over the Netherlands we use to calculate S, U and DTR. These variables were derived from the KNMI for 1 July 2015, a typical heat-wave day in the Netherlands. We calculated an weighted average with a 50 kilometre buffer.

In the original SVF map from KNMI, both high vegetation and buildings decrease the SVF, while only the effect of buildings and streets will increase the UHI_{max}. Furthermore, we are interested in the effect of buildings, but not in the buildings themselves. Therefore, we used information from the BAG (basic registration of buildings) to remove SVF data at locations of buildings. We did this at the original 1x1m maps. We used BAG data of 2012 as this is similar to the time that the AHN2 height dataset was collected in the Netherlands.

To remove the effect of high vegetation on the SVF we used the following rules of thumb:
If in a 250m radius around a grid cell more than 90 % of the cells contained >80% vegetation cover (the SVF of these cells were assigned as NoData) then the SVF of that cell was assigned as 1, e.g. clear view of the sky.

If in the 250m radius less than 80% of the cells contained >80% vegetation cover the mean SFV value was calculated for that grid cell. In this calculation of the mean SFV value, the original SFV value of the cells with >80% vegetation cover are not included.
If in the 250 m radius, between 80 and 90% of the cells contained >80% vegetation cover the SVF value was set at a value between the mean SFV (not including the SFV of cells containing > 80% vegetation cover) and 1. This is calculated as,

SFV_{new}= 10*(σ – 0.1)*$SFV_{mean250m}$ + 10*(0.2 - σ)*1,

where σ is the fraction of grid cells in the 250m radius with a SFV value.

Then an moving window with a radius of 500 meter was used to calculate the average SVF. The moving window of 250m was conducted on grid cells with a 10m resolution. These spatial averages were input for the calculations of UHI_{max} with and without vegetation, for 1 july 2015 (= demand).

12.2 Technical implementation

12.2.1 Implementation model

The urban cooling model is written in python and together with a yml file containing the environment needed to run the model stored in a repository online (https://git.wur.nl/roelo008/verkoeling/-/blob/master/environment.yml). The model calculates reduction of the urban heat island effect by vegetation.
Figure 12.1 gives an schematic overview of the steps in the model.
At the top, the input geospatial rasters tree cover, shrub cover and gras cover are first converted into arrays. In function "Functie 1", these three are added up to one vegetation cover map. In the function "Calculate fveg_avg0" for each cell the average vegetation cover within radius "radius fveg_m" is calulated, as arrays don't contain spatial information, the cell size of the rasters "px (m)" is required. This results in the array fveg_avg.
At the bottom, the geospatial rasters land use, sky view factor (SVF), building cover are first converted into arrays. The land use map is then combined with a look-up table "LU1" that identifies the agricultural classes and a look-up table "LU2" that identifies waterbodies and streams. The resulting arrays agri_arr and water_arr are used in the function "Calculate sfv_avg0". In this function the average SVF within radius "radius_svf (m)" is calculated. In this function the average SVF value is weighted by the average cover with SVF data. SVF measured on top of buildings (based on the original 1x1m maps), on water or on agricultural land are not taken into account. In the function "Calculate svf_avg" the spatial average svf_avg0 is corrected for large open area, i.e. more than 90% water or vegetated area in radius "radius svf (m)" resulting in a weighted and corrected spatial average sky view factor, the array svf_avg.
In the middle, the input geospatial raster with meteorological data is converted into the array "root4".
"Functie 2" calculates the UHI based on the following formula:

$$UHI_{max} = \left(2 - SVF - f_{veg}\right) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

Where svf_avg is used for SVF, fveg_avg is used for fveg and root4 is used for the quadratic root.
"Functie 3" calculates the UHI without vegetation based on the following formula:

$$UHI_{max,\ no\,veg} = (2 - SVF) * \sqrt[4]{\frac{S * DTR^3}{U}}$$

Using the arrays svf_avg and root4.
In "Functie 4" the difference in UHI due to vegetation is calculated as delta UHI = UHI_noveg – UHI.

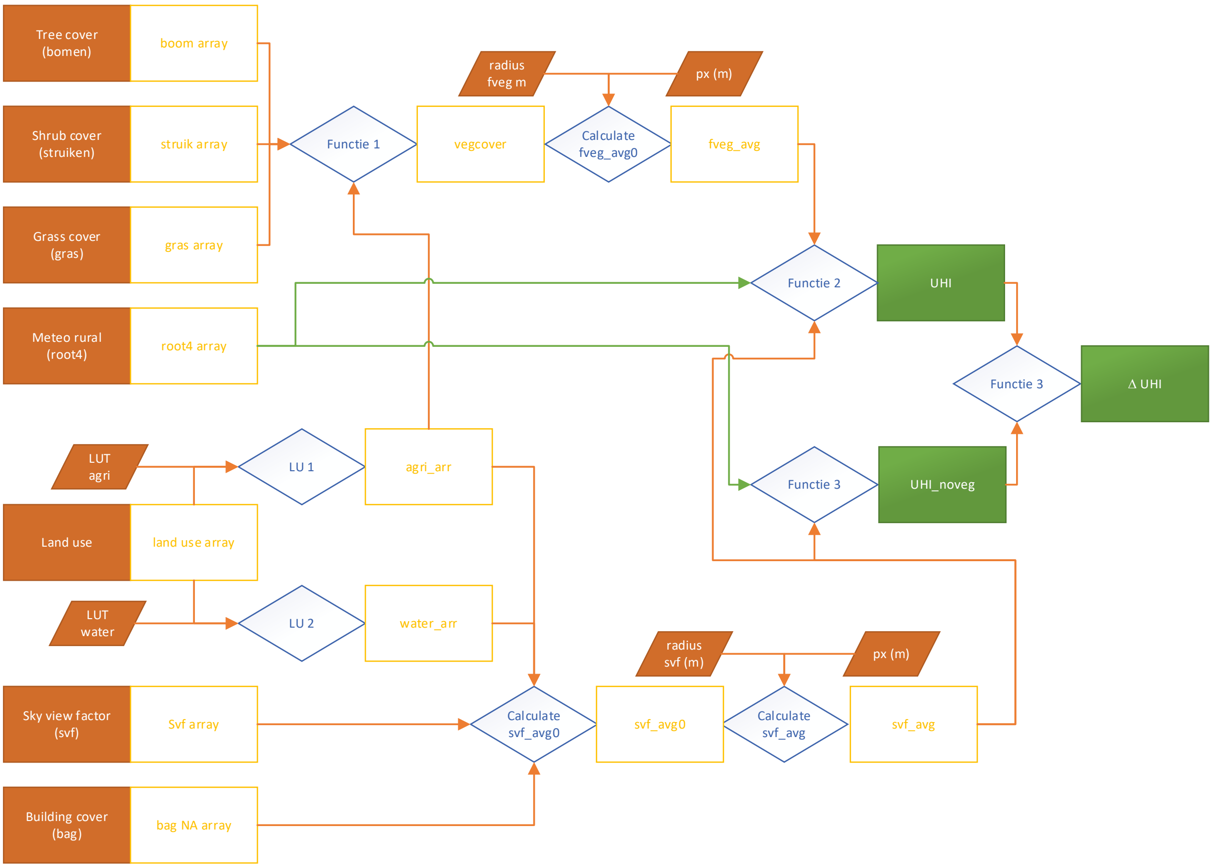

Figure 12.1 *Flow diagram of the urban cooling model.*

The filled orange boxes are input raster files (figure 12.1). The filled orange parallelograms are input variables, these are stored in one excel file (https://git.wur.nl/roelo008/verkoeling/-/blob/master/tests/dat/params_uhi.xlsx). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/rasters from the model. "Functie 1" is a function that sums the "boom", "struik", and "gras" arrays to a total vegetation cover "vegcover". "Calculate fveg_avg0" is a function that calculates the spatial average vegetation cover within a 500m radius, by taking a convolution between the vegetation cover array and an array where cells within the distance of the radius (from the centre of the array) are set to 1 and are set to 0 outside of the radius and calculating the average by dividing the result by the number of cells within the radius. "Calculate svf_avg0" is a function that calculates the spatial average sky view factor (SVF) within a 250m radius, by taking a convolution between the SVF array and an array where cells within the radius (from the centre of the array) are set to 1 and are set to 0 outside of the radius and calculating the average by dividing the result by the number of cells within the radius. In this function the average SVF value is weighted by the average cover with SVF data. SVF measured on top of buildings (based on the original 1x1m maps), on water or on agricultural land are not taken into account. In the function "Calculate svf_avg" the spatial average svf_avg0 is corrected for large open area, i.e. more than 90% water or vegetated area in radius "radius svf (m)" resulting in a weighted and corrected spatial average sky view factor, the array svf_avg. "Functie 2" calculates

$$UHI_{max} = (2 - SVF - f_{veg}) * \sqrt[4]{\frac{S*DTR^3}{U}}$$

and "Functie 3" calculates

$$UHI_{max,\ no\ veg} = (2 - SVF) * \sqrt[4]{\frac{S*DTR^3}{U}}$$

And "Functie 4" calculates the effect of vegetation on the reduction of the UHI: deltaUHI = UHInoveg – UHI.

Figure 12.2 shows the indicators that are calculated.

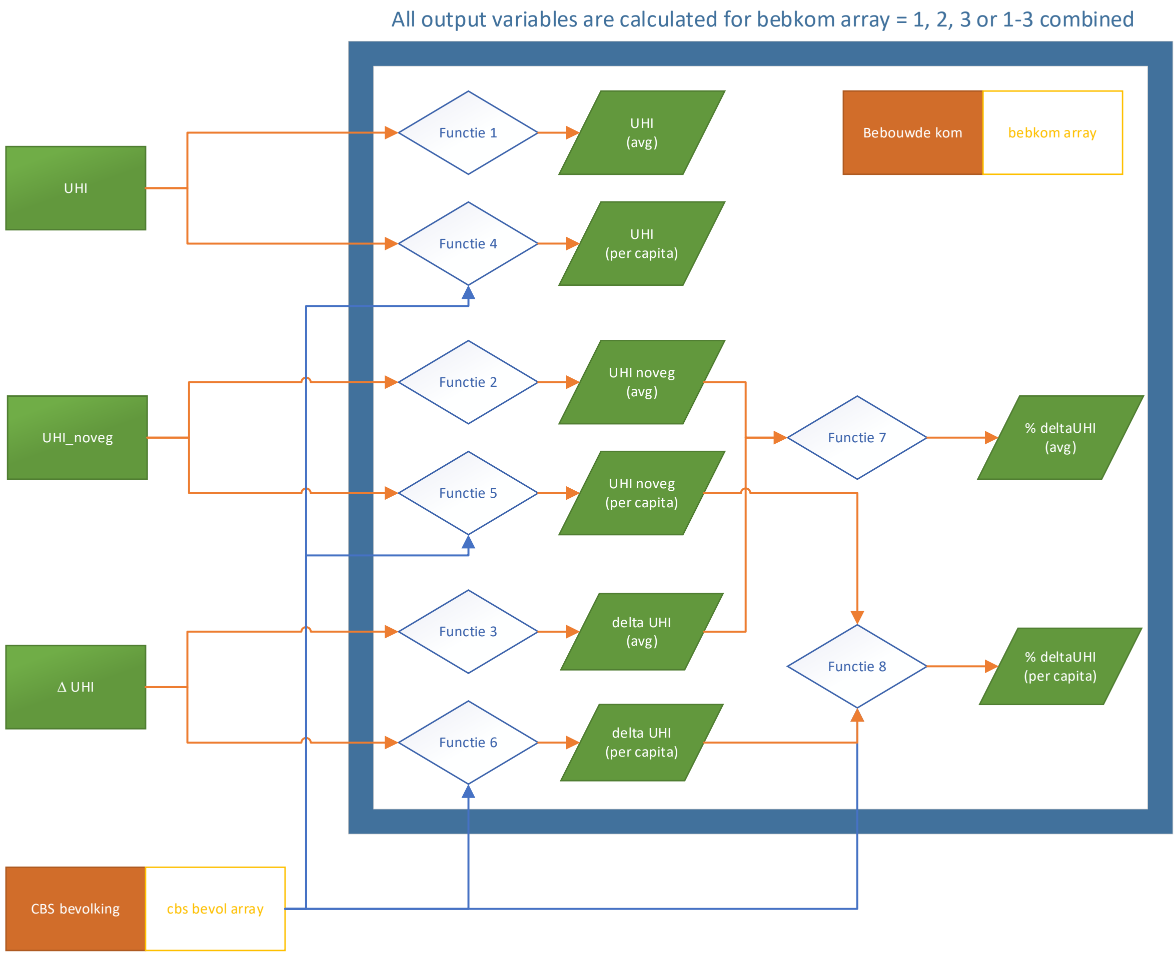

Figure 12.2 *Flow diagram output values of the urban cooling model.*

The filled orange boxes are input raster files (figure 12.2). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/rasters from the model. From each green box the mean value in in the built-up area (in "Functie 1", "Functie 2" and "Functie 3") is calculated and written to an output file: model_result.ini, which also stores the paths of all input files. Furthermore, for each green box the per capita weighted average is calculated (in "Functie 4", "Functie 5" and "Functie 6"). Furthermore, "Functie 7" and "Functie 8" the percentage of respectively the average or the per capita weighted average of the reduction that can be attributed to vegetation is calculated; % deltaUHI (avg) = 100* delta UHI (avg)/UHI noveg (avg). This is calculated for urbanisation classes 1, 2, 3 and all of these combined.

12.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9). An environment.yml file is available in git () that can be used to reproduce the exact environment used in the simulations. The model has be run on a computer with an Intel Xeon W-2133 3.6 GHz processor and 16.0 GB RAM. Due to memory limitations the variables are stored as float32.

12.2.3 Testing

There is a test data set that can be used to verify whether the model works as expected. This is a dataset from a small part of the Netherlands, the city Amsterdam, so that the test can be done in only a few minutes. More comprehensive testing, like testing for extreme input values or verification with field measurements has not been done. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

12.3 Input and output, Parameters and variables

12.3.1 Parameters and variables

The parameters are stored in a excel file which can be found at:
https://git.wur.nl/roelo008/verkoeling/-/blob/master/tests/dat/params_uhi.xlsx
Parameters:
This excel file contains three sheets.
The first sheet ('water') contains a look-up table to mask water based on the LCEU land use classes, where LCEU classes 51 (sea), 52 (lakes and ponds) and 53 (rivers and streams) are 1 and the remaining LCEU classes are 0.
The second sheet ('agri') contains a look-up table to select agricultural LCEU classes. Here LCEU classes 1 (non-perennial plants), 2 (perennial plants), 4 (meadows (grazing)) and 5 (bushes and hedges bordering fields / faunarand) are 1 and the remaining classes are 0.
The third sheet "constants" contains the model constants:

- Pixel size of the input rasters ('px') in meter
- The radius ('radius_svf_m') of the moving average of the sky view factor in meter, i.e. the distance at which cells are included in calculating the spatial average value in a grid cell.
- The radius ('radius_veg_m') of the moving average of vegetation cover in meter, i.e. the distance at which cells are included in calculating the spatial average value in a grid cell.
- The maximum distance ('radius_meteo_km') at which meteorological data is included in the simple (linear) spatial interpolation.

The default values are set at:

key	value
px	10
radius_svf_m	250
radius_veg_m	500
radius_meteo_km	50

The excel file with the parameters is an input variable of the simulation. It is therefore possible to use a copy of the excel file with alternative parameter values as an input file.

Input variables
The model consists of ten mandatory and eight optional variables
Mandatory variables:

1. land_use — Geospatial raster showing land use following LCEU categories
2. bomen — Geospatial raster showing tree-coverage on scale 0-100
3. struiken — Geospatial raster showing shrub-coverage on scale 0-100
4. gras — Geospatial raster showing grass-coverage on scale 0-100
5. svf — Geospatial raster showing sky view factor, excl. buildings on scale 0-1
6. na_bag — Geospatial raster showing m2 buildings per cell in SVF map, range 0-100
7. beb_kom — Geospatial raster with urbanisation level
8. inw — Geospatial raster showing population count per pixel.
9. Params — Excel sheet with dictionaries for masks and model constants
10. Scenario — Scenario name

Optional variables:
1.--out_dir: output directory
2.--root4*: Geospatial raster of ((S*(DTR^3))/U)^(1./4), default: ../data/root4_10.tif
3.--mask: Geospatial raster with mask for missing SVF data (0=SVF data missing, 1=SVF data present), default: ../data/svf10m_mask.tif. For scenario analysis use the default.
4.--write_rasters: write geospatial ouput rasters to output directory.
5.--reporting: write an text file with key outcomes

6.--test_input: verify model initialization, do nothing else
7.--env_gdal_path Path of gdal folder in python environment
8.--service Calculate contribution of ecosystems to reduction UHImax, output: raster and zonal statistics

12.3.2 Calibration

The parameters of the model have been calibrated Theewes et al. (2016), which can be accessed at https://doi.org/10.1002/joc.4717, based on data of 14 cities in Northwest Europe, including 9 cities in the Netherlands. The optimal values were,

$1.94 - 0.93 \cdot SVF - 0.88 \cdot f_{veg}$.

They simplified this to ($2 - SVF - f_{veg}$)

12.3.3 Input and output

Output

The output values can be divided in two groups. There are 16 output values related to UHImax weigthed by population density and 16 output values related to a spatial average of UHImax. Of the 16 values four are per capita values/spatial averages in the highest urbanity class (bebkom=1), four in the second highest urbanity class (bebkom=2), four in the even lower urbanity class (bebkom=3), and four for the per capita value/spatial average over these three urbanity classes (bebkom=1,2&3). Below only the four values with the per capita value/spatial average in the highest urbanity class are given. But the same values are calculated for the other (values ending with '_bk2' or '_bk3') and the combined urbanity classes (values ending with '_bk123').

1. weighted_dC_UHI: per capita average UHI max (°C)
2. weighted_dC_UHI_noveg: per capita average UHI max (°C) without vegetation
3. weighted_dC_deltUHI: per capita average reduction in UHI max (°C) due to vegetation
4. weighted_perc_deltUHI: per capita average reduction in UHI max (%) due to vegetation
5. area_dC_UHI: spatial average UHI max (°C)
6. area_dC_UHI_noveg: spatial average UHI max (°C) without vegetation
7. area_dC_deltUHI: spatial average reduction in UHI max (°C) due to vegetation
8. area_perc_deltUHI: spatial average reduction in UHI max (%) due to vegetation

These output values are written in model_result.ini in the output directory

Optional output

(optional, --write_rasters)

1. _UHI.tif Geospatial raster showing UHImax with vegetation
2._UHI_noveg.tif Geospatial raster showing UHImax without vegetation
3._deltUHI.tif Geospatial raster showing reduction in UHI due to vegetation
4._deltUHI_bk.tif Geospatial raster showing reduction in UHI due to vegetation (bk=1)
5._deltUHI_bk2.tif Geospatial raster showing reduction in UHI due to vegetation (bk=2)
6._deltUHI_bk3.tif Geospatial raster showing reduction in UHI due to vegetation (bk=3)
7._deltUHI_bk123.tif Geospatial raster showing reduction in UHI due to vegetation in (bk=1, 2 and 3)

(optional, --service)

8....dienst.tif Geospatial raster showing the contribution of ecosystems to the reduced UHImax in the cities (bebkom=1)
9.zs_uhi_bk1_eu.csv CSV file with a table with per ecosystem type, the area in m^2, the mean and standard deviation of the service and the sum of the contribution to the reduction of the temperature in °C

12.3.4 Standard indicators

Supply

Supplies a cooling effect for the Urban Heat Island (UHI) during heat waves.

Demand

No increase in temperature for urban residents during a heat wave (degrees Celsius).

Combination of supply and demand
% avoided temperature rise of the UHI during a heat wave provided by vegetation (degree Celsius/capita).

See also Table 1.1.

12.4 Evaluation of model functioning

12.4.1 Sensitivity analysis

A sensitivity analysis has not been conducted yet. However, Dirksen et al. (2019), which can be found at https://doi.org/10.1016/j.uclim.2019.100498, have conducted a sensitivity analysis on how sensitive the model is for the sky-view-factor. It showed that using averages based on 1m SVF resolution maps gave the best results. The input maps in this model are at 10m, but are averages from the original 1m raster.

12.4.2 Uncertainty analysis

An uncertainty analysis has not been conducted yet.

12.4.3 Validation

The model is not validated yet.

12.4.4 General assessment of model quality

There has not been done a general assessment of model quality.

12.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

12.5.1 Reliability

A Very high, B. high, **C. sufficient**, D. moderate, E. low

12.5.2 Completeness

Completeness: **A. (almost) complete, B. contains most important aspects**, C. contains some aspects.

12.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- Testing

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- Calibration

- **Input and output**
- **Origin Input data**

ST.4Model functioning

- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

12.5.4 Future model development options

- More research needs to be done on the effects of greenery on the attenuation of UHI. What is the effect of different types of vegetation (including vertical greenery) and its quality (including during drought) on the attenuation of UHI? And what arrangement of vegetation is most effective (a little everywhere or larger units like parks)?
- There is also the question of the effect of parks and greenery on quality of life in the surroundings.
- The effects of water on UHI also need to be studied more thoroughly.
- The CICES classification identifies atmospheric composition and climate regulation as a third-level ecosystem service. This service involves control of temperature, humidity and wind to keep the urban climate favourable. In this service, only temperature was considered, so it does not include all aspects, although certainly the most important.

12.6 Literature

Dirksen, M., Ronda, R. J., Theeuwes, N. E., & Pagani, G. A. (2019). Sky view factor calculations and its application in urban heat island studies. *Urban Climate*, *30*, 100498.

KNMI (2020). Bewerking data door Datagraver. https://twitter.com/Datagraver/status/1166409194012119041/photo/1

Kovats, R.S. & Hajat, S., 2008. Heat stress and public health: a critical review. Annual Review of Public Health 29, 41-55.

Theeuwes, N.E., Steeneveld, G.J., Ronda, R.J., Holtslag, A.A.M., 2016. A diagnostic equation for the daily maximum urban heat island effect for cities in northwestern Europe. Int. J. Climatol. 37: 443 – 454.

13 Pest control

Paul van Rijn (UVA), Marjolein Lof (WU), Remon Koopman (RIVM), Bart de Knegt (WENR)

13.1 Theoretical rationale

13.1.1 General description of model

Natural pest control is a regulating service defined as the ecosystems' contributions to the prevention or reduction of effects of pests on crop production by providing shelter and alternative food sources to natural enemies of pest species. Currently the model includes the contribution of the ecosystems to the visitation of the crop fields by arthropod natural enemies, the link to crop production is not included yet. The pest control model is developed for the Netherlands, but the extent is based on the extent of the input land use map. Therefore, it can also be used for other regions outside the Netherlands or potentially other entire countries with some adjustment of the parameters. The current parameterization is valid for the Netherlands.

Natural enemies of insect pests require sufficient resources in the agricultural landscape. Ecosystems differ in the degree at which they can provide shelter and alternative food sources to natural enemies. This furthermore depends on the requirements of the natural enemies. The model assumes that arthropod natural enemies (primarily insects and spiders) are indeed present in habitats that are suitable (as actual observation data of the specific natural enemies is not available) and that they contribute to pest control in the crop fields. The model assumes that all crops in arable farming, fruit and vegetable cultivation and in open ground horticulture can profit from natural pest control. The model predicts the potential pest control level if there are no pesticides applied. The contribution of the ecosystem types depends on the distance to the cultivated crop.

13.1.2 Conceptual and formal model

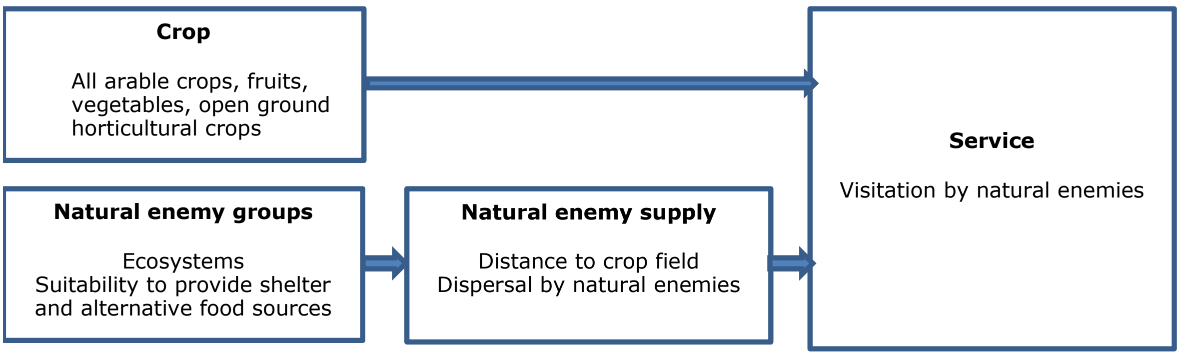

Figure 13.1 *The conceptual schedule of the natural pest control ecosystem services model. The model includes crops of which the production is potentially reduced due to damage by insect pests, and supply of natural enemies by ecosystems that vary in their suitability to provide shelter and alternative food sources for different groups of arthropod natural enemies.*

Potential pest control demand

It is assumed that all arable agriculture, fruit and vegetable cultivation and open ground horticulture potentially require pest control. For the spatial location of crops the basic registration of crop fields (BRP, "basis registratie gewaspercelen") (see: https://data.overheid.nl/dataset/10674-basisregistratie-gewaspercelen--brp-) can be used. Currently, in the harmonized land use map that is used for all ecosystem services these crops are selected (Annex 9). The BRP contains the location of each crop field and the type of crop that is cultivated. At present, it is assumed that all crop types have the same level of demand for pest control.

Natural enemies

Three groups of natural enemies are distinguished (Table 13.1) based on their dispersing ability and their dependence on landscape elements. The first group are ground-dwelling natural enemies (e.g. ground beetles and wolf spiders) that have a limited dispersal ability. The second group are flying natural enemies (e.g. lady beetles and flowerbugs) that have a larger dispersal ability than the crawling natural enemies. The last group are flying natural enemies (e.g. predatory hoverflies and parasitoid wasps) that require as adults nectar and/or pollen as the main food source. These flying natural enemies generally have large dispersal abilities, but the level of pest control depends on floral resources close to the crop fields. Ideally, the distribution of the groups of natural enemies is based on spatial maps representing their population density. However, these maps are currently not available. Similar to the pollination model, it is assumed that suitability of semi-natural habitats for the specific natural enemy groups and their proximity, can be used as a proxy for natural enemy distribution. For pollinators, it has been shown by Kennedy et al. (2013) that the proxy for pollinator distribution based on the suitability of the surrounding land cover for nesting and floral resources and assuming that nearby resources contribute more than distant resources, is a good predictor for pollinator density in crop fields. Also, for natural enemies the composition of the landscape is a predictor of their density and their effect on pest control (Goedhart et al., 2018). Especially the amount of woody and herbaceous semi-natural habitats are important characteristics of the landscape (Chaplin-Kramer et al., 2011, Rusch et al., 2016, Dainese et al., 2019) and well as the amount of suitable floral resources (Ramsden et al. 2015; Woodcock et al., 2016; Van Rijn et al., 2019)

The natural pest control model divides the ecosystem types in five habitat types (Table 13.2), based on the relationship of the three predator groups with these habitats: flower-rich herbaceous habitats (like flower field margins), flower-poor herbaceous habitats (like roadsides or ditch banks in agricultural landscapes), woody habitat with shrub layer, including hedgerows), trees without shrubs, and habitats that do not contribute to pest control. Herbaceous habitat is considered flower-rich when expected to have a cover of at least 25% forbs (non-grasses) that potentially produce flowers suitable for natural enemies (Van Rijn & Wäckers, 2016). The first four habitat types, that contribute to the pest control service, are input for the model. These maps are then linked with values for the suitability of these habitats for supporting each natural enemy group, ranging between 0 (unsuitable) and 100 (most suitable) (Table 13.3). These values were based on a literature review (e.g. Bartual et al., 2019) and expert judgement. Studies have shown that that the length of the borders of semi-natural habitats of often more important than their area covered (Martin et al., 2019), therefore only the outer 30 meter of larger semi-natural habitats is considered source habitat. Annual Cropland is considered a source habitat for ground-dwelling natural enemies only, as only ground and rove beetles can live year-round in and on arable land (Jowett et al., 2019).

Table 13.1 *Classification of natural enemies.*

Group	Mobility	Dependence on nectar	Examples
Crawling	Low	no	Carabid beetles, wolf spiders
Flying	Higher	no	ladybirds, predatory bugs, rove beetles, hammock spiders
Flying nectivorous	Highest	yes	parasitic wasp, hover fly, lacewing

Table 13.2 *Classification of ecosystems.*

	Category	**Examples**
Herbaceous		
	flower rich	Perennial flower rich flower field margins, flower rich nature areas
	flower poor	Dunes, heathlands, flower rich meadows, ditch banks, roadsides, dykes
Woody	with shrubs	deciduous forest, coppice, thicket, wooded banks, hedges
	without shrubs	Avenue trees, coniferous forest
not functional elements		Water, arable land, grassland, streets, urban area

Supply of natural enemies

Different species of natural enemies move at different length scales. As mentioned above the different natural enemies groups were distinguished based on dispersal ability, the ground-dwelling predators have a low dispersal range, whereas the flying natural enemies have a much longer dispersal range. the nectivorous flying natural enemies are expected to disperse from the sources habitats over even longer distances, but can only have an effect on pest control when they can survive and produce offspring, for which they need floral resources on a relatively short distance from the crop field (Van Rijn et al., 2013). Similar to pollinator dispersal we assume that distribution from the suitable source habitats can be described with a negative exponential.

We assume that natural enemies from all suitable habitats in the local landscape contribute to natural pest control. To obtain the relative visitation rate *v* (scaled 0-100) in a crop in map unit *c* and natural enemy group *p* we calculate,

$$v_{cp} = \sum_{h=1}^{H} S_{hp} \frac{e^{-\frac{1}{\alpha_p} d_{hc}}}{\sum e^{-\frac{1}{\alpha_p} d}}$$

where V_{cp} is the relative visitation rate in a crop per natural enemy group, S_{hp} represents the relative predator abundance (scaled 0 – 100, where 100 marks maximum suitability) in map unit *h* (based on the suitability of the habitat in map unit *h* for natural enemy group *p*), d_{hc} is the distance between map unit *h* and the crop in map unit *c*. This is implemented by taking the convolution of the distribution of the natural enemy group *p* (based on habitat suitability) and the negative exponential, with decay rate $1/\alpha_p$. Where α_p (in meters) differs for the three natural enemy groups *p* (Table 13.3).

The flying natural enemies that depend on nectar require floral resources close to the crop fields. This is modelled with an additional spatial model, that assumes that the effectivity of pest control is highest at the floral resources and decreases with distance from the floral resources following a 2D Gaussian distribution with an alpha of 100m (Table 13.3), with a range between 0 and 1, and multiplying this effectivity with the visitation rate (or density) of the flying nectivore natural enemy.
The model assumes that flying nectivores contribute more to pest control than the ground-dwelling and other flying natural enemies. The relative contribution of the three groups to pest control in the field is calculated based on the weights as presented in Table 13.3.

Table 13.3 *Influence of landscape elements on groups of natural enemies.*

Function landscape element:		Source area			Nectar and pollen
Group natural enemy:		A. Crawling	B. Flying	C. Flying nectivorous	C. Flying nectivorous
Distance function (kernel)		Neg. exp.	Neg. exp.	Neg. exp.	Gaussian
Distance parameter, alpha (m)		50	400 *	600	100
Habitat value per gridcel (% of maximum)	Crop parcel itself (distance dependent)	30	0	0	0.01
	perrenial, flower rich	100	70	70	1.0
	perrenial, flower poor	100	40	40	0.4
	forest edge, hedges	100	100	100	0.6
	Solitary tree/line	0	40	40	0
		som B	som B	Som B x Som V	
Proportion of total		25%	25%	50%	

*) Alpha=400 m -> 10% of the maximum value to 1200 meter van lineaire bron

13.2 Technical implementation

13.2.1 Implementation model

The natural pest control model is written in python and together with a yml file containing the environment needed to run the model stored in a repository online (https://git.wur.nl/lof001/plaagbestrijding). The model calculates the relative visitation (%) of natural enemies of aphids in the crop fields.

The input rasters/arrays in Figure 13.2 are the crop fields, and forest edge, flowery edge, flower-poor edge and tree-line edge. These last four can either be a direct input from the model when the optional parameter –area2border is set to *False*, or in the default setting they are the result of a pre-processing calculation as depicted in Figure 13.3. The forest edge, flowery edge, flower-poor edge and tree-line edge arrays are processed in Function 1 to serve as input for the allocation of the source habitats and nectar resources. In this function the value of the array (range 0-16) is compared to a threshold (“thres_source”, see §13.3.1) and all values equal or higher are considered source habitat and get value 1 all others get value 0. The value of the array (0-16) stems from the number of 2.5 meter grid cells within the 10 meter grid cell.

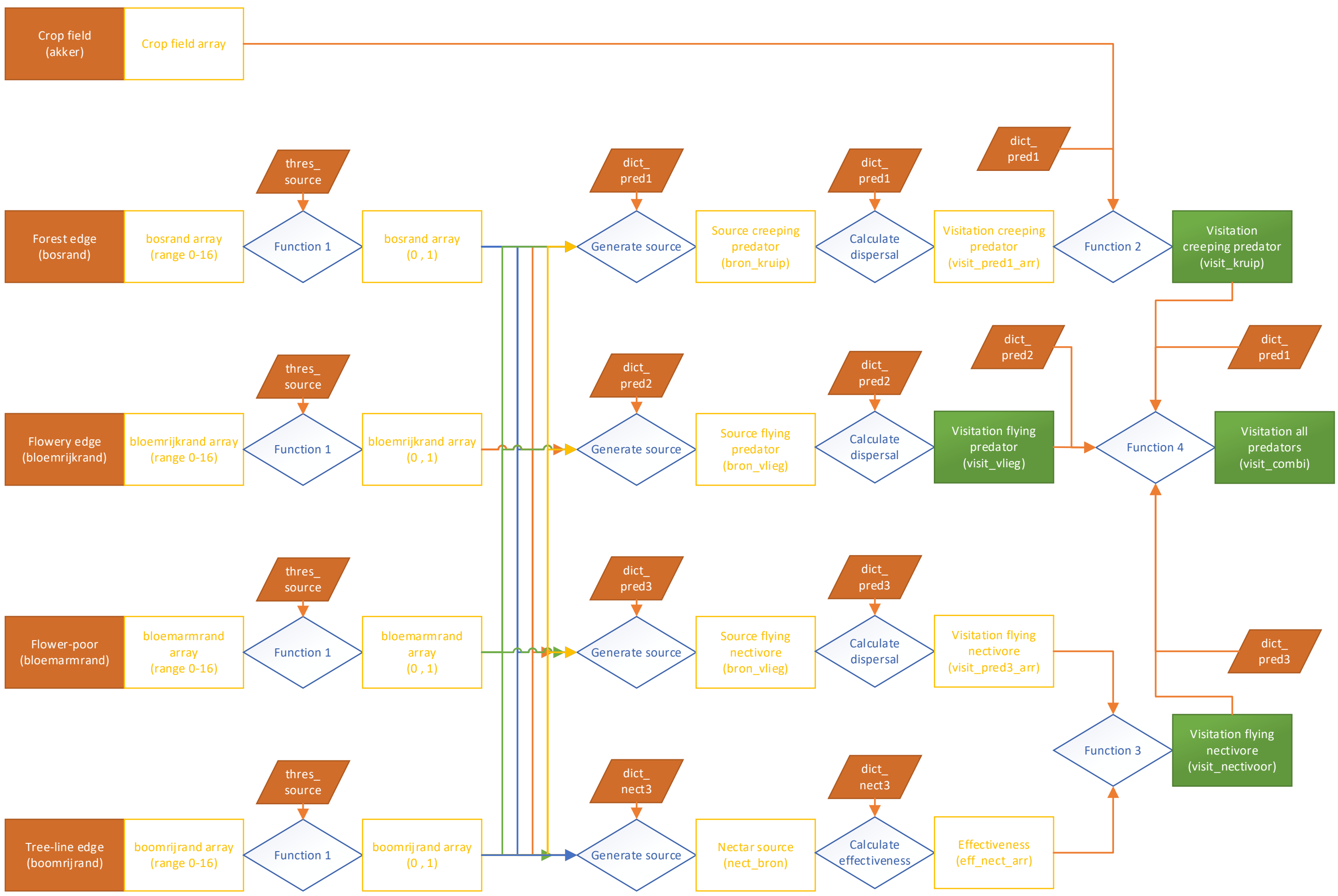

Figure 13.2 *Flow diagram of the natural pest control model.*

The filled orange boxes are input raster files (Figure 13.4). The filled orange parallelograms are input variables, these are stored in one excel file (https://git.wur.nl/lof001/plaagbestrijding/-/blob/master/tests/dat/pc_lut.xlsx). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/rasters from the model. From each green box the mean value in a crop field is calculated and written to an output file: model_result.ini, which also stores the paths of all input files. "Generate source" is a function that combines the "bosrand" (forest edge), "bloemrijkrand" (flowerrich edge), "bloemarmrand" (flower poor edge) and "boomrijrand" (row of trees) arrays with the predator specific habitat suitability as source habitat (stored in "dict_pred"). "Calculate dispersal" is a function that performs a convolution of the predator source array and the dispersal kernel of the predator. This dispersal kernel is a 2D negative exponential kernel with a predator specific decay rate α in meter (stored in "dict_pred"). "Calculate effectiveness" is a function that performs a convolution of the nectar source array and gaussian distribution kernel, based on parameters stored in "dict_nect3" (see §13.3.1). In function 1 the value of the array (range 0-16) is compared to a threshold ("thres_source", see §12.3.1) and all values equal or higher are considered source habitat and get value 1 all others get value 0. In function 2 in-field presence of crawling predators is added to the relative visitation by crawling predators from other sources. "visit_kruip" = min(100, "visit_pred1_arr" + "w_akker"). In function 3 the relative visitation of flying nectivores is multiplied with their effectiveness (based on availability of nectar sources). "visit_nectivoor" = min(100, "visit_pred3_arr" * "eff_nect_arr"). In function 4 the combined relative visitation is calculated by adding a the relative visitation of the three predator groups and correcting them for their relative weight in the final pest control. "visit_combi" = "frac_pred1"*"visit_kruip" + "frac_pred2"*"visit_vlieg" + "frac_pred3"*"visit_nectivoor", with "frac_pred1"+"frac_pred2"+"frac_pred3" = 1.

Next, in function "generate source", the four habitats are combined to a dictionary of the specific predator ("dict_pred", see §13.3.1) containing values for suitability as source habitat (ranging from 0-100). This results in a spatial array with the predator source suitability. Source suitability is used as a proxy for predator supply by the ecosystem, a value of 100 indicates the highest predator density. The flying nectivore also requires nectar, the function "generate source" is also used to combine the four habitats with a

dictionary for the nectar resource (“dict_nect”) containing values for suitability as nectar source (ranging 0-1). This results in a spatial array with the suitability as nectar source for flying nectivores. Nectar source suitability is used as a proxy to calculate effectiveness of the flying nectivores, a value of 1 indicates that all flying nectivores can effectively control pests.
It is assumed that the effectiveness of flying predators that require nectar depends on the proximity to nectar sources. At the nectar source pest control is optimal and it decreases with distance from the source following a Gaussian distribution. In the function “calculate effectiveness”, the effectiveness of the flying nectivores is calculated by taking the convolution between the nectar source array and a Gaussian distribution kernel, with standard deviation “alpha_m” in meter. This results in the effectiveness array (“eff_nect_arr”).

For the predators, in the function “calculate dispersal”, the distribution of predator visitation is calculated by taking a convolution between the predator supply (e.g. predator source array) and a kernel describing the redistribution of the predators based on expert judgement. Similar to pollinator dispersal, the redistribution kernel is taken as a negative exponential with decay rate ɑ, stored in “dict_pred”. To calculate the redistribution kernel the function calculate dispersal furthermore needs the pixel sIze of the raster (in m) stored in “dict_pred”. For efficient calculation151able151onon “calculate dispersal” divides the area (i.e. the Netherlands or a province) in smaller areas when it is bigger than a pre-set number of cells. To also include the visitation by predators from outside the smaller area, a parameter for the width of the buffer (in m) around the smaller area that needs to be included is input for the function “calculate dispersal”, stored in “dict_pred”. This calculation results in an visitation array.

For the flying predator (“visit_vlieg”) no further steps are needed.
It is assumed that crawling predators are always present in the crop fields. In function 2, the standard presence is added to the visitation array, taking into account that the maximum visitation is 100. “visit_kruip” = min(100, “visit_pred1_arr” + “w_akker”). This results in the relative visitation rate of crawling predators (“visit_kruip”). The constant value for presence in the fields, “w_akker”, is stored in “dict_pred1”. The presence of crawling predators in the crop fields might depend on management and pesticide use. This is currently not included in the model.

To calculate the effective pest control of the flying nectivores, in function 3 the relative visitation of the flying nectivores (“visit_pred3_arr”) is multiplied with effectiveness to control the pests in the crop fields based on the nectar resources close to the fields (“eff_nect_arr”), taking into account that the maximum visitation is 100. “visit_nectivoor” = min(100, “visit_pred3_arr” * ”eff_nect_arr”). This results in the relative visitation by flying nectivores (“visit_nectivoor”).

Finally, in function 4 the combined relative visitation is calculated by adding a the relative visitation of the three predator groups and correcting them for their relative weight in the final pest control, this relative weights “frac” are stored in the dictionaries of the predators and add up to 1. “visit_combi” = “frac_pred1”*”visit_kruip” + “frac_pred2”*”visit_vlieg” + “frac_pred3”*”visit_nectivoor”, with “frac_pred1”+”frac_pred2”+”frac_pred3” = 1.

For the output the mean values of each of the output rasters (“visit_combi”, “visit_kruip”, “visit_vlieg”, “visit_nectivoor”) in the crop fields (i.e. cells where the value of the crop_field_array is equal or higher than the parameter ”select_cropfields”, see §13.3.1) is calculated.

By default it is assumed that the source rasters contain source areas. In the pre-processing module the edges of these source areas are calculated (Figure 13.3). If these are already calculated, these can be used as input directly and by setting the optional variable “area2border” to *False* this pre-processing module is skipped.

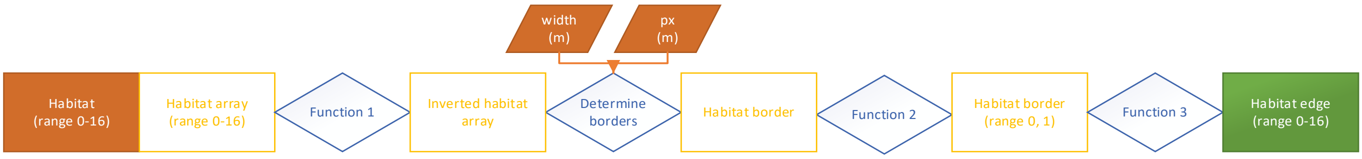

Figure 13.3 *Flow diagram pre-processing module of natural pest control model that selects the edges of source habitats.*

The filled orange box is an input raster file (figure 13.3). The orange/white boxes are intermediate arrays. The filled orange parallelograms are input variables, these are stored in one excel file (https://git.wur.nl/lof001/plaagbestrijding/-/blob/master/tests/dat/pc_lut.xlsx). The green filled box is the output array/raster of the module. Function 1 transforms the habitat array in an inverted habitat array. The original array has a range of 0-16, where the value represents the number of 2.5x2.5m cells in the 10x10m cell of that specific habitat type. In function 1 values higher than 2 are set to 0, and the other values (0,1,2) are set to 1. Resulting in an inverted habitat where non-habitat cells have value 1 and habitat cells have value 0. In function "Determine borders" a moving window process where all cells within "width_m" from a non-habitat cell get value 1 and all others 0 is approximated with a convolution between the inverted habitat and a simple kernel; kernel = numpy.where(dist <= width_m, 1, 0), where dist is the distance from the centre of the kernel. In function 2 the resulting array "habitat border" is multiplied with the original habitat array (range 0-16), as a result non-habitat cells are set to 0 (because these are 0 in the original habitat array), and edge cells will have a value >=1 and habitat cells further than "width_m" away from the edge will have a value 0 (because these are 0 in "habitat border"). The values of 1 and bigger are then set to 1. Resulting in the habitat border array with 0 for non-edge cells and 1 for edge cells. In function 3 the habitat border (0,1) array is multiplied with the original habitat array, and the habitat cells with values (0,1,2) are included again. To also include small scale linear elements.

13.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9). An environment.yml file is available in git (https://git.wur.nl/lof001/plaagbestrijding/-/blob/master/environment.yml) that can be used to reproduce the exact environment used in the simulations. The model has be run on a computer with an Intel Xeon W-2133 3.6 GHz processor and 16.0 GB RAM. Due to memory limitations the variables are stored as float32.

13.2.3 Testing

There is a test data set that can be used to verify whether the model works as expected. This is a dataset from a small part of the Netherlands so that the test can be done in only a few minutes. This area, the municipality of Hoeksche Waard, was chosen because it is a study area where the influence of field margins on pest control is studied. More comprehensive testing, like testing for extreme input values or verification with field measurements has not been done.

13.3 Input and output, Parameters and variables

13.3.1 Parameters and variables

The parameters are stored in a excel file which can be found at:
https://git.wur.nl/lof001/plaagbestrijding/-/blob/master/tests/dat/pc_lut.xlsx
Parameters:
This excel file contains two sheets. The first sheet "constant" contains the model constants:
- Pixel size of the input rasters ('px') in meters
- Width of the borders that are taken into account as source or food habitat ('width_m') in meters*

- The parameters 'xmin', 'xmax', 'ymin' and 'ymax' can be used to set the extent of the area of interest, these are given in meters and based on an rDnew projection.
- A threshold for selection of crop fields ('select_cropfield') in the raster 'akkers'. This is used to select the area where crawling predators are present in the crop fields and for calculations of average values within the crop fields for the output.
- A minimum threshold of number of 2.5x2.5m cells in the 10x10m cell that a habitat should contain to be included as source habitat.

* Natural enemies primarily overwinter in forest edges (up to 30m) therefore only the outer 30m of forest are taken into account in the calculations. The current version, also only takes the outer 30m of the other habitat types into account.

The default values are set at:

key	value
px	10
width_m	30
xmin	10000
xmax	280000
ymin	300000
ymax	620000
select_cropfield	1
thres_source	3

The second sheet "params_pred" contains the parameters related to suitability of the habitats for the three predator types and parameters related to their dispersal (see also Table 3). The parameters in the sheet are given per predator type (pred1=crawling predators, pred2= flying predators, and pred3=flying predators that depend on nectar). The last column (nect3) contains the parameters that are needed to calculate what range the flying predators that need nectar have enough energy to control the pest.
The parameter 'alpha_m' is the decay rate of the negative exponential function used to calculate predator visitation given in meter. For the range where flying nectivores are effective, 'alpha_m' is the standard deviation of the gaussian function given in meters.

- The width of the buffer for calculation of predator visitation in meters ('buffer_m'). This is linked to the decay rate, for strong decay a smaller buffer can be used.
- The parameters that start with a 'w_' represent the relative weight of the habitats as source habitat (columns pred1, pred2 and pred3) in range 0-100, and the relative suitability as nectar source (column nect3) in range 0-1.
  - 'w_akker' gives the presence of crawling predators in the crop fields – input raster akkers.
  - 'w_bloemrijk1j' gives the suitability of annual flower rich habitats, these are currently not taken into account in the model
  - 'w_bloemrijk' gives the suitability of flowery habitats – input raster 'bloemrijk'
  - 'w_bloemarm' gives the suitability of flower-poor habitats – input raster 'bloemarm'
  - 'w_bosrand' gives the suitability of forest edges – calculated from input raster 'bos'
  - 'w_boomrij' gives the suitability of tree lines and forest edges without shrubs as undergrowth – calculated from input raster 'boomrij'
- The parameter 'frac' is used as weight for the relative importance of the predator group (pred1, pred2 and pred3) in the delivered pest control. The values of these three groups should add up to 1. The value under nect 3 is a dummy value this is not used.
- The parameter 'fact_nu' is currently not used. It is linked to a model where predators have a preference for certain habitats over other habitats.

The default values are set at:

key	pred1	pred2	pred3	nect3
alpha_m	50	400	600	100
buffer_m	1000	4000	6000	1000
w_akker (crop fields)	30	0	0	0
w_bloemrijk1j (flower rich habitats)	0	0	0	1
w_bloemrijk (flowery habitats)	100	70	70	1
w_bloemarm (flower-poor habitats)	100	40	40	0.4
w_bosrand (forest edges)	100	100	100	0.6
w_boomrij (tree lines)	0	40	40	0
frac	0.25	0.25	0.5	1
fact_nu	1	1	1.1	1

In the script the column with the names (key) are linked to the values (pred1, pred2, pred3 or nect3) and stored in dictionaries ("dict_pred1", "dict_pred2","dict_pred3" and "dict_nect3" in Figure 13.2).
The excel file with the parameters is an input variable of the simulation. It is therefore possible to use a copy of the excel file with alternative parameter values as an input file.

Input variables
The model consists of eight mandatory and eight optional variables
Mandatory variables:
1. land_use: Geospatial raster showing land use following LCEU categories
2. bos*: Geospatial raster met bos(randen) (forest edges)
3. boomrij*: Geospatial raster met bomenrijen (tree lines)
4. bloemrijk*: Geospatial raster met bloemrijk(e randen) (flowery habitats)
5. bloemarm*: Geospatial raster met bloemarm(e randen) (flower-poor habitats)
6. akkers*: Geospatial raster met akkers (crop fields)
7. params: Excel sheet with lookup tables and model parameters and constants
8. scenario: Name of the scenario calculated, is used in the names of the output files

The Geospatial rasters marked with '*' are aggregated rasters where the value represents the number of cells at 2.5mx2.5m in the 10m cell that contain the specific habitat, ranging from 0 cells to 16 cells. The 10x10m cell is included as a source or food habitat when the number of 2.5mx2.5m cells is equal or higher than the threshold number set by the parameter "thres_source". This way also small linear features are taken into account.
Optional variables:––out_dir: output directory ––area2borders: reduce source area to only the borders/edges, default=true––set_extent: use values from params to set extent, otherwise use extent of land_use map––write_rasters: write geospatial ouput rasters to output directory––reporting: write an text file with key outcomes ––test_input: verify model initialization, do nothing else––test: verify model with test set, do nothing else––env_proj_path Path of proj folder in python environment

13.3.2 Calibration

The model has not been calibrated yet.

13.3.3 Input and output

Output
Output values:
1. perc_visit_combi: mean visitation by all predators in crop fields
2. perc_visit_kruip: mean visitation by crawling predators in crop fields
3. perc_visit_nectivoor: mean visitation by flying predators that need nectar in crop fields
4. perc_visit_vlieg: mean visitation by flying predators in crop fields

These output values are written in model_result.ini in the output directory

Optional output
1. pred_all.tif Geospatial raster showing predator visitation in crop fields (optional, --write_rasters)
2. pred_kruip.tif Geospatial raster showing predator visitation in crop fields (optional, --write_rasters)

3. pred_nectivoor.tif Geospatial raster showing predator visitation in crop fields (optional, --write_rasters)
4. pred_vlieg.tif Geospatial raster showing predator visitation in crop fields (optional, --write_rasters)
5. bosrand16.tif Geospatial raster containing forest edges, range 0-16, based on 'bos' raster (optional, --area2borders)
6. bloemrijkrand16.tif Geospatial raster containing edges of flower rich areas, range 0-16, based on 'bloemrijk' raster (optional, --area2borders)
7. bloemarmrand16.tif Geospatial raster containing edges of flower poor areas, range 0-16, based on 'bloemarm' raster (optional, --area2borders)
8. boomrijrand16.tif Geospatial raster containing tree line edges, range 0-16, based on 'boomrij' raster (optional, --area2borders)

13.3.4 Standard indicators

Offering
Supplies natural enemies of pests in agricultural crops.

Question
Demand for pest suppression of pest-susceptible agricultural crops to prevent loss of yield.

Combination of supply and demand
Average density of natural enemies in agricultural crops that are susceptible to pests (0-100).

See also Table 1.1.

13.4 Evaluation of model functioning

13.4.1 Sensitivity analysis

A sensitivity analysis has not been conducted yet.

13.4.2 Uncertainty analysis

An uncertainty analysis has not been conducted yet.

13.4.3 Validation

The model is not validated yet.

13.4.4 General assessment of model quality

Currently, no general assessment of model quality has been done.

13.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects
Legenda: **complete**, partly (in)complete, incomplete.

13.5.1 Reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low

13.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

13.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- **Testing**

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- Calibration
- **Input and output**
- **Origin Input data**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

13.5.4 Future model development options

- One of the most important wishes for the future is to translate the model results (pest density) to what this means for agricultural crop yields. The question here is at what pest density the use of plant protection products can be omitted for the various crops.
- Furthermore, the pest density indicator is now expressed as a percentage. We would also like to express that indicator as the density of pest suppressors.
- As with pollination, the effect of pest suppression depends on the specific crop. We could therefore take the crop into account in the future. In that case, the spatial effects of interactions between crop parcels can also be taken into account.
- There is also the question of the importance of different habitats as source areas for pest suppressors. Little specific knowledge is currently available about this, and further research is desirable.
- The same is true for habitats as a source of floral food. For example, in the Hoeksche Waard, relatively more is known about the flower richness of individual field margins and their suitability for natural enemies. This information enhances the explained variance of the model. However, information on flower richness/composition of field margins and other habitats is not currently available for the whole of the Netherlands. In the future, we would like to estimate this aspect of habitats more accurately.
- Further research is being used to validate model results with field measurements of aspects such as aphid growth rates and caterpillar parasitisation.
- Also, this year we are committed to doing a validation, sensitivity analysis and an uncertainty analysis to determine which factors have the greatest explanatory effect and determine the magnitude of the uncertainties around the model outputs.
- While it was being set up and parameterised, the model focused heavily on suppressing aphids. However, there are many other types of pests that cause damage to agricultural crops, as well as crop diseases such as viruses, fungi and bacteria. In time, we would like to include more types of pests and diseases in the model.
- The model now assumes pest suppression in the absence of pesticides. In the future, we would also like to include the effects of using or not using pesticides on pests and pest suppressors.
- In the CICES system, natural pest control is defined very broadly (Haines-Young & Potschin, 2013) and comprises pest and disease regulation in natural systems, agro-ecosystems (agriculture and livestock) and

human populations. This includes the suppression of invasive species. The elaboration of this ecosystem service in this chapter focused on natural pest regulation in agricultural areas, especially above ground. In doing so, the criteria include the most important aspects, but are not comprehensive.

13.6 Literature

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14 Water retention

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14.1 Theoretical rationale

14.1.1 General description of model

The capacity of soils to capture rain water depends on the soil type and the presence of vegetation. Rainwater infiltration is a regulating service defined as the percentage of the population that lives in areas with a higher rainwater infiltration capacity than the norm for one hour. This service provided both by the soil and the vegetation.The model is developed for the Netherlands, but the extent is flexible as it depends on the input land use map. Therefore, it can also be used for regions or other countries. It is assumed that the infiltration capacity per soil- and vegetation type provided in the tables below represents reality in the Netherlands reasonably well. Local soil compaction and the possible influence of tilling and ploughing was not taken into account here though. In addition the occurrence of e.g. clayey and loamy deposits at greater depths below the surface were not taken into account, possibly leading to local errors where these deposits do occur.

14.1.2 Conceptual and formal model

Infiltration capacity depends on soil type, soil moisture and the presence of vegetation. A look up table approach is used to combine the soil map with total infiltration in 1 hour in moist and dry soils and for dense and no vegetation (table 14.1). In unpaved areas, rain water can infiltrate both in vegetated and in open areas, while in paved areas, rain water can only infiltrate in vegetated areas. In dry soils, vegetation enhances infiltration capacity. Furthermore, vegetation has a certain capacity to intercept rainwater on their surface (table 14.2). The supply of the service is calculated as the sum of the total infiltration of rainwater in the soil in one hour and the interception of rainwater by the vegetation.
For the calculation of infiltration capacity of rain water, we combined a soil map that contains soil types in urban areas with three vegetation cover maps of trees, shrubs and grass and a land use map to distinguish between paved and unpaved areas. Cells were classified as paved or unpaved based on the ecosystem type (table 14.3).
Infiltration capacity is calculated using,

$$\text{Infiltration}_{\text{unsaturated,unpaved}}(x,y,t) = p_{\text{vegetated}}(x,y) * \text{infiltration}_{\text{vegetated}}(\textit{soil type }(x,y),t) + p_{\text{open}}(x,y) * \text{infiltration}_{\text{open}}(\textit{soil type }(x,y),t)$$

for unsaturated soils in unpaved areas,

$$\text{Infiltration}_{\text{unsaturated,paved}}(x,y,t) = p_{\text{vegetated}}(x,y) * \text{infiltration}_{\text{vegetated}}(\textit{soil type }(x,y),t)$$

for unsaturated soils in paved areas, respectively

$$\text{Infiltration}_{\text{saturated,unpaved}}(x,y,t) = \text{infiltration}_{\text{open}}(\textit{soil type }(x,y),t)$$

for saturated soils in unpaved areas, and

$$\text{Infiltration}_{\text{saturated,paved}}(x,y,t) = p_{\text{vegetated}}(x,y) * \text{infiltration}_{\text{saturated}}(\textit{soil type }(x,y),t)$$

for saturated soils in paved areas.

In these equations, $p_{vegetated}$ is the total fraction of the cell that is occupied by forest, shrubs and grass and p_{open} is the remaining fraction, i.e. soil without vegetation. Cells are classified as paved or unpaved based on the ecosystem type (table 14.3).
Infiltration capacity in unsaturated soil is calculated based on the Horton model that calculates current infiltration rate based on an initial infiltration capacity, f_0, and a final infiltration capacity, f_c, and the time since the start of the infiltration, t, and a constant k that models how fast the infiltration capacity declines. The Horton model (Horton, 1933):

$$f(t) = f_c + (f_0 - f_c)\, e^{-kt}$$

The Horton model can be integrated to calculate the total infiltration in time *t,*

$$F(t) = f_c\, t + ((f_0 - f_c)*(1 - e^{-kt})\,/k)$$

In this model the total infiltration is based on the infiltration capacity in 60 minutes (table 14.1).
To calculate interception by the vegetation, the three vegetation maps; tree map, shrub map and grass map are combined with a look-up table with interception of rainwater by trees, shrubs and low grass and forest litter (table 14.2). We assume that interception of litter only takes place at forest floor. So interception by litter is linked to forest ecosystem types only. Based on the assumption that interception of the vegetation is linked to tree, shrub and low vegetation cover. In the original low vegetation map, low vegetation on agricultural fields were not included. Based on the land use map, the low vegetation map is adjusted to account for crop and grass cover in the fields.

Table 14.1 *Initial infiltration capacity, final infiltration capacity and total infiltration in 60 minutes for saturated soils and unsaturated (dry) soils, depending on soil type and presence vegetation (Akan et al., 1993).*

	Infiltration (mm/h (per m^2))			Infiltration (mm in 1h (per m^2)	
	Initial infiltration capacity, f_0		Final infiltration capacity, f_c	Total infiltration in 60 minutes, $F(60)$	
	Dry soil		Saturated soil	Dry soil	
Soil type	**Vegetated[1]**	**Open[1]**		**Vegetated**	**Open**
Heavy clay soil	50	25	0.5	12.3	6.3
Clay soil	50	25	1.5	13.0	7.1
Organic soils	50	25	2.2	13.6	7.6
Loam soil	150	75	2.1	37.3	19.4
Sandy loam soil	150	75	6.0	40.2	22.4
Loamy sand soil	150	75	11.0	44.0	26.2
Sandy soils	250	125	20.0	74.7	45.0

[1] Based on a relationship between values of initial infiltration for moist and dry soils and sparse and dense vegetation proposed by Akan et al. (1993) (i.e. infiltration in soil with dense vegetation is 2 * infiltration in soil with sparse to no vegetation).

Table 14.2 *Interception of precipitation of trees, shrubs and grass (Nedkov and Burkhard, 2012).*

	Interception (mm)	
Vegetation type	**Vegetation**	**Litter**
Trees	3.0	5.8
Shrubs	1.0	
Grass	1.3	

Table 14.3 *Division in paved (impermeable for rain water) and unpaved (permeable for rain water) soil based on ecosystem type.*

	Ecosystem types
unpaved	All agricultural ecosystems (except green houses and built-up farm yards), all dune ecosystems, all forest and other natural ecosystems and other unpaved terrain, river flood plains and tidal salt marshes
paved	All built up areas, green houses and built-up farm yards.

14.2 Technical implementation

14.2.1 Implementation model

The rainwater infiltration model is written in python and together with a yml file containing the environment needed to run the model stored in a repository online (https://git.wur.nl/roelo008/2l_infiltratie). The model calculates the total infiltration in one hour depending on soil type and the interception of rainwater by vegetation cover.
At the top, the grass, shrub and tree cover arrays are combined into one vegetation cover array, taking into account that agricultural fields (that were identified by a lookup table approach in LU1 based on the land use map) also contains low vegetation. Furthermore, in "Calculate interception" the interception of rainwater by the vegetation is calculated based on total vegetation cover, tree, shrub and grass cover and forest types (based on the land use map). In the bottom, the total infiltration in unsaturated soils with vegetation (using LU3 and the Bofek array), in unsaturated soils without vegetation (using LU4 and the Bofek array) and in saturated soils (using LU5 and the Bofek array) is calculated.
The land use map is classified into paved/unpaved/water ('puw') in lookup table LU2. This is used in the function "Calculate infiltration" to calculate the total infiltration by the soil, taking into account the classification into paved/unpaved and the infiltration for vegetated or bare unpaved soil. `infiltratie = (puw==1 | puw==2)* (vegcov)* infveg + (puw==2)*(100-(vegcov))*infnoveg` For saturated soils vegetated and open have the same infiltration capacity, i.e. inveg=infsat and infnoveg=infsat. Functie 2 adds the total infiltration in an unsaturated soil to the interception by the vegetation to calculate the total rain captured by the ecosystem and stores this as a raster infil SCEN unsat. Functie 3 adds the total infiltration in a saturated soil to the interception by the vegetation to calculate the total rain captured by the ecosystem and stores this as a raster infil SCEN sat.

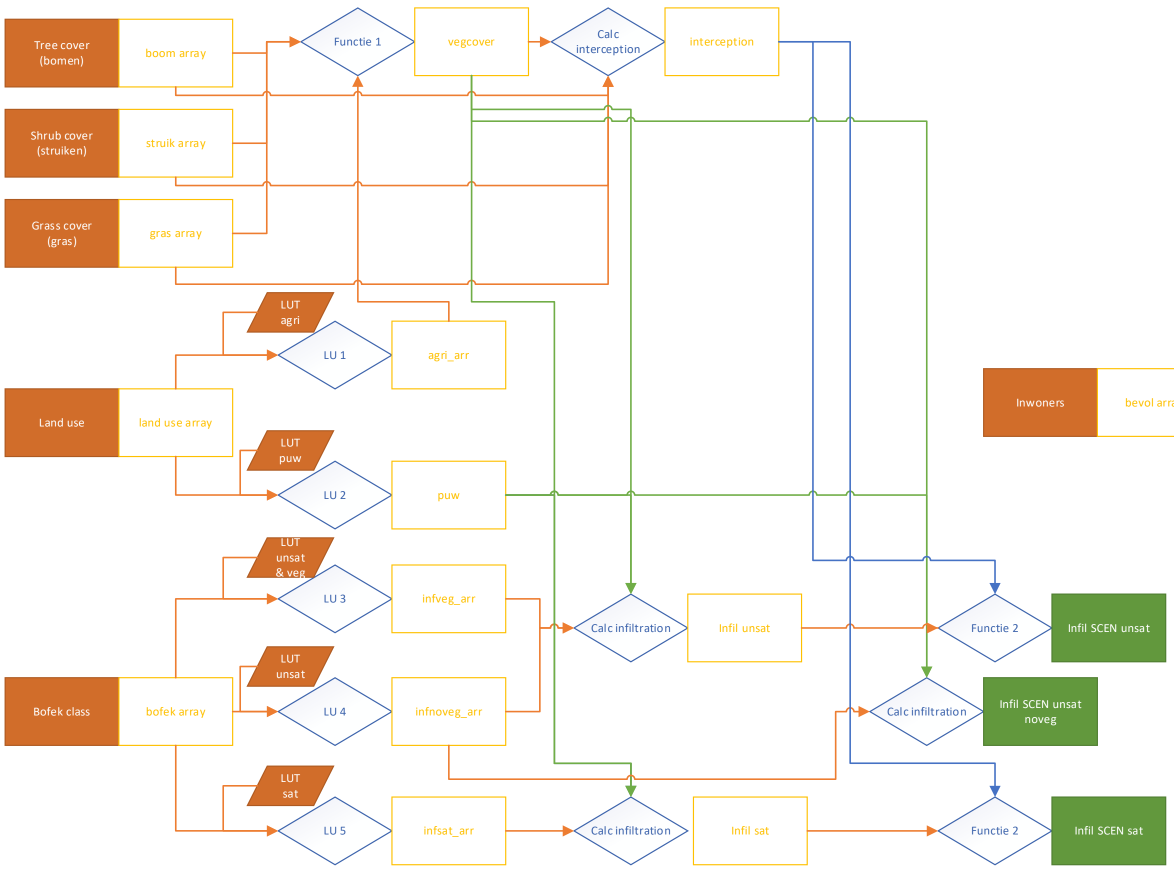

Figure 14.1 *Flow diagram of the rainwater infiltration model.*

The filled orange boxes are input raster files (figure 14.1). The filled orange parallelograms are input variables or lookup tables, these are stored in one excel file (https://git.wur.nl/roelo008/2l_infiltratie/-/blob/master/tests/dat/infil_params.xlsx). The orange/white boxes are intermediate arrays. The green filled boxes are output arrays/rasters from the model. From the output rasters output values are calculated (not shown), these are written to an output file: model_result.ini, which also stores the paths of all input files. "Functie 1" is a function that combines the grass, shrub and tree cover arrays into one vegetation cover array, taking into account that agricultural fields also contains low vegetation. LU1 combines the land use array with the lookup table with agricultural classes. LU2 combines the land use array with the lookup table which classifies the land uses into paved/unpaved/water ('puw'). LU3 combines the Bofek array with a lookup table that combines the Bofek classes with total infiltration in unsaturated soils with vegetation. LU4 combines the Bofek array with a lookup table that combines the Bofek classes with total infiltration in unsaturated soils without vegetation. LU5 combines the Bofek array with a lookup table that combines the Bofek classes with total infiltration in saturated soils with or without vegetation. "Calculate interception" (top) is a function that calculates the interception of rainwater by the vegetation, based on total vegetation cover, tree, shrub and grass cover. "Calculate infiltration" (bottom, 3x) is a function that calculates the total infiltration by the soil, taking into account the classification into paved/unpaved and the infiltration for vegetated or bare unpaved soil. `infiltratie = (puw==1 | puw==2)* (vegcov)* infveg + (puw==2)*(100-(vegcov))*infnoveg` For saturated soils vegetated and open have the same infiltration capacity, i.e. inveg=infsat and infnoveg=infsat. "Functie 2" adds the total infiltration in an unsaturated soil to the interception by the vegetation to calculate the total rain captured by the ecosystem and stores this as a raster infil SCEN unsat. "Functie 3" adds the total infiltration in a saturated soil to the interception by the vegetation to calculate the total rain captured by the ecosystem and stores this as a raster infil SCEN sat.

14.2.2 Technical environment

The model has been programmed in Python (Python 3.7.9). An environment.yml file is available in git (https://git.wur.nl/roelo008/2l_infiltratie/-/blob/master/environment.yml) that can be used to reproduce the exact environment used in the simulations. The model has be run on a computer with an Intel Xeon W-2133 3.6 GHz processor and 16.0 GB RAM. The variables are stored as float32.

14.2.3 Testing

There is a test data set that can be used to verify whether the model works as expected. This is a dataset from a small part of the Netherlands so that the test can be done in only a few minutes. More comprehensive testing, like testing for extreme input values or verification with field measurements has not been done. The results for the current situation and of a future scenario (Breman et al., 2022) have been judged on their plausibility.

14.3 Input and output, parameters and variables

14.3.1 Parameters and variables

The parameters are stored in a excel file which can be found at:
https://git.wur.nl/roelo008/2l_infiltratie/-/blob/master/tests/dat/infil_params.xlsx

Parameters:
- Look-up table with classification of the land use types (using lceu classification) into paved (1), unpaved (2), water (3) and unknown (0), see 'on_verhard' sheet.
- Look-up table with classification of the land use types (using lceu classification) into agricultural (1) and other (0), see 'agri' sheet.
- Look-up table with total infiltration in 1/10 mm in unsaturated soil with vegetation per bofek soil type, see 'infiltratie_veg' sheet.
- Look-up table with total infiltration in 1/10 mm in unsaturated soil without vegetation per bofek soil type, see 'infiltratie_no_veg' sheet.
- Look-up table with total infiltration in 1/10 mm in saturated soil with or without vegetation per bofek soil type, see 'infiltratie_saturated' sheet.
- Look-up table with interception of rainfall by vegetation in 1/10 mm for low vegetation, shrubs, trees and forest litter layer, see 'infiltratie_veg' sheet.
- Pixel size of the input rasters ('px') in meter, constant, see 'other_params' sheet in the parameter excel file.
- Total land area ('nl_onshore') in km^2, constant, see 'other_params' sheet in the parameter excel file. This is used to calculate the percentage of area with total infiltration ≥the norm infiltration (see next parameter).
- The set norm for total rainfall in one hour ('norm') in mm, see 'other_params' sheet in the parameter excel file.
- The infiltration and interception are given in 1/10 of a mm, "multiply_mm" corrects the results for this factor 10 difference, constant, see 'other_params' sheet in the parameter excel file.
- The vegetation cover is given in percentages and not as a fraction, "multiply_cov" corrects the results for the factor 100 difference, constant, see 'other_params' sheet in the parameter excel file.

The excel file with the parameters is an input variable of the simulation. It is therefore possible to use a copy of the excel file with alternative parameter values as an input file.

Default values for paved/unpaved/water and agricultural land based on lceu classification:

	'on_verhard'	**'agri'**
eu	Ovw	agri
0	0	0
1	2	1
2	2	1
3	1	0
4	2	1
5	2	1
6	1	0
11	2	0
12	2	0
13	2	0
20	2	0
21	2	0
22	2	0
23	2	0
24	2	0
25	2	0
26	2	0
27	2	0
28	2	0
29	2	0
31	2	0
32	2	0
41	1	0
42	1	0
43	1	0
44	1	0
45	1	0
46	1	0
47	1	0
48	1	0
51	3	0
52	3	0
53	3	0
999	0	0
255	0	0

where eu is the land use class using the lceu classification.

Used values for interception of rainfall by vegetation:

vegtype	mmx10
low_veg	13
shrubs	10
trees	30
litter	58

Values used for total infiltration by soil in one hour based on soil saturation presence of vegetation and bofek classification:

		'infiltratie_veg'	'infiltratie_no_veg'	'infiltratie_saturated'
Soil type	**bc**	mmx10	mmx10	mmx10
Heavy clay soil	6	123	63	5
Clay soil	2	130	71	15
Organic soils	7	136	76	22
Loam soil	1	373	194	21
Sandy loam soil	3	402	224	60
Loamy sand soil	5	440	262	110
Sandy soil	8	747	450	200
No data	0	0	0	0

where bc is the bofek class.

Default values 'other_params' are set at:

Parameter	Value	Unit
px	10	m
nl_onshore	33893	km^2
norm	6	mm
multiply_mm	10	-
multiply_cov	100	-

14.3.2 Calibration

The model has not been calibrated yet.

14.3.3 Input and output

Structure * format * quantities * units * precision * description * link variables & parameters * version echo

Input variables

The model consists of eight mandatory and seven optional variables

Mandatory variables:

1. land_use: Geospatial raster showing land use following LCEU categories
2. soil_type: Geospatial raster (.tif) with main bofek categories for soil types.
3. bomen: Geospatial raster (.tif) with tree cover (range 0-100).
4. struiken: Geospatial raster (.tif) with shrub cover (range 0-100).
5. gras: Geospatial raster (.tif) with low vegetation cover (range 0-100).
6. inw: Geospatial raster (.tif) with population count per pixel.
7. params: Excel sheet with lookup tables and model parameters and constants
8. scenario: Name of the scenario calculated, is used in the names of the output files

Optional variables:

1. --out_dir: output directory
2. --write_rasters: write geospatial ouput rasters to output directory
3. --reporting: write an text file with key outcomes
4. --test_input: verify model initialization, do nothing else
5. --test: verify model with test set, do nothing else
6. --check_maxmm Check maximum mm infiltration and interception
7. --env_proj_path Path of proj folder in python environment

Output

Output values:
true_pxls_unsat = sum, i.e. pixel count where value >= norm, unsaturated soil
true_pxls_veg = sum, i.e. pixel count where value >= norm due to vegetation
true_pxls_sat = sum, i.e. pixel count where value >= norm, saturated soil
true_area_unsat = area where value >= norm, unsaturated soil
true_area_veg = area where value >= norm due to vegetation, unsaturated soil
true_area_sat = area where value >= norm, saturated soil
true_perc_unsat = percentage of area where value >= norm, unsaturated soil
true_perc_veg = percentage of area where value >= norm due to vegetation, unsaturated soil
true_perc_sat = percentage of area where value >= norm, saturated soil

scenario population above threshold as number and percentage for unsaturated soil
scen_above_pop_unsat
scen_below_pop_unsat
scen_above_perc_unsat
scen_below_perc_unsat

scenario population above threshold due to vegetation as number and percentage for unsaturated soil
scen_above_pop_veg
scen_above_perc_veg

scenario population below and above threshold as number and percentage for saturated soil
scen_above_pop_sat
scen_below_pop_sat
scen_above_perc_sat
scen_below_perc_sat

# mean per capita infiltration (in mm) due to soil (and vegetation) and percentage extra reduction due to vegetation
mm_unsat_soil_veg = mean per capita infiltration (in mm) due to soil (and vegetation) in unsaturated soil
mm_unsat_veg = mean per capita infiltration (in mm) due to vegetation in unsaturated soil
mm_perc_unsat_veg = percentage of per capita infiltration (in mm) due vegetation in unsaturated soil
mm_sat_soil_veg veg = mean per capita infiltration (in mm) due to soil (and vegetation) in saturated soil
mm_sat_veg = mean per capita infiltration (in mm) due to vegetation in saturated soil
mm_perc_sat_veg = percentage of per capita infiltration (in mm) due vegetation in saturated soil

These output values are written in model_result.ini in the output directory.

Optional output consists of 3 sets of output geospatial raster files:
One set showing total infiltration and interception by soils and vegetation in mm in four situations; 'unsat.tif', 'unsat_noveg.tif', 'unsat_byveg.tif' and 'sat.tif'.
One set showing population count above or below the norm infiltration; 'scenario_pop_above_thres_unsat.tif', 'scenario_pop_above_thres_unsat_by_veg.tif', 'scenario_pop_below_thres_unsat.tif', 'scenario_pop_above_thres_sat.tif', 'scenario_pop_below_thres_sat.tif'
One set showing where total infiltration and interception by soils and vegetation is above the norm (marked with 1) in respectively unsaturated soils, in unsaturated soils due to vegetation and in saturated soils; 'above_thres_unsat.tif', 'above_thres_unsat_by_veg.tif', 'above_thres_sat.tif'

14.3.4 Standard indicators

Supply
Supply of well drained soils and vegetation.

Demand
Demand for well drained soils including vegetation (>6mm/hour) so urban areas where people live will not flood.

Combination of supply and demand
% people living at places with a water retention capacity greater than 6mm/hour of saturated soils (mm/hour).

Also see Table 1.1.

14.4 Evaluation model functioning

14.4.1 Sensitivity analysis

A sensitivity analysis has not been performed. Although a scenario has been run with more measures to purify water and the results indicate the differences are plausible (Breman et al. 2022).

14.4.2 Uncertainty analysis

An uncertainty analysis has not been conducted yet.

14.4.3 Validation

The model is based on the Horton model for water infiltration (Horton, 1933). The model has not been validated for the Netherlands.

14.4.4 General assessment of model quality

There has not been done a general assessment of model quality.

14.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

14.5.1 Reliability

A Very high, B. high**,** C. sufficient, **D. moderate**, E. low

14.5.2 Completeness

Completeness: A. (almost) complete, **B. contains most important aspects, C. contains some aspects.**

14.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- Testing

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- Calibration
- **Input and output**
- **Origin Input data**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

14.5.4 Future model development options

- A better knowledge of the effects of land use changes in water conservation areas on evening out peak discharges can help optimise the ecosystem function of water retention.
- In addition to water storage in cities, it is also desirable to investigate the flood risks of rivers, brooks and streams and the area that is below sea level (see CICES classification) and the influence of land use on water storage capacity.
- More consideration should be given to the differences between water storage, water capture and water runoff and the role that ecosystems can play in these aspects.
- It is not known how much, where, or what the impact of drainage systems and pipes is on water storage capacity.

14.6 Literature

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15 Soil fertility (hydrology)

Martin Mulder (WENR).

To determine the reduction on agricultural crop production due to damage from overly wet or dry conditions, the meta-relationships of the *Waterwijzer Landbouw* (WWL)[3] (Water Guide for Agriculture) are used. Organic components, earthworms and other species help to improve the soils and make nutrients available. As such, the WWL is part of the NC-Model, but the model is not included in the ICT shell. However, the model can be run with the input files that are also used for other ecosystem service models. As such, the WWL also has its own development strategy and its own status A track. Status A has already been granted for SWAP, and is pending for WOFOST. Most of the text shown below is taken from the WWL report (Werkgroep Waterwijzer Landbouw, 2018).

15.1 Theoretical rationale

15.1.1 General description of model

Soil fertility is the capacity of the soil to supply a crop with nutrients and not too much water and not too little. Soil fertility is determined by the chemical, physical and biological characteristics of soils. Soil biota like nematodes, earthworms, fungi, bacteria make a soil fertile. More variation in species is better for the fertility of the soil. Besides soil life also nutrients in the soil and the soil organic content is important for a healthy soil. Soil organic content (humus) can retain water so plants can get moist from the soil. Organic particles can also act as a buffer for minerals so nutrients can will be available longer.

Waterwijzer Landbouw (Water Guide for Agriculture) is a model for determining the effect on agricultural production due to changes in hydrological conditions in the Netherlands. The model is based on a conventional agricultural practices. Yield could possibly differ for practices that are based on agro-ecological principles or strip culture. These changes can be caused, for example, by water management, reclamation projects or drinking water extraction, but also by the climate. *Waterwijzer Landbouw* can be used not only to determine agricultural yield losses (damage), but also to optimise water management on local, regional and national scales under changing conditions, including changing climate.

15.1.2 Conceptual model and formal model

To assess the impact of climatic and/or hydrological changes on the performance of agricultural crops, the essential processes that describe the interaction between soil, water, crop and atmosphere must be explicitly considered, see Figure 15.1.

This process knowledge was operationalised and assessed against data from commercial farms. For the most common agricultural crops, potential and actual crop yields are determined by simulations with the hydrological model SWAP[4] (Soil-Water-Atmosphere - Plant; Van Dam et al., 2008; Kroes et al., 2017) for the unsaturated zone, coupled with the dynamic crop growth model WOFOST[5] (WOrld FOod Studies; Boogaard et al., 2014; De Wit et al., 2019).

The quantification of agronomic yield loss takes direct and indirect effects into account. Direct effects relate to the transpiration reduction due to excessively dry or wet conditions during the growing season (when the crop is in the field), and indirect effects relate to the growing season itself (such as delayed sowing or

[3] https://waterwijzerlandbouw.wur.nl
[4] https://swap.wur.nl
[5] http://www.wofost.wur.nl

harvesting times due to reduced soil bearing capacity during excessively wet conditions or delayed crop emergence in the case of a cold spring).

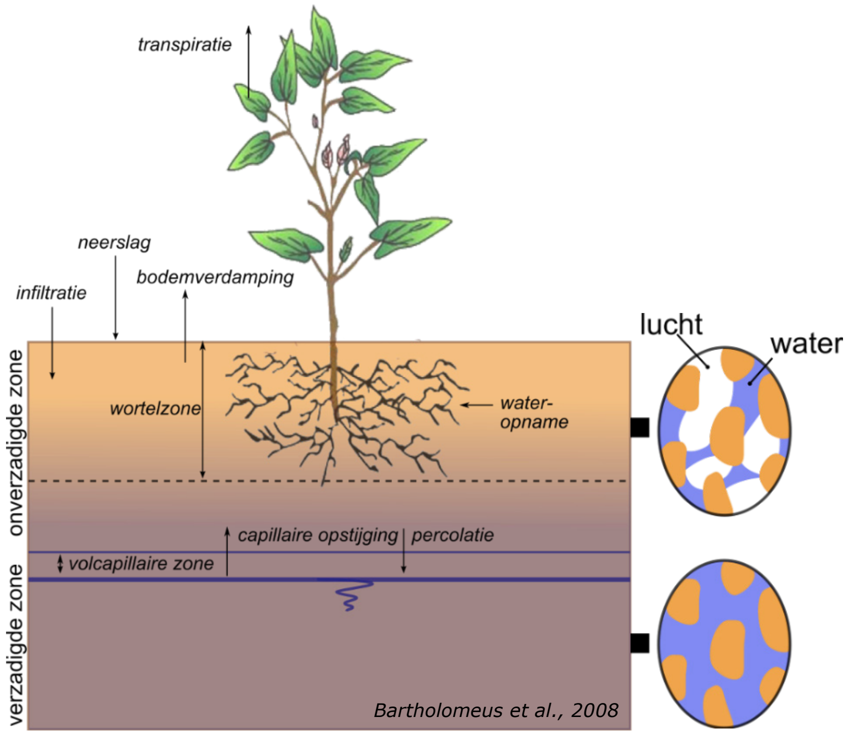

Figure 15.1 *Schematic representation of soil hydrological processes involved in the simulation of crop yield.Translation: transpiratie = transpiration, infiltratie = infiltration, neerslag = precipitation, bodemverdamping = soil evaporation, wortelzone = rootzone, wateropname = water uptake, capillaire opstijging = capillary ascent, percolatie =percolation, volcapilaire zone = fullcapillaire zone, verzadigde zone = saturated zone, onverzadigde zone = unsaturated zone , lucht = air, water = water.*

With this detailed modelling toolbox, a large number of simulations were carried out for combinations of the most common crops and soil types under different hydrological and meteorological conditions to create the user-friendly WWL table. Based on these simulations, relationships were derived between groundwater level characteristics GHG (Mean Highest Groundwater Level) and GLG (Mean Lowest Groundwater Level) and crop yield. In this way results from the detailed process models are simplified with meta-relationships, which are summarised in the WWL table in the NC-Model.

15.2 Technical implementation

15.2.1 Implementation model

Approximately one million calculations were performed for combinations of the most common crops and soil types under various hydrological and meteorological conditions. For unique combinations of crop, irrigation, soil and meteorology, meta-relationships were then derived that relate crop yields to the groundwater level characteristics of the Mean Highest Groundwater Level (GHG) and Mean Lowest Groundwater Level (GLG)..

The metamodel used is a ‘random forest’ model (Breiman, 2001). With this metamodel, a whole forest of regression trees is derived that together predict yield loss (ensemble modelling). This type of model is known for its good predictive power. Separate models were derived for total yield loss, indirect and direct effects, and models for drought stress, oxygen stress and salt stress.

Using the meta-relationships, a database was populated with all possible combinations of groundwater level characteristics. This database can be accessed with the WWL table, see Figure 15.2.

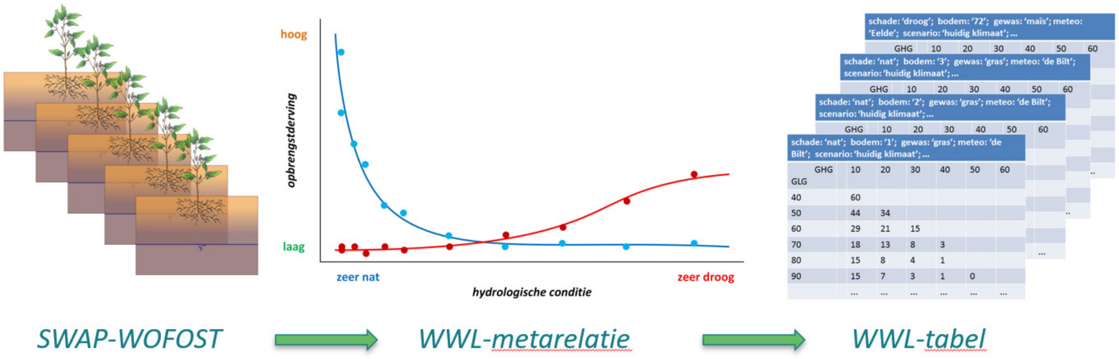

Figure 15.2 *Schematic representation of the creation of the database that is accessed with the WWL table.*

15.2.2 Technical environment

The SWAP-WOFOST simulations were performed using SWAP version 4.2.0. To use the WWL table, R[6] software (version 4.1.0 or later) must be installed with the following packages: *WWL table*.

15.2.3 Testing

When deriving the meta-relationships, we tracked the performance of the meta-relationship compared to the model simulation. More than 90% of the meta-relationships have an R^2 higher than 0.8 (An R^2 of 1.0 represents the perfect meta-relationship), see Figure 15.3. For the remaining meta-relationships, the performance is slightly lower.

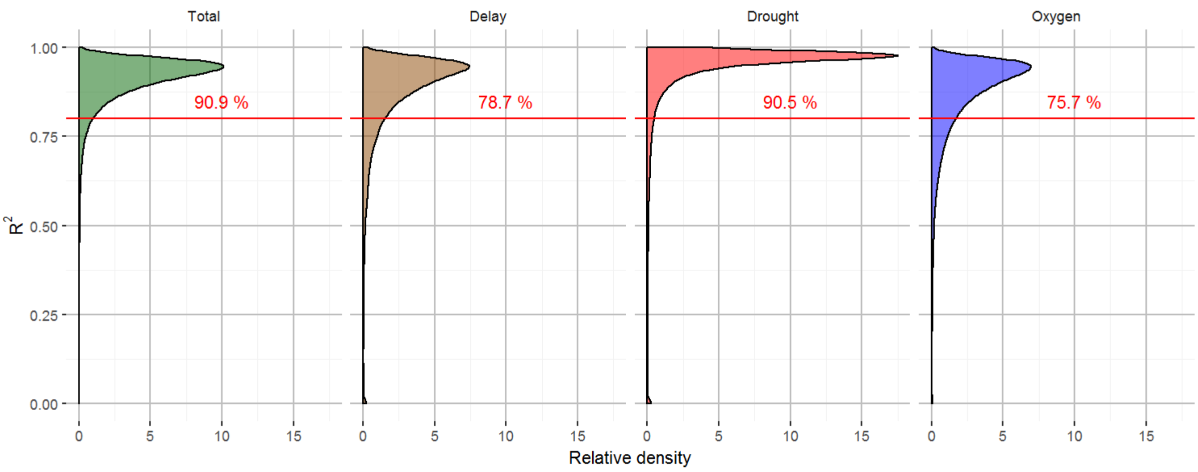

Figure 15.3 *Spread in the performance of WWL meta-relationships relative to the original model simulation expressed as R^2.*

[6] http://www.r-project.org (R Core Team, 2014)

15.3 Input and output, parameters and variables

15.3.1 Parameters and variables

To use the WWL table, information is needed about:

- Land use;
- Irrigation sprinkler locations;
- Soil type;
- Groundwater flow;
- Meteorology

The output of the WWL table consists of the potential crop yield and yield loss:

- Potential crop yield
  - biomass (expressed in kg dry matter ha^{-1}, kg ha^{-1} or parts of ha^{-1} depending on crop type)
  - feed value (expressed in VEM ha^{-1} (=Voeder Eenheid Melk/Feed Unit Milk) or DVE ha^{-1}(Darm Verteerbaar Eiwit/Intestinal Digestible Protein); if applicable)
  - Euros (expressed in € ha-1)
- Total yield loss (%)
  - Yield loss due to indirect effects (%)
  - Yield loss due to direct effects (%)
    - Yield loss due to excessively dry conditions (%)
    - Yield loss due to excessively wet conditions (%)

15.3.2 Calibration

This model has not yet been calibrated.

15.3.3 Input and output

Input

Land use

Meta-relationships were derived for the most common crops in the Netherlands, see Table 15.1. For grass, two grassland management variants were taken into account. Table 15.1 also shows the crop codes used in the *Waterwijzer Landbouw*; these differ from BRP (Basisregistratie Percelen), LGN (Landelijk Grondgebruiksbestand Nederland) or NHI[7] (*Nederlands Hydrologisch Instrumentarium*/Hydrological Toolkit for the Netherlands). For the crop map, the nature and landscape master file was used (see Chapter 3). The crops related to agronomic land use were translated into one of the crop codes as used in the WWL.

Table 15.1 *Crops in the WWL.*

Crop code	
1	Grass (for mowing)
5	Grass (for grazing)
6	Silage maize
7	Winter wheat
8	Spring barley
9	Ware potatoes
10	Starch potatoes
12	Sugar beets
13	Sown onions
20	Tulip
22	Apple trees
23	Avenue trees

[7] https://nhi.nu

Irrigation sprinkler locations
Irrigation is not taken into account in the NC-Model.

Soil type
The NHI uses soil units that are based on the Bodemkaart van Nederland[8] (Soil map of the Netherlands – 2020; scale 1:50,000). As a result, 368 unique soil profile sketches with descriptions of the soil profile up to 1.2 m below ground level are used (De Vries, 1999). The soil profiles consist of soil horizons. 'Building blocks' of physical soil characteristics from the Staring series (Heinen et al., 2020) are available for each soil horizon.

The WWL meta-relationships used in the WWL table (version 3.0.0) were derived for clusters of the above soil units: BOFEK 2020 (Heinen et al., 2021). Based on eight key figures for physical soil characteristics, the 368 soil profiles were clustered so that soil profiles in the same cluster possess similar physical properties. BOFEK 2020 distinguishes 79 soil clusters. For each soil cluster, the area-weighted dominant soil profile is used to derive WWL meta-relationships.

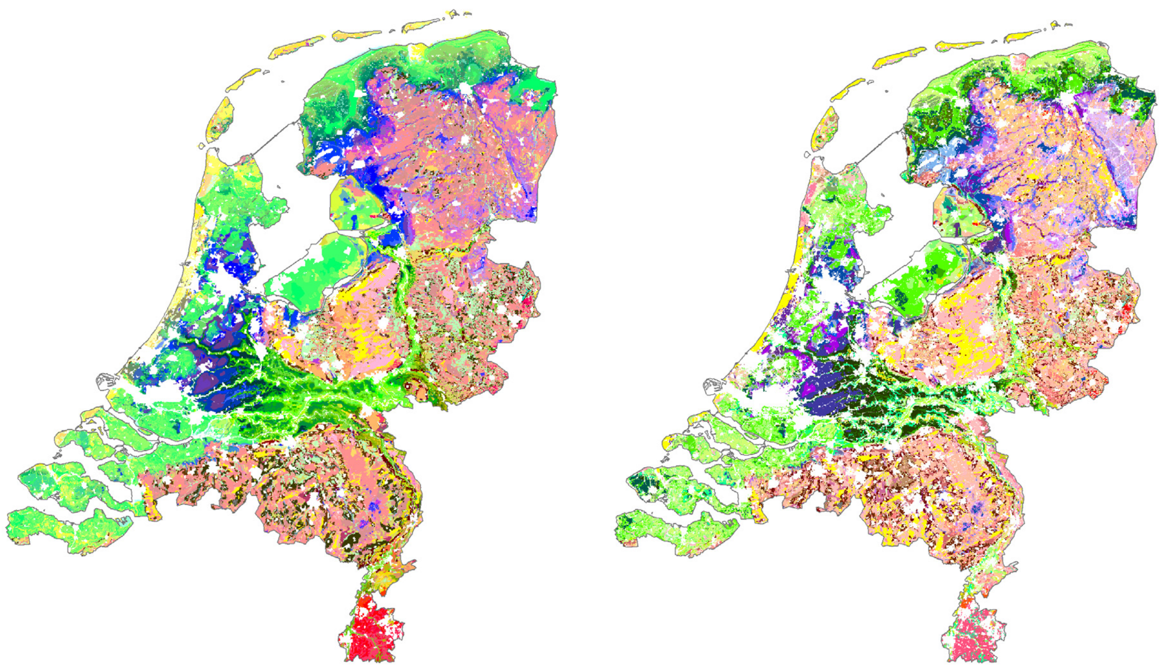

Figure 15.4 *Soil map of the Netherlands (left) and the BOFEK2020 (right).*

Groundwater flow
The groundwater gradient simulated by the *Landelijk Hydrologische Model* (National Hydrological Model – LHM) is characterised in the GHG and GLG (source: LHM 4.1.0; determined over the period 1998 - 2006).

Meteorology
The WWL meta-relationships were derived for five KNMI weather stations: De Kooy, De Bilt, Eelde, Vlissingen or Maastricht. In total, the LHM uses 31 different weather stations of the KNMI. It is necessary to determine for each of these weather stations which weather station the meteorological conditions best correspond to, see Figure 15.5.

[8] https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/modellen/bodemkaart-sgm

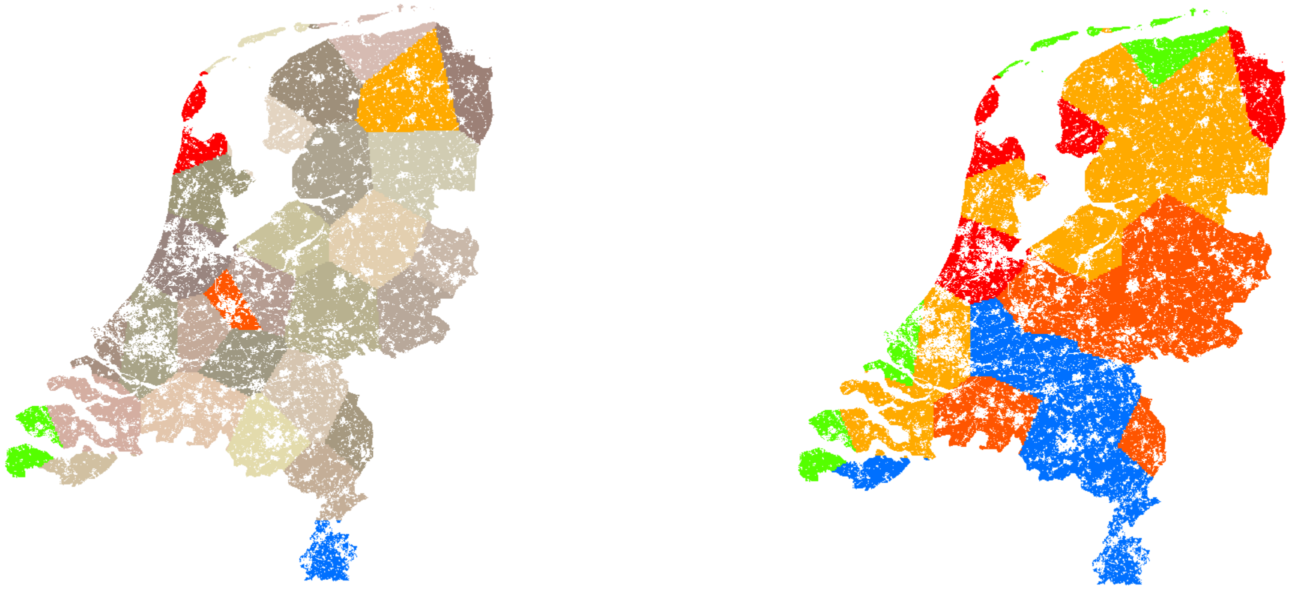

Figure 15.5 *Location of all weather stations in the LHM (left) and the homogenised weather stations for which meta-relationships were derived (right).*

For the period 1991 - 2020, meteorological conditions from all weather stations in the LHM were retrieved and processed into model inputs for SWAP-WOFOST. Data are missing for a large number of weather stations. The missing data were filled in with data from the homogenised weather stations De Kooy, De Bilt, Eelde, Vlissingen or Maastricht (which contained complete measurement series except for a few days). The choice of the homogenised weather station is based on similar meteorological conditions: radiation, humidity, temperature, wind and precipitation.

Output

As a result, the WWL table yields the crop response per specified spatial unit. The crop response consists of a potential crop yield expressed as biomass (kgdm ha^{-1}, kg ha^{-1} or pieces ha^{-1}), feed units milk (kVEM ha^{-1}), gut digestible protein (kDVE ha^{-1}) or euros (€ ha^{-1}) and of the relative yield loss expressed as a percentage (see Table 15.2). The total yield loss can be broken down into a proportions due to indirect effects and direct effects. Indirect effects result from a shift in the growing season associated with conditions too wet to perform tillage; direct effects are due to transpiration reduction during the growing season. This reduction can be caused by drought stress, oxygen stress and salt stress.

Table 15.2 *Result of the WWL table*

Variable	Description	Unit
Potential crop yield		
hrvpotbio [1]	Biomass	kg_{dm} ha^{-1} kg ha^{-1} pieces ha^{-1}
Hrvpotvem	Feed unit milk	kVEM ha^{-1}
Hrvpotdve	Gut digestible protein	kDVE ha^{-1}
Hrvpoteur	Euro	€ ha^{-1}
Yield loss		
Dmgtot	Total	%
Dmgind	Indirect effects	%
Dmgdir	Direct effects	%

Variable	Description	Unit
Dmgdry	Drought stress	%
Dmgwet	Oxygen stress	%
Dmgsol	Salt stress	%
[1] The unit of biomass depends on the crop (hydrological potential harvest).		

For translation into an economic effect in euros, the potential crop yield is multiplied by a crop price, see Table 15.3.

For livestock feed crops, this is done by multiplying the potential yield in feed value (expressed in kVEM ha^{-1} and kDVE ha^{-1}) by the feed value prices for VEM and DVE (€ 0.167 $kVEM^{-1}$ and € 0.671 $kDVE^{-1}$). For details see the final report of *Waterwijzer Landbouw*.

For arable crops where the potential crop yield is expressed in kgdm ha^{-1}, a translation is first made to crop yield in total wet weight (kg ha^{-1}) before multiplying by the crop price.

For the crops lettuce, cauliflower, tulip and lily, potential crop yields are expressed in pieces (pieces ha^{-1}).

Table 15.3 *Translation to economics; crop prices and dry matter contents used in WWL.*

Crop	Unit of crop yield	DM [%]	PRICE	Unit price
Grass (for mowing)[1]	kg_{dm} ha^{-1}			
Grass (for grazing)[1]	kg_{dm} ha^{-1}			
Silage maize[1]	kg_{dm} ha^{-1}			
Winter wheat	kg_{dm} ha^{-1}	85.0	0.19	€ kg^{-1}
Spring barley	kg_{dm} ha^{-1}	85.0	0.19	€ kg^{-1}
Ware potatoes	kg_{dm} ha^{-1}	21.5	0.16	€ kg^{-1}
Starch potatoes	kg_{dm} ha^{-1}	24.5	0.07	€ kg^{-1}
Sugar beets	kg_{dm} ha^{-1}	24.5	0,056	€ kg^{-1}
Sown onions	kg ha^{-1}		0.14	€ kg^{-1}
Tulip[2]	pieces ha^{-1}		0.43	€ $piece^{-1}$
Apple trees	kg ha^{-1}		0.735	€ kg^{-1}
Avenue trees	kg ha^{-1}		4570	€ kg^{-1}
[1] For livestock feed crops, the crop yield in feed value (kVEM ha^{-1} and kDVE ha^{-1}) is translated into an economic effect.				

The crop prices listed in Table 15.3 are used by default by the WWL table. If desired, it is possible to adjust crop prices.

15.3.4 Standard indicators

All indicators are about conventional agriculture.

Supply
Supply of fertile soils for crop production (i.e. with good hydrology).

Demand
Demand for fertile soils for agricultural crops (i.e. with good hydrology).

Combination of supply and demand
% avoided harvest loss of crops due to fertile soils defined by their hydrology (kg/ha/yr).

See also Table 1.1.

15.4 Evaluation of model functioning

15.4.1 Sensitivity analysis

Not applicable.

15.4.2 Uncertainty analysis

Not applicable.

15.4.3 Validation

Models are always a limited representation of reality. Assessment and validation are required to know to what extent simulation models are useful. The challenge here is that this requires assessment of both hydrology and crop growth, preferably simultaneously.
Conventional Crop growth should depend here only on meteorological conditions, soil and hydrology and should be independent, for example, of agricultural management or nutrient availability. In practice, this combination of conditions is difficult to achieve. This applies not only to field studies and regional studies, but also to more controlled field trials. With attention to these challenges, several validation studies have been conducted to date. Below we outline what has been done so far and what we believe is needed in the future.

Validations SWAP-WOFOST
The underlying models SWAP and WOFOST have been assessed with some regularity in the past, separately and in combination. The calculation algorithm of SWAP was technically assessed by comparison with analytical solutions for infiltration into a layered soil profile. This assessment showed very good agreement. Several studies in the Netherlands and abroad have validated SWAP(-WOFOST) with hydrological data (see SWAP website[4]), two examples are: Bonfante et al. (2010) and Ma et al. (2011). Other examples involving hydrology and crop growth data include Eitzinger et al. (2004), Kroes et al. (2018) and Hu et al. (2019), Van Dam et al. (2008) cites several validation studies. Crop-specific validation studies of WOFOST are listed on the WOFOST website[5].

Validations involving the Waterwijzer Landbouw
During the development of the *Waterwijzer Landbouw*, data-based assessment also took place at a number of points. A list of reports and scientific publications can be found in Publication Overview - Stowa[9], which also includes several validation studies. Early in the development phase, validation took place with measurement data from the test facilities at Zegveld, Cabauw and Roswinkel. This study showed that the version used at that time, based on SWAP, including simulation of oxygen stress according to Bartholomeus et al. (2008), and WOFOST, could estimate crop transpiration with acceptable accuracy. (2008), and WOFOST, could estimate crop transpiration with acceptable accuracy. Grass yields were also examined in this study based on a previous link between SWAP and the *BedrijfsBegrotings Programma Rundvee* (BBPR)/Farm Budgeting Programme for Cattle (Schils et al., 2007, Waterpas; De Vos et al., 2006). In doing so, comparisons were made with measured yields. The conclusions was that the model outputs were sufficiently realistic to make estimates for Dutch commercial farms. In 2015, simulated crop yields for grassland and silage maize were validated by Kroes et al. for several locations in the Netherlands (trial facilities at Zegveld and Ruurlo, Cranendonck and Dijkgraaf). This was done as part of the *Waterwijzer Landbouw* project. After the first edition of *Waterwijzer Landbouw* in 2018, the development of the modelling tools has continued.

Finally, a validation study of the *Waterwijzer Landbouw* has recently (2021) been conducted for regional simulations and for some agricultural parcels (Mulder et al., 2021). To specifically assess the effects of hydrological conditions, dry periods from the years 2018-2020 and a period of flooding from the year 2016 were evaluated. This validation was performed with both the WWL table and WWL-regional. Crop growth was compared to green biomass (NDVI) data from the *Groenmonitor* (vegetation map of the Netherlands). The timing of crop transpiration and development of harvestable product, due to drought stress, corresponded

[9] https://waterwijzer.nl/publicaties

well with the dynamics in the green biomass data at the agricultural parcel level. There is an explicit intention to conduct more validation studies.

15.4.4 Overall assessment of model quality

The NHI Programme Team, on behalf of the Regional and National Model Instrumentation Steering Committee (RLMI), prepared a service development in response to client needs for the NHI/NWM Scientific Advisory Committee (WAC) in the spring 2021 regarding the use of the *Waterwijzer Landbouw* (WWL) and the SWAP-WOFOST models integrated therein. This all took place against the background of the intention to include the WWL within the management and maintenance of the NHI instrumentation and the discussion among Dutch hydrologists and stakeholders around the WWL about its applicability and validity. The recommendations of the Scientific Advisory Committee (WAC) can be found on the NHI website[10].

15.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **<u>complete</u>**, <u>partly (in)complete</u>, incomplete.

15.5.1 Summary reliability

A Very high, B. high, C. sufficient, **D. moderate**, E. low

15.5.2 Summary completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

15.5.3 Status A progress

ST.1: Model description
- **<u>General description</u>**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **<u>Implementation</u>**
- **<u>Technical environment</u>**
- Testing

ST.3: Description parameters, variables, input and output
- **<u>Parameters and variables</u>**
- Calibration
- **<u>Input and output</u>**
- **<u>Origin Input data</u>**

ST.4Model functioning
- Sensitivity analysis
- Uncertainty analysis
- Validation
- Monitoring of use
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation chapter 20.

[10] https://nhi.nu/nl/files/5116/4638/7313/Def_Advies_WAC_WWL_v_2.3_februari_2022.pdf

15.5.4 Future model development options

- The effects of climate change in recent years (increased temperatures, more and longer droughts, and sometimes more peak precipitation and wind) affect yield loss directly and indirectly. More insight is needed into the effects of extreme years on crop yield loss.
- The amount of yield loss where there is no artificial irrigation appears to be relatively small. Whether the results of the WWL are realistic should be examined.
- Alternative forms of agriculture such as strip farming, circular agriculture and various kinds of infiltration systems in peatlands cannot yet be calculated directly with the model.
- Soil fertility consists of a number of aspects, and we have looked at only some of them. These include aspects such as the ability of the soil to hold water for crop growth, but also to drain water sufficiently. Soils that are too wet or too dry cause yield losses. Soil organisms, organic matter content, soil structure, soil nutrients and fertiliser application also determine the capacity of the soil to grow crops. These factors also interact with each other. For example, the organic matter content and soil organisms affect the structure of the soil and thus the availability of nutrients and the ability of the soil to hold water and drain sufficiently.

15.6 Literature

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WWL tabel. https://waterwijzerlandbouw.wur.nl/downloads/3.0/WWL_tabel.pdf

16 Natural heritage

To assess the state of the natural heritage, the MNP model (MetaNatureplanner/ Model for Nature Policy) was used. The model (version 4.0.2(.60)) already has status A. For a detailed description of the model, see Pouwels et al., 2017 and Pouwels et al., 2016a. The texts below are largely taken from this publication.

16.1 Theoretical rationale

16.1.1 General description of model

The Model for Nature Policy (MNP – version 2.0) determines the effects of policies and management interventions on biodiversity. The model establishes relationships between environmental, water and spatial conditions and the sustainable conservation of biodiversity. It is used for signalling, policy evaluation and national and regional foresight. The output is aggregated into indicators that align with Dutch and European policy. The results of the model align with the goals of the Birds and Habitats Directives (BHD) and the biodiversity goals for the European Biodiversity Strategy (CBD, 2020). The model uses parameter values and simplified response curves from a number of more advanced process models, such as LARCH and the *Natuurplanner*, augmented by and improved with, for example, empirically determined optimal groundwater levels and critical values for atmospheric deposition. Unlike the *Natuurplanner*, the MNP does not describe soil chemistry changes or competitive relationships between species, but directly establishes a simplified relationship between abiotic factors such as nitrogen deposition and groundwater levels and the quality of a species' habitat. Together with the area of habitat, it then determines the likelihood of species occurrence.

The model consists of three components that together calculate the impact of various pressure factors on biodiversity targets (see Figure 16.1):

1. First, habitat suitability is determined based on local environmental pressures (nitrogen deposition, groundwater level and soil pH). For each species, its habitat requirements are compared with the environmental conditions in the scenario being assessed.
2. The second step determines whether the quality and size of the habitats are sufficient to ensure sustainable survival. This uses the concept of key areas and there is some trade-off between area and quality of habitat.
3. Finally, the results are summarised as policy-relevant indicators, a species indicator and an ecosystem indicator, which can also be linked to policy goals.

This determines the proportion of species for which habitat conditions are sufficient to maintain these species. The model does not assess whether the species actually occur.

The model was parameterised for 329 species (including target species) from the species groups vascular plants, butterflies and breeding birds. Collectively, the three species groups provide a good picture of the impact of various pressures on Dutch biodiversity because they act at different spatial scales: habitat, vegetation structure and landscape, respectively. These species groups also form the basic groups for monitoring nature quality in various programmes and policies such as the nature and landscape grant scheme (SNL) and the assessment of the quality of habitat types as specified in the Habitat Directive. In addition, sufficient information on habitat preference and sensitivity to environmental conditions is available for these species groups.

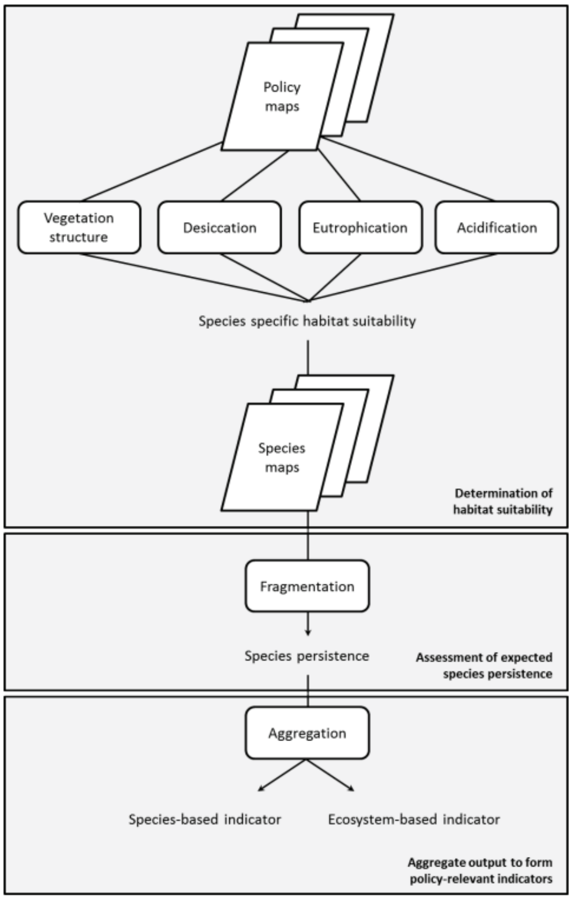

Figure 16.1 *Schematic representation of the MNP's mode of operation.*

16.1.2 Conceptual model and formal model

Determine habitat quality

The quality of species habitat is often determined by a combination of biotic and abiotic conditions (Grinnell, 1917; Hirzel and Le Hay, 2008). A basic condition for the occurrence of species in this regard is often the ecosystem that is present. For example, marsh species may only have suitable habitat in a marsh ecosystem and not in a forest system. In various ecosystems, most biotic relationships, such as host plant-butterfly, prey-predator, and species competition, occur naturally and have feedback mechanisms through which they balance each other (Pimm, 1982). However, even though these interactions together are complex and by definition not stable (Montoya et al., 2006), the complexity of the whole is very important for the stable occurrence of a species within this system (Bascompte and Jordano, 2007). The model assumes that the interactions within the systems provide this stability and so does not account for these species-specific interactions. In recent years, nature management in the Netherlands has focused on restoring or mitigating the abiotic conditions of ecosystems. Fertilisation, desiccation, acidification and fragmentation are considered to be the main pressure factors affecting terrestrial nature (Wamelink et al., 2013) and currently, in the Netherlands as a whole, largely determine the distribution and population size of BHD species (Van Kleunen et al., 2007). In the MNP, the first three factors are used to determine habitat suitability. Fragmentation is included in the next step of the MNP.

For a more detailed elaboration of this step, see Pouwels et al. (2016a: § 2.4-§ 2.6).

Determine sustainable occurrence of species

Besides the deterioration of habitat quality, many natural areas in the Netherlands are becoming smaller and more isolated (Jongman, 2002).
The concept of the Nature Network of the Netherlands (NNN) is specifically aimed at counteracting this and even partially restoring it.

However, the extent to which areas are large enough for a species to occur sustainably depends on species-specific characteristics.

Species such as honey buzzard and hen harrier require large areas of contiguous habitat to host a stable population (Verboom et al., 2001), while for some butterfly and plant species, suitable habitats become quickly isolated due to limited dispersal capacity (Opdam et al., 2008).

For expected growth, two methods are available: the yield tables of Janssen et al. Theoretically, a species could sustainably occur in a landscape if a single, large viable population is present.

As catastrophes can cause a single large population to suddenly disappear, the MNP designates a species as sustainable only if multiple large populations are present.

The concept of key areas is used for this purpose (Verboom et al., 2001). The number of populations needed depends on how sensitive a species is to catastrophes (Foppen et al., 1998).

Butterflies are more sensitive to stochastic processes than vascular plants and birds.

For a more detailed elaboration of this step, see Pouwels et al. (2016a: § 2.10, § 2.11 & §2.13).

Aggregation to policy-relevant indicators
The MNP provides many intermediate and final results for individual species. By aggregating these, the results can be displayed as policy-relevant indicators. By presenting the results as an indicator relevant to the policy, it can serve as a boundary object (Star & Griesemer, 1989). The MNP aggregates the final results into two indicators, a species indicator and an ecosystem indicator. By making a targeted selection of, for example, protected species from the Birds Directive (breeding birds) and typical species for the protected habitat types from the Habitats Directive, an analysis can focus on the impact of measures on this specific nature policy. In some cases, the researchers develop their own indicators, for example to compare scenarios.

For a more detailed elaboration of this step, see Pouwels et al. (2016a: §2.2, §2.3 & §2.14).

16.2 Technical implementation

16.2.1 Implementation model

Figure 16.2 shows a technical representation of the MNP with the following components: habitat quality, determining sustainable occurrence of species, and aggregation to indicators.

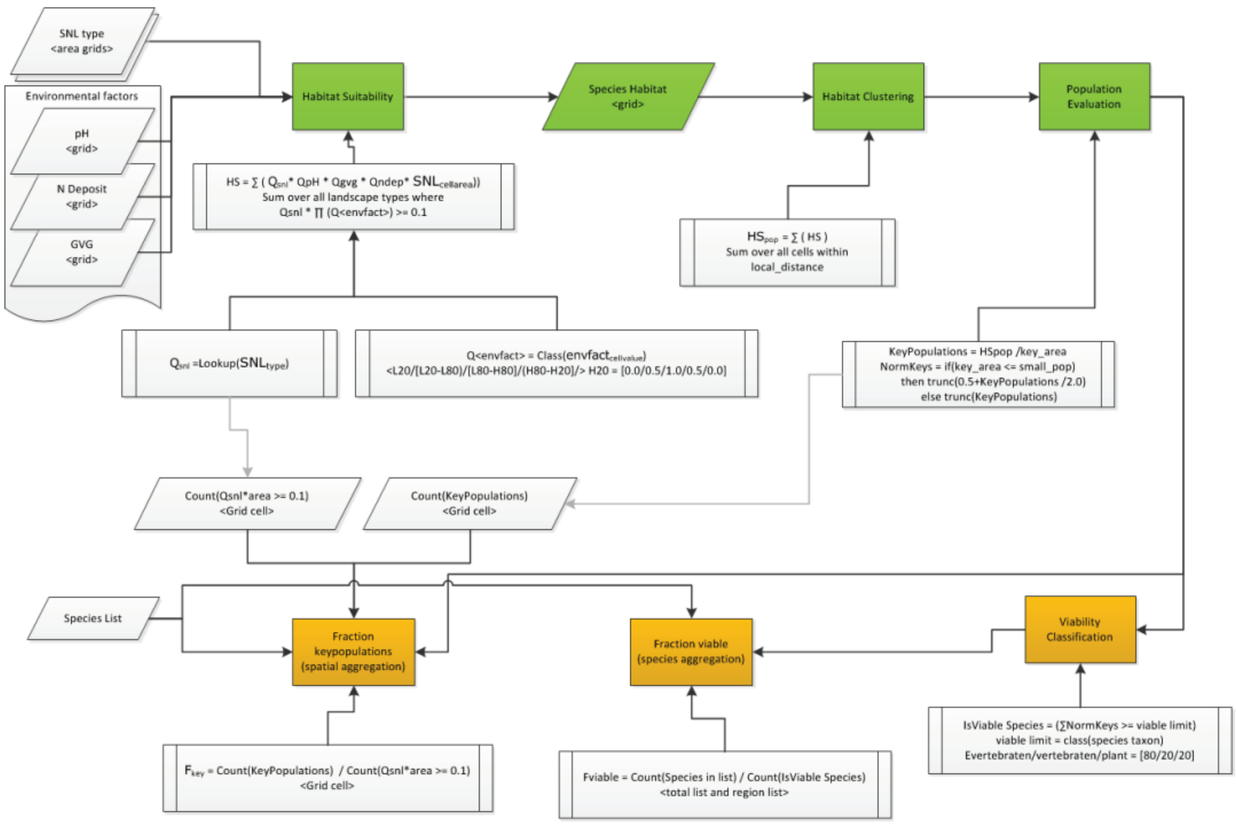

Figure 16.2 *Technical representation of the MNP.*

For more information, see Chapters 1, 2, and 12 in Jochem (2017) and Annex 7 of Pouwels et al. (2017).

16.2.2 Technical environment

The model was implemented in C++ (Builder XE7 (IDE)) on Windows 7 Enterprise with Service Pack 1 and a 64-bit operating system. Required auxiliary software consists of Firebird for the database, 7-zip for input files, ArcGis and/or Excel for post-processing output files (if desired).

For more information, see Jochem (2017) and Pouwels et al. (2017).

16.2.3 Testing

The test was conducted with a simple landscape and fictitious species. In doing so, the input files and parameters for the fictitious species were chosen so that the result could be easily recalculated in Excel and that all thresholds used in the Model for Nature Policy 2.0 were tested. No errors were found during the test. The difference between the model outputs and the Excel calculation is at most 0.02% and can be attributed to rounding.

16.3 Input and output, parameters and variables

16.3.1 Parameters and variables

In addition to some default parameters in the model, there are values for at least 16 parameters per species. For an application such as the *Evaluatie Natuurpact* (Natuurpact evaluation – Pouwels et al., 2017), which modelled 146 species, this results in thousands of parameter values. In addition to these parameters, the model uses other variables, but the values for these variables are intermediate results of calculations. Jochem (2017; Section 3.7) provides an overview of all the variables and their relationships. This is shown in Annex 3. Table 1 lists the parameters that must be entered into the MNP. In the first step, the majority of parameters are used. In this step, the degree of suitability is determined by multiplying the impact of all pressure factors by the quality of the habitat based on the vegetation type present:

$HSI_i = f(VT_i) \times f(Ndep_i) \times f(GVG_i) \times f(pH_i)$

Where i is a random grid cell, HSIi (Habitat Suitability Index; US Fish and Wildlife Service 1981) is the degree of suitability in the given cell for a specific species, $f(VT_i)$[11] is the degree of suitability based on the vegetation type present, $f(Ndep_i)$ is the degree of suitability based on the amount of nitrogen deposition, f(GVGi) is the degree of suitability based on the mean spring groundwater level, and $f(pH_i)$ is the degree of suitability based on soil pH. The HSIi has to meet a minimum requirement (minHSI) to be included in step 2, where it is determined in which areas a species can realise a key area. To do this, the values in all grid cells within the local distance are added together. This summed value is compared to the area standard for a key area (Total area of key area). By then aggregating all areas, it is possible to assess whether a species has sufficient key areas in the landscape and can potentially occur sustainably (Species Group). To do this, it is first determined for each area whether it should be included for more key areas (threshold area requirement & number of key areas per habitat). Step 3, uses variables and no longer uses parameters (Jochem, 2017).

Table 16.1 *Parameters of the MNP (only available in Dutch). The names in the variables refer to Jochem (2017). The 'step' column indicates in which step (Figure 1) the parameters are used. When '-' is shown in the column under number per species, it means that it is a parameter that is constant for all species. Reference 1 refers to this document, reference 2 refers to Pouwels et al. (2016a) and reference 3 to Jochem (2017).*

Parameter	Variabele	Stap	Aantal per soort	Uitleg	Referentie
VT_i	Q_{snl}	1	≥ 1	De mate van geschiktheid op basis van het aanwezige vegetatietype	1: § 3.1.2- § 3.1.4 2: § 2.4 3: § 3.7.4
$Ndep_i$	Q_{Ndep}	1	4	De mate van geschiktheid op basis van de hoeveelheid stikstofdepositie. Per soort wordt een waarde gegeven voor de klassegrenzen L20/L80/H80/ H20 (zie figuur in Bijlage 3)	1: § 3.4 2: § 2.6 3: § 3.7.4
GVG_i	Q_{GVG}	1	4	De mate van geschiktheid op basis van de gemiddelde voorjaarsgrondwaterstand Per soort wordt een waarde gegeven voor de klassegrenzen L20/L80/H80/H20 (zie figuur in Bijlage 3)	1: § 3.3 en § 3.5 2: § 2.6 3: § 3.7.4

[11] For the Model for Nature Policy and MNP, area measurements have always been used. However, it is also possible to provide a relative measure of potential population size in a cell instead of the degree of suitability. In that case the database should include the density of a species for a particular vegetation type. It is crucial, however, that the values for the sizes of the key areas in the database are then converted to population sizes rather than areas, as is currently the practice.

Parameter	Variabele	Stap	Aantal per soort	Uitleg	Referentie
pH_i	Q_{pH}	1	4	De mate geschiktheid op basis van de bodem-pH Per soort wordt een waarde gegeven voor de klassegrenzen L20/L80/H80/H20 (zie figuur in Bijlage 3)	1: § 3.4 en § 3.1.5 3: § 3.7.4
Lokale afstand	local_ distance	2	1	Parameter voor de cluster afstand van een soort gebaseerd op home range	1: § 3.1.5 2: § 2.11 3: § 3.7.6
Oppervlakte sleutelgebied	key_area	2	1	Parameter met de norm voor een KeyPopulation	1: § 3.1.5 2: § 2.11 3: § 3.7.6
Soortgroep	species_ taxon	2	1	Soortengroep waartoe een soort behoort. Aan deze groep is het aantal sleutel-gebieden dat in het landschap aanwezig moeten zijn om duurzaam voor te kunnen komen, gekoppeld.	2: § 2.13 3: § 3.7.6
minHSI	HS_{min}	1	-	Minimale waarde van mate van geschikt-heid op basis van het aanwezige vegetatie-type en alle drukfactoren om mee te doen in de verder analyses. Standaard waarde is 0.1.	2: § 2.4 3: Annex 3
Drempel oppervlakte-behoefte	small_pop	2	-	Parameter die gebruikt wordt om te bepalen op welke wijze grote leefgebieden voor meerdere leefgebieden meegerekend mag worden. Default waarde is 500 ha en refereert naar de oppervlaktebehoefte voor sleutelgebieden van soorten.	2: § 2.13 3: Annex 3
Aantal sleutel-gebieden per leefgebied	sp_slope	2	-	Parameter die gebruikt wordt om te bepalen hoe vaak grote leefgebieden voor meerdere gebieden meegerekend mag worden. Default waarde is 2.	2: § 2.13 3: Annex 3

[12]

16.3.2 Calibration

For a description of the calibration, see Section 6.1 of Pouwels et al., 2017.

16.3.3 Input and output

Input
The MNP needs four different input maps, the management or vegetation type, the soil pH, the spring groundwater table and the nitrogen deposition.

Management type
Dutch nature management organisations use maps of nature management type for planning. This nature management type targets the conservation and/or restoration of a certain nature type in nature areas. As the nature type map for the current situation we used the map accompanying the Dutch national subsidise system for nature management. We further refined this map for some nature management types using remote sensing data, soil type and groundwater table (see further Wamelink et al. in press). In total 53 nature types are distinguished.

Soil pH
The soil pH map is based on field data in the form of vegetation plots collected between 1990 and 2015 and a pH indicator system based on field measurements (Wamelink et al., 2005). For 271,693 vegetation plots with unknown soil pH the pH was estimated by calculating the average of the pH indicator values of the

[12] Currently, Species group has 2 parameters. The boundary of "not sustainable" and "possibly sustainable" is no longer used for this indicator and the most recent PBL studies.

present species in the plot. By applying an interpolation method with maps for vegetation type, groundwater table and soil type as input a pH map was constructed for all (semi) terrestrial nature types within the National Nature Network. More information about the procedure can be found in Wamelink et al. (2019). pH values are provided on 2.5*2.5m grid basis.

Spring groundwater level
Mean spring groundwater levels (msl) correlate with species occurrence in the Netherlands (Witte, 2002; Wamelink et al., 2002). Water management organisation use mean spring groundwater level l as an important indicator for stress caused by desiccation. The mean spring groundwater level map was constructed analogue to the soil pH map. Instead of vegetation plots from 1990 onwards we used plots from 2004 till 2016. The map based on the estimated msl was merged with a msl map based on piezometer information from that same period (Sanders et al., 2022).

Nitrogen deposition
Emission control policies often use deposition maps to indicate effects on nature (see e.g. Wamelink et al. 2009; De Vries et al, 2010; Dirnböck et al, 2017). A national map for nitrogen deposition is calculated for every year by the RIVM, we used the version of 2015 (RIVM, 2016). The deposition contains both dry and wet deposition and deposition of both oxidised (NO_x) and reduced (NH_y) nitrogen. The nitrogen deposition is given on a 250*250m grid size.

Output
The biodiversity indicators (see Section 2.13 in Pouwels et al., 2017) calculated by MNP can be presented in various ways (Annex 1 in Pouwels et al., 2017). Usually the results are presented in the form of bar graphs or pie charts. The results are also presented on a map. This has the advantage of enabling stakeholders to review the results against their local knowledge of areas, thus gaining confidence in the MNP's methodology (Irvine et al., 2009).

16.3.4 Standard indicators

Supply
Supply of habitat in good condition (environmental and spatial).

Demand
1) halt biodiversity loss by 2030 and achieve recovery by 2050 & no threatened species, 2) no BHD species and Habitats threatened with extinction.

Combination of supply and demand
% species which have good environmental and spatial conditions to guarantee their sustainable occurrence (# species that could occur sustainably).

See also Table 1.1.

16.4 Evaluation of model functioning

16.4.1 Sensitivity analysis

The sensitivity analysis showed that the model outputs are most sensitive to a variation in value of the parameters related to key area size, sustainability standard, desiccation and fertilisation. Since the key area size for plants and the sustainability standard also have a high level of uncertainty, better substantiation is recommended. Due to the relatively strong effect of small changes in the desiccation and fertilisation parameters, they could be overly positive in terms of the range of optimal conditions. This should be considered in the future.

For more information, see Pouwels et al., 2017.

16.4.2 Uncertainty analysis

An uncertainty analysis was carried out to assess the variation of the model output due to uncertainties in the estimated values of the input parameters. To this end, a probability distribution was assigned to each input parameter. This distribution represents the uncertainty in the estimated value of the parameter. All model parameters were included in the analysis. However, the input maps were excluded from the analysis. Thus, any effects of uncertainty in the input maps were not considered. Many of the model parameters are defined separately for each species. These parameters were varied independently for each species. A few model parameters (such as carrying capacity at suboptimal conditions or responsiveness to environmental conditions) are parametrised in the model for groups of species, or for the collection of all modelled species. For these parameters, the variations are assumed to be the same for all species to compute maximum sensitivity and uncertainty. To compute realistic uncertainty we assumed these model parameters to be independent from each other and thus were varied per species.

As main output we considered the fraction of viable species (F_{viable}). The uncertainty analysis is aimed at quantifying the variation of this output over the space of all input parameter distributions. This quantification was achieved by drawing a Monte Carlo sample from parameter space. To ensure a balanced coverage of parameter space we used a replicated Latin hypercube design (Pleming and Manteufel, 2004). We drew 100 Latin hypercube samples, each of which contained 10 samples. Each of these cubes was designed to provide a balanced sampling from parameter space. In total, the analysis was thus based on 1000 parameter settings. For each of these settings the corresponding model output was obtained by running the model. The uncertainty of the model output that resulted from the uncertainties in all input parameter estimates was then expressed as a 95% tolerance interval based on the obtained output data.

16.4.3 Validation

Validation of indicators
Modelled species specific output maps were checked by experts of NGOs (SOVON: the Dutch Centre for Field Ornithology; the Vlinderstichting: Dutch Butterfly Conservation). The output of the first step of the MNP, habitat suitability maps, was compared to actual distribution maps of species. Although habitat suitability does not necessarily have to correspond with species occurrence, as suitable habitat may be (or seem) unoccupied due to local extinction and/or lack of colonization, unsuitable habitat may be (or seem) occupied due to extinction debt (Tilman et al., 1997) or observation of non-resident (dispersing) individuals. The output maps of the model were classified into 'good', 'moderate' and 'bad'. The expert judgement demonstrated that there is a sufficient match between modelled and empirical data for approximately 69% of the species considered by the MNP. The percentage of good models is the lowest for vascular plants; 59%. In policy assessments we only use those species for which the model output was judged as 'moderate' or 'good'. We also tested the validity of the final indicators by comparing model output against empirical measurements of the present state of biodiversity. In a first comparison, the species-based biodiversity indicator was compared against actual Red Lists of threatened species. The second test compared the spatially explicit output of the ecosystem-based biodiversity indicator against biodiversity hotspot maps in the Netherlands.

Model validation using Red list data
The modelled species-based indicator was compared against the current Red List status of the selected species (Van Swaay et al., 2010; Bilz et al., 2011; BirdLife International, 2015). The Red List status is a widely accepted way of indicating the probabilities of extinction of plant and animal species and is a frequently used indicator in nature policy (EEA, 2007). Criteria such as rate of decline, population size, area of geographical distribution and degree of fragmentation are used to classify Dutch Red List species into 5 groups (Maes & Van Swaay, 1997). These groups are 1) extinct in the Netherlands, 2) critically endangered, 3) endangered, 4) vulnerable, 5) sensitive and 6) non- threatened. It is expected that the 'persistent species' in the MNP model have larger population sizes and larger distribution areas. Therefore they are less affected by fragmentation than non-persistent species and are expected to generally be classified as less threatened according to the Red List.
For the Red list category of non-threatened species, the highest percentage of persistent species was modelled by the MNP, namely 60%. For the category of extinct species this percentage was only 5%. For the

in-between categories, the percentage of persistent species was found to gradually reduce from 59% to 47%, to 35% and finally to 21%. Wilcoxon signed-rank tests showed that the distribution of persistent and non-persistent species, according to the MNP over the Red List categories, differed significantly for all three taxonomic groups ($p<0.001$), with more threatened species within the non-persistent set.

Model validation using distribution data
The modelled ecosystem-based biodiversity indicator was compared to field data. National maps that indicate how many target species of certain habitat types are present – so-called hot-spot maps – were derived from nation-wide survey data provided by NGOs. Similarly to MNP output, they also were based on target species within the taxonomic groups of vascular plants, butterflies and breeding birds (Van Hinsberg et al., 2011). Habitat areas with modelled high values for ecosystem-based biodiversity indicators are generally expected to accommodate a larger number of species.
Pearson's Product-Moment Correlation confirms the expected positive correlation coefficients, which were found for 11 of the 12 ecosystems considered by the MNP. However, correlation coefficients were rather low and ranged from 0.2 to 0.66 (all significant at $p<0.01$), showing that hot spots based on occurrence could only be partially predicted by modelled 'community's richness in species' values.

Validation with monitoring data BHD
In addition, a comparison of model results with species conservation status from recent official monitoring reports has recently been made (Pouwels & Henkens, 2020). In the summarised assessments from the latest official monitoring reports, the modelled and measured figures are also very similar for both current and future status (Pouwels & Henkens, 2020). This is also true if the measurements only concern terrestrial nature.
Regarding of the order of magnitude of target coverage and the expected developments in achieving targets, the model-based indicator is similar to the statements based on measurements.

To what extent the model correctly estimates the status of habitat types remains unclear.
Validation is still difficult because measurements of the state of conservation of individual typical species are lacking.
However, measurements are available on the conservation status of habitat types (LNV, 2019b), but this dichotomous assessment provides little insight into the extent to which components vary (subtypes and typical species).

All in all, the statements from the model remain indications and not predictions. For this purpose, the model is an simplified representation of reality (Van der Hoek et al., 2017).

For more information, see Pouwels et al. (2017).

16.4.4 Overall assessment of model quality

The tests of the MNP (Sections 4.5 and 4.6) show that the model functions as expected. The technical changes did not cause any deviation in the results from the standard test file. Also, no errors were found when testing the added functionalities: the inclusion of acidification and the elaboration into a provincial indicator.

The species assessment shows that predicting suitable habitat is more difficult for plant species than for breeding birds and butterflies. This is mainly due to the level of detail of the input files. For many plant species, the input still contains too little detail, which can lead to a large overestimation. In addition, plant species may be present for long periods of time when the corresponding site is actually unsuitable (Vellend et al., 2006; Helm et al., 2006). Also, many plant species do not spread as quickly as butterflies and breeding birds. As a result, suitable habitats (expansions of nature areas) may not yet be colonised (Ozinga et al., 2005, 2009). This time-lag plays a role especially for plant species and there is a chance that the model shows a different picture than the current distribution pattern, causing the model to be assessed as 'poor' for this particular species. Incorporating processes such as time-lag requires not only historical information but also a method that incorporates species succession and dynamics (Wamelink et al. 2009, 2011a).

The validation of the aggregated data from the MNP 4.0 showed that there is a clear relationship between the rarity of species in the Netherlands and the sustainability predicted by the model. This enhances its usefulness for the application from the Nature Pact Evaluation. A second validation showed a weak relationship between provinces' interest in conserving species from the Birds and Habitats Directives according to the distribution of these species and the outcome of the MNP model. From the above it can be concluded that statements at a national level have greater significance than those at a provincial level. Back-casting is a validation option that has not been used any further. It may be possible to use old data to verify whether the model is predicting progress or decline for a species. This prediction can be compared to the trend of a species. For some species, these trends are also available at the provincial level. Research is currently taking place to set up these historical datasets.

The sensitivity analysis shows that there are hardly any differences from the results for the Model for Nature Policy 2.0 and that the recommendations for that model also apply to the MNP 4.0. This concerns a better rationale for the key area size and sustainability standard for plants. A reflection on the parameters for desiccation and fertilisation has already taken place during the development of the MNP 4.0.

16.5 Summary model quality and wishes for the future

See paragraph 1.3 for the explanation of the aspects. Also see chapter 20 for a summary of all status-A parts of all ecosystem services models.
Legenda: **complete**, partly (in)complete, incomplete.

16.5.1 Summary reliability

A. very high, **B. high, C. sufficient**, D. moderate, E. low

16.5.2 Summary completeness

Completeness: A. (almost) complete, **B. contains most important aspects**, C. contains some aspects.

16.5.3 Status A progress

ST.1: Model description
- **General description**
- **Description conceptual and formal model**

ST.2: Technical implementation
- **Implementation**
- **Technical environment**
- **Testing**

ST.3: Description parameters, variables, input and output
- **Parameters and variables**
- **Calibration**
- **Input and output**
- **Origin Input data**

ST.4Model functioning
- **Sensitivity analysis**
- **Uncertainty analysis**
- **Validation**
- **Monitoring of use**
- **General assessment**

Zie voor DO.5: modelontwikkeling, DO. 6: organisatie en IU.7: gebruikersdocumentatie hoofdstuk 19.

16.5.4 Future model development options

Wishes emerging from audit recommendations:

- The input files could be documented separately at level status A
- The validation could 1) look more deeply into the cause behind the differences between the datasets used and 2) explore alternative methods.
- The critical analysis could be explicitly linked back to the interaction between the model delineation, the validation results and the sensitivity analysis.

Wishes emerging from the use of the model:

- Due to the many issues involved in nitrogen and BHD, the model could be made more suitable for use in this domain.
- Climate change will also play an increasingly important role in whether or not nature goals can be achieved.
- The agricultural area, water and urban area could be added. For the agricultural area, MNP agricultural (Visser et al., 2019) could be used, and for water, some steps have already been taken.
- More species groups could be added, especially those included in the Birds and Habitats Directives and SNL.
- Statements could be made about the basic quality of nature.
- Automatic validation of the determination of management types of species could be added.

Wishes emerging from the technology:

- It is extremely important that the MNP be technically simplified to make it more accessible to a larger group of modellers at WENR.

For further information, see the external review of the model conducted in 2021 (Van Hinsberg et al., in prep.).

16.6 Literature

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17 Outdoor recreation

Inez Woltjer (WENR), Sjerp de Vries (WENR), Bart de Knegt (WENR)

17.1 Theoretical rationale

17.1.1 General description of model

AVANAR is a Dutch acronym that can be roughly translated as Alignment of Supply and Demand for Nature as a Recreation Space. The model confronts the local supply of recreational opportunities in a natural setting with the local demand for such opportunities. Based on the assumptions and key figures used, the model calculates where sufficient or insufficient local supply is present in the residential area. In particular, AVANAR has been developed and used for the recreational activities of hiking and biking. This report provides a more detailed description of AVANAR version 4.0. AVANAR 4.0 is based on the earlier version AVANAR 2.0. Version 2.0 has been described previously (De Vries et al., 2004; De Vries and Staritsky, 2016). The present report supplements previous documentation mainly in terms of technical details, input and output.

Scope
AVANAR is intended to gain insight into outdoor recreation on a national or regional scale with the aim of formulating the recreational challenge for area development (De Vries et al., 2004). For the area used in the analysis, it is advisable that the study area be buffered by at least twice the maximum standard distance chosen within the analysis (De Vries et al., 2004, para. 4.1.3).

17.1.2 Conceptual and formal model

To place the more technical components of AVANAR in context, we have provided a brief overview of the model. To begin with, we address below the various components of the conceptual model that underlies AVANAR (see Figure 17.1).

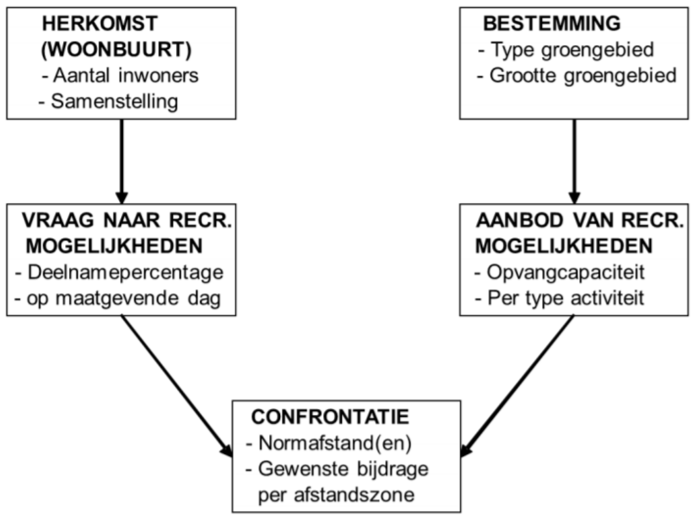


Figure 17.1 *Conceptual schematic AVANAR. On the one side is demand based on the number of residents in the neighbourhood and their demographic composition. On the other is supply based on the various types of natural/agricultural areas and the size of those areas. Supply and demand are compared to determine the extent to which local supply can accommodate local demand. Translation: Herkomst (Woonbuurt) aantal inwoners samenstelling = Origin (neighbourhood) number of inhabitants composition); Bestemming type groengebied, grootte groengebied = destination type of green area, size of green area; vraag naar recreatiemogelijkheden deelnamepercentage op maatgevende dag = demand for recreationareas participationpercentage decisive day ; aanbod van recreatiemogelijkheden opvangcapaciteit per type activiteit = supply of recreational opportunities collection capacity per activity type; confrontatie normafstand(en) gewenste bijdrage per afstandzone = confrontation standard distance(s) wanted contribution per distancezone.*

Determining local demand

To quantify the local demand for a given recreation activity, two pieces of information are needed: the size of the population per area of spatial origin and the percentage of that population that participates in that activity on the normative day – also known as the standard day. The standard day is defined as the fifth busiest day of the year. This means that sufficient local supply must still be available on that day. The fact that demand exceeds supply on the other four days is considered acceptable. In the standard analysis, the areas of spatial origin are based on the 100 metre x 100 metre grid cells used by the Central Bureau of Statistics (CBS). For each 100 metre x 100 metre grid cell, the number of inhabitants is known. Demand is determined by multiplying the national participation rate for the relevant recreation activity by the size of population in the relevant grid cell.

If desired, the local population can be segmented so that different participation rates can be used for each segment. This is particularly relevant if the distinct population groups have different spatial distributions in addition to different participation rates (De Vries, 1999). As these conditions are seen as appropriate here, two population segments are distinguished in the standard analysis: 1) Dutch natives/inhabitants with Western immigration background, and 2) inhabitants with a non-Western immigration background (De Vries et al., 2004, Appendices 1 & 2). For each CBS grid cell, the proportion of inhabitants with a non-Western immigration background is known. Segmentation involves adding together the demand from the various population groups. In spatial terms, the total demand from the grid cell is allocated to the centroid of the grid cell. In other words, it is assumed that everyone lives at the centre of that grid cell. This demand calculation is performed for all grid cells.

Determining supply

In the standard analysis, supply is primarily based on the Nature and Landscape Master File (see Chapter 3). The "other agricultural land use" category is broken down into six subclasses based on (a) the density of trails and roads on site and (b) the visual openness of the landscape on site. Visual openness is determined in AVANAR version 4 based on the occurrence of vertical natural landscape elements such as forests, hedges and wooded banks. Path density and openness are two factors that more generally play an important role in route-related activities such as hiking and cycling for assigning recreational capacity to a land-use category: the higher the path density and the more enclosed the area, the higher the recreational capacity. Based on these factors, forest and parkland therefore have the highest recreational capacity for hiking for example. Recreational capacity is expressed as the number of participants that one hectare of the area type in question can accommodate per day. A grid with 25 x 25 metre cells is then applied to the land-use file. A table defining the supply capacity per land use type (supply category) for the specific recreational activity is then used to 'translate' the land-use file into a recreational supply file.

Confronting local supply with demand
To determine whether sufficient local supply for a particular recreational activity is available, 'local' must first be defined. Standard distances are used for this purpose. In the standard analysis for hiking, the standard distance is 10 kilometres. In addition, 50% of the required capacity must be available closer to home – within 2.5 kilometres. The latter is called the short standard distance. After this, the capacity present in a supply grid cell is allocated among the 25-metre grid cells with recreation demand within the standard distances, first for the short standard distance. Allocation is proportional to the amount of demand from within the grid cell. Because a grid cell with recreation demand is 'offered' capacity from all supply grid cells within the standard distance, the sum of this supply may exceed the demand of that grid cell (for that standard distance). In that case, capacity is returned to the supply grid cell by the demand grid cell. This return is also proportional, but now according to what the demand grid cell received from the various supply grid cells. Then the second round starts for the short standard distance, and the process continues until there is no more significant change due to demand being met or no supply being available (iterative process). If too little supply for a demand grid cell was available within the short standard distance (<50% total demand), then the residual demand remains for the maximum standard distance of 10 kilometres (which thus exceeds 50% of total demand). A demand grid cell is never allocated more supply than it needs according to the standards used. The same process used for the short standard distance is then repeated for the maximum standard distance.

Assumptions and limitations
- Based on a set of normative assumptions, the model determines whether sufficient supply is available locally to meet local demand. Here the model limits itself to the quantitative confrontation of supply with demand.
- If the available capacity has been used and there is residual demand, then the model behaves as if this demand remains because no capacity is available to meet the demand.
- To determine local demand, the model uses the national participation rate (or an estimation of this rate) for the relevant recreation activity for the identified population group on the standard day.
- The recreational capacities allocated to land uses are normative choices and are not empirically based.
- In addition, the analysis uses direct line distances rather than road distances.

More information can be found in Section 1.3 of De Vries and Staritsky, 2016.

17.2 Technical implementation

17.2.1 Implementation model

Below is a brief description of the computational process that takes place after the AVANAR analysis is launched, in 10 steps (see also Figure 17.2. The letters in the description refer to that flowchart, where S stands for Supply grid and D stands for Demand grid.

1. For each supply grid cell, all requested capacity within the respective standard distance is summed (◇ S2).
2. This summed demand is subtracted from the available supply (◇ S3).

2.a If the summed demand exceeds the supply, then the remaining supply is set to 0 (S3 = 0).

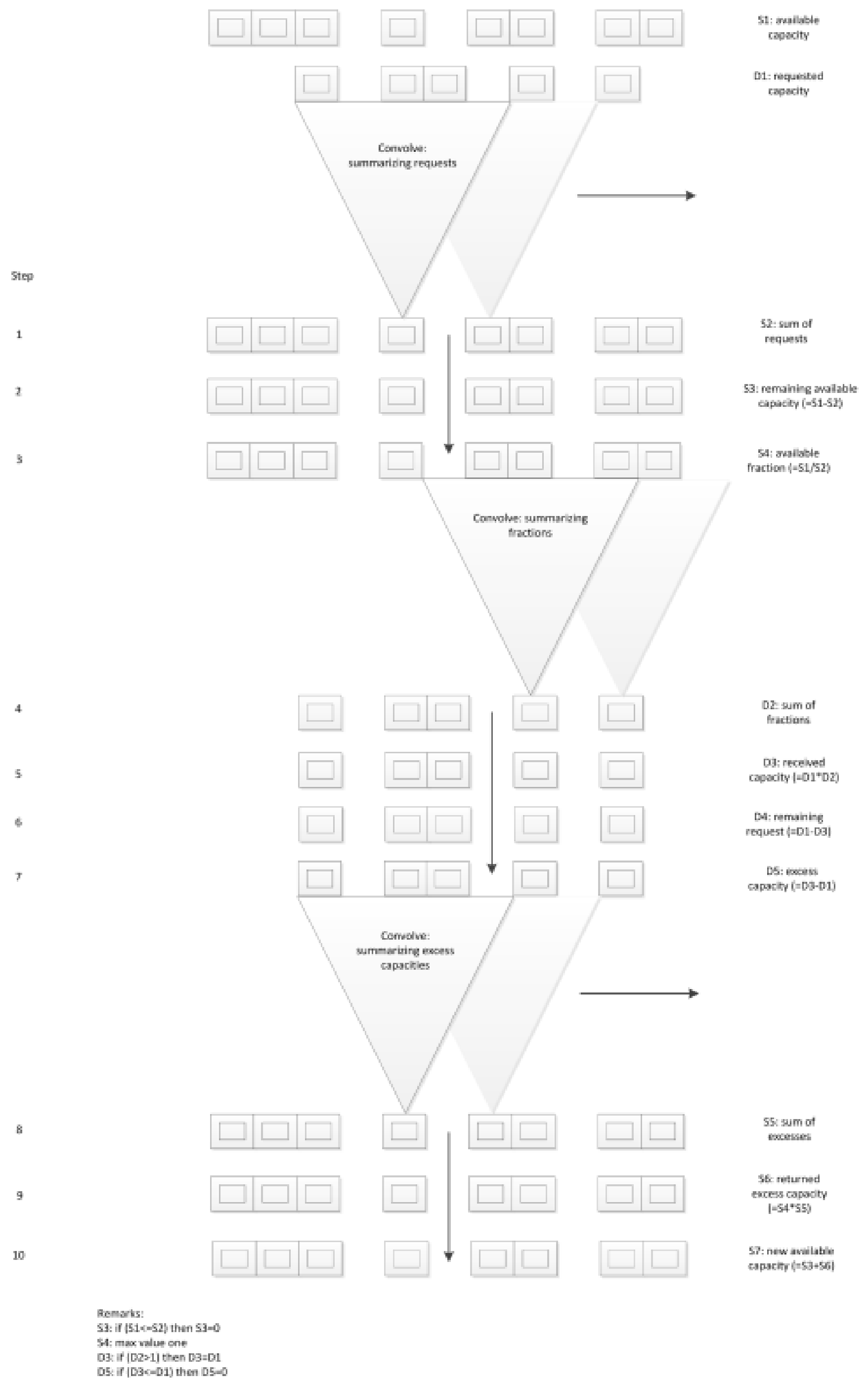
3. The fraction of the required capacity that can be allocated from the supply grid cell is determined (◇ S4).

3.a If the summed demand does not exceed the capacity of the supply grid cell, the requested capacity is made available to the respective demand grid cells (S4 = 1)

4. For each demand grid cell, the fractions of available capacity from the various supply grid cells are summed (◇ D2)

5. The received capacity is calculated (◇ D3)
5.a If the capacity received is greater than the demand, then it is reduced to the demand (D3 = D1). Note: this is done only after step 7 (in connection with determining the capacity to be returned).
6. The remaining demand is determined (◇ D4)
7. The excess capacity received is determined; this must be returned to the relevant supply grid cells (◇ D5)
7.a If the capacity received is less than the demand, then there is nothing to return (D5 = 0)
8. The sum of capacities to be returned is determined per supply grid cell (◇ S5)
9. How much of this returned capacity the supply grid cell may claim is determined; this is proportional to the contribution of this supply grid cell (◇ S6)8
10. The supply grid cell capacity still available for the next round is determined (◇ S7)
    A second allocation round starts at Step 1, but now with the remaining capacity (S7) and remaining demand (D4; the latter for the relevant standard distance). This process is repeated until there is no more capacity to allocate (no more supply capacity to allocate anywhere within this standard distance, or the demand is fully accommodated everywhere).

After this, the process is repeated for the next (larger) standard distance. If not enough capacity was available in the previous earlier round (for the smaller standard distance) to meet the demand share for that standard distance, then the unmet demand is included in the next standard distance.



17.2.2 Technical environment

The AVANAR model has been programmed in Python (Python 3.9.1) and uses PCRaster (version 4.3.0), Rasterio (version 1.1.8), Pandas, Numpy and Gdal. An avanar_4.yml file is available in git (https://git.wur.nl/Woltj002/avanar_4_ict_schil), that can be used to reproduce the exact conda-environment used in the simulations.

17.2.3 Testing

The test set is described in Chapter 3 of De Vries and Staritsky (2016). This test was not performed for version 4. However, tests were done with a test set for part of North Holland, including Amsterdam, and with the entire national map with both version 2 and version 4. The results of version 4 were compared with previous versions and they were consistent. This test set with the results are available on Github (https://git.wur.nl/Woltj002/avanar_4_ict_schil).

17.3 Input and output, Parameters and variables

17.3.1 Parameters and variables

- Demand for recreation
  - Participation rate per population group
  - Number of inhabitants
  - Migration background of residents
- Supply of natural/agricultural recreation areas
  - Recreational visitor capacity of various types of nature
    - Areas closed to recreation (e.g., inaccessible areas such as military sites).
  - Recreational visitor capacity of agricultural area
    - Path density
    - Visual openness
  - Standard distances for hiking.

Pre-processing of files
The above files are used to create a supply map for hiking based on the recreational visitor capacity of various types of nature. The file of areas closed to recreation is used to zero out the recreational capacity in those areas. The path density and visual openness files are used to subdivide the recreational visitor capacity of the remaining agricultural area into six classes (three classes of path density combined with two classes of visual openness).

17.3.2 Calibration

A calibration has not been performed.

17.3.3 Input and output

Demand
- GIS files with population density and composition (source) Statistics Netherlands (CBS):
  Grid (25 m), number of people per grid cell, integer or float, geotiff format (.tif)
  - all2017_25_nl_LZW.tif: numbers of inhabitants – non-Westerm immigration background, CBS data 2017
  - aut2017_25_nl_LZW.tif numbers of inhabitants – Dutch natives, CBS data 2017

Supply
- GIS file with landscape, expressed in values for hiking capacity.
  Grid (25 m), number of people who can hike per grid cell, float, geotiff format (.tif)
  - supwan_v4_25_LZW.tif: landscape, recreation capacity for hiking (number of people per 25 m) (derived from grid *Huidig_Avanar_SuitWandelen_18102021.tif (10m), result of pre-processing. See explanation below)*
- Standard distances, used for hiking. It is assumed that within a distance of 2500 metres, 50% of the inhabitants who want to hike (who "have demand") find the space to do so ("there is supply from the landscape"), and that the other 50% find hiking space further away – outside the first ring – at a maximum distance of 10,000 metres

Output
- GIS file showing demand for walking capacity in the living environment
  Grid (125 m), number of people per grid cell, integer, geotiff format (.tif)
  - grdem_ag_int_WAN_Huidig_INT.tif: number of inhabitants * participation percentage
- BCWAN1_Huidig.tif: Available capacity within first ring (= demand is met). Grid (125 m)

- BCWAN2_Huidig.tif: Available capacity within second ring (= demand is met). Grid (125 m)
- RVWAN_Huidig.tif: Remaining demand (number of people whose demand is not met). Grid (125 m)
- AVANAR_result_WAN_Huidig.csv:
  Table information with a selection of results from the above four output grids in separate columns. The selection consist of grid cells in which a deficit was found (RVWAN > 0):
  - x, y: coordinates of the centre of 125 m grid cell
  - grdem_ag_int_WAN: number of people who want to hike (demand = number of inhabitants x participation percentage.)
  - BCWAN1: Available capacity in first ring (2500 m)
  - BCWAN2: Available capacity second ring (10,000 m)
  - RV: Remaining demand
- AVANAR_Scen_1.txt: Calculation of percentage of inhabitants whose demand is not met

Calculation of percentage of inhabitants whose demand is not met:
- Demand: grdem_ag_int_WAN_Huidig_INT.tif: TOTAL DEMAND for hiking capacity, expressed as the number of people who want to hike (per 125 m^2) = 1,844,367 (see vat.table. "NUMBER" = "value" * "count"), sum of "NUMBER" for all of the Netherlands)
- Unmet demand: AVANAR_result_WAN_Huidig.csv: UNMET DEMAND, portion of TOTAL DEMAND for which remaining demand is >0. SUM of column "grdem_ag_int_WAN" = 477,909
- Percentage unmet demand = (UNMET DEMAND/TOTAL DEMAND) * 100
  - percentage without unmet demand = 100 - percentage unmet demand
  - (477,909/1,844,367) * 100 = 25.9 percentage of people who have unmet demand (for hiking capacity in their living environment)

17.3.4 Standard indicators

Supply
Supply of natural and agricultural areas for recreation.

Demand
Demand for sufficient space for recreation (hiking) from places where people live.

Combination of supply and demand
percentage of people with a demand for recreation with sufficient natural/agricultural space in their living environment.

See also Table 1.1.

17.4 Evaluation model functioning

17.4.1 Sensitivity analysis

Sensitivity analyses were performed for version 1.3 of AVANAR (De Vries et al., 2004, H5). These analyses looked at standard day/participation rates, recreational capacity per land-use class, standard distances and share per standard distance.

These previous analyses showed that AVANAR results are highly sensitive to the participation rate used and the recreational capacity of agricultural land in particular, and somewhat less sensitive to the selected standard distances and share per standard distance.

For more information, see Section 3.1 of De Vries and Staritsky (2016).

17.4.2 Uncertainty analysis

No quantitative uncertainty analysis (calculation of confidence intervals) has yet taken place.

17.4.3 Validation

De Vries et al. (2014) found that large unmet demands for hiking possibilities in natural/agricultural areas within 2.5 km are associated with 20% fewer recreational hikes requiring at least an hour of travel away from home; this percentage becomes even higher when looking specifically at walks in green, natural surroundings. Indeed, people with such a high unmet demand were more likely to walk in their own neighbourhood or in the city centre. Previous research, based on a precursor to AVANAR in which a single standard distance of 5 km was used in the calculations, showed that larger calculated hiking deficits are associated with being less able to find peaceful and spacious surroundings outside the residential environment (De Vries et al., 2004b, H5). This supports the hypothesis about the influence of unmet demands on the quality of the recreational experience. Sijtsma et al. (2012) found that large unmet demands for hiking within 2.5 km are associated with about 25% more vacation days per year during which people spend the night away from home. It should be noted, however, that in that study it was not possible to determine whether that extra vacation time away from home was also spent in greener surroundings. Previous research (De Vries et al., 2004b, H5) had found that when there is a large deficit of hiking opportunities in natural/agricultural areas, people are more likely to have a permanent recreational accommodation elsewhere, such as a holiday home, a modular home or an allotment house where overnight stays are allowed. These two findings support the hypothesis of compensatory behaviour.

In summary, in most cases there are significant and meaningful relationships between the calculated unmet demands and the adverse effects one would expect in the case of actual unmet demands. Consequently, the standard AVANAR analysis appears to generate informative results.

17.4.4 General assessment of model quality

The previous version of AVANAR has an A Status. This version described here is no different in content, but has been reprogrammed. The outcomes of the old version and the new version were compared. The differences between versions were mainly due to improved input files. Especially for the supply of recreational sites, the current file is an improvement.

17.5 Summary model quality and wishes for the future

See Section 1.3 for an explanation of the aspects.
Legend: **<u>complete</u>**, <u>partially complete</u>, missing.

17.5.1 Reliability

A. very high, B. high, **C. adequate**, D. moderate, E. low

17.5.2 Completeness

Completeness: A. complete or nearly complete, **B. contains the most important aspects, C. contains some aspects.**

17.5.3 Status A progress

ST.1: Model description
- **<u>General description</u>**
- **<u>Description of conceptual and formal model</u>**

ST.2: Technical implementation
- **<u>Implementation</u>**
- **<u>Technical environment</u>**
- **<u>Testing</u>**

ST.3: Description of parameters, variables, inputs and outputs
- **<u>Parameters and variables</u>**

- Calibration
- **Input and output**
- **Origin of input data**

ST.4: Model functioning

- **Sensitivity analysis**
- Uncertainty analysis
- **Validation**
- **Monitoring usage**
- General assessment

See for DO.5: model development, DO. 6: organisation and IU.7: user documentation Chapter 20.

17.5.4 Future model development options

- In addition to recreational visitor capacity, it is also important to include the attractiveness of nature for this ecosystem service.
- Empirically determine the recreational visitor capacities of different types of nature.
- In addition to day recreation, include overnight stays and tourism from abroad.
- CICES (Haines-Young & Potschin, 2013) divides cultural services into four parts. The first two involve physical and experiential interactions. This involves experiencing plants, animals and seascapes and landscapes. Examples mentioned include hiking, boating, sport fishing, hunting, whale and bird watching, snorkelling and diving. In this chapter, we looked only at hiking. Although this is by far the most important form of recreation (NBTC-NIPO, 2013), it is not complete.

17.6 Literature

NBTC-NIPO Research (2013), Continu vrijeTijdsonderzoek 2012-2013, Den Haag: NBTC-NIPO Research.

Sijtsma, F. J., De Vries, S., Van Hinsberg, A & Diederiks, J. (2012). Does 'grey' urban living lead to more 'green' holiday nights? A Netherlands Case Study. Landscape Urban Plan., 105(3), 250-257. http://www.sciencedirect.com/science/article/pii/S0169204611003720

Vries, S. de (1999). Quick recreation demand assessment at the local level; the Dutch experience. World Leisure & Recreation, 41(1), 15-19. http://dx.doi.org/10.1080/10261133.1999.9674136

Vries, S. de, Hoogerwerf, M. & Regt, W.J. de (2004). AVANAR: een ruimtelijk model voor het berekenen van vraag-aanbodverhoudingen voor recreatieve activiteiten; basisdocumentatie en Sensitivity analysiss. Alterra-rapport 1094. Wageningen: Alterra. http://edepot.wur.nl/42511

Vries, S. de, Hoogerwerf, M. & Regt, W. (2004b). Analyses ten behoeve van een Groene Recreatiebalans voor Amsterdam; AVANAR als instrument voor het monitoren van vraag- en aanbodverhoudingen voor basale openluchtrecreatieve activiteiten. Alterra-rapport 988. Wageningen, Alterra. http://edepot.wur.nl/31113

Vries, S. de, Goossen, M. & de Knegt, B. (2014). Groene recreatie in de leefomgeving. In: De Knegt, B. (Red.), Graadmeter Diensten van Natuur; vraag, aanbod, gebruik en trend van goederen en diensten uit ecosystemen in Nederland. WOt-rapport 13. Wageningen: WOT Natuur & Milieu, WUR
http://edepot.wur.nl/323172

Vries, S. de & I.G. Staritsky (2016). Recreatiemodel AVANAR 2.0 nader beschreven en toegelicht; Achtergronddocumentatie voor Status A. Wettelijke Onderzoekstaken Natuur & Milieu, WUR. WOt-technical report 80. 44 blz.; 3 fig.; 5 tab.; 11 ref; 5 Bijlagen.

18 Food and fodder production

Bart de Knegt (WENR)

There are no credible models for the Netherlands available yet estimating food production as an ecosystem services. Currently, models are available for agricultural production based on soil, groundwater, climate, and crop type (e.g., *Waterwijzer Landbouw, IMAGE-GLOBIO*), however this raises the question of what share the ecosystem has in producing food outside human inputs such as labour, capital and knowledge. In the future we intend to determine food production by the provision of the underlying regulatory ecosystem services (also called intermediate ecosystem services): soil fertility, pest suppression, pollination, and erosion. In this way, no double counting of ecosystem services occurs. After all, the contribution of ecosystems to the production of food consists of the product of the intermediate regulatory ecosystem services as mentioned above. As an example, we can take the production of apples. First of all, good soil fertility is necessary for apple trees to be able to produce apples. If the soil fertility is not limiting, the flowers of the apple tree need to be pollinated, otherwise no apples will grow on the tree. If these conditions are met, then apples should not be affected or eaten by pests and diseases. Finally, it is also necessary to ensure that the apple trees are not destroyed due to water or wind erosion.

19 Model development, organisation and user documentation

Bart de Knegt (WENR), Levi Biersteker (WENR), Rene Jochem (WENR), Janien van der Greft (WENR)

19.1 Model development

19.1.1 Development plan

Development plan
For the model as a whole, there is a development plan. For each model, there is also a development plan with components we would like to address. The development plans for each model are described in the relevant chapters. Here, we elaborate on the development plan for the model as a whole.

Discussions were held with both the model developers and the client (PBL) regarding wishes for further development of the NC-Model. On 1 November 2021, discussions were held at PBL with leaders of the most important PBL products. Their wishes were as follows:

Technology
- Making the model operational for requested applications.
- Technically streamlining the model so that it can be easily rotated (with a push of a button).
- Making the model available to PBL by working with Microsoft Azure Platform cloud computing and Virtual Machines.
- Testing the model

Using the model
- To make the model suitable for uses such as the Nature Outlook and Agricultural Nature Outlook, the Nature Pact Evaluation (research in transition zones), The Nature Balance (especially the Nature Services Indicator), the *Ruimteverkenning* (linking with the *Ruimtescanner*), calculating the effects of election programmes of political parties and for monitoring and assessing thematic issues (e.g. NOVI and landscape policy).

Quality
- Make the model scientifically robust by obtaining quality status A.
- Publish the model in an academic journal.
- Enhance and qualitatively improve a number of ecosystem service models (especially agriculture-related ecosystem services such as food production and pest suppression) and carbon sequestration.
- Perform sensitivity analyses.
- Perform uncertainty analyses.

Current situation
In 2021, work was done on the following:
- Making the content of the ecosystem service models more credible.
- Developing a shell so that all the individual ecosystem service models can be run easily.
- Preparing the instrumentation to share with PBL (AZURE and Virtual Machines)
- Organising the input maps.
- Reporting according to status A standards.

For 2022, financial resources are available to continue working on items 1 through 7. Action plans for these components will be finalised by January 2022

19.1.2 Version control

Version control of the individual models is arranged through wurgithub. Version control of the ICT shell is done via TortoiseSVN. The development versions of the individual ecosystem services models and adaptations of the ESDShell are also on the wurgithub, but will only be included as production versions if approved. Acceptance criteria also apply to models that use final results from other models (e.g., the forest carbon sequestration model uses inputs from the wood growth model). In addition, changes to the ICT shell (Chapter 2) must also be approved based on acceptance criteria. However, acceptance criteria for this agreement have not yet been adopted. Acceptance criteria include explicit discussions of changes and tests to determine the consequences of the new version for the final outcomes, but the criteria have not yet been formalised.

19.2 Model Organization

19.2.1 Metadata

Field Name	Value (please enter a value in each cell)
Name of the Model	NC-Model/NC-Model
Literature Reference	De Knegt et al. in prep.
Model Location	https://git.wur.nl/
Subject & Purpose	The NC-Model calculates supply and demand for goods and services and determines the contribution of ecosystems to this process, such as the pollination of agricultural crops. Inputs for ecosystem services in the NC-Model include land-use maps, soil maps, and maps with groundwater levels, acidity, and nitrogen deposition. In the NC-Model, these ecosystem service calculations are brought together in a single shell (the ecosystem servicesDshell). The model has three main uses: 1) Determining the current state of ecosystem services, 2) Determining the effects of scenarios, 3) Determining where interventions help to achieve societal tasks through ecosystem services.
Method	A set of ecosystem service models that look at the demand for goods and services and the supply from ecosystems. For the individual ecosystems, supply is determined using underlying models. The NC-Model shell brings together the results of these models in table and map form.
Accuracy	Statements about the supply of and demand for ecosystem services can be made at the national level and regional level. It is still unknown to what extent the results are reliable at lower scale levels.
Scope	The Netherlands and regions within it; statements can possibly be made at a lower level.
Status of the Model	In development
Keywords (semi-colon separated)	ecosystem services; demand; supply; use
Illustration picture	https://www.google.com/search?q=ecosysteemdiensten+in+nederland&rlz=1C1GCEA_enNL886NL886&sxsrf=AOaemvLaq4bcVObd-0RtlR1spnbJ8-240g:1637070965213&source=lnms&tbm=isch&sa=X&ved=2ahUKEwiMrOnKhJ30AhVM-aQKHc-KBQIQ_AUoAXoECAEQAw&biw=1097&bih=535&dpr=1.75#imgrc=AirRweY-HqYqcM
Contributors (WUR)	Bart de Knegt, Levi Biersteker, Michiel van Eupen, Nanny Heidema, Rene Jochem, Marjolein Lof, Hans Roelofsen, Inez Woltjer
Contributors (external)	Ton de Nijs, Remon Koopman, Martina Paulin (RIVM)
Name of the Project	Natuurlijk Kapitaal Model – NC-Model
Development Environment (Programming Language)	primarily open source software (especially Python)
Platform	Python

Field Name	Value (please enter a value in each cell)
Auxiliary software	Python
File Format	.py
Version Number	1.0
Availability outside WUR	Yes, for PBL, consortium parties and other interested parties.
Modification Date	1-1-2022
Contact person:	Bart de Knegt (WUR)
Restrictions on use (legal or otherwise)	no
Costs to use	Internal: costs for MS Azure
Licenses	no
Remarks	

19.2.2 Management plan

The WENR project team is responsible for content, development and management.

Regular contact takes place with PBL, CBS, RIVM and other research institutes for the harmonisation and coordination of models and data. This coordination should eventually lead to as many of the same results and messages about ecosystem services from the aforementioned institutes as possible, but the responsibility of statements lies with the institutes that make them. WENR is the owner the NC-Model as developed at WENR. In time, all research institutes can work towards an NC-Model that is completely harmonised, but there is still a need to discuss whether this is desirable based on the various objectives and responsibilities of these institutes.

WOT funds the project through PBL and LNV, so PBL is co-owner of the model. Funding for development and management is on a project basis and is therefore ad hoc. This poses a risk to sustaining the model for the long term.

Ideally, the development of the model should be divided into four parts:

- Substantive development
  - Improve the individual ecosystem service models.
  - ESDShell development.
- The use of the model in projects
  - Ideally, the model should be used in a separate project so that model use does not interfere with model development.
- Technical maintenance
  - Ensure that the model continues to work technically.
  - Version control
- Strategic Overview
  - The choice of the of the direction of the model, its uses and its results.

19.2.3 Dependencies and relationships with other models or data sets

The availability and quality of the input maps needed to run the model are not part of the NC-Model itself. These include input maps for the current situation and maps for scenarios. These maps are needed to run the model. However, the question is whether there are critical sources that can be used to estimate the reliability of those maps. And perhaps agreements should be made about the continuity of supply of these maps. It might be a good idea to examine whether and where there are risks in data provision.

Internally, there is a dependence on the forest carbon sequestration model, and the production of biomass for energy generation from forest sources depends on the wood growth model. Thus, the results of the wood growth model must be run first in order to run the other two models.

The *Waterwijzer Landbouw* (WWL) model is part of the NC-Model, but is not included in its ICT shell. The input maps for all other models are harmonised with the WWL. In this sense, the model has been made consistent in terms of statements. Status A was recently awarded for the underlying calculation algorithm of the WWL (SWAP-WOFOST).

PBL can use the model results for WOT products.

19.2.4 External use

Yes, by PBL, the consortium parties and other interested parties.

19.3 User Documentation

19.3.1 Interpretation of results

Interpretation of the results is not easy and cannot be described in a straightforward manner. The standard procedure is for one of the members of the development group to be involved with the interpretation of the results.

At its core, the results always relate to the demand for the goods and services and the supply from ecosystems. This results are expressed as a percentage, because the units per ecosystem service are always different. This ensures comparable presentation of results across all ecosystem services. In a number of cases, the ecosystem service must be supplied at locations where there is a corresponding demand. This is especially the case for regulatory and cultural services, with the exception of natural heritage and carbon sequestration. Production services do not have to be supplied at the locations where there is a corresponding demand. In this case, the demand is determined by national demand. In case of model runs in which both demand for and supply of goods and services change, a comparison with the current or reference situation is more difficult.

Work is also ongoing to express the results in other ways besides relating demand to supply. This makes it possible to represent ecosystem services in biophysical terms as well. In addition, results can be displayed on a land area or per capita basis depending on the ecosystem service. Calculating outcomes in multiple indicators can provide greater insight into the model results, assuming the interpretation is correct.

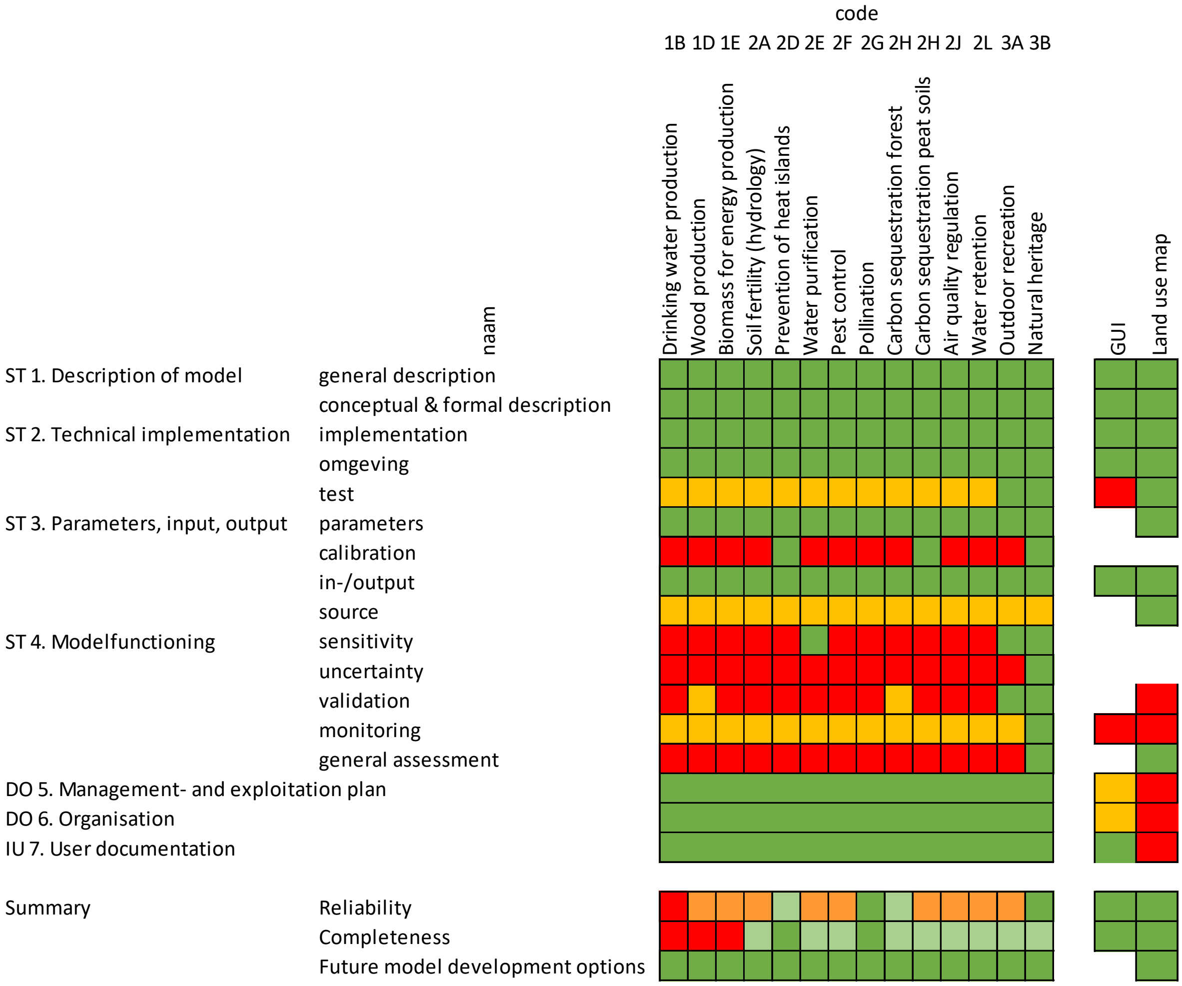
In time, it will also be possible to display results of uncertainties and sensitivities. Even then, it is important to interpret and use them correctly.

19.3.2 User manual

The ESDShell is explained in Chapter 2. The dynamic technical documentation with dependencies is available in a separate document. This contains a wiki that is generated on the fly and thus generates the most up-to-date documentation. This wiki is primarily aimed at model developers. In time, this wiki will replace technical reporting. It was used to develop documentation for three ecosystem services. In time, the reporting should be included for all ecosystem services.

20 Status A Self-assessment summary

The data presented here on the self-assessment status A is taken from the underlying chapters. An official self-assessment has not yet taken place with the audit committee. The data below can thus be considered as a first step towards a self-assessment. Here, it is especially important that we work towards obtaining status A for the whole as we go along.



21 Other benefits of nature

The ecosystem services currently presented are not an exhaustive list that would ideally be included in the NC-Model (see Section 1.1.3). Some institutes also include services driven by abiotic processes such as energy from wind, solar, or geothermal sources or the supply of raw materials such as sand, gravel or precious metals.

Besides providing useful goods and services for people, green spaces provide other benefits. We can classify these benefits as human well-being indicators. RIVM and WUR have developed a number of indicators for this purpose. The maps made in scenarios for the Nature Outlook 2050, for example, are also suitable as inputs to these models and can be used to calculate other benefits. These are the following indicators:

- Avoided GP visits as a result of green space in the living environment
- Reduction in premature deaths due to increased cycling to and from work through green spaces
- Reduced risk of obesity due to more exercise as a result of more green space in the environment.

In addition, a number of parties including CBS and WU are working on methods to express ecosystem services in monetary values. The standards developed for this purpose by the UN in the context of natural capital accounts (system of environmental accounting) are still under development (https://seea.un.org/).

Justification

WOt technical report 236
BAPS project number: WOT-04-011-037.08

This project was supervised by Wim Nieuwenhuizen (WENR) and Clara Veerkamp (PBL). The methodology was coordinated with them. Furthermore, the method was discussed with experts from RIVM, Statistics Netherlands and WU. All the chapters were reviewed by one or more experts.

The authors would like to thank everyone for their contribution to this report.

Approved by external contact person

job title: Researcher Environmental Science

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date: 18-01-2023

Approved by internal contact person

name: Wim Nieuwenhuizen

date: 10-1-2023

Annex 1 Land cover look-up tables

LU 1 in model scheme.
The Look-up and reclass table depends on the type of land cover input map.
Examples of land cover maps and the reclassification (that are used in separate model runs):

- Land cover/ecosystem functional unit (LCEU)
- Top10/Top10NL/Basisregistratie Topografie (BRT)
- Forest type cover

A1.1 Look-up table LCEU

Example a of legend of the LCEU land cover map;
Input map for model runs and specific scenario of which the actual wood production was calculated.

Table A1.1 *Look-up table land cover type to forest type (left) and the land cover legend (right)*

Land cover class id	Forest type id
1	0
2	0
3	0
4	0
5	0
6	0
21	2
22	3
23	1
24	0
25	0
26	0
28	0
29	0
31	0
41	0
42	0
43	0
44	0
45	0
46	0
47	0
48	0
51	0
54	0
92	0
113	0

land cover class id	Land cover class description (dutch)
1	Eenjarige gewassen
2	Meerjarige gewassen
3	Kassen
4	Weiland
5	Faunarand
6	Bebouwd erf
21	Loofbos
22	Naaldbos
23	Gemengd bos
24	Heide
25	Zandverstuivingen
26	Zoetwater wetlands
28	Openbaar groen
29	Overig onverhard terrein
31	Uiterwaarden
41	Woongebied
42	Kantoren en bedrijven terrein Industrie
43	Kantoren en bedrijventerrein Diensten
44	Kantoren en terreinen Overheid
45	Wegen, parkeerterreinen, vliegvelden en overig verhard terrein
46	Kantoren en bedrijven terrein bosbouw
47	Kantoren en bedrijven terrein visserij
48	Kantoren en bedrijven niet commerciële dienstverlening
51	Zee
54	Water
92	Overig bouwland BRP
113	Overig bouwland BRT

Land cover class id	Forest type id
114	0
127	0
142	0
143	1
144	0

land cover class id	Land cover class description (dutch)
114	Overig grasland BRT
127	Overige openbare voorzieningen BBG_22
142	Overig agrarisch BBG_51
143	Overig bosterrein BBG_60
144	Overig droog natuurlijk terrein BBG_61

A1.2 Look-up table Top10

Table A1.2 *Look-up table Top10 (2019) (wood production id's)(left) and the legend (right)*

top10 TDN or visualisation id	Forest type id
-14080	2
-14060	1
14060	1
14062	1
14070	2
14080	2
14082	2
14090	3
14110	3
14170	2
14175	2
Other id’s	0

Value	Omschrijving
-14080	bos: loofbos
-14060	bos: gemengd bos
14060	bos: gemengd bos
14062	bos: gemengd bos, op vast deel van brug
14070	bos: griend
14080	bos: loofbos
14082	bos: loofbos, op vast deel van brug
14090	bos: naaldbos
14110	dodenakker met bos
14170	populierenbos
14175	populierenbos, met riet
Other id’s	Non-forest cover types

For more information (in Dutch):
https://www.geobasisregistraties.nl/basisregistraties/topografie
https://www.pdok.nl/introductie/-/article/basisregistratie-topografie-brt-topnl

A1.3 Look-up table Forest type map

A land cover map can be pre-processed to Forest type land cover map which becomes the input map. Because the model expects a land cover map and according look-up table. In that case of an Forest cover and type input raster (with the correct forest type id’s), a one-to-one look-up table is needed.

Table A1.3 *Look-up table land cover forest type to forest type (left) and forest type legend (right)*

land cover class id	Forest type id
0	0
1	1
2	2
3	3

forest type (id)	forest type (description)
1	mixed wood
2	deciduous
3	coniferous

Annex 2 Look-up tables soil texture (LU 3 and 4)

The look up table for reclassifing BOFEK units (input map) to Texture class (alternative input map), Texture group (Annex 1, LU 4) and Texture type (Annex 1, LU 3).

BOFEK Code (input map)	Texture class code	Texture class name	Texture class id (optional input prepartion)	Texture group	Texture group id (Appx 1, LU 4)	Texture type	Texture type id (Appx 1, LU 3)
101	V	peat	7	peat and sandy soils	1	Heavy	1
102	V	peat	7	peat and sandy soils	1	Heavy	1
103	V	peat	7	peat and sandy soils	1	Heavy	1
104	V	peat	7	peat and sandy soils	1	Heavy	1
105	V	peat	7	peat and sandy soils	1	Heavy	1
106	V	peat	7	peat and sandy soils	1	Heavy	1
107	V	peat	7	peat and sandy soils	1	Heavy	1
108	V	peat	7	peat and sandy soils	1	Heavy	1
109	V	peat	7	peat and sandy soils	1	Heavy	1
110	V	peat	7	peat and sandy soils	1	Heavy	1
201	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
202	E	clay	2	(heavy) clay soils	4	Heavy	1
203	V	peat	7	peat and sandy soils	1	Heavy	1
204	V	peat	7	peat and sandy soils	1	Heavy	1
205	Z	sandy	8	peat and sandy soils	1	Light	2
206	Z	sandy	8	peat and sandy soils	1	Light	2
301	Z	sandy	8	peat and sandy soils	1	Light	2
302	Z	sandy	8	peat and sandy soils	1	Light	2
303	S	loamy sand soils	5	loamy sand soils	2	Light	2
304	Z	sandy	8	peat and sandy soils	1	Light	2
305	Z	sandy	8	peat and sandy soils	1	Light	2
306	Z	sandy	8	peat and sandy soils	1	Light	2
307	S	loamy sand soils	5	loamy sand soils	2	Light	2
308	S	loamy sand soils	5	loamy sand soils	2	Light	2
309	Z	sandy	8	peat and sandy soils	1	Light	2
310	Z	sandy	8	peat and sandy soils	1	Light	2
311	Z	sandy	8	peat and sandy soils	1	Light	2
312	S	loamy sand soils	5	loamy sand soils	2	Light	2
313	S	loamy sand soils	5	loamy sand soils	2	Light	2
314	S	loamy sand soils	5	loamy sand soils	2	Light	2
315	S	loamy sand soils	5	loamy sand soils	2	Light	2
316	S	loamy sand soils	5	loamy sand soils	2	Light	2
317	S	loamy sand soils	5	loamy sand soils	2	Light	2
318	S	loamy sand soils	5	loamy sand soils	2	Light	2
319	S	loamy sand soils	5	loamy sand soils	2	Light	2
320	Z	sandy	8	peat and sandy soils	1	Light	2

BOFEK Code (input map)	Texture class code	Texture class name	Texture class id (optional input prepartion)	Texture group	Texture group id (Appx 1, LU 4)	Texture type	Texture type id (Appx 1, LU 3)
321	S	loamy sand soils	5	loamy sand soils	2	Light	2
322	Z	sandy	8	peat and sandy soils	1	Light	2
323	Z	sandy	8	peat and sandy soils	1	Light	2
324	Z	sandy	8	peat and sandy soils	1	Light	2
325	S	loamy sand soils	5	loamy sand soils	2	Light	2
326	Z	sandy	8	peat and sandy soils	1	Light	2
327	Z	sandy	8	peat and sandy soils	1	Light	2
401	E	clay	2	(heavy) clay soils	4	Heavy	1
402	E	clay	2	(heavy) clay soils	4	Heavy	1
403	E	clay	2	(heavy) clay soils	4	Heavy	1
404	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
405	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
406	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
407	E	clay	2	(heavy) clay soils	4	Heavy	1
408	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
409	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
410	E	clay	2	(heavy) clay soils	4	Heavy	1
411	E	clay	2	(heavy) clay soils	4	Heavy	1
412	E	clay	2	(heavy) clay soils	4	Heavy	1
413	E	clay	2	(heavy) clay soils	4	Heavy	1
414	E	clay	2	(heavy) clay soils	4	Heavy	1
415	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
416	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
417	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
418	E	clay	2	(heavy) clay soils	4	Heavy	1
419	E	clay	2	(heavy) clay soils	4	Heavy	1
420	E	clay	2	(heavy) clay soils	4	Heavy	1
421	E	clay	2	(heavy) clay soils	4	Heavy	1
422	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
501	E	clay	2	(heavy) clay soils	4	Heavy	1
502	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
503	U	heavy clay soils	6	(heavy) clay soils	4	Heavy	1
504	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
505	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
506	L	sandy loam soils	3	(sandy) loam soils	3	Heavy	1
507	A	loam soils	1	(sandy) loam soils	3	Heavy	1

Annex 3 Groundwater levels

The look up tables for reclassifying mean highest and lowest groundwater levels into (13) groundwater classes.

Table A3.1 *The look up tables (Annex. 1, (LU 6 and 7) for reclassifying the mean highest and lowest groundwater tables to a groundwater level class.*

GHG	GHG class
<-1,10]	1
<10,20]	2
<20,30]	3
<30,40]	4
<40,50]	5
<50,60]	6
<60,70]	7
<70,80]	8
<80,90]	9
<90,100]	10
<100,110]	11
<110,120]	12
<120,24500]	13

GLG	GLG class
<-1,10]	1
<10,20]	2
<20,30]	3
<30,40]	4
<40,50]	5
<50,60]	6
<60,70]	7
<70,80]	8
<80,90]	9
<90,100]	10
<100,110]	11
<110,120]	12
<120,24500]	13

Annex 4 Drainage class (groundwater)

Raclassification of the mean groundwater classes and two texture type classes to nine drainage classes (Annex 1, LU 8).

GLG class	GHG class	Texture type	drainage class (groundwater)
1	1	1	7
2	1	1	7
2	2	1	7
3	1	1	7
3	2	1	7
3	3	1	7
4	1	1	7
4	2	1	7
4	3	1	7
4	4	1	7
5	1	1	6
5	2	1	6
5	3	1	6
5	4	1	6
5	5	1	6
6	1	1	6
6	2	1	6
6	3	1	6
6	4	1	6
6	5	1	6
6	6	1	6
7	1	1	6
7	2	1	6
7	3	1	6
7	4	1	6
7	5	1	6
7	6	1	6
7	7	1	6
8	1	1	6
8	2	1	6
8	3	1	6
8	4	1	6
8	5	1	6
8	6	1	6
8	7	1	6
8	8	1	6
9	1	1	5
9	2	1	5

GLG class	GHG class	Texture type	drainage class (groundwater)
1	1	2	7
2	1	2	7
2	2	2	7
3	1	2	7
3	2	2	7
3	3	2	7
4	1	2	7
4	2	2	7
4	3	2	7
4	4	2	7
5	1	2	7
5	2	2	7
5	3	2	7
5	4	2	7
5	5	2	7
6	1	2	6
6	2	2	6
6	3	2	6
6	4	2	6
6	5	2	6
6	6	2	6
7	1	2	6
7	2	2	6
7	3	2	6
7	4	2	6
7	5	2	6
7	6	2	6
7	7	2	6
8	1	2	6
8	2	2	6
8	3	2	6
8	4	2	6
8	5	2	6
8	6	2	6
8	7	2	6
8	8	2	6
9	1	2	6
9	2	2	6

GLG class	GHG class	Texture type	drainage class (groundwater)
9	3	1	5
9	4	1	5
9	5	1	5
9	6	1	5
9	7	1	5
9	8	1	5
9	9	1	5
10	1	1	5
10	2	1	5
10	3	1	5
10	4	1	5
10	5	1	5
10	6	1	5
10	7	1	5
10	8	1	5
10	9	1	5
10	10	1	5
11	1	1	5
11	2	1	5
11	3	1	5
11	4	1	5
11	5	1	5
11	6	1	5
11	7	1	5
11	8	1	5
11	9	1	5
11	10	1	5
11	11	1	5
12	1	1	5
12	2	1	5
12	3	1	5
12	4	1	5
12	5	1	5
12	6	1	5
12	7	1	5
12	8	1	5
12	9	1	5
12	10	1	5
12	11	1	5
12	12	1	5
13	1	1	9
13	2	1	9
13	3	1	8
13	4	1	8
13	5	1	8

GLG class	GHG class	Texture type	drainage class (groundwater)
9	3	2	6
9	4	2	6
9	5	2	6
9	6	2	6
9	7	2	6
9	8	2	6
9	9	2	6
10	1	2	6
10	2	2	6
10	3	2	6
10	4	2	6
10	5	2	6
10	6	2	6
10	7	2	6
10	8	2	6
10	9	2	6
10	10	2	6
11	1	2	5
11	2	2	5
11	3	2	5
11	4	2	5
11	5	2	5
11	6	2	5
11	7	2	5
11	8	2	5
11	9	2	5
11	10	2	5
11	11	2	5
12	1	2	5
12	2	2	5
12	3	2	5
12	4	2	5
12	5	2	5
12	6	2	5
12	7	2	5
12	8	2	5
12	9	2	5
12	10	2	5
12	11	2	5
12	12	2	5
13	1	2	9
13	2	2	9
13	3	2	8
13	4	2	8
13	5	2	4

GLG class	GHG class	Texture type	drainage class (groundwater)
13	6	1	4
13	7	1	4
13	8	1	4
13	9	1	3
13	10	1	3
13	11	1	3
13	12	1	3
13	13	1	2

GLG class	GHG class	Texture type	drainage class (groundwater)
13	6	2	4
13	7	2	3
13	8	2	3
13	9	2	3
13	10	2	2
13	11	2	2
13	12	2	2
13	13	2	1

Annex 5 Drainage class (soil)

Reclassification of the first groundwater level class and the two soil texture type classes into seven drainage classes.

		Soil texture type	
		heavy	light
Gt id	Gt code	1	2
1	VI	4	3
3	II	6	6
4	Vb	5	4
5	VII	3	2
6	IV	5	5
7	III	5	5
8	I	7	7
9	VIII	2	1
10	IIIb	5	5
11	V	5	4
12	IIb	6	6
13	sVII	3	2
14	sVI	4	3
15	sV	5	4
16	Va	5	4
17	IIIa	5	5
18	sVb	5	4
19	IVu	5	5
20	sVa	5	4
21	bVI	4	3
22	bVII	3	2
23	bV	5	4

Annex 6 Drainage group

Figure 1

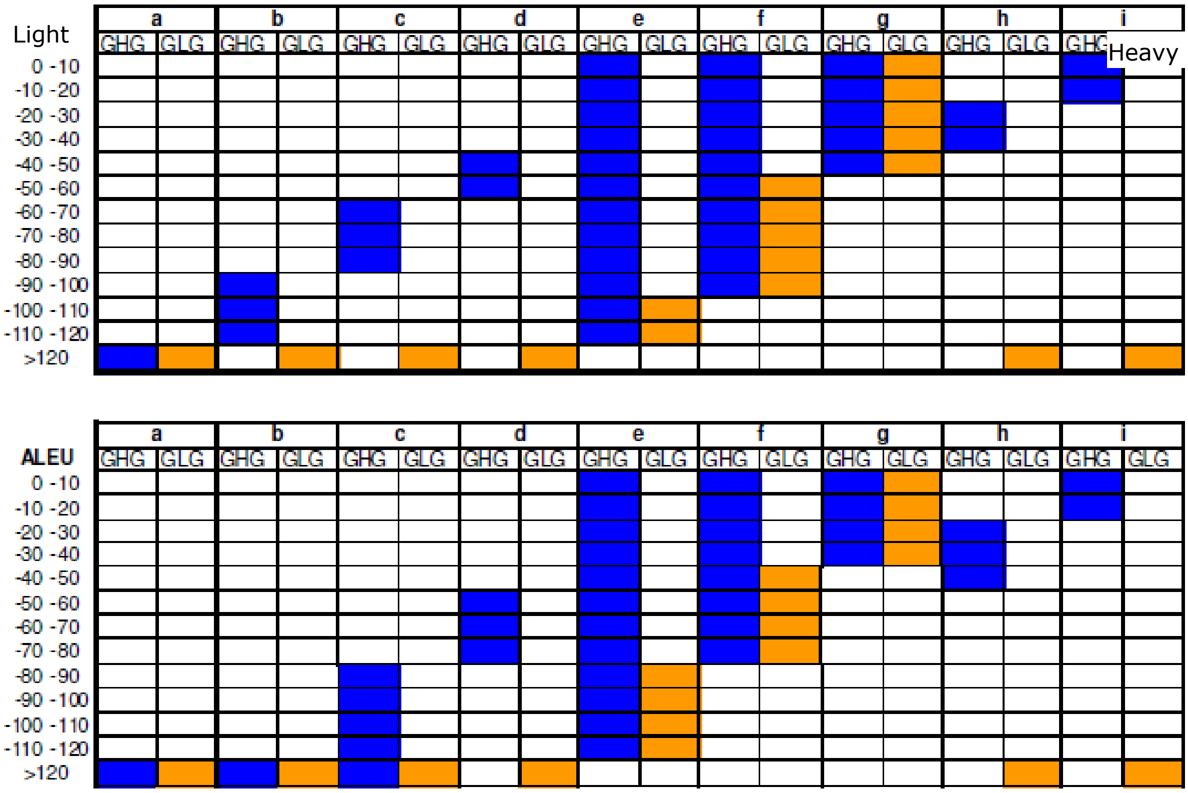


Table A6.1 *Description of drainage classes and groups and the reclassification of drainage class id's to drainage group ids (LU 9).*

Drainage class id	Drainage class code (RIVM figures and tables)	Description drainage class	Description drainage group	Drainage group id
1	A	excessively drained soils (very dry)	Very dry	1
2	B	well-drained soils (dry)	Dry	2
3	C	moderately well drained soils (medium dry)	Dry	2
4	D	insufficiently drained soils (moderately wet)	Moist-wet	3
5	E	rather poorly drained soils with groundwater permanently (wet)	Moist-wet	3
6	F	poorly drained soils with groundwater permanently (very wet)	Wet	4
7	G	extremely poorly drained soils (very wet)	Wet	4
8	H	poorly drained soils with backwater (temporary groundwater) (very wet)	Moist-wet	3
9	I	rather poorly drained soils with backwater (temporary groundwater) (wet)	Wet	4

Annex 7 Annual increment (Vito)

Reclassification of texture group, drainage group and forest type to Annual increment (Vito)
(LU 9 in Annex 1)

Table A7.1 *Reclassification of texture group, drainage group and forest type to Annual increment (Vito)*

Texture group	Drainage group	Forest type	Annual increment (Vito) (m^3 wood ha^{-1} yr^{-1})
1	1	1	4
1	1	2	4
1	1	3	7
1	1	0	0
1	2	1	6
1	2	2	6
1	2	3	9
1	2	0	0
1	3	1	6
1	3	2	6
1	3	3	7
1	3	0	0
1	4	1	5
1	4	2	5
1	4	3	2
1	4	0	0
2	1	1	5
2	1	2	5
2	1	3	8
2	1	0	0
2	2	1	8
2	2	2	8
2	2	3	10
2	2	0	0
2	3	1	8
2	3	2	8
2	3	3	8
2	3	0	0
2	4	1	6
2	4	2	6
2	4	3	2
2	4	0	0
3	1	1	3
3	1	2	3
3	1	3	4
3	1	0	0

Texture group	Drainage group	Forest type	Annual increment (Vito) (m^3 wood ha^{-1} yr^{-1})
3	2	1	11
3	2	2	11
3	2	3	10
3	2	0	0
3	3	1	10
3	3	2	10
3	3	3	7
3	3	0	0
3	4	1	7
3	4	2	7
3	4	3	2
3	4	0	0
4	1	1	3
4	1	2	3
4	1	3	4
4	1	0	0
4	2	1	9
4	2	2	9
4	2	3	8
4	2	0	0
4	3	1	10
4	3	2	10
4	3	3	6
4	3	0	0
4	4	1	6
4	4	2	6
4	4	3	0
4	4	0	0

Annex 8 Water purification

Marsh buffer strips, helophyte filters and nature-friendly banks
Below are the results of a literature study on the definition, operation and purification effect of three measures in and near surface water: marsh buffer strips, helophyte filters and nature-friendly banks. The text is taken from the report on the impact of water quality measures as part of the *Nationale Analyse Waterkwaliteit* (National Water Quality Analysis – Groenendijk et al., in prep.).

Natural purification processes
Before addressing the treatment measures, we first provide an overview of the natural treatment processes that underlie the purifying effect of the measures (Table A8.1). The first three processes in the table deal with the loss of N to the air, a form of direct removal of N from the water system. The remaining measures, which apply to both N and P, are forms of temporary storage in the water system, which may result in permanent storage. This permanent storage can be viewed as a form of removal. For P, this permanent storage is the only purification mechanism, while N can also be removed directly via gaseous release to the air. P can be removed directly only through mowing and dredging, and subsequent disposal of the grass clippings and dredged material.

Table A8.1 *Overview of treatment processes for nitrogen (N) and phosphorus (P) (Vymazal 2007, Kadlec et al. 1996, Kadlec et al. 2009)*

Process	Description	Has an impact on
Ammonia volatilisation	Conversion of ammonium (NH_4) dissolved in water to ammonia (NH_3). In fact, this ammonium (NH_4) forms a chemical equilibrium with gaseous components (NH_3). At higher pH, this balance shifts toward the gaseous components, leading to significant volatilisation above a pH of 8.	N
Denitrification	Conversion of nitrate (NO_3) dissolved in water into nitrogen gas (N_2) and sometimes nitrous oxide (N_2O), by bacteria that convert organic matter, using nitrate as an oxidiser, in the absence of oxygen. Denitrification occurs primarily when the temperature is sufficiently high, sufficient decomposable organic matter is available, and the pH is neither too high nor too low (optimum pH is between 6 and 8).	N
Anammox	Conversion of nitrite (NO_2) and ammonium (NH_4) dissolved in water into nitrogen gas (N_2), also called **an**aerobic **amm**onium **ox**idation (anammox). Like denitrification, anammox is a biological (bacterial) process. The magnitude of this process is relatively unknown compared to denitrification, although recent research on a helophyte filter shows that it can be significant: one-third of the nitrogen gas produced was from anammox and the rest from denitrification (Zhu et al. 2011).	N
Plant uptake (in combination with mowing)	Uptake of nutrients (NO_3, NH_4 and PO_4) by plants for their growth and maintenance. This is a form of temporary storage; when plant material dies, the nutrients are returned to the water column. Mowing and disposing of the clippings removes nutrients absorbed by plants from the system.	N & P
Sorption to beds of lakes and watercourses	Adhesion of N (NH_4) and P (PO_4) to organic or inorganic material in the soil. This process is reversible. With changing conditions, the bond can be released (desorption) for example when the nutrient concentration in the water decreases. Sorption capacity depends on soil composition. For example, NH_4 can bind well to clay and PO_4 binds well to clay, iron, aluminium and lime. If large amounts of such material is present, the P can react with it and then precipitate.	N & P
Burial	Burial of dead organic matter (detritus) containing nutrients (N_{org} and P_{org}) in the sediment. This burial is caused by new accretion of sediment/sludge due to sedimentation of detritus and suspended sediment particles. With sufficient accretion, the underlying sediment will eventually be 'buried'.	N & P

Description of measures
Table B1.2 provides an overview and description of the purification measures in the purification tool. The description of the helophyte filter is limited to the flow field and does not address the two other main types of helophyte filters: the horizontal and vertical flow-through helophyte filters. This is because these two

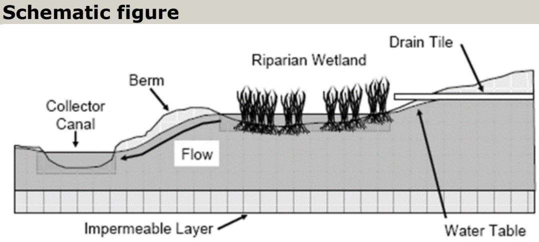
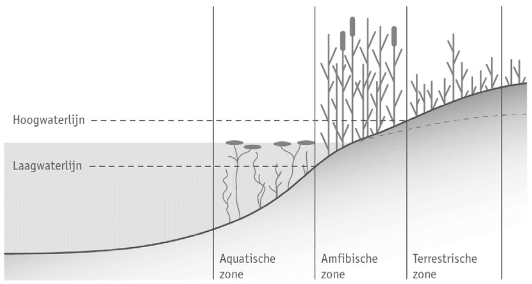
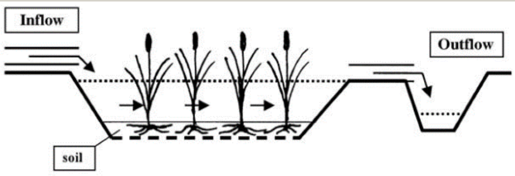
types are mainly used for urban wastewater treatment, while the purification tool focuses on surface water purification, such as that provided by helophyte filters. The measures have some overlap. For example, a nature-friendly bank can be viewed as a form of a marsh buffer strip. Although marsh buffer strips are often constructed with nutrient removal as the main goal, in the case of nature-friendly banks the nature function is paramount and nutrient removal is seen as a positive side effect.

The type of water treated varies according to the measure that is implemented. For example, marsh buffer strips mainly purify outflow and runoff water, possibly supplied through drain pipes, while nature-friendly banks (NFBs) purify relatively more surface water. A helophyte filter (flow field) is mainly used in rural areas to purify surface water by diverting water from the watercourse through the flow field.

Space requirements also vary according to the measure that is implemented. Marsh buffer strips and nature-friendly banks often require the expansion of banks, at the expense of land. Preferably they are at least 5 to 10 metres wide for effective operation. Helophyte filters are generally constructed outside the watercourse. Their optimal size depends on the quantity and nutrient richness of the water to be treated.

In addition to positive effects such as nutrient purification and nature value, a measure can also have adverse side effects. For example, N removal via denitrification is often accompanied by the formation of greenhouse gases such as nitrous oxide (N_2O). In addition, if they are not maintained regularly, purification measures can eventually become a source of P. This is the case when the soil is saturated with P and therefore can start to release P. This process takes place mainly in the summer.

Table A8.2 *Overview, description and schematic figure of three of the four purification measures from the purification tool.*

Measure	Description	Schematic figure
Marsh buffer strip	Strip of riparian wetland with reeds that collects runoff and water before it enters the watercourse. For optimal functioning, the marsh buffer strip should be at least 5 to 10 metres wide (figure taken from: Appelboom & Fouss, 2006).	
Nature-friendly bank	Banks where express consideration is given to nature and landscape in addition to water retention. They often have a gentle slope that leads to a gradient of aquatic and riparian plants. The water level is preferably dynamic (source: Stowa, 2011).	
Helophyte filter	Flow field: Shallow pond or watercourse planted with reeds. A flow field is often constructed so that the direction of flow, residence time, and water level can be controlled to optimise the purification effect (source: Spoelstra et al., 2010; Vymazal, 2007).	

Removal of contaminants (purifying effect)
The literature review showed that the purifying effect can vary greatly between measures but also within a single measure. Indeed, the purifying effect is highly site-specific and depends on several factors:

1. Measure: how large/wide is the purification measure and does all the water pass through it or only a portion? Are the water residence times long enough for the water to be sufficiently purified?
2. Nutrient richness of the water to be purified: how much N and P does the water to be treated contain and in what form? The total purifying capacity (in kg) of a facility often increases as the water contains more N and P, while the relative purifying capacity (in %) may decrease.

3. Age: the efficiency of the measure often decreases with age. This is especially the case for P, because P purification occurs primarily through storage/binding to the soil and the measure can become P-saturated over time. This is a well-known shortcoming of helophyte filters, which can even become a source of P over time.
4. Management: is the measure periodically maintained (mowed or dredged)? And are the grass clippings and dredged material disposed of? If so, more N and P is removed.
5. Soil: does the soil or the bed of the watercourse contain sufficient degradable organic matter as a substrate for denitrification? How much P can the soil bind and to what extent is the soil P-saturated? For example, removing a nutrient-rich layer of topsoil usually has a positive effect on P removal, but may have a negative effect on N removal if the remaining soil contains less organic matter and thus provides less substrate for denitrification.
6. Local hydrology: What are the dominant leaching and runoff flow paths? (See Figure B1.1.) Do the flow paths run through the purification measure or go under it? Is there pipe drainage? And how permeable is the soil? Is there seepage or runoff and how iron-rich is this seepage? Does the measure run dry more often? In fact, iron-rich seepage and temporary dry spells enhance P removal.

Furthermore, purification capacity changes throughout the year (De Klein et al., 2008, Van Gerven et al., 2009). For example, N removal in the surface water system is often higher in the warmer half year than in the colder half year, because the main N removal processes – such as denitrification and N uptake by plants – are mainly active during the growing season. P removal has different annual dynamics: P binding in the beds of lakes and watercourses occurs mainly in the winter. While P uptake by plants is higher in the summer, there is also a greater chance of P release from the beds of lakes and watercourses (Van Gerven et al., 2011).

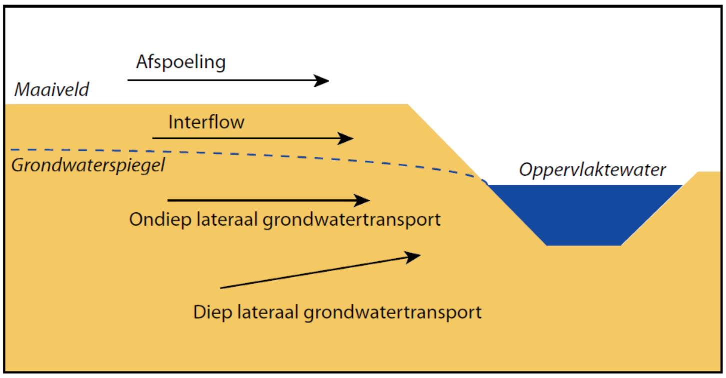


Figure A8.1 *Potential pathways of water and nutrients from soil to surface water (source: Stowa, 2008).*

Effectiveness according to the literature review

The many factors that influence purification capacity mean that the effect of a measure varies greatly in space and time and is therefore difficult to predict. The treatment efficiencies shown in Table B1.3 for this reason provide only an indication of the expected effect. Caution is also required when applying effects reported in other countries to the Dutch situation. The Netherlands is characterised by little relief and often has limited space to construct purification measures such as marsh buffer strips and helophyte filters. The lack of relief often results in less surface runoff than in sloping areas in other countries. As a result, measures such as buffer strips often have less effect by definition because the flow-through rate is lower (Stowa, 2008). The limited available space in the Netherlands for the construction of purification measures results in limited widths of buffer strips and nature-friendly banks and thus a more limited purification capacity. In the Netherlands they are generally no more than 10 metres wide, while studies from other counties generally report strips and banks that are wider than 50 metres. In addition, differences in climate often mean that purification efficiencies reported in other countries cannot be applied one-to-one to the Dutch situation.

Table A8.3 *Effectiveness of N and P removal measures in and near surface waters , expressed as a purification percentage and an absolute quantity. Shown as mean, as mean ± standard deviation, or as minimum - maximum. The number of systems examined is indicated by n. The efficiencies that are applicable to the Dutch situation are highlighted in beige.*

Measure	**Where**	**N removal**		**P removal**		**Source**
		%	**kg N/ha**	**%**	**kg P/ha**	
Marsh buffer strip	The Netherlands	7.5 ± 2.5 (n=1)	180 ± 60 (n=1)	up to 100[a] (n=1)	12 ± 0.6 (n=1)	Stowa, 2008
	Other countries	72 ± 12 (n=7)	39 – 372 (n=13)	30–90 (n=3)	0.1 – 30 (n=20)	Mayer, 2007; Kronvang et al., 2005; Kovacic et al., 2000; Dosskey, 2001; Syversen, 2005; Uusi-Kamppa, 2005; Hoffmann et al., 2007; Mitsch et al., 1995; Jaynes and Isenhart, 2019
Nature-friendly bank	The Netherlands	unknown[b]	unknown[b]	unknown[b]	unknown[b]	Stowa, 2011
Flow field (helophyte filter)	The Netherlands	72 (n=10)	145 (n=10)	60 (n=10)	10 (n=10)	Verhoeven et al., 1999; Stowa, 2001; Diepen et al., 2002; Schreijer et al., 2003; Klok et al., 2003; Meuleman et al., 2003; Clevering et al., 2004; Stowa, 2005; Clevering et al., 2006; Mulder et al., 2009
	Other countries	41[c] (n=85)	2470[c] (n=85)	49[c] (n=85)	700[c] (n=85)	Vymazal, 2007[c]

[a] P removal very high due to low P supply and iron-rich soil
[b] Little is known about the exact purification capacity of nature-friendly banks (NFBs). It is likely that the purification capacity is similar to that of a marsh buffer strip, although it will be lower rather than higher because NFBs are not constructed with nutrient removal as the main objective, and marsh buffer strips are.
[c] The studied helophyte filters purify wastewater with an average concentration of about 50 mgN/l and 9 mgP/l. When applied to surface water (with lower concentrations), the yield (in kg/ha) will be lower than indicated here.

Unfertilised zones
The following is a description of the methodology used to determine the purifying effect of unfertilised zones. This description is taken from the report on the impact of water quality measures as part of the *Nationale Analyse Waterkwaliteit* (National Water Quality Analysis – Groenendijk et al., in prep.).

Unfertilised zone
A unfertilised zone is also called a dry buffer strip. This is a unfertilised strip at the margin of an agricultural parcel adjacent to a watercourse. The strip often has natural vegetation (see Figure B2.1). Such buffer strips affect the transport of substances from ground level and from the shallow soil to the watercourse.

Figure A8.2 *Example of unfertilised zone*

Scope
An analysis was conducted to determine which agricultural parcels lend themselves to the creation of dry buffer strips, as well as how wide the unfertilised zone could be. The result is that 40% of all agricultural parcels in the Netherlands lend themselves to the construction of dry buffer strips, resulting in a total buffer strip length of 140,000 km and an area of 350 km^2 assuming a width of between 2 and 5 metres. The following explains how these figures were determined.

Suitable parcels and associated buffer strip width:
- Agricultural parcels (*Basis registratie Percelen*/Basic Registration Land Parcels 2018) with grassland, arable land or other unprotected crops.
- Agricultural parcels of sufficient size (>2500 m^2).
- Parcels of which at least 10% of the margins are adjacent to watercourses. The location of the watercourses is derived from the *TOP10-waterlopenkaart* (watercourse map). We excluded watercourses in the category ‘ditches and dry ditches’ as well as watercourses wider than 12 metres. Through a comprehensive GIS analysis, the distance from parcel margin to nearest watercourse was determined for each parcel, with the margin divided into 100 points. It was assumed that the parcel margin is adjacent to the watercourse if the distance to the watercourse is less than 5 metres. This resulted in the percentage of the parcel perimeter that is adjacent to a watercourse (see Figure B2.2).
- Parcels without pipe drainage or where less than 10% of the area is equipped with such drainage.
- Buffer strip width: for parcels of grassland on peat soil with groundwater level III and below, the buffer width was set at 2 metres. A buffer width of 5 metres was assumed for the other parcels. The area was then calculated as the portion of the perimeter adjacent to a watercourse multiplied by the buffer width. If the area was greater than 5% of the parcel area, the width was adjusted so that the area was at most 5%, but with a minimum buffer width of 2 metres. We excluded several elongated and narrow parcels that consisted of more than 100% buffer strip after the maximum narrowing of the watercourse to 2 metres.

The resulting area of the dry buffer strips is shown in Figure B2.3. Due to the criterion of a minimum buffer strip width of 2 metres, the area percentage in wet peatlands can exceed 5%.

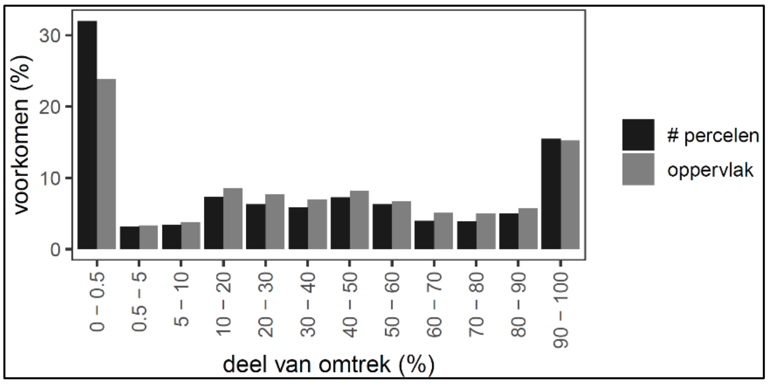


Figure A8.3 *Proportion of parcel margin adjacent to a watercourse, shown as a histogram for all agricultural parcels in the Netherlands, where occurrence is expressed as percentage of total number of parcels and as total area of all parcels.*

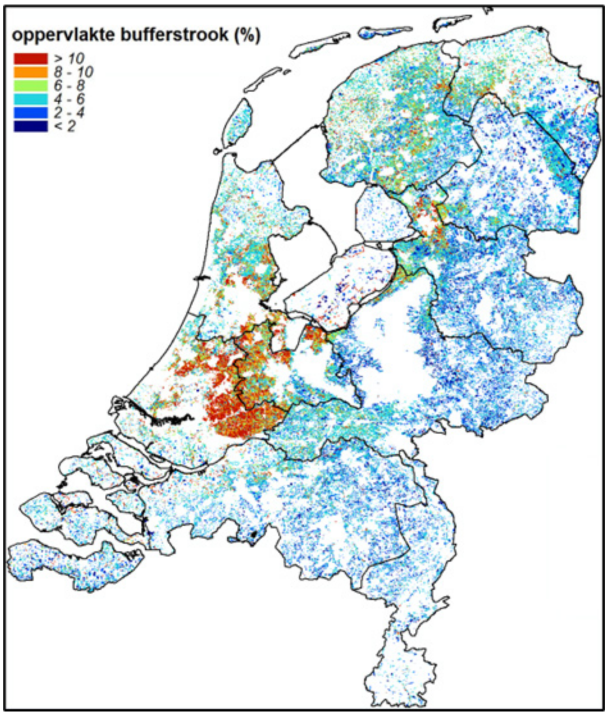


Figure A8.4 *Area of dry buffer strips as a percentage of parcel area, for the more than 283,000 agricultural parcels in the Netherlands that lend themselves to dry buffer strips.*

Purification yield for nitrogen

For nitrogen, the N purification percentage of the buffer strip (N_{BS} in %) is related to the buffer strip area percentage (A_{BS}) via

$$N_{BS} = 2 \times A_{BS}$$

where N_{BS} is truncated at a maximum of 75% for parcels with very large buffer strip area. The factor of 2 in the formula represents a fertilisation effect (factor of 1: nitrogen leaching is lower because buffer strip is not fertilised) and an interception effect (factor of 1: some of the nitrogen leaching and runoff is purified by the buffer strip). The calculated purification percentage thus varies between 0% and 75%, and is 10% to 20% for the majority of parcels. The average purification is 14% for parcels with a buffer strip. These numbers are substantially in line with experimental results, which show a large spread and an average of around 15% for a buffer strip width of 5 metres. For example, under Belgian conditions, Van der Welle and Decleer (2001) reported a nitrogen purification rate of 15% for a buffer strip width of 5 metres. Based on model calculations, Noij et al. (2012) reported a range of 10% to 20% for a buffer strip width of 5 metres under Dutch conditions.

Purification yield for phosphorus

For phosphate, it is assumed that a buffer strip (BS) mainly affects surface transport via surface runoff. Surface runoff is influenced by a number of factors, including the roughness of the ground surface, soil type, cultivation method, slope and size of the parcel. We assumed that the amount of phosphorus removed by a buffer strip (P_{BS} in kg ha^{-1} year^{-1}) depends on the surface runoff (q_{runoff} in mm/year), the P concentration in the runoff water (c_{runoff} in mgP/l), and the capacity of the buffer strip to remove phosphate in runoff water (P_{eff} as a fraction [-]):

$$P_{BS} = \frac{1}{100} \times q_{runoff} \times c_{runoff} \times P_{eff}$$

where:

$$q_{runoff} = q_{Horton,ref} \times \left(\frac{24}{distance\ to\ watercourse}\right)^{0.5} \left(\frac{slope}{0.89}\right)^{0.5} + q_{Dunne}$$

$$P_{eff} = 0.895\left(1 - e^{-0.16 \times buffer\ strip\ width}\right) \times \left(\frac{parcel\ perimeter}{buffer\ strip\ length}\right)^{0.5}$$

And where the factor of 1/100 comes from conversion to the correct units.

The runoff (q_{runoff}) consists of 'Horton overland flow' (q_{Horton}) which occurs when soil becomes compacted and of 'Dunne overland flow' (q_{Dunne}) which occurs when the underlying soil is saturated. We assumed that the average Horton flow ($q_{Horton,ref}$) is 40 mm/year for a standard parcel on peat, clay or loess soil and 20 mm/year for a standard parcel on sandy soil. A standard parcel of this kind has a median distance from the watercourse*(distance to watercourse*) of 24 metres and a median slope *(slope*) of 0.89%. If the parcel is completely surrounded by ditches, this 24 metres corresponds approximately to a parcel width of 100 metres. The slope percentage was derived from the AHN2 (Current Dutch Elevation map version 2) for each 5 metre grid and then processed into a median value per parcel using a procedure called 'grid statistics for polygons'. Horton flow increases as the parcel is closer to the watercourse and has a steeper slope. The Dunne flow depends on the groundwater level and is 75 mm/year for wet parcels (GT Ia, IIa, IIIa, Vao and Vad), 30 mm/year for fairly wet parcels (GT Ic, IIb, IIIb, Vbo and Vbd), 7.5 mm/year for parcels with GT IIc and 0 mm/year for dry parcels (G ≥ VI). The resulting total runoff (q_{runoff}) is shown in Figure B2.4 (left).

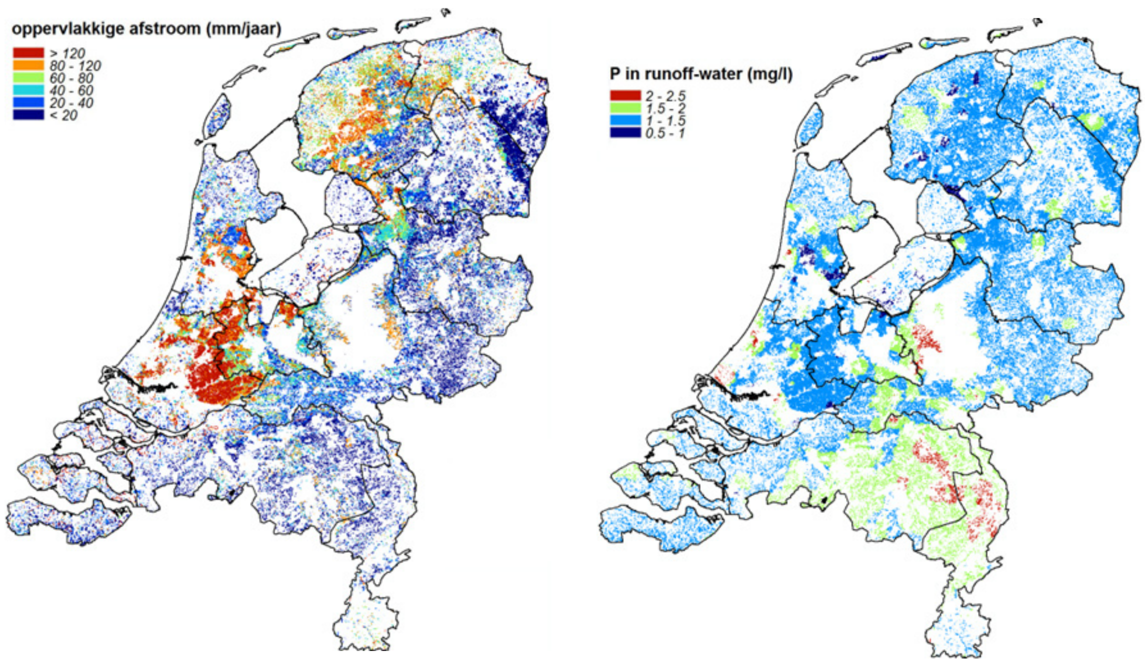


***Figure A8.5** Calculated surface runoff (left) and*
assumed P concentration in runoff water (right), for the parcels that lend themselves to buffer strips.

The P concentration in runoff water depends on many factors. The time of fertiliser application in relation to the time of measurement plays a role, as does the phosphate situation in the soil. Several studies indicate that there is a large spread in measured P levels in runoff water and in ground level water. In clay soil areas, P levels seem to be somewhat higher than in areas with sandy soils and peat soils. For the calculations, the concentration of P in runoff water (crunoff) was derived from estimates of phosphate content (Pw value) in the top 25 cm of the soil. Figure B2.4 (right) shows the resulting phosphate concentration of the runoff water, with a mean value of 1.4 mgP/l. This value is consistent with data from a number of previous studies on P concentrations in puddles on the surface and in soil moisture in the layer 0 - 10 cm deep.

In a next step, the P effluent was calculated (qrunoff x crunoff). This was compared to the total nutrient effluent from the parcel, as calculated with STONE (Wolf et al. 2003). If the effluent was greater than the leaching and runoff, then we corrected the effluent to 100% of the leaching and runoff.

As a final step, the proportion of the calculated P effluent ($q_{runoff} \times c_{runoff}$) captured by the buffer strip (P_{eff}) was determined. The first part of the formula used for the P_{eff} purification fraction was obtained from a meta-analysis on buffer strip purification by Zhang et al. (2010). According to this formula, buffer strips 5 metres wide have a purification capacity of about 50%. For strips 2 metres wide, the purification capacity is about 25%. This purification capacity was corrected for the length of the buffer strip in relation to the perimeter of the parcel (second part of the formula for P_{eff}), where we assumed that a shorter strip has a higher purification capacity because this strip has proportionally more runoff water to purify. P_{eff} is truncated at 75% so that the purifying effect of the buffer strip never exceeds 75%.

Scaling up to the purification tool

The resulting purification capacity of parcels with dry buffer strips is expressed as a percentage of the total nutrient effluent from leaching and runoff as calculated by STONE (Figure B2.5). For N the average purification is 14%, for P it is 12%. These percentages are translated per parcel (area-weighted average) to the catchments used by the purification tool. The result is the amount of N and P that can be removed per catchment with full implementation of unfertilised zones.

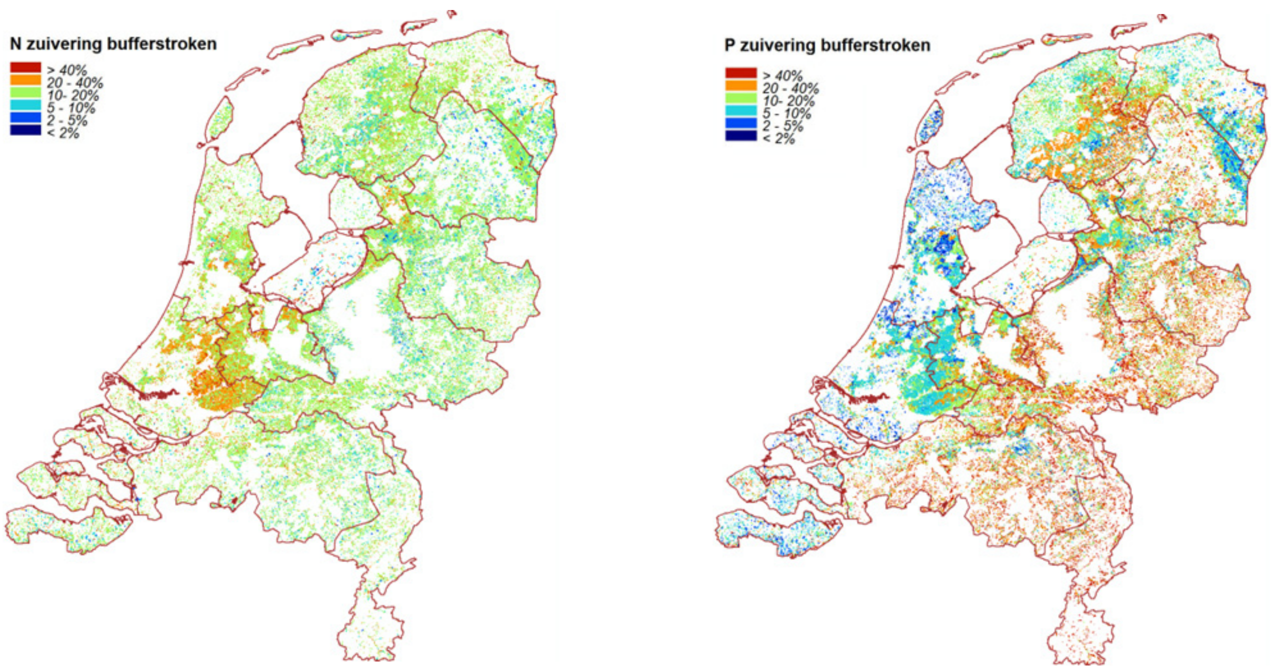


Figure A8.6 *Purifying effect of dry buffer strips on runoff, for nitrogen (left) and phosphate (right).*

Annex 9 Crops potentially affected by pests

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	174	Bloemzaden open grond	ja
Bouwland	233	Tarwe, winter-	ja
Bouwland	234	Tarwe, zomer-	ja
Bouwland	235	Gerst, winter-	ja
Bouwland	236	Gerst, zomer-	ja
Bouwland	237	Rogge (geen snijrogge)	ja
Bouwland	238	Haver	ja
Bouwland	241	Kapucijners (en grauwe erwten)	ja
Bouwland	242	Bonen, bruine-	ja
Bouwland	244	Erwten, groene/gele (groen te oogsten)	ja
Bouwland	246	Karwijzaad (oogst dit jaar)	ja
Bouwland	247	Blauwmaanzaad	ja
Bouwland	256	Bieten, suiker-	ja
Bouwland	257	Bieten, voeder-	ja
Bouwland	258	Luzerne	ja
Bouwland	259	Maïs, snij-	ja
Bouwland	262	Uien, zaai-	ja
Bouwland	263	Uien, zilver-	ja
Bouwland	308	Erwten (droog te oogsten)	ja
Bouwland	311	Bonen, veld- (onder andere duiven-, paarden-, wierbonen)	ja
Bouwland	314	Triticale	ja
Bouwland	316	Maïs, korrel-	ja
Bouwland	317	Maïs, corncob mix	ja
Bouwland	344	Rand, grenzend aan blijvend grasland of een blijvende teelt, hoofdzakelijk bestaand uit een ander gewas dan gras	nee
Bouwland	346	Tagetes erecta (Afrikaantje)	ja
Bouwland	347	Tagetes patula (Afrikaantje)	ja
Bouwland	375	Hop	ja
Bouwland	381	Teff	ja
Bouwland	382	Spelt	ja
Bouwland	426	Overige groenbemesters, vlinderbloemige-	ja
Bouwland	427	Overige groenbemesters, niet-vlinderbloemige-	ja
Bouwland	428	Gele mosterd	ja
Bouwland	511	Cichorei	ja
Bouwland	515	Zonnebloemen	ja
Bouwland	516	Miscanthus (olifantsgras)	ja
Bouwland	652	Meekrap	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	653	Teunisbloem	ja
Bouwland	654	Brandnetel	ja
Bouwland	655	Zwarte mosterd	ja
Bouwland	663	Lupinen, niet bittere	ja
Bouwland	664	Raapzaad	ja
Bouwland	665	Sojabonen	ja
Bouwland	666	Vlas, olie-. Lijnzaad niet van vezelvlas	ja
Bouwland	669	Zwaardherik (aaltjesvanggewas)	ja
Bouwland	670	Japanse haver	ja
Bouwland	671	Raketblad (aaltjesvanggewas)	ja
Bouwland	796	Kerstbomen	ja
Bouwland	799	Klaver, rode	ja
Bouwland	800	Rolklaver	ja
Bouwland	801	Esparcette	ja
Bouwland	802	Wikke, bonte	ja
Bouwland	803	Wikke, voeder-	ja
Bouwland	814	Maïs, suiker-	ja
Bouwland	853	Bonen, tuin- (droog te oogsten) (geen consumptie)	ja
Bouwland	854	Bonen, tuin- (groen te oogsten)	ja
Bouwland	863	Bos zonder herplantplicht	nee
Bouwland	864	Bos (set aside regeling)	nee
Bouwland	944	Hennep, vezel-	ja
Bouwland	964	Dahlia, overige bloemkwekerijgewassen	ja
Bouwland	965	Dahlia, droogbloemen	ja
Bouwland	967	Gladiool, overige bloemkwekerijgewassen	ja
Bouwland	968	Gladiool, droogbloemen	ja
Bouwland	970	Hyacint, overige bloemkwekerijgewassen	ja
Bouwland	973	Iris, overige bloemkwekerijgewassen	ja
Bouwland	976	Krokus, overige bloemkwekerijgewassen	ja
Bouwland	979	Lelie, overige bloemkwekerijgewassen	ja
Bouwland	982	Narcis, overige bloemkwekerijgewassen	ja
Bouwland	985	Tulp, overige bloemkwekerijgewassen	ja
Bouwland	988	Zantedeschia, overige bloemkwekerijgewassen	ja
Bouwland	991	Overige bloemen, overige bloemkwekerijgewassen	ja
Bouwland	992	Overige bloemen, droogbloemen	ja
Bouwland	994	Amaryllis, overige bloemkwekerijgewassen	ja
Bouwland	997	Dahlia, bloembollen en - knollen	ja
Bouwland	998	Gladiool, bloembollen en - knollen	ja
Bouwland	999	Hyacint, bloembollen en - knollen	ja
Bouwland	1000	Iris, bloembollen en -knollen	ja
Bouwland	1001	Krokus, bloembollen en - knollen	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	1002	Lelie, bloembollen en -knollen	ja
Bouwland	1003	Narcis, bloembollen en -knollen	ja
Bouwland	1004	Tulp, bloembollen en -knollen	ja
Bouwland	1005	Zantedeschia, bloembollen en -knollen	ja
Bouwland	1006	Overige bloemen, bloembollen en -knollen	ja
Bouwland	1007	Amaryllis, bloembollen en -knollen	ja
Bouwland	1010	Sierui, overige bloemkwekerijgewassen	ja
Bouwland	1012	Sierui, bloembollen en -knollen	ja
Bouwland	1013	Blauw druifje, overige bloemkwekerijgewassen	ja
Bouwland	1015	Blauw druifje, bloembollen en -knollen	ja
Bouwland	1019	Valeriaan, productie	ja
Bouwland	1020	Valeriaan, zaden en opkweekmateriaal	ja
Bouwland	1021	Knoflook	ja
Bouwland	1022	Quinoa	ja
Bouwland	1023	Pastinaak, productie	ja
Bouwland	1024	Pastinaak, zaden en opkweekmateriaal	ja
Bouwland	1025	Pioenroos, overige bloemkwekerijgewassen	ja
Bouwland	1026	Pioenroos, droogbloemen	ja
Bouwland	1027	Pioenroos, bloembollen en -knollen	ja
Bouwland	1028	Lavas (Maggiplant), productie	ja
Bouwland	1030	Wilde marjolein (Oregano), productie	ja
Bouwland	1033	Igniscum Candy	ja
Bouwland	1034	Kanariezaad	ja
Bouwland	1035	Naaldaar (Setaria)	ja
Bouwland	1036	Wortelpeterselie	ja
Bouwland	1037	Peterselie, productie	ja
Bouwland	1038	Peterselie, zaden en opkweekmateriaal	ja
Bouwland	1039	Chrysant, overige bloemkwekerijgewassen	ja
Bouwland	1042	Angelica, productie	ja
Bouwland	1043	Angelica, zaden en opkweekmateriaal	ja
Bouwland	1044	Papaver	ja
Bouwland	1045	Adonis	ja
Bouwland	1046	Vergeet mij nietje	ja
Bouwland	1047	Cranberry	ja
Bouwland	1048	Echinacea (zonnehoed), productie	ja
Bouwland	1050	Leeuwenbekjes	ja
Bouwland	1067	Bos- en haagplanten, open grond,	ja
Bouwland	1068	Buxus, open grond,	ja
Bouwland	1069	Ericaceae (Zoals erica, calluna, rododendron, azalea), open grond,	ja
Bouwland	1070	Laanbomen/parkbomen, onderstammen, open grond,	ja
Bouwland	1071	Laanbomen/parkbomen, opzetters, open grond,	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	1072	Laanbomen/parkbomen, spillen, open grond,	ja
Bouwland	1073	Rozenstruiken (incl, zaailingen en onderstammen), open grond,	ja
Bouwland	1074	Sierconiferen, open grond,	ja
Bouwland	1075	Sierheesters en klimplanten, open grond,	ja
Bouwland	1076	Trek- en besheesters, open grond,	ja
Bouwland	1077	Vruchtbomen, moerbomen, open grond,	ja
Bouwland	1078	Vruchtbomen, onderstammen, open grond,	ja
Bouwland	1079	Vruchtbomen, overig, open grond,	ja
Bouwland	1080	Vaste planten, open grond,	ja
Bouwland	1081	Bos- en haagplanten, pot- en containerveld,	ja
Bouwland	1082	Buxus, pot- en containerveld,	ja
Bouwland	1083	Ericaceae (Zoals erica, calluna, rododendron, azalea), pot- en containerveld,	ja
Bouwland	1084	Laanbomen/parkbomen, onderstammen, pot- en containerveld,	ja
Bouwland	1085	Laanbomen/parkbomen, opzetters, pot- en containerveld,	ja
Bouwland	1086	Laanbomen/parkbomen, spillen, pot- en containerveld,	ja
Bouwland	1087	Rozenstruiken (incl. zaailingen en onderstammen), pot- en containerveld,	ja
Bouwland	1088	Sierconiferen, pot- en containerveld,	ja
Bouwland	1089	Sierheesters en klimplanten, pot- en containerveld,	ja
Bouwland	1090	Trek- en besheesters, pot- en containerveld,	ja
Bouwland	1091	Vruchtbomen, moerbomen, pot- en containerveld,	ja
Bouwland	1093	Vruchtbomen, overig, pot- en containerveld,	ja
Bouwland	1094	Vaste planten, pot- en containerteelt,	ja
Bouwland	1095	Appelen. Aangeplant lopende seizoen.	ja
Bouwland	1096	Appelen. Aangeplant voorafgaande aan lopende seizoen.	ja
Bouwland	1097	Peren. Aangeplant lopende seizoen.	ja
Bouwland	1098	Peren. Aangeplant voorafgaande aan lopende seizoen.	ja
Bouwland	1099	Wijndruiven	ja
Bouwland	1100	Overige pit- en steenvruchten (zoals perziken, tafeldruiven)	ja
Bouwland	1869	Bessen, blauwe	ja
Bouwland	1870	Pruimen	ja
Bouwland	1872	Kersen, zuur (opbrengst bestemd voor verwerkende industrie)	ja
Bouwland	1873	Bessen, zwarte (opbrengst verwerkt voor verwerkende industrie)	ja
Bouwland	1874	Overig kleinfruit (zoals kruisbessen, kiwi's)	ja
Bouwland	1876	Snijgroen	ja
Bouwland	1922	Koolzaad, winter (incl. boterzaad)	ja
Bouwland	1923	Koolzaad, zomer (incl. boterzaad)	ja
Bouwland	1925	Overige akkerbouwgewassen	ja
Bouwland	1931	Uien, poot- en plant- (incl. sjalotten)	ja
Bouwland	1949	Aardperen	ja
Bouwland	2014	Aardappelen, consumptie	ja
Bouwland	2015	Aardappelen, poot NAK	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	2016	Aardappelen, poot TBM	ja
Bouwland	2017	Aardappelen, zetmeel	ja
Bouwland	2025	Aardappelen, bestrijdingsmaatregel AM	ja
Bouwland	2032	Maïs, energie-	ja
Bouwland	2325	Bessen, rode	ja
Bouwland	2326	Frambozen	ja
Bouwland	2327	Bramen	ja
Bouwland	2328	Kersen, zoet	ja
Bouwland	2645	Notenbomen	ja
Bouwland	2652	Overige granen	ja
Bouwland	2700	Aardbeien open grond, vermeerdering	ja
Bouwland	2701	Aardbeien open grond, wachtbed	ja
Bouwland	2702	Aardbeien open grond, productie	ja
Bouwland	2703	Aardbeien open grond, zaden en opkweekmateriaal	ja
Bouwland	2704	Aardbeien op stellingen, vermeerdering	ja
Bouwland	2705	Aardbeien op stellingen, wachtbed	ja
Bouwland	2706	Aardbeien op stellingen, productie	ja
Bouwland	2707	Aardbeien op stellingen, zaden en opkweekmateriaal	ja
Bouwland	2708	Andijvie, productie	ja
Bouwland	2710	Asperges, oppervlakte die productie oplevert	ja
Bouwland	2711	Asperges, oppervlakte die nog geen productie oplevert	ja
Bouwland	2712	Asperges, zaden en opkweekmateriaal	ja
Bouwland	2715	Boerenkool, productie	ja
Bouwland	2716	Boerenkool, zaden en opkweekmateriaal	ja
Bouwland	2717	Bospeen, productie	ja
Bouwland	2718	Bospeen, zaden en opkweekmateriaal	ja
Bouwland	2719	Broccoli, productie	ja
Bouwland	2720	Brocolli, zaden en opkweekmateriaal	ja
Bouwland	2721	Chinese kool, productie	ja
Bouwland	2723	Courgette, productie	ja
Bouwland	2724	Courgette, zaden en opkweekmateriaal	ja
Bouwland	2725	Knolselderij, productie	ja
Bouwland	2726	Knolselderij, zaden en opkweekmateriaal	ja
Bouwland	2727	Knolvenkel/venkel, productie	ja
Bouwland	2729	Komkommer, productie	ja
Bouwland	2731	Augurk, productie	ja
Bouwland	2732	Augurk, zaden en opkweekmateriaal	ja
Bouwland	2735	Pompoen, productie	ja
Bouwland	2736	Pompoen, zaden en opkweekmateriaal	ja
Bouwland	2737	Koolraap, productie	ja
Bouwland	2739	Koolrabi, productie	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	2741	Kroten/rode bieten, productie	ja
Bouwland	2742	Kroten/rode bieten, zaden en opkweekmateriaal	ja
Bouwland	2743	Kruiden, productie	ja
Bouwland	2744	Kruiden, zaden en opkweekmateriaal	ja
Bouwland	2745	Paksoi, productie	ja
Bouwland	2747	Peulen, productie	ja
Bouwland	2748	Peulen, zaden en opkweekmateriaal	ja
Bouwland	2751	Pronkbonen, productie	ja
Bouwland	2752	Pronkbonen, zaden en opkweekmateriaal	ja
Bouwland	2753	Raapstelen, productie	ja
Bouwland	2755	Rabarber, productie	ja
Bouwland	2756	Rabarber, zaden en opkweekmateriaal	ja
Bouwland	2757	Radijs, productie	ja
Bouwland	2758	Radijs, zaden en opkweekmateriaal	ja
Bouwland	2759	Rodekool, productie	ja
Bouwland	2761	Savooiekool, productie	ja
Bouwland	2763	Schorseneren; productie	ja
Bouwland	2764	Schorseneren, zaden en opkweekmateriaal	ja
Bouwland	2765	Selderij, bleek- en groen-, productie	ja
Bouwland	2766	Selderij, bleek- en groen-, zaden en opkweekmateriaal	ja
Bouwland	2767	Sla, ijsberg-, productie	ja
Bouwland	2768	Sla, ijsberg-, zaden en opkweekmateriaal	ja
Bouwland	2769	Sla; radicchio rosso, productie	ja
Bouwland	2771	Sla; overig, productie	ja
Bouwland	2772	Sla; overig, zaden en opkweekmateriaal	ja
Bouwland	2773	Spinazie, productie	ja
Bouwland	2774	Spinazie, zaden en opkweekmateriaal	ja
Bouwland	2775	Spitskool, productie	ja
Bouwland	2776	Spitskool, zaden en opkweekmateriaal	ja
Bouwland	2777	Spruitkool/spruitjes, productie	ja
Bouwland	2778	Spruitkool/spruitjes, zaden en opkweekmateriaal	ja
Bouwland	2779	Stamsperziebonen (=stamslabonen), productie	ja
Bouwland	2780	Stamsperziebonen (=stamslabonen), zaden en opkweekmateriaal	ja
Bouwland	2781	Stoksnijbonen en stokslabonen, productie	ja
Bouwland	2782	Stoksnijbonen en stokslabonen, zaden en opkweekmateriaal	ja
Bouwland	2783	Waspeen, productie	ja
Bouwland	2784	Waspeen, zaden en opkweekmateriaal	ja
Bouwland	2785	Winterpeen, productie	ja
Bouwland	2786	Winterpeen, zaden en opkweekmateriaal	ja
Bouwland	2787	Witlofwortel, productie	ja
Bouwland	2788	Witlofwortel, zaden en opkweekmateriaal	ja

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Bouwland	2789	Witte kool, productie	ja
Bouwland	2790	Witte kool, zaden en opkweekmateriaal	ja
Bouwland	2791	Overige niet genoemde bladgewassen, productie	ja
Bouwland	2792	Overige niet genoemde bladgewassen, zaden en opkweekmateriaal	ja
Bouwland	2793	Overige niet genoemde groenten, productie	ja
Bouwland	2794	Overige niet genoemde groenten, zaden en opkweekmateriaal	ja
Bouwland	2795	Bloemkool, winter, productie	ja
Bouwland	2796	Bloemkool, winter, zaden en opkweekmateriaal	ja
Bouwland	2797	Bloemkool, zomer, productie	ja
Bouwland	2798	Bloemkool, zomer, zaden en opkweekmateriaal	ja
Bouwland	2799	Prei, winter, productie	ja
Bouwland	2800	Prei, winter, zaden en opkweekmateriaal	ja
Bouwland	2801	Prei, zomer, productie	ja
Bouwland	2802	Prei, zomer, zaden en opkweekmateriaal	ja
Bouwland	3500	Klaver, Alexandrijnse	ja
Bouwland	3502	Bladkool	ja
Bouwland	3503	Bladraap	ja
Bouwland	3504	Bladrammenas	ja
Bouwland	3505	Deder	ja
Bouwland	3506	Engels raaigras	ja
Bouwland	3507	Ethiopische mosterd	ja
Bouwland	3508	Facelia	ja
Bouwland	3509	Festulolium	ja
Bouwland	3510	Franse boekweit	ja
Bouwland	3512	Italiaans raaigras	ja
Bouwland	3513	Westerwolds raaigras	ja
Bouwland	3517	Sarepta mosterd/Caliente	ja
Bouwland	3519	Soedangras/Sorghum	ja
Bouwland	3521	Stoppelknollen	ja
Bouwland	3522	Timothee	ja
Bouwland	3523	Veldbeemdgras	ja
Bouwland	3524	Klaver, witte	ja
Bouwland	3736	Vlas, vezel-	ja
Bouwland	3803	Rand, grenzend aan bouwland, hoofdzakelijk bestaand uit een ander gewas dan gras. (EA: beheer)	nee
Bouwland	3804	Rand, grenzend aan bouwland, hoofdzakelijk bestaand uit een ander gewas dan gras. (EA: onbeheerd)	nee
Braakland	2300	Onbeteelde grond vanwege een teeltverbod/ontheffing	nee
Braakland	3801	Tijdelijk onbeteelde grond, i.v.m. publieke werken	nee
Braakland	3802	Tijdelijk onbeteelde grond, anders dan voor publieke werken	nee
Grasland	265	Grasland, blijvend	nee
Grasland	266	Grasland, tijdelijk	nee
Grasland	331	Grasland, natuurlijk. Hoofdfunctie landbouw.	nee

CAT_GEWASCATEGORIE	GWS_GEWASCODE	GWS_GEWAS	plaagonderdrukking vraag
Grasland	332	Grasland, natuurlijk. Hoofdfunctie natuur.	nee
Grasland	333	Rand, grenzend aan blijvend grasland of een blijvende teelt, hoofdzakelijk bestaand uit blijvend gras	nee
Grasland	334	Rand, grenzend aan bouwland, hoofdzakelijk bestaand uit blijvend gras	nee
Grasland	336	Grasland, natuurlijk. Areaal met een natuurbeheertype dat overwegend voor landbouwactiviteiten-GLB wordt gebruikt	nee
Grasland	370	Rand, grenzend aan blijvend grasland of een blijvende teelt, hoofdzakelijk bestaand uit tijdelijk gras	nee
Grasland	372	Rand, grenzend aan bouwland, hoofdzakelijk bestaand uit tijdelijk gras	nee
Grasland	383	Graszaad	ja
Grasland	804	Klaverzaad	ja
Grasland	1921	Graszoden	ja
Grasland	1926	Agrarisch natuurmengsel	nee
Grasland	3805	Rietzwenkgras, industriegras	nee
Grasland	3807	Rietzwenkgras, anders dan voor industriegras	nee
Natuurterrein	335	Natuurterreinen (incl. heide)	nee
Overige	343	Sloot, grenzend aan beheerde akkerrand	nee
Overige	662	Bos (SBL-regeling)	nee
Overige	794	Woudbomen met korte omlooptijd (excl. Wilgenhakhout)	nee
Overige	795	Wilgenhakhout	nee
Overige	1936	Bos, blijvend, met herplantplicht	nee

Annex 10 Translation of Top10NL visualisatiecodes to BNL-codes

Value	Omschrijving	BNL_type	BNL_code	Vorm
-12000	bron, wel	Bron, wel	0	L
12000	bron, wel	Bron, wel	0	L
12005	bron, wel	Bron, wel, met riet	0	L
15000	aanlegsteiger	geen	0	L
-15000	aanlegsteiger	geen	0	L
15030	boom	geen	0	P
15090	koedam	geen	0	L
-15090	koedam	geen	0	L
15130	geluidswering	geen	0	L
-15130	geluidswering	none	0	L
15190	hekwerk	none	0	L
-15190	hekwerk	none	0	L
15210	hoogspanningsleiding	none	0	L
15250	kabelbaan	none	0	L
15460	muur	geen	0	L
-15460	muur	geen	0	L
15490	paalwerk	geen	0	L
15570	schietbaan	geen	0	L
-15570	schietbaan	geen	0	L
15610	sluisdeur	geen	0	L
-15610	sluisdeur	geen	0	L
15630	stormvloedkering	geen	0	?
15650	strekdam, krib, golfbreker	geen	0	L
-15650	strekdam, krib, golfbreker	geen	0	L
15670	stuw	geen	0	L
-15670	stuw	geen	0	L
15690	tol	geen	0	L
15720	verkeersgeleider	geen	0	L
-15720	verkeersgeleider	geen	0	L
15760	wegafsluiting	geen	0	L
-15760	wegafsluiting	geen	0	L
15860	overig	geen	0	?
-12700	zee	Zee	10	V
12700	zee	Zee	10	V
-12500	meer, plas	Meer, plas	20	V
12500	meer, plas	Meer, plas	20	V
-12505	meer, plas, met riet	Meer, plas, met riet	21	V
12505	meer, plas, met riet	Meer, plas, met riet	21	V
-12810	water op brug	Waterloop	30	V
-12800	water in sluis	Waterloop	30	V
-12430	waterloop > 125 meter	Waterloop	30	V
-12420	waterloop 50-125 meter	Waterloop	30	V
-12410	waterloop 12-50 meter	Waterloop	30	V
-12400	waterloop, 6-12 meter	Waterloop	30	V
12400	waterloop, 6-12 meter	Waterloop	30	V
12410	waterloop 12-50 meter	Waterloop	30	V
12420	waterloop 50-125 meter	Waterloop	30	V
12430	waterloop > 125 meter	Waterloop	30	V
12800	water in sluis	Waterloop	30	V
12810	water op brug	Waterloop	30	V
12820	water in sluis en op brug	Waterloop	30	V
-12415	waterloop 12-50 meter, met riet	Waterloop, met riet	31	V
-12405	waterloop, 6-12 meter, met riet	Waterloop, met riet	31	V
12405	waterloop, 6-12 meter, met riet	Waterloop, met riet	31	V
12415	waterloop 12-50 meter, met riet	Waterloop, met riet	31	V
12425	waterloop 50-125 meter, met riet	Waterloop, met riet	31	V
12435	waterloop > 125 meter, met riet	Waterloop, met riet	31	V
-12600	droogvallend	Droogvallend	40	V
12600	droogvallend	Droogvallend	40	V
12605	droogvallend, met riet	Droogvallend, met riet	41	V
-12610	droogvallend (LAT)	Droogvallend (LAT)	45	V
12610	droogvallend (LAT)	Droogvallend (LAT)	45	V
10200	autosnelweg	Autosnelweg	50	V
10201	autosnelweg, op vast deel van brug	Autosnelweg	50	V
10202	autosnelweg, op beweegbaar deel van brug	Autosnelweg	50	V
10300	hoofdweg, snelverkeer	Hoofdweg	51	V
10301	hoofdweg, snelverkeer, op vast deel van brug	Hoofdweg	51	V
10302	hoofdweg, snelverkeer, op beweegbaar deel van brug	Hoofdweg	51	V
10310	hoofdweg, geen snelverkeer	Hoofdweg	51	V

Value	Omschrijving	BNL_type	BNL_code	Vorm
10311	hoofdweg, geen snelverkeer, op vast deel van brug	Hoofdweg	51	V
10312	hoofdweg, geen snelverkeer, op beweegbaar deel van brug	Hoofdweg	51	V
10400	regionale weg, snelverkeer	Regionale weg	52	V
10401	regionale weg, snelverkeer, op vast deel van brug	Regionale weg	52	V
10410	regionale weg, geen snelverkeer	Regionale weg	52	V
10411	regionale weg, geen snelverkeer, op vast deel van brug	Regionale weg	52	V
10412	regionale weg, geen snelverkeer, op beweegbaar deel van brug	Regionale weg	52	V
10500	lokale weg, snelverkeer	Lokale weg	53	V
10501	lokale weg, snelverkeer, op vast deel van brug	Lokale weg	53	V
10502	lokale weg, snelverkeer, op beweegbaar deel van brug	Lokale weg	53	V
10510	lokale weg, geen snelverkeer	Lokale weg	53	V
10511	lokale weg, geen snelverkeer, op vast deel van brug	Lokale weg	53	V
10512	lokale weg, geen snelverkeer, op beweegbaar deel van brug	Lokale weg	53	V
10600	straat	Straat	54	V
10601	straat, op vast deel van brug	Straat	54	V
10602	straat, op beweegbaar deel van brug	Straat	54	V
10720	overig, gemengd verkeer, half verhard	Overige infrastructuur, half verhard	55	V
10721	overig, gemengd verkeer, half verhard, op vast deel van brug	Overige infrastructuur, half verhard	55	V
10722	overig, gemengd verkeer, half verhard, op beweegbaar deel van brug	Overige infrastructuur, half verhard	55	V
10730	overig, gemengd verkeer, onverhard	Overige infrastructuur, onverhard	56	V
10731	overig, gemengd verkeer, onverhard, op vast deel van brug	Overige infrastructuur, onverhard	56	V
10740	overig, fietsers, bromfietsers	Infrastructuur, langzaam verkeer	57	V
10741	overig, fietsers, bromfietsers, op vast deel van brug	Infrastructuur, langzaam verkeer	57	V
10742	overig, fietsers, bromfietsers, op beweegbaar deel van brug	Infrastructuur, langzaam verkeer	57	V
10750	overig, voetgangers, buiten overig verkeersgebied	Infrastructuur, langzaam verkeer	57	V
10751	overig, voetgangers, buiten overig verkeersgebied, op vast deel van brug	Infrastructuur, langzaam verkeer	57	V
10752	overig, voetgangers, buiten overig verkeersgebied, op beweegbaar deel van brug	Infrastructuur, langzaam verkeer	57	V
10760	overig, voetgangers, binnen overig verkeersgebied	Infrastructuur, langzaam verkeer	57	V
10761	overig, voetgangers, binnen overig verkeersgebied, op vast deel van brug	Infrastructuur, langzaam verkeer	57	V
10780	parkeerplaats of parkeerplaats: carpool of parkeerplaats: P+R	Parkeerplaats	58	V
10781	parkeerplaats of parkeerplaats: carpool of parkeerplaats: P+R, op vast deel van brug	Parkeerplaats	58	V
-14000	aanlegsteiger	Overige infrastructuur	59	V
10000	startbaan, landingsbaan	Overige infrastructuur	59	V
10100	rolbaan, platform of overig, vliegverkeer	Overige infrastructuur	59	V
10101	rolbaan, platform, op vast deel van brug	Overige infrastructuur	59	V
10700	overig, busverkeer	Overige infrastructuur	59	V
10701	overig, busverkeer, op vast deel van brug	Overige infrastructuur	59	V
10702	overig, busverkeer, op beweegbaar deel van brug	Overige infrastructuur	59	V
10710	overig, gemengd verkeer, verhard of onbekend	Overige infrastructuur	59	V
10711	overig, gemengd verkeer, verhard of onbekend, op vast deel van brug	Overige infrastructuur	59	V
10712	overig, gemengd verkeer, verhard of onbekend, op beweegbaar deel van brug	Overige infrastructuur	59	V
13200	dok	Overige infrastructuur	59	V
14000	aanlegsteiger	Overige infrastructuur	59	V
14002	aanlegsteiger, op vast deel van brug	Overige infrastructuur	59	V
-14182	spoorbaanlichaam, op vast deel van brug	Spoorbaanlichaam	70	V
-14180	spoorbaanlichaam	Spoorbaanlichaam	70	V
14180	spoorbaanlichaam	Spoorbaanlichaam	70	V
14182	spoorbaanlichaam, op vast deel van brug	Spoorbaanlichaam, op brug	71	V
14183	spoorbaanlichaam, op beweegbaar deel van brug	Spoorbaanlichaam, op brug	71	V
-13300	huizenblok	Gebouw	90	V
-13000	overig gebouw, laagbouw of onbekend	Gebouw	90	V
13000	overig gebouw, laagbouw of onbekend	Gebouw	90	V
13100	overig gebouw, hoogbouw	Gebouw	90	V
13300	huizenblok	Gebouw	90	V
13400	kas, warenhuis	Kas	95	V
-14130	grasland	Grasland	100	V
14130	grasland	Grasland	100	V

Value	Omschrijving	BNL_type	BNL_code	Vorm
14132	grasland, op vast deel van brug	Grasland	100	V
14135	grasland, met riet	Grasland, met riet	101	V
-14010	akkerland	Bouwland	110	V
14010	akkerland	Bouwland	110	V
14012	akkerland, op vast deel van brug	Bouwland	110	V
14015	akkerland, met riet	Bouwland	110	V
14040	boomgaard	Boomgaard	120	V
-14125	fruitkwekerij, met riet	Fruitkwekerij	121	V
14120	fruitkwekerij	Fruitkwekerij	121	V
14122	fruitkwekerij, op vast deel van brug	Fruitkwekerij	121	V
14050	boomkwekerij	Boomkwekerij	122	V
14052	boomkwekerij, op vast deel van brug	Boomkwekerij	122	V
-14200	braakliggend	Braakliggend	130	V
14200	braakliggend	Braakliggend	130	V
14205	braakliggend, met riet	Braakliggend, met riet	131	V
14110	dodenakker met bos	Bos op dodenakker	140	V
-14060	bos: gemengd bos	Gemengd bos	141	V
14060	bos: gemengd bos	Gemengd bos	141	V
14062	bos: gemengd bos, op vast deel van brug	Gemengd bos	141	V
-14080	bos: loofbos	Loofbos	142	V
14080	bos: loofbos	Loofbos	142	V
14082	bos: loofbos, op vast deel van brug	Loofbos	142	V
14090	bos: naaldbos	Naaldbos	143	V
14092	bos: naaldbos, op vast deel van brug	Naaldbos	143	V
14170	populierenbos	Populierenbos	144	V
14175	populierenbos, met riet	Populierenbos	144	V
14070	bos: griend	Griend	145	V
-14190	zand	Zand	150	V
14190	zand	Zand	150	V
14192	zand, op vast deel van brug	Zand	150	V
14195	zand, met riet	Zand, met riet	151	V
-14210	duin	Duin	160	V
14210	duin	Duin	160	V
14212	duin, op vast deel van brug	Duin	160	V
14215	duin, met riet	Duin, met riet	161	V
-14140	heide	Heide	170	V
14140	heide	Heide	170	V
14142	heide, op vast deel van brug	Heide	170	V
14145	heide, met riet	Heide, met riet	171	V
-14162	overig grondgebruik, op vast deel van brug	Overig grondgebruik	200	V
-14160	overig grondgebruik	Overig grondgebruik	200	V
-14100	dodenakker	Overig grondgebruik	200	V
-14030	bebouwd gebied	Overig grondgebruik	200	V
-14020	basaltblokken, steenglooiing	Overig grondgebruik	200	V
14020	basaltblokken, steenglooiing	Overig grondgebruik	200	V
14022	basaltblokken, steenglooiing, op vast deel van brug	Overig grondgebruik	200	V
14030	bebouwd gebied	Overig grondgebruik	200	V
14100	dodenakker	Overig grondgebruik	200	V
14160	overig grondgebruik	Overig grondgebruik	200	V
14162	overig grondgebruik, op vast deel van brug	Overig grondgebruik	200	V
14163	overig grondgebruik, op beweegbaar deel van brug	Overig grondgebruik	200	V
14165	overig grondgebruik, met riet	Overig grondgebruik, met riet	201	V
-12300	waterloop 3 - 6 m	Waterloop lijnvormig	300	L
-12200	waterloop 0,5 - 3 m	Waterloop lijnvormig	300	L
12200	waterloop 0,5 - 3 m	Waterloop lijnvormig	300	L
12300	waterloop 3 - 6 m	Waterloop lijnvormig	300	L
12205	waterloop 0,5 - 3 m	Waterloop lijnvormig, met riet	301	L
12305	waterloop 3 - 6 m	Waterloop lijnvormig, met riet	301	L
-12201	waterloop 0,5 - 3 m, in duiker	Waterloop lijnvormig, in duiker	309	L
-12202	waterloop 0,5 - 3 m, in afsluitbare duiker	Waterloop lijnvormig, in duiker	309	L
-12203	waterloop 0,5 - 3 m, in grondduiker	Waterloop lijnvormig, in duiker	309	L
-12204	waterloop 0,5 - 3 m, in afsluitbare grondduiker	Waterloop lijnvormig, in duiker	309	L
-12100	greppel, droge sloot	Greppel	310	L
12100	greppel, droge sloot	Greppel	310	L
12105	greppel, droge sloot	Greppel, met riet	311	L
-12101	greppel, droge sloot, in duiker	Greppel, in duiker	319	L
-12102	greppel, droge sloot, in afsluitbare duiker	Greppel, in duiker	319	L
-12103	greppel, droge sloot, in grondduiker	Greppel, in duiker	319	L
-12104	greppel, droge sloot, in afsluitbare grondduiker	Greppel, in duiker	319	L
15020	bomenrij	Bomenrij	400	L
-15020	bomenrij	Bomenrij	400	L
15180	heg, haag	Heg, haag	410	L
-15180	heg, haag	Heg, haag	410	L

Annex 11 BNL_codes derived from Top10NL

BNL_code	BNL_type
10	Zee
20	Meer, plas
21	Meer, plas, met riet
30	Waterloop
31	Waterloop, met riet
40	Droogvallend
41	Droogvallend, met riet
45	Droogvallend (LAT)
50	Autosnelweg
51	Hoofdweg
52	Regionale weg
53	Lokale weg
54	Straat
55	Overige infrastructuur, half verhard
56	Overige infrastructuur, onverhard
57	Infrastructuur, langzaam verkeer
58	Parkeerplaats
59	Overige infrastructuur
70	Spoorbaanlichaam
71	Spoorbaanlichaam, op brug
90	Gebouw
95	Kas
100	Grasland
101	Grasland, met riet
110	Bouwland
120	Boomgaard
121	Fruitkwekerij
122	Boomkwekerij
130	Braakliggend
131	Braakliggend, met riet
140	Bos op dodenakker
141	Gemengd bos
142	Loofbos
143	Naaldbos
144	Populierenbos
145	Griend
150	Zand
151	Zand, met riet
160	Duin
161	Duin, met riet
170	Heide
171	Heide, met riet
200	Overig grondgebruik
201	Overig grondgebruik, met riet
300	Waterloop lijnvormig
301	Waterloop lijnvormig, met riet
309	Waterloop lijnvormig, in duiker
310	Greppel

BNL_code	BNL_type
311	Greppel, met riet
319	Greppel, in duiker
400	Bomenrij
410	Heg, haag

Annex 12 BNL_codes for urbanity and business park

BNL_Code	BNL_type
Bebouwde kom	
0	Geen kern
1	Kern met OAD >= 2500
2	Kern met OAD >= 1500 en < 2500
3	Kern met OAD >= 1000 en < 1500
4	Kern met OAD >= 500 en < 1000
5	Kern met OAD < 500
Bedrijventerrein	
0	Geen bedrijventerrein
1	Bedrijventerrein >= 10 ha
2	Bedrijventerrein < 10 ha

Annex 13 Effect of (in)directe drivers on ecosystem services

Legenda
red text: priority to get data on dose-response function
blue text: dose-response functions already available
black text: important factor, but no priority

Supply and demand of ecosystem services and their relationships with climate change, land use change, nitrogen deposition and land management (after De Vries et al. 2014, 2015).

	(customised from CICES version 4.3) Provisioning services		Climate change (temp, precip, CO2)		Nitrogen (application/deposition)		Land management (landuse intensity)		Landuse change (amount, configuration)		Other important factors?	
			supply	demand	supply	demand	supply	demand	supply	demand	supply	demand
1a	Food production: crop productio	Expected direction of impact	Increase in crop production, depending on region		Increase in crop production		increase/decrease		increase/decrease			
		Mechanism	CO_2 fertilization increases crop growth and so does temperature increase in colder regions (NL). Climate change may decrease growth in warm regions (more drought stress)	overall increase of crops expected due to increase of population and changing diet	N fertilization increases crop growth in N limited systems	overall increase of crops expected due to increase of population and changing diet	Agricultural intensification (fertilization, drainage, scale) increases crop production and vice versa	increase of crop demand expected due to increase of population and changing diet	more agriculture leads to more production and vice versa	overall increase of crops expected due to increase of population and changing diet		
		Available models with response data	WOFOST model		WOFOST model		CAPRI (EU) in combination with SIMPLACE for Europe. WOFOST model for the Netherlands (empirical model, such as QUEFTS)		VITO-algorithms			
1b	Food production: biodiversity based (wild plants and animals/fish)	Expected direction of impact	increase/decrease		increase/decrease		increasing/decreasir		increase/decrease			
		Mechanism	Climate change affects plant and faunal species diversity and thereby biodiversity-based products	no change expected	N induced eutrophication and soil acidification affects plant and faunal species diversity and thereby biodiversity-based products	no change expected	Natural land management (use intensity) affects biological diversity and thereby biodiversity-based products	no change expected	More (semi)natural areas leads to more biodiversity based products and vice versa	no change expected		
		Available models with response data	GLOBIO and PROPS models for world and Europe (Netherlands, respectively)		GLOBIO and PROPS models for world and Europe (Netherlands, respectively)		GLOBIO model for world; SUMO model for the Netherlands		VITO-algorithms			
2	Wood	Expected direction of impact	Increase/decrease in forest (wood) growth, depending on region		Increase/decrease in forest (wood) growth depending on N forest status (region)		increase/decrease		increase/decrease			
		Mechanism	CO_2 fertilization increases forest growth and so does temperature increase in colder regions (NL). Climate change may decrease growth in warm regions (more drought stress)	no change expected	In N limited systems, N deposition increases forest growth and related tree carbon sequestration. At elevated N deposition in N saturated systems, forest growth may decline due to acidification and pest and diseases	no change expected	Increase of wood increment depending on tree species, harvest frequency, drainage, selective logging, grazing etc	no change expected	More forest especially productive tree species increases wood production and vice versa	no change expected		
		Available models with response data	EUgrow model for Europe, LPJml for world		EUgrow model for Europe, LPJml for world		EFISCEN (-SPACE)		VITO-algorithms, EFISCEN(-SPACE)			

3	Drinking water	Expected direction of impact	Impacts on ground water recharge and drainage		Impacts on ground water recharge and drainage	increase	increasing/decreasing	increasing/decreasing	increase/decrease	increase/decrease	
		Mechanism	Climate change will affect precipitation surplus and thus ground water recharge and drainage	no change expected	N induced impacts on growth may affect water uptake and freshwater supply (subtle changes).	N pollution decreases the amount of available clean water.	Forest management and agricultural management influences pollution leakage to soil and groundwater	Changes in landuse intensity and water use efficiency affects need for water (irrigation) and risks of runoff of pollutants (agriculture/silviculture)	More natural areas increase the infiltration and filtration capacity to recharge groundwater	overall increase of demand for fresh drinking water is expected due to increase of population	
		Available models with response data	SWAT, SWAP, many other models		No models	?	EFISCEN (-SPACE), ?	?	?	?	
4	Non-drinking water	Expected direction of impact	Impacts on ground water recharge and drainage	increase/decrease	Impacts on ground water recharge and drainage	increase	increasing/decreasing	increasing/decreasing	increase/decrease	increase/decrease	
		Mechanism	Climate change will affect precipitation surplus and thus ground water recharge and drainage (also changes in temporal waterstress: flooding, drought)	Temperature and precipitation pattern changes need for irrigation (agriculture)	N induced impacts on crop growth may affect water uptake and thus changing the water supply (subtle changes)	N pollution decreases the amount of available clean water.	Forest management and agricultural management influences evapotranspiration and pollution leakage to soil and groundwater	Changes in landuse intensity and water use efficiency affects need for water (irrigation) and risks of runoff of pollutants (agriculture/silviculture)	More natural areas increase the infiltration and filtration capacity to recharge groundwater	Overall change of demand for fresh water for irrigation is expected due to changes in landuse	
		Available models with response data	SWAT, SWAP, many other models	?	No models?	?	EFISCEN (-SPACE)?	?	?	?	
5	Biomass for energy	Expected direction of impact	Increase in crop production, depending on region	Less energy needed	Increase in crop production, depending on region		increasing/decreasing		increase/decrease		
		Mechanism	CO_2 fertilization increases crop growth and so does temperature increase in colder regions (NL). Climate change may decrease growth in warm regions (more drought stress)	Higher winter temperatures decreases energy needed for heating houses etc.	N fertilization increases crop growth, and deposition influences forest	no change expected	nature, forest, agricultural management influences biomass production	no change expected	More natural areas, especially those of high productivity of biomass increase possiblitities for biomass production	no change expected	
		Available models with response data	WOFOST model	?	SMART-SUMO-NTM?		?		VITO-algoritmes		

Regulating services

6a	Carbon sequestration: Forest	Expected direction of impact	Increased or decreased carbon sequestration in forests, depending on region		Increased or decreased carbon sequestration in forests, depending on region		Increased or decreased carbon sequestration in forests, depending on measures		increase/decrease		
		Mechanism	CO_2 fertilization increases forest growth and so does temperature increase in colder regions and thus tree carbon sequestration. Climate change may decrease forest growth and thus tree carbon sequestration in warm regions (more drought stress). Warmer temperatures will also increase soil respiration and decrease soil carbon sequestration	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	In N limited systems, N deposition increases forest growth and related tree carbon sequestration and it causes an increased litterfall and reduced decomposition, leading to soil carbon sequestration. At elevated N deposition in N saturated systems, forest growth may decline due to acidification and pest and diseases	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	Land (forest/agricultural) management affects (i) soil carbon inputs (e.g. harvest residue management) and soil losses (e.g. harvetsing techniques) and thus soil carbon emissions	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	More forest especially fast growing one increases carbon seqestration.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	
		Available models with response data	EUgrow-VSD+ model for Europe, LPJml for world		EUgrow-VSD+ model for Europe, LPJml for world		Many soil C models, such as RothC, combined with models calculating the C input such as EUgrow or EFISCEN for forests and MITERRA/INITIATOR for agricultural soils		VITO-algoritmes, EFISCEN(-SPACE)		
6b	Carbon sequestration: Peat	Expected direction of impact	Increased/decreased carbon sequestration in peat lands		Increased/decreased carbon sequestration in peat lands		increase/decrease		increase/decrease		
		Mechanism	Climate will affect net primary productivity and species composition of peat land forming species and also microbial activity of peat lands (Juul Limpens can tell)	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	1) At low N deposition, additional atmospheric N deposition may stimulate net primary productivity. At high rates of N deposition, species composition changes lead to loss of peat land forming species and changed microbial activity causing degradation of peat lands. 2) Increased N loading, either by fertilizer or deposition will Increased N2O and CO2 emissions.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	Ground water table (drainage) affects CO2 and methane emissions of peat.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	Conversion of nature into agriculture and the other way around as well as different types of nature affects the stocks and seqestration of carbon.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	
		Available models with response data	?		DNDC model, empirical model		?		VITO-algoritmes		
6c	Carbon sequestration: Agriculture	Expected direction of impact	Increased/decreased carbon sequestration agricultural soils		Increased/decreased carbon sequestration agricultural soils		Increased/decreased carbon sequestration agricultural soils		Increased/decreased carbon sequestration agricultural soils		
		Mechanism	CO_2 fertilization increases crop growth and so does temperature increase in colder regions and thus carbon sequestration. Climate change may decrease crop growth and thus carbon sequestration in warm regions (more drought stress). Warmer temperatures will also increase soil respiration and decrease soil carbon sequestration.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	N application and to a lesser extent N deposition, stimulate net primary productivity.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	Intensity of agricultural use affects CO2 and methand sequestration/emission of agricultural lands.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	More agricltural lands, crop choice and location (soil type) influence carbon seqestration.	overall change of CO2 emissions expected due to increase of population and effects of policy to achieve climate targets (Paris-agreement etc).	
		Available models with response data	EUgrow-VSD+ model for Europe, LPJml for world		EUgrow-VSD+ model for Europe, LPJml for world		Many soil C models, such as RothC, combined with models calculating the C input such as EUgrow and MITERRA/INITIATOR for agricultural soils		VITO-algoritmes		

7	Soil quality regulation (soil fertility)	Expected direction of impact	increase/decrease		N eutrophication and N induced soil acidification causes a decrease in soil C/N ratio, in available BC and Al pools and in pH in non –agricultural soils	decrease	increase/decrease	increase/decrease	increase/decrease		
		Mechanism	Climate change affects soil carbon sequestration (see above) and nitrogen transformations	no change expected	In agricultural soils this is repaired by liming (not e.g. in China)	N deposition acts as a fertilizer for crops en thus decreases demand for fertile soils (eg. nutrients)	Land management affects (i) soil carbon contents (see above), (ii) soil P inputs and soil P accumulation depending on P status and thereby and thus soil P contents, (iii) soil cadmium (Cd) inputs and soil Cd accumulation depending on Cd status and thereby and thus soil Cd contents, (iv) soil compaction, depending on machinery loads	crop choice depending on soil capabilities reduce need for ground water lowering and use of fertilizers.	Use of soils that are naturally suitable for agricultural production increases overall soil quality	no change expected	
		Available models with response data	EUgrow-VSD+ model, various DGVMs (LPJml)		Many acidification models, such as VSD+ and SMART	?	Many models, such as RothC for soil C, INITIATOR/ANIMO for soil P and INITIATOR for soil Cd. We develop a DSS for all these impacts, including compaction, also based on meta-analysis of the literature (PhD Wim de Vries)	HELP tabeles?	VITO-algoritmes		
8	Erosion control (wind & water)	Expected direction of impact		increase demand	decrease		increase/decrease		increase/decrease		
		Mechanism	no change expected?	more wind erosion (storms) and more water erosion (more frequent heavy rainfall)	N and eutropication of ecosystems increase growth of vegetation and thus decreasing erosion risk	no change expected	Use of windbreaks (hedges) and landmanagment affects cover of vegetation and possibility of vegetation to fixate the soil.	no change expected	Vegetation on erosion susceptible areas decreases erosion.	no change expected	
		Available models with response data		?			?		VITO-algoritmes		
9	Water quality regulation (water purification)	Expected direction of impact	No clear effects		Decline in water quality regulation N eutrophication and N induced soil acidification causes a decrease in soil C/N ratio, in available BC and Al pools and in pH, lowering the N retention and acid buffer capacity and leading to:- Increasing NO3, Cd and Al concentrations in groundwater and surface water, which may exceed drinking water quality criteria in view of human health effects.	increase	increase/decrease		increase/decrease		
		Mechanism	Changed (increased) precipitation surplus and lower retention times may lower the water purification regulation	no change expected		N and P eutrophication increases demand for clean water	Land management affects (i) soil P contents (see above) and thus soil P losses to surface water and (iii) soil N losses to surface water leading to: Fish dieback by algal blooms and anoxic zones (eutrophication).	no change expected	More helofytes, especially located at places with pollution, help to purify water.	no change expected	
		Available models with response data	?		VSD+ model, PC Ditch, PC Lake, WATERNOOD, KRW verkenner (Dutch models).	PC Ditch, PC Lake, WATERNOOD, KRW verkenner (Dutch models)?	ANIMO, INITIATOR, Global NEWS. PC Ditch, PC Lake, WATERNOOD, KRW verkenner (Dutch models).		PC Ditch, PC Lake, WATERNOOD, KRW verkenner (Dutch models).		

10	Air quality regulation	Expected direction of impact	Change in air quality regulation		Change in air quality regulation		Change in air quality regulation		Change in air quality regulation	
		Mechanism	Climate change will affect forest stand structure and tree vitality thus affecting the filtering (dry deposition) of air pollutants such as ammonia (NH_3), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM_{10} and $PM_{2.5}$), all affecting human health and ecosystems.		Land use change affects the roughness of vegetation thus affecting the filtering (dry deposition) of air pollutants such as ammonia (NH_3), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM_{10} and $PM_{2.5}$), all affecting human health and ecosystems.		Land management change, such as tree species choice after clear cut, affects the roughness of vegetation thus affecting the filtering (dry deposition) of air pollutants such as ammonia (NH_3), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM_{10} and $PM_{2.5}$), all affecting human health and ecosystems.		Nitrogen/acid deposition affects forest stand structure and tree vitality thus affecting the filtering (dry deposition) of air pollutants such as ammonia (NH_3), nitrogen oxides (NO_x), ozone (O_3) and particulate matter (PM_{10} and $PM_{2.5}$), all affecting human health and ecosystems.	
		Available models with response data	Problem is link climate change and vitality/stand structure (no model). Further: OPS model		OPS model: this model predicts air pollutant concentrations and dry deposition as a function of the roughness of vegetation and should be able to assess impact of land use changes		OPS model: this model predicts air pollutant concentrations and dry deposition as a function of the roughness of vegetation and should be able to assess impact of land management changes		Problem is link N/acid deposition and vitality/stand structure (no model). Further: OPS model	
11	Regulation of pests/disease by natural enemies	Expected direction of impact	increase	Increase/decrease of pests	decrease	Increase in forest pests	increase/decrease		increase/decrease	
		Mechanism	Increase in number of natural enemies species and decrease of generation time	Increase in pests (agriculture, forest)? Decrease of severity of pests due to mild winters	decrease in natural	Increase in bark or foliar N concentrations can attract higher infestation rates, such as beech bark disease	Landuse intensity affects use of fertilizer, pesticides, groundwater table. Landuse also affects quality of natural elements within the agrarian landscape. This affects habitat for natural enemies of pests thus changing the ability to supress pests/diseases.	no change expected	More natural elements (e.g. hedges, ditches), especially near fields that are susceptible to pests and diseases, enhance the capacity to suppress plagues.	no change expected
		Available models with response data	?	?	?	No model	?		VITO-algoritmes	
12	Pollination	Expected direction of impact	increase		decrease		increase/decrease		increase/decrease	
		Mechanism	Increase in number (and abundance?) of pollinator species	no change expected	eutrophication leads to loss of species richness. This affects quantity and quality of pollinators	no change expected	Landuse intensity affects use of fertilizer, pesticides, groundwater table. Landuse also affects quality of natural elements within the agrarian landscape. This affects habitat for pollinators thus changing the ability to pollinate.	no change expected	More natural elements (e.g. hedges, ditches), especially near crops that need to be pollinated, enhance the capacity to pollinate	no change expected
		Available models with response data	?		?		?		VITO-algoritmes	
13	Water storage	Expected direction of impact	increase supply	increase demand			increase/decrease		increase/decrease	
		Mechanism	Increase/decrease of evapotranspiration of soils influences water storing capacity of soils	Changes in rainfall intensity and amount, higher temperatures changes probability of floods.	no change expected	no change expected	Naturalness and structure of streams (meandering) and space determines capacity for water storage	no change expected	More areas that could inundate during high water increase water storage capacity.	no change expected
		Available models with response data	?	check models of CAS (climate adaptive systems)			Check models of CAS (climate adaptive systems)		?	
14	Coastal protection (and rivers/streams)	Expected direction of impact		higher demand	increase		increase/decrease		increase/decrease	
		Mechanism	no change expected	sea level rise, more storms and wind causes higher waves and more erosion of coast	Eutrophication leads to more biomass and fixation of dunes	no change expected	Use of vegetation and allowing natural processes like vegetation growth to fixate dunes and reedbeds to break waves	no change expected	Natural areas near the coast (dunes) and along dams and dykes increase protection against water.	no change expected
		Available models with response data		?	?		?		VITO-algoritmes	
15	Absorption of noise, wind, visual disturbance	Expected direction of impact							increase/decrease	increase
		Mechanism	no change expected	no change expected	no change expected	no change expected	no change expected	no change expected	More vegetation around areas where people live and work increases adsorption of noise, wind and visual disturbance	The human population is growing. This leads to more infrastructure. Both lead to a higher demand for absorption of wind, noise and visual disturbances
		Available models with response data							VITO-algoritmes	VITO-algoritmes
16	Climate control in cities	Expected direction of impact		Increase					increase/decrease	
		Mechanism	no change expected (or is the cooling of vegetation and water desity dependent?)	Increase of temperature and growth of cities increases urban heat island effect	no change expected	no change expected	no change expected	no change expected	More vegetation (especially big trees, parks) in heavily urbanized areas decrease temperature. The effect van water could both be cooling as well as heating (at night).	no change expected
		Available models with response data		?					VITO-algoritmes	

Cultural services

17	Natural heritage	Expected direction of impact	decrease		N deposition may change heathlands into grasslands, affecting historically important landscapes		increase/decrease		increase/decrease		
		Mechanism	Impacts biodiversity changes negatively. Only mobile species (with wings etc.) can cope with shifting climate envelopes	no change expected	Nitrogen induces the increase in nitrophilic species like stinging nettles and algal blooms reducing recreational and aesthetic values of nature. Extreme examples include closed beaches due to algal blooms resulting from N-induced eutrophication in estuaries and coastal ecosystems. Eutrophication is also affection biodiversity in a negative way leading to deteriorated landscapes with less biodiversity and a lower natural heritage values.	no change expected	Steering on patterns or processes influences the naturalness of nature. In case of high environmental pressures and lack of natural processes active nature management (mowing, sod cutting) could be the only possiblity to maintain present ecological values	no change expected	The increase of nature areas and its connectivity leads to more species that can be sustained and also leads to a higher quality of nature.	no change expected	Desiccation, availability of natural processes
		Available models with response data	GLOBIO (world), BioScore (EU), MNP (Neth.)		GLOBIO (world), BioScore (EU), MNP (Neth.)		?		GLOBIO (world), BioScore (EU), MNP & LARCH (Neth.)		
18	Symbolic value of nature	Expected direction of impact	decrease		N deposition may change heathlands into grasslands, affecting historically important landscapes		increase/decrease		increase/decrease		
		Mechanism	Impacts biodiversity changes negatively. Only mobile species (with wings etc.) can cope with shifting climate envelopes	no change expected	Nitrogen induces the increase in nitrophilic species like stinging nettles and algal blooms reducing recreational and aesthetic values of nature. Extreme examples include closed beaches due to algal blooms resulting from N-induced eutrophication in estuaries and coastal ecosystems. Eutrophication is also affection biodiversity in a negative way leading to deteriorated landscapes with less biodiversity and a lower symbolic values.	no change expected	steering on patterns or processes influences the naturalness of nature. In case of high environmental pressures and lack of natural processes active nature management (mowing, sod cutting) could be the only possiblity to maintain present ecological values	no change expected	The increase of nature areas and its connectivity leads to more species that can be sustained and also leads to a higher quality of nature.	no change expected	
		Available models with response data	GLOBIO (world), BioScore (EU), MNP (Neth.)		GLOBIO (world), BioScore (EU), MNP (Neth.)		?		GLOBIO (world), BioScore (EU), MNP (Neth.)		
19	Outdoor recreation	Expected direction of impact	decrease/increase	decrease/increase			increase/decrease		increase/decrease		
		Mechanism	some outdoor recreational activities are determined by climate criteria. For instance water and air temperature, windspeed and indirect via biodiversity affects possibilities for outdoor recreation, sailing, beach activities, ice skating etc.	demand for outdoor activities (for instance ice skating, sailing, beach activities) depends on climate	Nitrogen induces the increase in nitrophilic species like stinging nettles and algal blooms reducing recreational and aesthetic values of nature. Extreme examples include closed beaches due to algal blooms resulting from N-induced eutrophication in estuaries and coastal ecosystems.	no change expected	accessibility and management focussing on preservation and development of attractive ecological elements affects the capacity and recreational values of nature	no change expected	More attractive natural areas, especially near places where people lve, leads to more opportunities for recreation.	overall demand of recreational activities changes due to popuation growth, eduaction, etnicity and education	
		Available models with response data	?	?	AVANAR (Dutch model) & BelevingsGIS (Dutch model) in combination with MNP		AVANAR (Dutch model) & BelevingsGIS (Dutch model) in combination with MNP		AVANAR (Dutch model) & BelevingsGIS (Dutch model) in combination with MNP		
20	Science and education	Expected direction of impact	?	?	?	?	?		?		
		Mechanism	?	?	?	?	?	no change expected	?	no change expected	
		Available models with response data	?	?	?	?	?		?		

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