Thinking in Systems, Thinking in Nature

Evaluating the long-term performance of Nature Based Solutions

Dissertation

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Dedicated to my grandmother,

who taught me as a child to hug the trees

Después de tanta espera,
esto es el ocio. ¿Qué hare con él?

-La tregua-

Mario Benedetti

Eidesstattliche Versicherung

Declaration on oath

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Dissertationsschrift selbst verfasst

und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe.

I hereby declare, on oath, that I have written the present dissertation by my own and have not used other than

the acknowledged resources and aids.

Hamburg, den 9.12.2020 Unterschrift:

Summary

Climate change impacts and the ongoing environmental degradation are reducing the resilience and adaptation capacity of European socio-environmental systems. Since the beginning of this century, the role of nature has increasingly been seen as a crucial component to cope with climate change impacts while improving the resilience of ecosystems and society. Enhancing and protecting natural capital and its associated ecosystem services have become the core of action of different national and international development policies. The concept of Nature-Based Solutions (NBS) is being emphasised as an opportunity to address biodiversity and climate crisis simultaneously. The critical element differentiating NBS from other adaptation approaches is their capability of producing several benefits simultaneously. This approach highlights the relevance of nature and suggests the adoption of a systematic approach that considers at the same level of importance the social, environmental and economic dimensions of sustainable development. Despite their potential, several barriers and the short compilation of evidence on NBS effectiveness are limiting the total uptake of the concept into national development policies and adaptation actions.

Consequently, the central focus of this research is to explore ways to operationalise the NBS concept for adaptation and sustainable development planning. For that, this dissertation seeks to increase the evidence-based on the long-term effectiveness of NBS for addressing different societal challenges. This research has critically evaluated the NBS concept as well as the main trade-offs in their long-term performance. In this sense, different approaches have been proposed to improve the decision-making process and the adaptation capacity of NBS. The study is divided into four consecutive chapters that explore different aspects relevant to the design and implementation of NBS. Stakeholders engagement and participatory modelling approaches have been the backbone of this research. For this reason, the conceptual and methodological assessment of NBS carried out in this study, has been tested and validated by end-users and stakeholders in two case studies, Copenhagen city and Medina Del Campo Groundwater Body (Spain).

Zusammenfassung

Die Folgen des Klimawandels und die anhaltende Umweltzerstörung reduzieren die Resilienz und Adaptionsmöglichkeiten der Europäischen sozio-ökologischen Systeme. Seit dem Anfang des 20. Jahrhunderts, wurde die Rolle der Natur als entscheidene Komponente im Kampf gegen die Folgen des Klimawandels und zur Stärkung der Resilienz von Ökosystem sowie unserer Gesellschaft, immer wichtiger. Die Stärkung und der Schutz von Natur und deren Einfluss auf das Ökosystem ist der Kern der Maßnahmen von vielen verschiedenen Nationalen und internationalen Richtlinien. Das Konzept von Nature-Based-Solutions (NBS) wird hervorgehoben als Möglichkeit die Biodiversität zu stärken und die Klimakrise gleichzeitig zu bekämpfen. Darin besteht auch der größte Unterschied zu anderen Ansätzen, welche oftmals nur eine Problematik angehen. NBS hebt die Relevanz der Natur hervor und schlägt vor, dass eine Strategie verfolgt wird in der die Umwelt, Soziale und die wirtschaftliche Dimension mit dem gleichen Augenmark in der nachhaltigen Entwicklung betrachtet werden, Nichtsdestotrotz ist aufgrund von Barrieren und der geringen Anzahl von Beweisen für die Effektivität von NBS, das Konzept nur selten ein Teil von nationaler Entwicklungspolitik und Adaptionsstrategien.
Als Konsequenz, liegt der zentrale Focus dieser Forschung darauf Wege zu finden das Konzept NBS für Adaptionsstrategien und nachhaltiger Entwicklung nutzbar zu machen.

Das Ziel dieser Dissertation ist es die Beweislage der Langzeiteffekte von NBS als Lösung für gesellschaftliche Herausforderungen zu stärken. Diese Arbeit evaluiert das NBS Konzept kritisch und geht ein auf die Kompromisse die für diese Langzeiteffekte gemacht werden. Diese Dissertation ist in 4 Teile unterteilt, die jeweils einen unterschiedlichen Aspekt des Designs und der Implementierung von NBS analysieren. Das Rückgrat der Forschung ist das Engagement von Interessengruppen und participatory modelling. Aus diesem Grund, wurde das konzeptionelle und methodische Assessment von NBS dieser Dissertation getestet und validiert von Interessengruppen und Endverbrauchern in zwei Studien in Kopenhagen und Medina Del Campo Groundwater Body (Spanien).

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Eulalia Gómez

List of publications resulting from dissertation

The four main chapters presented in this dissertation have all either been published, accepted or submitted to peer-reviewed scientific journals or technical books. The following table summarises the authorships and the publication state of the chapters composing this dissertation.

Chapter Number	Title	Authors	Status	Journal/ book	Impact Factor
2.	An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice.	Gómez Martín, Eulalia Máñez Costa, María Schwerdtner Máñez, Kathleen	Published	Ecological Economics	3.895
3.	Using a system thinking approach to assess the contribution of Nature Based solutions to sustainable development goals.	Gómez Martín, Eulalia Giordano, Raffaele Pagano, Alessandro van der Keur, Peter Máñez Costa, María	Published	Science of the total Environment	6.551
4.	Integrated analysis: a qualitative Systems Dynamic Model to understand the Medina del Campo system.	Gómez Martín, Eulalia Máñez Costa, María Giordano, Raffaele Pagano, Alessandro	Accepted	Book Chapter, Edited and published by The Duero River Basin Authority (CHD) [1]	-
5.	Assessing the long-term effectiveness of Nature Based Solutions under different climate change scenarios.	Gómez Martín, Eulalia Máñez Costa, María Egerer, Sabine Schneider, Uwe	Submitted	Science of the total Environment	6.551

[1] *From book: Mayor, B., López Gunn, E., Marcos, C. (Eds). (2021). Exploring Nature-based and management solutio for climate adaptation in Medina del Campo groundwater body: Lessons learned from the NAIAD project. Publicaciones de la Confederación Hidrográfica del Duero, Valladolid, España.*

Other publications not included in this dissertation

Peer-reviewed scientific journals

- Giordano, R., Costa, M.M., Pagano, A., Pluchinotta, I., Zorrilla-Miras, P., Rodriguez, B.M., **Gomez, E**., Lopez-Gunn, E., 2020. A Participatory Modelling approach for enabling Nature-based Solutions implementation through Networking Interventions.
- Costa, M.M., Marchal, R., Moucolon, D., **Gómez, E**., 2020. The insurance effect of nature-based solutions to support climate adaptation.

Book Chapters

- Mayor, B., de la Hera-Portillo A., Llorente M., Heredia J…, **Gómez, E.**, Zorrilla-Miras P., Rica, M. Vay L., Rubio F., Marín-Lechado C., Ruíz-Constán A., Bohoyo-Muñoz F., Marcos, C., López Gunn E. (in prep). *Multidisciplinary assessment of Nature Based strategies to address groundwater overexploitation and drought risk in Medina del Campo Groundwater Body.* In: Lopez-Gunn et al. Greening Water Risk: Natural Assurance Schemes. Springer book series Water Security in a New World (forthcoming).
- Ejsing Jørgensen M., Kidmose J., van der Keur P., **Gomez, E**., Giordano, R. and Henriksen H. J. (in prep). *Urban river restoration - a scenario for Copenhagen*. In: Lopez-Gunn et al. Greening Water Risk: Natural Assurance Schemes. Springer book series Water Security in a New World (forthcoming).

Declaration of Authorship

Eulalia Gómez Martín,

Born in Spain, 27th of February, 1990

I, hereby declare my share in the authorship of the dissertation chapters (research articles/book chapters), which are either submitted, accepted or published to peer-reviewed journals or as a book chapters, as following:

Chapter	Title	Contribution of the first author (Eulalia Gómez Martín)	Contribution of co-authors
2.	An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice	**Conceptualisation** (predominantly) **Literature review** (completely) **Analysis of the results** (completely) **Manuscript writing** (predominantly)	**Conceptualisation:** María Máñez Costa **Manuscript editing:** María Máñez Costa Kathleen Schwerdtner Máñez
3.	Using a system thinking approach to assess the contribution of Nature Based solutions to sustainable development goals.	**Conceptualisation** (predominantly) **Literature review** (completely) **Data collection** (predominantly) **Model development** (predominantly) **Analysis of the results** (completely) **Manuscript writing** (predominantly)	**Conceptualisation:** Raffaele Giordano Alessandro Pagano Peter van der Keur María, Máñez Costa **Data collection:** Peter van der Keur **Model development:** Raffaele Giordano Alessandro Pagano **Manuscript editing:** Raffaele Giordano Alessandro Pagano Peter van der Keur
4.	Integrated analysis: a qualitative Systems Dynamic Model to understand the Medina del Campo system.	**Conceptualisation** (partially) **Model development** (completely) **Analysis of the results** (completely) **Manuscript writing** (predominantly)	**Conceptualisation:** María, Máñez Costa Raffaele Giordano Alessandro Pagano **Manuscript editing:** Alessandro Pagano

Chapter	Title	Contribution of the first author (Eulalia Gómez Martín)	Contribution of co-authors
5.	Assessing the long-term effectiveness of Nature Based Solutions under different climate change scenarios	**Conceptualisation** (predominantly) **Literature review** (completely) **Data Collection** (completely) **Model development** (predominantly) **Analysis of the results** (completely) **Manuscript writing** (predominantly)	**Conceptualisation:** María, Máñez Costa **Model development:** Sabine Egerer **Manuscript editing:** María Máñez Costa Sabine Egerer Uwe Schneider

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Abbreviations

ACUAES	Aguas de las cuencas de España
BAU	Business as Usual
CAP	Common Agricultural Policies
CBD	Convention on Biological Diversity
CC	Climate change
CCAP	Copenhagen Climate Adaptation Plan
CHD	Confederación Hidrografica del Duero
CLD	Causal Loop Diagram
COP	Conference of the Parties
CORDEX	COordinated Regional climate Downscaling Experiment
DRR	Disaster Risk Reduction
EC	European Commission
EQ	Environmental Quality
ES	Ecosystem Services
ETP	Potential Evapotranspiration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
Fc	Basic soil Infiltration
FCM	Fuzzy Cognitive Maps
GDP	Gross domestic product
GHG	Greenhouse gas
GI	Green Infrastructure
GM	Group Model
GMB	Group Model Building
GSM	Green Space Management
GW	Groundwater
GWE	Groundwater extractions
HEE	Hydrological extreme events
IC	Institutional collaboration

IPCC	Intergovernmental Panel on Climate Change
IPD	Insurance & Pension Denmark
IUCN	International Union for Conservation of Nature
Kp	Slope
Kv	Vegetation fraction
MA	Millennium Ecosystem Assessment
MCGB	Medina del Campo Groundwater body
MCGWB	Medina del Campo Groundwater Body
MCS	Medina del Campo System
MEA	Millennium Ecosystem Assessment
NAIAD	NAture Insurance value: Assessment and Demonstrations
NAS	Natural Assurance Schemes
NBS	Nature Based Solutions
NCA	Non-citizens awareness scenario
NGO	Non-governmental organization
NJEO	New jobs and economic opportunities
NWRM	Natural Water Retention Measures
QSDM	Qualitative System Dynamics Model
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SC	Soil Conservation
SD	System Dynamics
SDGs	Sustainable Development Goals
SDM	System Dynamics Model
SER	Society for Ecological Restoration
UCCL	Association of Young Farmers (Jóvenes Agricultores)
UN	United Nations
UN-REDD	United Nations Programme on Reducing Emissions from Deforestation and Forest Degradation
UNEP	United Nations Environment Programme
WWAP	World Water Assessment Programme
WWF	World Wide Fund for Nature

Chapter 1:

Introduction

1. Introduction

During the 20th century, the use of fossil fuels has increased ten times compared to pre-industrial levels. Since then, the average global temperature has increased about 0.8 °C, and it is estimated that it will increase further between 1.8 and 4 °C by the end of this century (Masson-Delmotte et al., 2018; IPCC, 2014). The increased surface temperature will aggravate environmental problems such as ocean acidification, land degradation or biodiversity loss (Cao et al., 2007; Henry et al., 2007; Skogen et al., 2018). As a consequence of Climate Change, will alter significantly the hydrologic cycle. This has resulted in spatial and temporal changes in the distribution of water resources at the local and global scale (Middelkoop et al., 2001). This will be manifested via changes in extreme weather events. The IPCC estimates that climate change is likely to generate losses in European GDP by up to 77% by 2030 (IPCC, 2014). This, along with the ongoing environmental degradation, is reducing the resilience and adaptation capacity of European socio-environmental systems (Adger et al., 2005; Jabareen, 2013).

In response to these challenges, new measures and policy frameworks have emerged aiming to cope with climate change impacts while enhancing the resilience of ecosystems and society.

Over the past twenty years, the role of biodiversity and ecosystems has increasingly been seen as crucial components in national and international development policies. Biodiversity conservation and other related approaches such as natural capital or ecosystem services have been highlighted in policy agreements including the Convention on Biological Diversity (CBD) (UNEP, 1993), the UN's Millennium Ecosystem Assessment (MA, 2005), the Sendai Framework for Disaster Risk Reduction (United Nations, 2015), the European Green Deal (European Commission, 2019) or the 2030 Agenda for Sustainable Development (Colglazier, 2015). Enhancing and protecting natural capital and associated ecosystem services have become the core of action of adaptation strategies and EU research programs, i.e. Ecosystem-based Adaptation, Green Infrastructure, Ecosystem-based Disaster-Risk Reduction or Natural Water Retention Measures (Cohen-Shacham et al., 2016; Faivre et al., 2017; Munang et al., 2013; Schäffler and Swilling, 2013). Among all these approaches, the concept of Nature-Based Solutions (NBS) is emphasised as an opportunity to simultaneously mitigate biodiversity and climate crises (Cohen-Shacham et al., 2016; IUCN, 2016). This approach is grounded on the idea that enhancing and protecting ecosystem functions provides multiple benefits for society, thereby ensuring sustainable delivery of ecosystem services (ES) and buffering the adverse impacts of climate change. For example, wetlands may reduce the vulnerability of communities to extreme weather events by acting as a natural barrier against storms (Gedan et al., 2011).

The European Commission developed a new programme for research and innovation, 'Horizon 2020'. This framework stresses the link between NBS and European targets for economic growth and transformational pathways for sustainable development (Maes and Jacobs, 2015). The European Commission defines NBS as: "… *living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits*[2] " (Maes and Jacobs, 2017). The NBS approach is used as an 'umbrella' concept that supports and builds on closely related approaches, such as ecosystem services, ecosystem-based mitigation and adaptation green and blue infrastructure or natural capital (Nesshöver et al., 2017). All these approaches highlight the relevance of nature and suggest the adoption of a systematic approach that equally considers social, environmental and economic dimensions of sustainable development.

The key element distinguishing NBS from other adaptation approaches such as the construction of hard engineering structures, is their multifunctionality, meaning the capability of producing several benefits (co-benefits) simultaneously. For instance, green spaces in cities can improve air quality (environmental co-benefit) and decrease pollution-induced diseases (health co-benefit), thus, reducing healthcare expenses (economic co-benefits) (GreenUP, 2018; Somarakis et al., 2019). The ability to deliver bundles of ecosystem services make NBS a promising strategy to address interconnected societal challenges such as climate change, biodiversity loss, or growing demand for natural resources. Due to these characteristics, NBS have been frequently mentioned in national development and climate change policies. For example, 66% of Paris Agreement signatories include NBS in their Nationally Determined Contributions (NDCs). However, several barriers limit the large-scale implementation of NBS into national development policies and adaptation actions (Seddon et al., 2020). Firstly, the vague definition and the lack of a comprehensive and standardised classification, similar to the one developed by the Millennium Ecosystem Assessment for the ecosystem services (MA, 2005), complicate the differentiation between NBS and other environmental management strategies. For example, many afforestation projects have been mistakenly flagged as NBS. However, these initiatives are often focused on quantity rather than quality, frequently leading to maladaptation practices (Seddon et al., 2019). Besides, the lack of a common language and framework has hampered communication and discussion among practitioners, scientists and decision-makers (Abson et al., 2014; Brand and Jax, 2007; Star and Griesemer, 1989). Secondly, the insufficient scientific evidence on NBS long-term effectiveness has hampered the translation into measurable evidence-based targets, limiting the total uptake into national

[2] This dissertation has used the definition developed by the European Commission on NBS.

development policies and adaptation actions (Seddon et al., 2020). There have been various efforts to collate information of the benefits compared to alternative approaches, i.e. grey infrastructure (e.g.,(Commission, 2015; Connop et al., 2016; Denjean et al., 2017; Eggermont Hilde et al., 2015; Kabisch et al., 2017; WWF, 2019)). However, NBS knowledge and information on best practices are scattered across different disciplines. Furthermore, although many biodiversity-based measures have been implemented in rural areas to support the development of sustainable agriculture, the concept of NBS has been until now, urban-centric (Nesshöver et al., 2017). Consequently, business models and financial instruments designed to boost the mainstreaming of NBS into EU policies are often urban-centric. Besides, theoretical frameworks and indices developed to assess the long-term effectiveness of NBS are also oriented for cities (Faivre et al., 2017).

Thirdly, NBS studies are often focused on a subset of impacts rather than a comprehensive view of the system. Existing studies tend not to report concurrently on the social, economic and environmental dimensions of NBS, overlooking the complex relationships that connect different co-benefits. Additionally, the majority of reviews and NBS frameworks do not account for possible “disservices” that NBS may cause (GreenUP, 2018). The lack of a systemic assessment can potentially lead to the malfunctioning of NBS causing several undesired effects including biodiversity loss, fragmentation, change in water flow patterns, the spread of pests and diseases, or changes in local and regional water availability (Zhang et al., 2007). Being aware of the potential disservices as well as the synergies and trade-offs among co-benefits is critical for NBS evaluation, as it allows the identification of factors and elements to be considered in the prior stages of NBS implementation.

Fourthly, climate change impacts on NBS have not been carefully considered in the literature. It is known that increasing climate variability, mean temperature increase or change in precipitation patterns may have significant impacts on ecosystems, and consequently on NBS (Masson-Delmotte et al., 2018; Pecl et al., 2017). At the same time, an increase in the frequency and intensity of Extreme Weather Events may exceed the capacity of NBS to cope with these risks. Nevertheless, the majority of the studies investigating NBS effectiveness is limited to empirical studies, thus, ignoring factors that cannot be studied empirically, i.e. long-term climate change projections. For this reason, scenario modelling approaches considering temporal projections of climate are crucial for NBS adaptation planning. Finally, adaptation strategies, including NBS, are often approached from an expert-driven, single-focus and top-down perspective. However, NBS affect a wide range of stakeholders including NGOs, national and local governments, scientists or civil society members. Each societal group may have different views, values, assumptions and knowledge. These differences are usually not well represented in the design and implementation of NBS strategies, leading to conflicts and hampering the long-term effectiveness of NBS. For this reason, proactive involvement at all societal levels is needed to avoid trade-offs and to increase the social acceptance of NBS (Johnson and Walker, 2000; Pagano et al., 2019; Ridder and Pahl-Wostl, 2005).

1.2 Research aim, research questions and objectives

Several barriers are limiting the integration of NBS into national and international development policies. More research is needed on developing tools and methods to improve the capacity of policy makers to integrate NBS in development planning. Consequently, the central focus of this research is to explore ways to operationalise the NBS concept for adaptation and sustainable development planning. For that, this research seeks to increase the evidence on the long-term effectiveness of NBS for addressing different societal challenges. Therefore, the overall research aim is

to contribute to the science-based knowledge on NBS effectiveness for adaptive planning.

For addressing this aim, the research questions this thesis intends to answer are the following:

RQ1: Which criteria need to be considered prior to NBS design and implementation?

RQ1.1. Which criteria are considered to evaluate and implement NBS in existing NBS frameworks and classifications?

RQ1.2. Which criteria are not sufficiently considered in existing frameworks?

RQ1.3. Which are the main barriers limiting the integration of NBS into sustainable development policies and adaptation actions?

RQ2: How can the capability of NBS contribute to the achievement of different SDGs be enhanced?

RQ2.1. To what extent trade-offs among NBS co-benefits limit the long-term effectiveness of NBS?

RQ3: To what extent will Climate Change affect the long-term effectiveness of NBS?

RQ4: How can local and scientific knowledge be better integrated to facilitate NBS implementation?

To answer these research questions, the focus of this thesis is to identify the main limitations that hamper NBS effectiveness as well as to investigate different methods and strategies to overcome these barriers. In detail, the research objectives are the following:

- Objective 1: **Identify** important criteria for NBS selection.
- Objective 2: **Develop** an easy-to use classification scheme to set the basis for a common language and framework for NBS mainstreaming.
- Objective 3: **Propose** a method to assess the dynamic behaviour of trade-offs and synergies among co-benefits.
- Objective 4: **Evaluate** the dynamic behaviour of NBS under different socio-economic and climatic scenarios.
- Objective 5: **Test** the Participatory Modelling Approach as a tool to enhance the decision-making process of NBS.

1.3. Thesis structure

This research is divided into four consecutive research chapters that explore the different limitations of the NBS concept (see figure 1). Each chapter purposes different strategies to overcome these barriers as well as relevant elements that should be considered in the decision-making process of NBS design and implementation. The second chapter sets the conceptual basis for the empirical research carried out in chapters 3, 4 and 5. Chapter 4 explains in detail the participatory process used in Chapter 5. The overall research findings and research conclusions are summarized and integrated in Chapter 6.

This research builds on the work carried out in the EU Horizon 2020 research program NAIAD (Nature Insurance value: Assessment and Demonstration; grant agreement No 730497). The field-based methodology has been conducted in two of the NAIAD case studies, Copenhagen city and Medina del Campo Groundwater Body.

A summary of the main research aims and objectives of the research chapters is shown below.

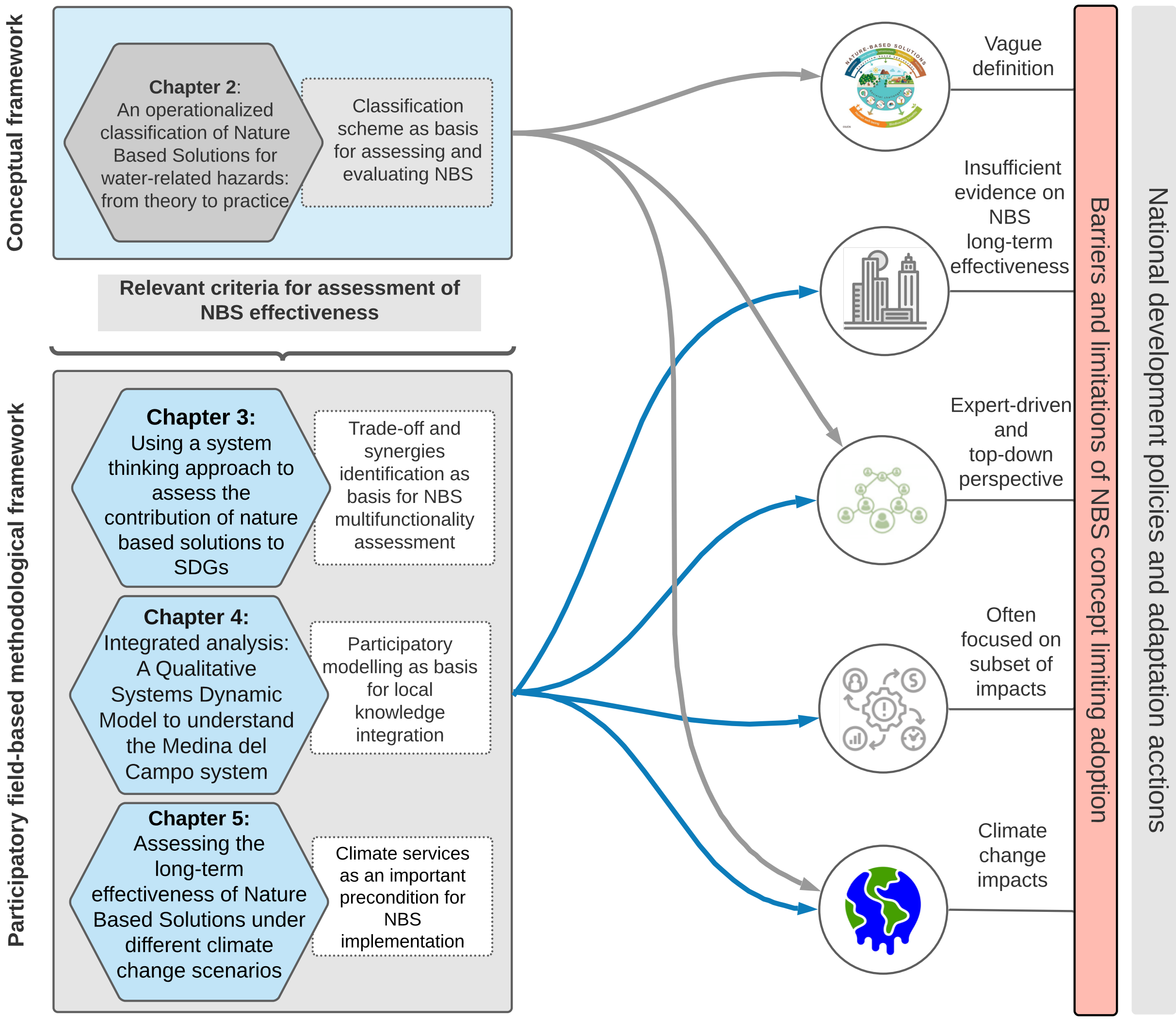

Figure 1. Structure of research to increase the evidence-based of NBS effectiveness. Each chapter seeks to identify and develop different strategies to overcome the barriers and limitations that are hampering the uptake of the NBS concept into National and international development policies and adaptation actions.

1.3.1. Summary chapter 2: An operationalised classification of Nature-Based Solutions for water-related hazards: From theory to practice

Despite the benefits and advantages of NBS over other adaptation approaches (i.e. dikes, dams, or other grey infrastructures) the lack of a common language and standardised framework for NBS have limited the spread of the NBS concept into the scientific literature. The vague and unclear definition of the term has contributed to the little uptake and implementation of the concept by national and international decision-makers. Also, the lack of a common and standardised classification containing the criteria needed to differentiate between NBS and other similar strategies hampers the transfer of the concept into risk mitigation and adaptation plans (Eggermont Hilde et al., 2015; Gómez Martín et al., 2019; WWAP, 2018). While several attempts of developing a standard classification for NBS exist, they are mostly descriptive and difficult to understand by non-experts (European Commission, 2015; Eggermont Hilde et al., 2015; European Environmental Agency, 2015). Besides, relevant elements to the evaluation and assessment of NBS are overlooked or are not considered systematically (GreenUP, 2018; Raymond et al., 2017). In response to these gaps, the objective of this chapter is to

develop a comprehensive and easy-to-use classification scheme as a basis for assessing and evaluating NBS under different socio-economic and climatic scenarios

Using the case of Hydrological Extreme Events (HEE) as a conceptual focus, the classification scheme was developed following a matrix structure. The classification was scientifically validated with an extensive literature review. It contains a portfolio of NBS as well as relevant criteria for their selection and evaluation. Specifically, it recognised two aspects of NBS that are often overlooked in NBS projects. Firstly, potential disservices or trade-offs that may arise when implementing NBS. And, secondly, the potential impacts of climate change on the long-term effectiveness of NBS. This chapter constitutes the theoretical framework on which the development of this dissertation is based.

1.3.2. Summary chapter 3: Using a system thinking approach to assess the contribution of nature-based solutions to sustainable development goals

NBS are usually implemented in socio-ecological systems that are governed by feedback loops, non-linearities and dynamic relationships that are continually changing over time (Nuno et al., 2014). NBS implementation may directly or indirectly affect multiple elements of the system, causing trade-offs and synergies. Identifying trade-offs among co-benefits may reveal the unintended consequences of NBS implementation. Being aware of these consequences at the first-stage of NBS design and implementation provides an opportunity to improve the balance between social, economic and environmental targets (Calliari et al., 2019; Haase et al., 2012). In response to this opportunity, the objective of this chapter is

developing a methodology to enhance NBS multifunctionality through the identification of trade-offs and synergies among co-benefits.

Specifically, this chapter assesses how NBS multifunctionality enhancement may affect the contribution of NBS to the achievement of different societal challenges. The work described in this chapter is case-specific. Using the case study of Copenhagen, the relationships between the co-benefits associated with the restoration of the Ladegaardsaa urban river were analysed. For that, a system thinking approach combined with knowledge-based modelling methods were used to simulate and model the main dynamics of the system. Stakeholders engagement and participatory modelling methods were used to integrate stakeholder's knowledge into the model development process.

1.3.3. Summary chapter 4. Integrated analysis: A Qualitative Systems Dynamic Model to understand the Medina del Campo system

NBS implementation is a complex process involving a variety of actors and societal groups, from civil society members, to scientists and policy-makers. Besides, the knowledge and information required to perform an appropriate NBS assessment are scattered across different stakeholders and governmental levels. For this reason, using the case study of Medina del Campo, this chapter aims to

present and describe in detail the participatory modelling approach implemented to obtain relevant bottom-up information and to organise the collective knowledge of stakeholders in a Qualitative System Dynamics Model (QSDM).

Stakeholders input was used to represent, in a graphical structure, key variables and relationships within the Medina del Campo System. The QSDM was used to set the basis to develop a quantitative stock-flow model used to analyse the added value of NBS as well as their long-term effectiveness. Additionally, the QSDM was used to define the model boundary and to identify the elements that influence the Medina del Campo system's behaviour. The quantitative system dynamics model is presented in chapter five.

1.3.4. Summary chapter 5. Assessing the long-term effectiveness of Nature-Based Solutions under different climate change scenarios.

Although NBS are increasingly been seen as a promising approach to address climate change mitigation and adaptation, more evidence is needed to understand the challenges and limitations of NBS under a climate change context (Harris et al., 2006; Seddon et al., 2019). Ignoring future climate conditions or the specific socio-economic context in with NBS are applied could lead to a decrease of the long-term effectiveness of these practices. Therefore, the main aim of this chapter is to

analyse the long-term effectiveness of NBS strategies under different scenarios of climate change.

For that, a participatory system dynamics approach has been implemented to understand the dynamic behaviour of different NBS strategies under different environmental change scenarios. Using the case study of Medina del Campo Groundwater body, this case-specific research seeks to contribute to the literature on NBS for rural areas. As explained in chapter four, participatory modelling was used to set the basis for the development of a stock-and flow system dynamic model.

1.3.5. Summary chapter 6: Conclusions, Limitations and Future Research

This thesis is structured in three research chapters and one concluding chapter summarizing the main findings as well as their contribution to the overall research aim of this project. Table 1.1 summarizes the contribution of each research chapter to both the research questions and objectives described in section 1.2.

Table 1.1. Contribution of the research chapters to the overall research aim

		C.2	C.3	C.4	C.5
Research Questions	**RQ1**: Which criteria needs to be considered prior to NBS design and implementation?	X	X		X
	RQ1.1. Which criteria are considered to evaluate and implement NBS in existing NBS frameworks and classifications?	X			
	RQ1.2. Which criteria are not sufficiently considered in existing frameworks?	X			
	RQ1.3. Which are the main barriers limiting the integration of NBS into sustainable development policies and adaptation actions?	X	X		X
	RQ2: How can be enhanced the capability of NBS to contribute to the achievement of different SDGs?		X		
	RQ2.1. To what extent trade-offs among NBS co-benefits limit the long-term effectiveness of NBS?		X		
	RQ3: To what extent will Climate Change affect the long-term effectiveness of NBS?				X
	RQ4: How can local and scientific knowledge be better integrated to facilitate NBS implementation?		X	X	X
Research objectives	**O1:** Identify important criteria for NBS selection	X			
	O2: Develop an easy-to use classification scheme to set the basis for a common language and framework for NBS mainstreaming.	X			
	O3: Propose a method to assess the dynamic behaviour of trade-offs and synergies among co-benefits.		X		
	O4: Evaluate the dynamic behaviour of NBS under different socio-economic and climatic scenarios.		X		X
	O5: Test the Participatory Modelling Approach as a tool to enhance the decision-making process of NBS.		X	X	X

1.4. Case studies

Multi-stakeholder participation was identified in the first stages of this research as a useful approach to integrate stakeholder's knowledge with scientific analysis. For this reason, the conceptual and methodological assessment of NBS carried out in this research, has been "road tested" and evaluated by end-users and stakeholders in two case studies, Copenhagen city (urban scale) and Medina del Campo Groundwater Body (rural scale).

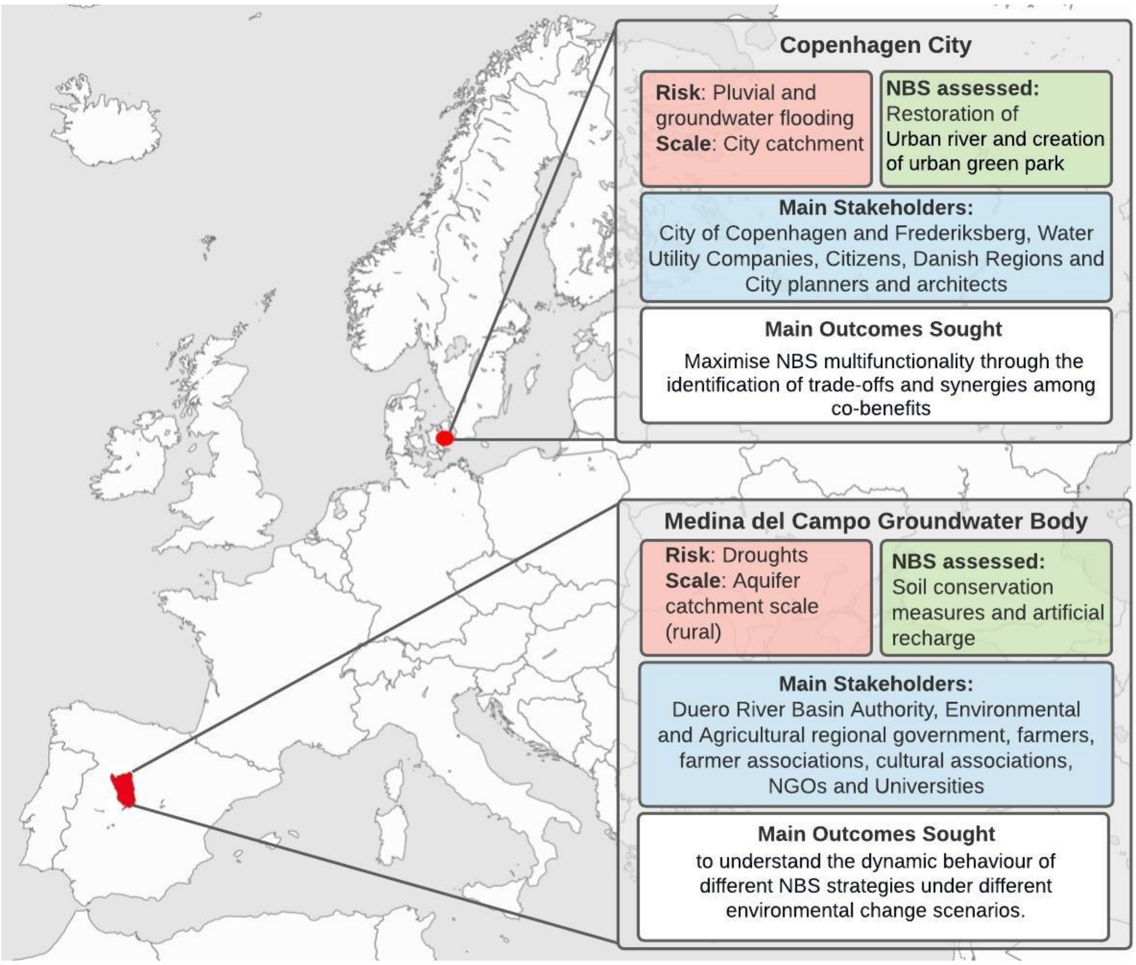

Figure 2. Case studies used as a framework for analysis

The two case studies are located in different countries covering different NBS cases, scales, risks and ecosystem management strategies. On the one hand, the restoration of a piped urban river (the Ladegaardsaa river) and the further development into an open river park was analysed as an opportunity to mitigate the impacts of intense pluvial flooding in Copenhagen city. This case study was used to 'test' the applicability of group model building techniques and semi-dynamic Fuzzy Cognitive Maps as a method for trade-off identification. The description of the research carried out is described in *chapter 3*.

On the other hand, the applicability of NBS for rural areas has been evaluated using the case study of Medina del Campo Groundwater body, located in the Duero River Basin (MCGB), north west-central Spain. A System Dynamic model describing the Medina del Campo system was used to assess the applicability of different NBS strategies to enhance groundwater-related ecosystem services. A quantitative system dynamics model was developed, starting from a participatory modelling phase in order to simulate the long-term performance of different adaptation strategies under a climate change context. The description of the research carried out is described in *chapter 4 and chapter 5*.

The field-based participatory modelling techniques were used to identify common denominators and barriers in urban and rural systems. The final aim was to demonstrate the need to adopt a system perspective to evaluate NBS effectiveness as well as to develop replicable and up scalable methods to formulate case-based planning and NBS implementation plans.

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Chapter 2:

An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice

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Methodological and Ideological Options

An operationalized classification of Nature Based Solutions for water-related hazards: From theory to practice

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ABSTRACT

Nature Based Solutions (NBS) are currently gaining importance in the EU policy agenda as a promising approach to mitigate and adapt to environmental and climate change. The main advantage of NBS over other adaptation strategies is their capability to deliver multiple benefits. They support the resilience of natural processes and help in reducing adaptation costs. In this paper, we address the current gaps in the literature by providing a comprehensive, easy-to-use classification scheme focussing on hydrological extreme events. The classification scheme is presented as a matrix and contains a portfolio of known NBS as well as the important criteria for their selection. Specifically, we have included disservices/ barriers, and the potential impacts of climate change on NBS. The matrix provides decision-makers with a tool that will guide them through the first phase of the complex process when choosing the most appropriative NBS for a specific challenge. In that way, we aim to support the spread of NBS in the scientific literature as well as their practical application.

1. Introduction

Climate change and environmental degradation are likely to accelerate losses in European GDP by up to 77% by 2030 (IPCC, 2014). This has boosted the development of new approaches which highlight the role of ecosystems in reducing the socio-economic and environmental costs of climate change. The most recent and perhaps also most promising approach is the concept of Nature Based Solutions (NBS). It is based on the principle that enhancing and protecting natural processes provides multiple benefits for society, thereby ensuring a sustainable delivery of ecosystem services (ES) and buffering the adverse impacts of climate change. For example, restoring or protecting riverine ecosystems can reduce the vulnerability of eroding riverbanks against current and projected increases of extreme rainfall, with manifold benefits to the social-ecological system around the watershed (Anbumozhi et al., 2005). Their main advantage over other adaptation strategies is their capability to deliver multiple benefits. The implementation of a particular NBS may create bundles of ecosystem services, together generating various social, economic and environmental co-benefits. For example, restoring or protecting coastal wetlands can increase resilience against storms by acting as a barrier against natural disasters. In addition, they provide multiple co-benefits, such as carbon sequestration, fish provision, job creation, or tourism (Woodward and Wui, 2001; Clarkson et al., 2014).

A number of definitions for NBS have been formulated (e.g. Cohen-Shacham et al., 2016; Maes and Jacobs, 2017; Eggermont et al., 2015). In this article, we use the definition applied by the European Commission which understands NBS as: "… living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to provide simultaneously economic, social, and environmental benefits.[1]" (Maes and Jacobs, 2017). This definition highlights the functional role of biodiversity and ecosystem functions and processes as part of an overall adaptation strategy to adapt and mitigate the impacts of climate change. For example, protecting and managing wetlands to enhance their water storage capacity is considered to be a NBS. On the contrary, technical adaptation measures to droughts such as water cisterns installation will not be considered a NBS as they do not use ecosystem functions to deliver benefits to society. Nature Based Solutions are often used as an umbrella concept, embedding a wide range of conservation and sustainability measures. Terms such as green infrastructures, ecosystem based adaptation, ecosystem based mitigation, hybrid infrastructures, ecosystem restoration or ecosystem protection are all framed under the NBS concept. For this reason, the NBS

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[1] According to this definition, approaches such as biomimicry should be considered as NBS since they are solutions inspired by nature. However, this approach is not contemplated in the text as many of the biomimicry solutions do not deliver multiple co-benefits.

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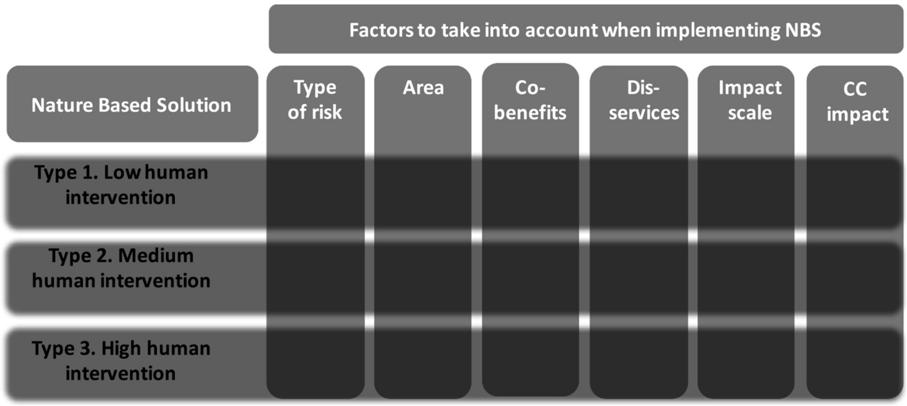

Fig. 1. Synthetized Metrix for the methodological framework. The horizontal axis represents the different types of NBS according to the different levels of human intervention. The vertical axis represents key information that should be considered before NBS implementation.

definitions found in literature are deliberately vague. However, all definitions share an emphasis on the need of finding a balance between social, economic and environmental targets when applying NBS, and highlight the importance of their long-term sustainability. A very illustrative example are the policies promoting forests as carbon sinks that have been gaining attraction over the past years. Existing international agreements and initiatives often pursue afforestation targets that are more focused on quantity rather than quality. These projects often use monocultures with non-native species, which can produce maladaptation to climate change in the long term and negatively impact biodiversity and sustainable development (Seddon et al., 2019). Despite their use of 'nature' to address a societal challenge, such initiatives fail to find the balance between social, economic and environmental targets, and would therefore not be considered as NBS.

Implementing NBS is not only a way for adapting to environmental change, but generally supports the shift to a greener economy and a more sustainable society (Faivre et al., 2017). At the same time, it helps to reduce the costs of adaptation by simply diminishing the risk in the face of uncertain events.

Baumgärtner and Strunz (2014) argue that the implementation of NBS increases systems capability to cope with extreme hydrological events (HEE), thereby representing an insurance value against unwanted regime shifts. We understand insurance value as "reflecting an ecosystem's capacity to remain in a given regime and retain its capacity to deliver vital ecosystem services in the face of disturbance and change" (Baumgärtner, 2008). The NBS concept, therefore, enhances the capability of social-ecological systems to cope with risks through exploiting the intrinsic resilience of natural processes. This makes the concept of NBS very valuable to both public and private investors that want to reduce their vulnerability to HEE. In addition, it provides an opportunity to capitalize these services in Natural Assurance Schemes (NAS). When talking about NAS, we refer to strategies aiming at internalizing the insurance value of ecosystems with the objective of improving awareness, valuation and inclusion of NBS in HEE (Denjean et al., 2017). Natural Assurance Schemes are very important in terms of re-distribution of HEE risks and therefore a co-benefit of NBS implementation relevant for different economic sectors, including the insurance sector.

Despite their great potential, the spread and standardisation of NBS in the scientific literature is limited. As a result, there is little uptake and implementation of the concept by national and international decision-makers. We believe that this is caused by the lack of a comprehensive, concise and easy to use classification for NBS. Similar to the case of the ecosystem services classification by the Millennium Ecosystem Assessment, a simple and commonly accepted NBS classification would support the transfer of the concept into adaptation and risk mitigation plans.

Existing classifications are mostly descriptive and difficult to understand and use by non-experts (WWAP, 2018; European Commission, 2015; European Environmental Agency, 2015; Eggermont et al., 2015). In addition, the majority of classifications do not mention undesired effects or "disservices" that may arise from malfunctioning or inefficient ecosystem management (European Commission, 2013; Cohen-Shacham et al., 2016; Zhang et al., 2007; Eggermont et al., 2015). For example, the project URBAN greenUP developed an easy-to-use catalogue of NBS focussing on urban areas, but gives little attention to disservices (GreenUP, 2018). The often cited Eklipse framework presents a set of indicators and assessment methods to evaluate the effectiveness of NBS projects, but is unable to assess the effectiveness of NBS for disaster risk reduction (Raymond et al., 2017), or to indicate possible disservices. Furthermore, none of the studies looking at NBS have taken the potential effects of climate change into account, although it is highly likely that climate change will have significant impacts on ecosystems in general (Pecl et al., 2017), and consequently on NBS. Any decision-making on a particular NBS requires scientifically based and customized information about the potential impacts of climate change (so-called climate services). To our knowledge, there is presently no classification which gathers all information relevant for making decisions on implementing NBS.

In response to these gaps, we present a comprehensive and easy-to-use classification scheme as a basis for assessing and evaluating NBS under different socio-economic and climatic scenarios. Scientifically validated with an extensive literature review, our paper contains three substantial contributions to the NBS concept. Firstly, using the case of HEE as a conceptual focus, we propose a classification of NBS for risks associated with such events. Secondly, we list the co-benefits and disservices that may potentially arise when implementing NBS. And thirdly, we discuss the potential impacts of climate change on NBS, which we believe is crucial for their planning and management. Our classification scheme provides decision-makers with a tool to design cost-effective adaptation measures able to deliver benefits under different environmental and socio-economic scenarios.

2. Methodological classification framework of NBS

Our framework is organized as a matrix (see Fig. 1). Following Eggermont et al. (2015), we distinguish between three types of NBS according to the level of human intervention (level of engineering required for enhancing the delivery of ecosystem services): Type 1, low intervention; Type 2, medium intervention; Type 3, high intervention. While the classification has correctly been criticized for being too narrow, as well as too difficult for implementation (Potschin et al., 2016), we found its intervention-based distinction to be a useful starting point for our work.

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An extensive literature review revealed a number of important factors that were not sufficiently considered in current classification schemes. These factors are: type of risk, area, co-benefits, disservices, impact scale, and the potential effects of climate change on NBS. For this reason, within each type of NBS, we have defined subtypes. In the vertical axis are information on the type of risk (HEE) to be considered, the area where the NBS is applied, the possible co-benefits of the NBS, and a column on the possible disservices. We have additionally included impact scale (local, regional, and global), and finally the potential effects of climate change on the NBS (see Appendices A).

2.1. Horizontal considerations of the NBS framework

2.1.1. NBS type 1: low human intervention

Some ecosystems play a fundamental role in regulating the hydrological cycle, and in protecting against the occurrence of flood events and water scarcity (Stürck et al., 2014; Sutton-Grier et al., 2015). The type of NBS that fall into this group include approaches that aim to preserve the integrity and stability of important ecological functions from a group of ecosystems and habitats without an intensive management, or an intervention into the system. The preservation of certain ecosystems can reduce the risks of HEE (World Bank, 2008). For example, applying conservation measures in wetlands which act as barriers against storms may reduce the vulnerability of coastal communities (Costanza et al., 2008). Applying measures to protect soil from wind and water erosion maintains soil stability and structure and is essential to keep an optimal infiltration rate and to preserve soil fertility and productivity (Blanchart et al., 1999). Strategies focused on maintaining the well-functioning of ecosystems are NBS type 1.

2.1.2. NBS type 2. Medium human intervention

This type of NBS clusters all management approaches that support the enhancement of important ecosystem services in a sustainable and multifunctional way. Within this group, we have included ecosystem restoration approaches, and management interventions in agricultural lands, forests, river morphologies, grasslands, pastures and meadows.

Ecosystem restoration approaches have been defined as “the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed” (SER, 2002). Frequently this degradation is the result of human activities that have disturbed the ecosystem in a direct or indirect way. Some restoration projects aim to restore the structure of a given ecosystem to the historic state prior to its disturbance. Others solely seek to re-establish the ecological processes and functions of a given ecosystem to return to the delivery of targeted ecosystem services.

Management interventions include a variety of measures for managing natural and man-made ecosystems. Agricultural practices such as crop rotation can improve the fertility and structure of soil by increasing the infiltration capacity. Altering deep-rooted and shallow-rooted plants can increase groundwater levels and contributes to a range of other services such as pollution removal or CO2 absorption (NWRM, 2014). Other agricultural practices such as intercropping or green covers to protect soil from erosion can also increase the infiltration rate (Zougmore et al., 2000; NWRM, 2014). Reducing soil surface exposure by maintaining an uninterrupted tree canopy can also provide a number of hydrological effects such as biodiversity preservation or reduction of water runoff. The reduction of exposure can be achieved with the appropriate forest management (Farley et al., 2005).

Another example is the establishment and maintenance of grasslands. Semi-natural grasslands buffer water flows through decreasing water run-off and at the same time attenuating soil erosion. They can also decrease water stress by increasing water retention capacity (Farley et al., 2005).

2.1.3. NBS type 3: creation of new ecosystems and hybrid solutions

The last group implies higher modification of ecosystems. The creation of new ecosystems that are designed and managed in a multipurpose way are also considered type 3. It comprises green (or blue if there are aquatic ecosystems involved) infrastructures which are defined as “a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services” (European Commission, 2013). The combination of nature and grey infrastructure is called a hybrid solution and sometimes involves the creation of new ecosystems. Hybrid structures are especially useful when space is limited, as is often the case in urban areas.

Green infrastructure and hybrid solutions are being increasingly considered in development planning. They are particularly relevant in urban environments, where more than 60% of the European population lives. Measures such as green roofs, permeable surface channels and rills are wide spread in cities to reduce water runoff and the heat island effect (European Commission, 2013). Many of these measures have proven to be more cost-effective when compared with traditional grey approaches such as dikes or levees (Liquete et al., 2016; Schäffler and Swilling, 2013). For example, green alleys or tree planting have been estimated to be 3–6 times more effective in managing storm-water and reducing temperatures than conventional methods. The city of Portland invested $8 million in green infrastructure, saving $250 million for hard infrastructure costs (Foster et al., 2011, Liquete et al., 2016; Schäffler and Swilling, 2013).

The creation of new ecosystems has been widely used for water retention or coastal protection measures (Piazza et al., 2005). There is a number of artificial wetlands that have been constructed in seriously degraded areas with water quality or drainage problems. Another example is the creation of artificial reefs to stabilize shorelines and protect coasts from wave erosion and flooding (Scyphers et al., 2011). Such new habitats and ecosystems may need a long time until they are fully established and able to deliver the intended ecosystem service. Until then, the ecosystem can be more vulnerable to disturbances and requires protection measures.

2.2. Vertical considerations of the NBS framework

2.2.1. Type of risk

We identify several types of risks by considering their origin, spatial, and temporal dimensions. Our classification covers the cases of droughts, floods, and water contamination. This is not intended to be an exhaustive list, but serves as a descriptive guidance.

We distinguish between five different types of floods: coastal, urban, fluvial, pluvial and flash floods. Each of them has different effects in terms of impacts, potential damages, and related costs. Additionally, we take into account water contamination, making a distinction between organic and inorganic contamination. Within droughts, we distinguish between the following types: meteorological, agricultural, hydrological, and socio-economic (Liu and Kogan, 1996). In this paper, we understand a meteorological drought as the duration of the dry period in reference to the normal dry period. We talk about an agricultural drought when the soil moisture is insufficient and results in lack of crop growth and production. Hydrological drought is referred to periods of shortfalls on surface and groundwater supply. Additionally, we consider socio-economic drought as droughts associated with the mismanagement of water supply and demand (Wilhite and Glantz, 1985). Depending on the type of drought, the suitability of NBS varies. For example, to reduce agricultural drought measures focused to maintain soil moisture will be appropriated, while measures to reduce the impacts of socio-economic droughts might include the restoration of natural vegetation and control surface flows (Sonneveld et al., 2018).

2.2.2. Area

Our approach distinguishes between three areas: rural, urban and peri-urban. Depending on the discipline, there are a number of definitions used for these categories. The categorization of rural and urban spaces depends exclusively on arbitrary delimitations, usually based on demographic components (i.e. population size), economic sectoral components (i.e. percentage of population working in the primary sector) and a socio-psychological component (i.e. values, attitudes, tastes and behaviours common for urban and rural areas) (Iaquinta and Drescher, 2000). These components may vary depending on the area where the NBS is going to be implemented. The majority of countries have their own, official definition of urban, rural and peri-urban areas.

For the purpose of this paper we have only considered demographic and economic sectoral components to differentiate between rural and urban areas. Urban areas are densely populated areas with generally more than 10.000 people and with low agricultural activities. Rural areas are low densely populated areas with generally less than 10.000 and with agriculture as the main economic sector. Peri-urban areas are areas currently in transition from strictly rural to urban.

Distinguishing between these categories is important, because the differences in demographic, economic and socio-economic factors influence NBS. For example, as explained previously, space restrictions are especially relevant for urban areas, while rural areas may have other limitations to consider, such as infrastructure access. For this reason, measures that have proven to be more effective and more easily to implement in certain areas (rural, urban and peri-urban), should be prioritized.

2.2.3. Co-benefits

One of the key aspects of NBS is their multifunctionality, their ability to provide several ecological, social, cultural and economic benefits (Hansen and DeFries, 2007; Kabisch et al., 2017). In our classification, we distinguish between primary benefits, referring here to the intended HEE risk reduction, and secondary benefits, referring to additional benefits or co-benefits. For example, while the primary benefit of dunes conservation is coastal flood protection, biodiversity maintenance is one of its potential co-benefits.

Following the Millennium Ecosystem Assessment, we classify co-benefits as provisioning, regulating, supporting and cultural ecosystem services (MA, 2005).

2.2.4. Disservices

Taking limiting factors such as structural complexity, required economic investment, or available space to implement NBS into account, as well as enabling NBS to adapt to changing conditions and disturbances is key for success. If the systemic implications of NBS are not adequately considered, intended services and benefits can turn into disservices. Such unintended negative side effects can potentially lead to the malfunctioning of a NBS and may cause a number of undesired effects including biodiversity loss, fragmentation, change in flow patterns, spread of pests and diseases, or changes in local and regional water availability (Zhang et al., 2007). For example, afforestation projects to control desertification may decrease water availability if non-suitable tree species are chosen. A very illustrative example is the Chinese Three Norths Shelter Forest System Project, a large-scale afforestation project implemented in arid and semiarid areas to stop desertification. The project ignored key differences in topography, climate and hydrology, which led to increased environmental degradation and devastating impacts on soil moisture, hydrology and vegetation coverage (Shixiong, 2008).

Identifying potential disservices is also necessary to effectively evaluate the life cycle cost of NBS, including all cost associated with designing, building and maintaining a functioning NBS. The vast majority of NBS require ongoing management. For example, parts of urban nature are maintained through trimming, irrigation or collecting leaf litter. Lack of funding or inefficient planning causes management failures, potentially resulting in decreasing ecosystem services delivery, the loss of social acceptance due to accidents, unpleasant views, damages in infrastructures, and several other issues, with impacts on costs. For example, if urban trees are not well managed, infrastructures such as pavements can be damaged by tree roots of fallen limbs, requiring costly repairs.

The relationship between the different ecosystem components and socio-economic factors is complex. For this reason, being aware of the potential disservices in the prior stages of NBS implementation may help to identify factors that need to be considered in the design and evaluation the NBS. Consequently, our classification also includes a column in which the most common disservices and socio-economic factors limiting the success of NBS implementation are listed. This list is designed to be used in the prior stages of the decision-making process. It only gives a general idea of the potential disservices that may arise if factors such as budget, maintenance cost or climate change impact are not considered. The table can be used to narrow down the list of potential disservices as a check box exercise.

2.2.5. Impact scale

The co-benefits delivered by NBS can have impacts at different spatial scales. For example, a reforestation project might have a primary impact at the local scale reducing soil erosion in hillsides and at the same time a global impact by capturing CO2. However, to facilitate management decisions we only consider, for each NBS, the scale of the impacts that the primary benefit may have. The definition of the scales depends on the particular context and should be clearly stated when assessing the impact of NBS. In our framework, we use the scale provided in the Eklipse framework which considers the impacts of NBS at the mesoscale (regional, metropolitan, urban) and microscale (neighbourhood/street, building) (Raymond et al., 2017).

2.2.6. Climate change impacts

The impacts of climate change on NBS need special consideration. The latest IPCC report makes specific reference to the impacts of climate change on ecosystem functions due to increasing and/or decreasing climate variability, increase in mean temperature, change in precipitation patterns, increase of extreme events, or sea level raise (IPCC, 2018). At the same time, an increase in the frequency and intensity of HEE may overwhelm the capability of NBS to cope with these risks. Changes in rain patterns may also affect water and energy demand exacerbating social and cultural divisions.

Potential impacts of climate change on NBS have not been adequately addressed in the literature so far (Seddon et al., 2019). However, such considerations are of utmost importance to make sure that the effects of NBS will last, especially in the long term. There are two relevant aspects: Firstly, the impacts of climate change on the performance of NBS and their effectiveness. And secondly, the costs that are related to dealing with and adapting to those impacts.

The effectiveness of NBS to cope with risk can be influenced in many ways. For example, higher-intensity of rain or flood events may saturate the capability of coastal habitats or green infrastructure to deal with these risks. Changes in the mean temperature, rain patterns, species distribution, fire patterns or HEE have important implications for practices such as ecological restoration. Future biophysical conditions arising as a result of climate change as well as other factors such as habitat fragmentation or land use change create novel environmental conditions never experienced in ecosystems before (Harris et al., 2006; Tilman and Lehman, 2001). For example, a number of plants are shifting their distribution ranges to higher elevations and latitudes (Chen et al., 2011). In some cases, this may challenge the capability of ecosystems to adapt and thus to deliver certain ES. Taking climate change into account is also key in afforestation projects, since droughts, fires, pests and diseases may determine long-term effectiveness of the project (Zhu et al., 2011).

Changes in species distribution range can even have implications for human health as human disease vectors such as mosquitoes are also temperature dependent. Consequently, changes in climate could lead to changes in the dynamics of diseases transmission (Afrane et al., 2012; Martens et al., 1999). This should be taken into account when it comes to the design of NBS. Areas with high risk of being affected by this phenomenon should pay more attention to the design and establishment of blue infrastructure since habitats with stagnant water play an important role in mosquitoes' life cycle.

The resources and cost of implementing NBS may increase in drier and warmer environments. For example, the maintenance of urban green infrastructures through irrigation can increase water use, potentially consuming more water than they infiltrate. The effectiveness of NBS can also be threatened by future development of disservices arising from new climatic conditions. For example, blue infrastructures may be more susceptible to algal blooms with increasing sea surface temperatures.

Considering the potential impacts of climate change in the first stages of NBS development is necessary for identifying factors that influence the delivery of ES and disservices associated with NBS as well as the capability of NBS to resist, recover or adapt to future conditions. This can help to design connected, heterogeneous and ecologically diverse NBS able to adapt to new climatic conditions (Seddon et al., 2019).

2.2.7. An example on how to use the methodological framework

In 2011 a climate adaptation plan was adopted by the city Council of Copenhagen in order to address the enormous challenges that the ongoing and future rainfall events are causing in the city. The Copenhagen Climate Adaptation Plan (CCAP) sets the framework for the implementation of climate adaptive measures in the City Administration area. As part of the CCAP, the Cloudburst Management Plan was developed to reduce the economic and societal problems caused by extreme flood events. The challenges arising from extreme rainfall could not be solved by a single initiative, such as upgrading the sewage system. For this reason, combined and coordinated actions had to be implemented. The development of projects promoting blue and green infrastructures is therefore a core aspect of the management plan (City of Copenhagen, 2012). In this section, we use the Copenhagen case to illustrate how our framework could be used in the first-stages of NBS implementation in an urban area with extreme rainfall problems.

The first step of the decision-making process is to identify the type of risk that the system is facing. In this case, the city of Copenhagen faces urban and pluvial flooding. At this stage, it is important to evaluate the probability of flooding vulnerability of the society in flood-prone areas.

Our table (see Appendices A) lists a number of measures that can be applied to reduce flooding in urban areas, ranging from restoration or conservation of upstream floodplain areas to the installation of hybrid infrastructures such as vegetated swales, filter strips or tree pits.

Given that NBS are site-specific, the success of any measure is tightly linked with the environmental and socio-economic conditions of the area in which they will be applied. To effectively evaluate the potential co-benefits and disservices which a NBS can produce, it is necessary to consider hydrological, climatic and socio-economic studies. The table provides a description with the most commonly delivered co-benefits and disservices of each NBS. This can serve as a fist analysis of the best approach that should be considered for a deeper assessment. For example, pollution and heat waves have been identified as increasing problems in the city of Copenhagen. This means that NBS delivering co-benefits related to climate regulation are highly likely to be more cost-effective, because they address several problems at the same time. Stream bed re-naturalization is usually a suitable measure to tackle urban, fluvial and pluvial flooding. However, the high- economic investment and the required ongoing management cost may be a barrier to the successful implementation of this NBS. In addition, this measure is only suitable if there is enough space. Other low-cost measures such as rain gardens, infiltration tranches or vegetated filter strips may be more adequate if space and budget are limiting factors.

Once the range of available alternatives have been identified, it is important to assess their long-term effectiveness, also under climate change projections. Our classification provides a first overview of the potential impacts that climate change may have on NBS. For example, if green roofs have been identified as an effective NBS, changes in rain patterns and species distribution should be taken into account in order to choose appropriate species or considering an increase of water demand.

3. Discussion

Nature Based Solutions are thought to be a promising approach for mitigating and adapting to environmental and climate change. However, their spread in the scientific literature as well as their practical implementation is currently hampered by the lack of a comprehensive, concise and easy to use classification. Although several classification schemes have been developed, we found that they have three important shortcomings. Firstly, they are often descriptive, which makes both their understanding by non-experts as well as an easy applicability challenging (WWAP, 2018; European Commission, 2015). Secondly, they do neither account for undesired effects (the so-called "disservices"), nor do they explicitly take implementation barriers into account. And thirdly, none of the existing classification schemes does take the potential effects of climate change into account. In light of current predications on the impacts of climate change on ecosystems and the services which they deliver, we see this shortcoming as a major limitation with respect to the long-term sustainability of NBS.

We have addressed all three shortcomings by developing a classification scheme which is comprehensive and clearly arranged. It includes potential disservices/barriers, and specifically addresses the potential effects of climate change. The classification scheme is organized as a matrix, and provides a suitable and easy-to-use tool which we hope will both be taken up by the scientific literature as well as be useful for decision-making.

It is remarkable that despite the importance of NBS in mitigating and adapting to climate change, there are almost no studies assessing their effectiveness in a climate change context. Like other ecosystems, NBS will also be affected by the impacts of a changing climate. Our classification scheme provides the criteria needed for developing climate services as an important precondition for NBS implementation. Climate services are scientifically based and customized information about the potential impacts of climate change on a particular system (Hewitt et al., 2012). Consequently, they need to be taken into account when choosing a NBS, to avoid increasing costs in the future or even a potential failure.

Our classification scheme does have two potential limitations which we will shortly discuss here. The first is some ambiguity in differentiating types of NBS based on the level of intervention required. However, this distinction is not always entirely clear. For example, the conservation of certain ecosystems such as semi-natural grassland or some types of forests (considered as type 1) requires ongoing management. Consequently, these NBS could also be included in type 2 (medium human intervention). Similar examples can be found for type 2 and type 3 strategies. For instance, some restoration approaches can be seen as NBS type 3 as they use grey infrastructures to recover ecosystem functions. A prime example is the use of concrete blocks to allow the establishment of marine life and encourage the growth of new reefs.

A second potential limitation is that our framework does not consider the cost of NBS implementation. We assume that in general the management and maintenance cost increase from type 1 to type 3. If the level of engineering or management is high, the cost of maintaining the well-functioning such type 3 NBS are also likely to be high, given that such manufactured Nature Based Solutions lack the self-regulation of a purely 'natural' ecosystem. In any case, decision-making on what NSB shall be implemented will always require a careful consideration of costs, for example in form of a cost-effectiveness analysis.

The primary aim of NBS is the delivery of ecosystem services, which is a basis for obtaining ecosystem benefits (Schwerdtner Máñez et al., 2014). Generally speaking, all types of NBS 1 and 2 can be expected to deliver a high amount of ES. These services are related to the inherent functioning of the ecosystem. While NBS type 3 might deliver fewer ecosystem services, the fact that they are engineered also means that they can be designed to delivery specific services. As a result, they might be more effective in solving particular problems. Such engineered systems may better fit into environments that do not allow for the establishment of "natural systems", for example, because of space restrictions. Hence, type 3 NBS are often found in urban areas, where they serve a particular aim, such as preventing urban floods.

The proposed classification scheme summarizes available options for NBS to HEE management. It does not only intend to potentially increase the adoption of NBS measures, but also aims to raise awareness about the added value of planning with NAS, namely to support the capability of ecosystems in reducing the negative effects of HEE through enhancing their insurance value.

Proactive involvement at all societal levels is needed to enhance ecosystem resilience, first in order to analyse the risks, and second to find leverage points for NBS implementation. The need of societal involvement goes far beyond implementing NBS, as it is also connected to insurance companies as "redistributors" of risk. Insurance companies have had important roles in the past, for example by supporting the establishment of fire departments in previous times to reduce the impacts of fire and the possible losses (Chester, 2018). It is time now for them to support the implementation of NBS, considering their implicit insurance value, to reduce the risks to HEE. We believe that our approach can facilitate this process.

4. Conclusions

Our classification scheme is a tool intended to support the spread and implementation of Nature Based Solutions as efficient measures to mitigate and adapt to environmental and climate change. Using the example of Hydrological Extreme Events (HEE) as a conceptual focus, we provide a portfolio of NBS which have proven to be effective in Disaster Risk Reduction (DRR) and climate change adaptation. Most importantly, we introduce the relevant criteria for supporting the complex decision-making processes for NBS. This provides decision-makers with an easy-to-use tool for NBS implementation. This is important not only for public bodies and decision-makers, but also for the private sector, including insurance companies. Given that insurance companies have an important role as "risk redistributors", and considering the inherent insurance value of NBS, we believe it is now time for insurance companies to get involved in NBS.

Declaration of competing interest

None.

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Appendix A. Supplementary data

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Appendices A

Types	Sub-type	Nature Based Solutions (NBS)	Type of Risk											Area		
			Floods					Water contaminatio		Drought						
			Flash floods	Coastal floods	Urban floods	Fluvial floods	Pluvial flooding	Organic	Inorganic	Meteorological Drought	Agricultural Drought	Hydrological Drought	Socioeconomic Drought	Rural	Peri-Urban	Urban
Type 1: Low Human intervention (Area-based Conservation measures)		Dunes conservation	X	X										X	X	X
		Wetlands conservation		X		X	X	X	X		X	X	X	X	X	X
		Mangrove forest conservation		X										X	X	X
		Coral reefs conservation		X										X	X	X
		Grassland conservation	X		X	X	X				X	X	X	X	X	X
		Forest conservation	X			X	X	X	X					X	X	X
		Floodplain conservation			X	X								X	X	X
		Soil conservation									X	X	X	X		

Nature Based Solutions (NBS)	Additional Ecosystem Services (co-benefits)																	
	Provision				Regulating							Supporting			Cultural			
	Nutrition	Materials	Energy	Genetic resources	Air quality	Erosion regulation	Climate regulation	Disease regulation	Water regulation	Water purification	Pollination	Soil formation	Nutrient cycling	Primary production	Recreational and ecotourism	Cultural heritage, Sense of place	Aesthetic	Educational and inspirational
Dunes conservation				X		X				X	X	X			X	X	X	X
Wetlands conservation	X	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X
Mangrove forest conservation	X	X	X	X		X	X	X	X	X		X	X	X	X	X	X	X
Coral reefs conservation	X	X		X		X	X		X	X		X	X	X	X	X	X	X
Grassland conservation	X	X		X		X			X	X	X		X	X		X	X	
Forest conservation	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X
Floodplain conservation	X	X		X		X	X		X	X		X			X			
Soil conservation	X					X			X	X		X	X					

Nature Based Solutions (NBS)	Ecosystem Disservices/iBarriers																				
	Loss of biodiversity/habitat	Nutrient runoff	Green gas emissions during constuction	Air quality problems (Allergies)	Damages in infrastructures	Accidents (Break up of branches)	Attraction of undesired plants or animals	Creation of fear	Spread of pest and diseases	Blocking of light, heat or views	Fruit and leaf fall	Animals excrements	High economic investment	Lack of connectivity	Poor management	Invasive species	Long-term benefits	Requires space	Complex design	Ongoing management needed	Change in flow patterns if bad designed
Dunes conservation							X									X		X			
Wetlands conservation							X		X							X		X			
Mangrove forest conservation							X		X	X								X			
Coral reefs conservation																					
Grassland conservation															X			X		X	
Forest conservation							X							X	X	X		X			
Floodplain conservation																		X			
Soil conservation													X							X	

Nature Based Solutions (NBS)	Impact Scale		Climate change impact on NBS to take into account							References
	Microscale	Mesoscale	change in mean temperature	Changes in rain patterns	Change in species distribution	Increase incidence of extream climatic events	Increase of sea level raise	Change in fire pathems	Changes in the intensity and variability of near-surface winds	
Dunes conservation	X	X			X	X	X		X	45], [10], [3], [46],[15],[58]
Wetlands conservation	X	X	X	X	X	X	X			24], [12], [11], [10], [69]
Mangrove forest conservation	X	X	X	X	X	X	X			[21], [3], [38]
Coral reefs conservation	X	X	X		X	X	X		X	[41], [2], [38], [57]
Grassland conservation	X	X	X	X				X		[28], [54], [70], [50]
Forest conservation	X	X	X	X	X	X		X		[14], [25], [10], [32]
Floodplain conservation	X	X		X	X	X	X			[52], [30], [42]
Soil conservation	X			X		X		X		[37], [8], [72]

Types	Sub-type	Nature Based Solutions (NBS)	Type of Risk											Area			Additional Ecosystem Services (co-benefits)																		Ecosystem Disservices/Barriers																					Impact Scale		Climate change impact on NBS to take into account							References
			Floods					Water contamination		Drought							Provision				Regulating							Supporting			Cultural																																			
			Flash floods	Coastal floods	Urban floods	Fluvial floods	Pluvial flooding	Organic	Inorganic	Meteorological Drought	Agricultural Drought	Hydrological Drought	Socioeconomic Drought	Rural	Peri-Urban	Urban	Nutrition	Materials	Energy	Genetic resources	Air quality	Erosion regulation	Climate regulation	Disease regulation	Water regulation	Water purification	Pollination	Soil formation	Nutrient cycling	Primary production	Recreational and ecotourism	Cultural heritage, Sense of place	Aesthetic	Educational and inspirational	Loss of biodiversity/habitat	Nutrient runoff	Green gas emissions during construction	Air quality problems (Allergies)	Damages in infrastructures	Accidents (Break up of branches)	Attraction of undesired plants or animals	Creation of fear	Spread of pest and diseases	Blocking of light, heat or views	Fruit and leaf fall	Animals excrements	High economic investment	Lack of connectivity	Poor management	Invasive species	Long-term benefits	Requires space	Complex design	Ongoing management needed	Change in flow patterns if bad designed	Microscale	Mesoscale	change in mean temperature	Changes in rain patterns	Change in species distribution	Increase incidence of extreme climatic events	Increase of sea level raise	Change in fire patterns	Changes in the intensity and variability of near-surface winds	
Type 2: Medium Human intervention	Interventions in Agricultural lands	Meadows and Pastures				X	X							X	X		X	X		X		X	X	X	X	X	X					X			X	X													X			X		X	X	X	X		X				X		[48], [28], [19]
		Buffer Strips and Hedges				X		X	X					X	X					X			X		X	X	X																					X	X			X		X		X									[27], [48], [1]
		Crop Rotation					X	X	X		X			X			X	X					X	X	X	X	X								X	X													X	X			X		X		X		X	X						[7], [34]
		Strip cropping along contours	X			X	X	X	X		X	X		X						X		X	X		X	X																							X						X		X									[48], [20]
		Intercropping						X	X		X	X		X			X			X		X			X			X	X						X	X												X						X		X		X	X						[72], [34]
		No till agriculture						X	X		X			X			X					X	X		X			X	X						X	X													X					X		X		X	X						48], [56], [66]
		Low till agriculture						X	X		X			X			X					X	X		X			X	X						X	X	X											X						X		X		X	X						[48], [56], [66]
		Green cover/cover crop	X				X				X			X						X		X	X	X	X	X		X																											X		X		X	X						[48], [33]
		Early sowing					X				X			X								X	X			X	X																X											X				X		X	X						[48], [39]
		Traditional terracing	X				X				X			X			X					X			X							X	X		X	X												X	X			X	X	X		X					X		X		[5], [48], [62]
	Interventions in Forest (Agroforestry)	Reduced stocking density	X				X							X			X					X			X			X							X														X							X									[48]
		Mulching	X								X			X			X					X			X																													X		X							X	[48], [43], [4]
		Peak flowcontrol structures in managed forests						X	X		X			X			X			X		X	X		X	X			X																					X					X		X					X				[48]
		Targeted planting for catching precipitation	X				X			X	X	X		X	X							X	X	X	X	X		X				X	X																		X		X	X	X		X	X		X	X				X	X	[48]
		Maintenance of forest cover in headwater areas						X	X		X	X	X	X	X			X	X		X	X	X		X	X		X	X		X		X																							X	X	X			X					[30], [48], [54], [71]
		Afforestation	X			X	X	X	X	X				X	X		X	X	X	X	X	X	X		X			X		X																	X	X		X	X	X	X	X	X	X	X	X	X	X			X		17], [35],[59], [61]
		Forest riparian buffers	X			X		X	X					X	X	X	X	X	X	X		X	X		X	X			X																		X				X						X		X	X				X		[1], [48], [49]
	River morfology intervention	Removal of dams and other longitudinal barriers				X						X		X	X	X	X			X		X					X											X											X										X	X								[48]
		Elimination of riverbank protection	X			X						X		X	X	X	X			X		X			X	X		X			X																	X								X	X	X								[48]
		Stream bed re-naturalization			X	X								X	X	X				X		X		X	X																							X				X		X		X	X	X				X				[16], [48], [36]
		Natural bank stabilisation				X		X	X					X	X	X	X			X		X	X		X		X																					X				X		X			X	X				X				[48]
		Re-meandering			X	X		X	X					X	X	X	X			X		X	X		X	X		X		X			X															X				X	X	X		X	X			X		X				[44], [48], [51]
	Interventions in grasslands, pastures and meadows	Prescribed Burning	X								X																								X		X																		X		X									[18], [55]
		Remove shrubs and trees	X								X									X			X			X	X																							X							X									[19]
		Mowing and grazing	X								X									X			X			X	X																												X		X									[9], [50]
		Managing succession	X								X									X			X			X	X										X																X	X		X		X	X		X				[23], [31]
		Planting	X								X									X			X			X	X																					X				X				X	X		X	X	X			X		[54]
	Ecosystem restoration approaches	Rehabilitating natural creeks and streams				X					X			X	X	X				X		X			X	X					X		X															X				X	X	X		X	X	X		X						[72], [48], [63]
		Reconnecting rivers to floodplains (flood bypasses)				X	X			X	X	X	X	X	X		X	X							X																							X				X				X	X									[52], [30], [42]
		Re-naturalization of polder areas				X						X		X	X		X		X			X			X							X	X															X				X		X			X									[48]
		Restoration of natural infiltration to groundwater									X	X		X	X																																	X				X	X	X		X	X	X		X						[22], [40]
		Riverbed material renaturalization				X		X	X			X		X	X	X	X					X				X		X																				X						X		X	X	X				X				[48]
		Reconnection of oxbow lakes				X						X		X								X			X	X					X																	X				X	X	X		X	X	X			X	X				[48]
		Restoration and reconnection of seasonal streams				X	X			X	X	X	X	X	X		X	X					X	X	X																											X	X	X		X	X									[72], [48], [63]
		Lake restoration				X						X		X	X	X	X			X		X			X	X					X	X	X	X							X		X					X				X	X	X	X		X	X			X					[25], [48]
		Coral reef restoration		X													X	X					X	X	X																						X				X		X				X		X	X	X					[41], [2], [3], [57], [26], [29], [60]
		Dunes restoration	X										X	X	X				X							X	X			X	X	X	X															X				X		X				X		X		X				X	[45], [10], [3], [46], [15], [58], [26], [29], [60]
		Mangrove forest restoration		X													X	X					X	X	X																						X				X		X				X		X	X	X					[21], [3], [38], [26], [29], [60]
		Floodplain restoration and management			X									X				X	X																												X				X		X				X		X	X	X					[26], [29],[60], [52]
		Wetland restoration		X	X	X	X	X	X	X		X		X	X		X	X		X			X	X	X								X		X												X				X						X		X	X	X					[24], [12], [11], [10], [69], [26], [29], 60]
		River bed restoration	X			X	X																																								X				X		X				X									[26],[29], [60]

Types	Sub-type	Nature Based Solutions (NBS)	Type of Risk											Area		
			Floods					Water contamination		Drought						
			Flash floods	Coastal floods	Urban floods	Fluvial floods	Pluvial flooding	Organic	Inorganic	Meteorological	Agricultural	Hydrological	Socioeconomic	Rural	Peri-Urban	Urban
Type 3: High Human intervention	Creation of new Habitats	Bioretention strips			X											
		Urban forest parks			X			X	X						X	X
		Coastal lagoon									X	X	X			
		Rain Gardens			X		X	X	X					X	X	X
		Tree Planting			X		X	X	X							X
		Infiltration Trenches									X	X	X	X	X	X
		Retention ponds			X		X	X	X					X	X	X
		Oyster reef		X												
		Coral reef		X												
		Constructed Wetlands		X		X	X	X	X	X		X		X	X	X
		Sediment capture ponds				X								X		
		Detention basins			X		X							X	X	X
		Drainage corridors			X		X	X	X							X
		Urban dunes		X	X										X	X
	Hybrid approaches	Green roofs			X		X								X	X
		Permeable surfaces			X		X	X	X						X	X
		Bioswales			X		X	X	X					X	X	X
		Channels and Rills									X	X	X	X	X	X
		Filster Strips									X	X	X	X	X	X
		Soakaways							X					X	X	X
		Infiltration Trenches			X						X	X	X	X	X	X
		Infiltration Basins			X		X	X	X						X	X
		Disconnection of Rooftop Runoff					X								X	X
		Blue roofs			X		X								X	X
		Vegetated Swales			X			X	X					X	X	
		Vegetated Filter Strips			X			X	X						X	X
		Stormwater Planters			X						X	X	X			
		Sand Filter			X			X	X							
		In Situ Water Harvesting (soil conservation)			X		X			X	X			X	X	X
		Ex Situ Water Harvesting			X		X		X							
		Establishing flood bypasses				X										
		Appropriate design of roads and stream crossings	X			X	X							X		
		Coarse woody debris			X	X								X		
		Storm water tree pits			X		X									

Nature Based Solutions (NBS)	Additional Ecosystem Services (co-benefits)																
	Provision				Regulating						Supporting			Cultural			
	Nutrition	Materials	Energy	Genetic resources	Climate regulation	Erosion regulation	Disease regulation	Water regulation	Water purification	Pollination	Soil formation	Nutrient cycling	Primary production	Recreational and ecotourism	Cultural heritage, Sense of place	Aesthetic	Educational and inspirational
Bioretention strips																	
Urban forest parks	X	X		X		X	X	X						X	X	X	X
Coastal lagoon																	
Rain Gardens	X				X	X							X				
Tree Planting													X				
Infiltration Trenches																	
Retention ponds													X				
Oyster reef	X	X			X	X	X	X									
Coral reef	X	X			X		X	X									
Constructed Wetlands	X	X	X	X		X							X		X		
Sediment capture ponds					X												
Detention basins													X				
Drainage corridors										X			X		X	X	X
Urban dunes				X		X	X						X				
Green roofs					X			X	X	X			X				
Permeable surfaces																	
Bioswales		X			X		X						X				
Channels and Rills																	
Filster Strips																	
Soakaways													X				
Infiltration Trenches																	
Infiltration Basins		X											X				
Disconnection of Rooftop Runoff																	
Blue roofs					X			X	X	X							X
Vegetated Swales					X					X							
Vegetated Filter Strips									X	X							
Stormwater Planters					X			X		X							
Sand Filter																	
In Situ Water Harvesting (soil conservation)	X	X					X										
Ex Situ Water Harvesting	X	X											X				
Establishing flood bypasses																	
Appropriate design of roads and stream crossings		X															
Coarse woody debris					X		X										
Storm water tree pits					X			X	X	X				X			

Nature Based Solutions (NBS)	Ecosystem Disservices/iBarriers																				
	Loss of biodiversity/habitat	Nutrient runoff	Green gas emissions during constuction	Air quality problems (Allergies)	Damages in infrastructures	Accidents (Break up of branches)	Atraction of undesired plants or animals	Creation of fear	Spread of pest and diseases	Blocking of light, heat or views	Fruit and leaf fall	Animals excrements	High economic investment	Lack of connectivity	Poor management	Invasive species	Long term benefits	Requires space	Complex design	Ongoing management needed	Change in flow patterns if bad designed
Bioretention strips																		X			
Urban forest parks				X		X	X	X	X	X	X	X	X							X	
Coastal lagoon													X				X		X		
Rain Gardens					X																
Tree Planting				X		X	X			X	X	X									
Infiltration Trenches																		X			
Retention ponds																		X			
Oyster reef													X				X		X		
Coral reef													X				X		X		
Constructed Wetlands																	X		X	X	
Sediment capture ponds																		X		X	
Detention basins																		X		X	
Drainage corridors																		X			
Urban dunes													X				X	X	X	X	
Green roofs					X	X								X		X			X	X	
Permeable surfaces					X																
Bioswales																					
Channels and Rills																					
Filster Strips																					
Soakaways																					
Infiltration Trenches																		X			
Infiltration Basins																					
Disconnection of Rooftop Runoff					X																
Blue roofs				X	X			X	X				X		X		X	X	X	X	
Vegetated Swales				X											X			X		X	
Vegetated Filter Strips															X			X		X	
Stormwater Planters																				X	
Sand Filter							X		X												
In Situ Water Harvesting (soil conservation)																					
Ex Situ Water Harvesting																		X			
Establishing flood bypasses																					
Appropriate design of roads and stream crossings																					X
Coarse woody debris																					
Storm water tree pits				X		X	X			X		X								X	

Nature Based Solutions (NBS)	Impact Scale		Climate change impact on NBS to take into account							References
	Microscale	Mesoscale	change in mean temperature	Changes in rain patterns	Change in species distribution	Increase incidence of extream climatic events	Increase of sea level raise	Change in fire patterns	Changes in the intensity and variability of near-surface winds	
Bioretention strips	X		X	X	X					[10], [24], [48]
Urban forest parks	X		X	X	X					[10], [24], [48]
Coastal lagoon	X		X	X	X					[64], [13]
Rain Gardens	X		X	X	X					[10], [24], [48]
Tree Planting	X		X	X	X					[10], [24], [48]
Infiltration Trenches	X									[10], [24], [48]
Retention ponds	X									[10], [24], [48]
Oyster reef	X									[53], [68]
Coral reef	X		X	X	X					[64]
Constructed Wetlands	X	X	X	X	X					[6], [65], [67]
Sediment capture ponds	X									[10], [24]
Detention basins	X									[10], [24], [48]
Drainage corridors	X									[10], [24], [48]
Urban dunes	X		X	X	X					[65]
Green roofs	X		X	X	X					[10], [24], [48], [47]
Permeable surfaces	X									[10], [24], [48]
Bioswales	X		X	X	X					[10], [24], [48]
Channels and Rills	X									[48]
Filster Strips	X									[10], [24], [48]
Soakaways	X									[48]
Infiltration Trenches	X									[10], [24], [48]
Infiltration Basins	X									[24], [48], [65]
Disconnection of Rooftop Runoff	X									[48], [65]
Blue roofs	X		X	X	X					[10], [24], [48]
Vegetated Swales	X		X	X	X					[10], [24], [48]
Vegetated Filter Strips	X		X	X	X					10], [24], [65]
Stormwater Planters	X		X	X	X					[10], [24], [65]
Sand Filter	X									[65]
In Situ Water Harvesting (soil conservation)	X									[24], [65]
Ex Situ Water Harvesting	X									24], [65]
Establishing flood bypasses	X									[10], [24], [48]
Appropriate design of roads and stream crossings	X									[48]
Coarse woody debris	X									[10], [24], [48]
Storm water tree pits	X		X	X	X					[10], [24], [48]

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Chapter 3:

Using a system thinking approach to assess the contribution of Nature Based solutions to sustainable development goals.

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Using a system thinking approach to assess the contribution of nature based solutions to sustainable development goals

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HIGHLIGHTS

- Evidence regarding the contribution of NBS to SDGs is needed.
- Understanding the dynamic evolution of co-benefits increases NBS effectiveness.
- The capacity of NBS for addressing SDGs is highly dependent on NBS multifunctionality.
- Engaging stakeholders in the first stages of NBS design and implementation is key.

GRAPHICAL ABSTRACT

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ABSTRACT

Climate change and the overexploitation of natural resources increase the need to integrate sustainable development policies at both national and international levels to fit the demands of a growing population. In 2015 the United Nations (UN) established the 2030 Agenda for sustainable development with the aim of eradicating extreme poverty, reducing inequality and protecting the planet. The Agenda 2030 highlights the importance of biodiversity and the functioning of ecosystems to maintain economic activities and the well-being of local communities. Nature Based Solutions (NBS) support biodiversity conservation and the functioning of ecosystems. NBS are increasingly seen as innovative solutions to manage water-related risks while transforming natural capital into a source of green growth and sustainable development. In this context, NBS could potentially contribute to the achievement of several Sustainable Development Goals (SDGs) by promoting the delivery of bundles of ecosystem services together generating various social, economic and environmental co-benefits. However, to achieve the full potential of NBS, it is necessary to recognize the trade-offs and synergies of the co-benefits associated with their implementation. To this aim, we have adopted a system perspective and a multi-sectoral approach to analyse the potential of NBS to deliver co-benefits while at the same time reducing the negative effects of water-related hazards. Using the case study of Copenhagen, we have analysed the relationships between the co-benefits associated with the scenario of the restoration of the Ladegaardsaa urban river. Our hypothesis is that enhancing the understanding of the social, economic and environmental factors of the system,

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including mutual influences and trade-offs, could improve the decision-making process and thereby enhance the capability of NBS to contribute to the achievement of the SDGs.

1. Introduction

Climate change and the overexploitation of natural resources have increased the need to integrate sustainable development policies at both national and international levels to fit the demands of a growing population (Colglazier, 2015). The potential contribution of ecosystems for dealing with societal challenges has been increasingly emphasized in the frame of global agendas such as the Sendai Framework for Disaster Risk Reduction (United Nations, 2015), the Strategic Plan for Biodiversity (Secretariat of the Convention on Biological Diversity, 2010) or the 2030 Agenda for Sustainable Development. The latter was agreed on in 2015 by the United Nations with the aim of eradicating extreme poverty, reducing inequality and protecting the planet. The agenda contains 17 Sustainable Development Goals (SDGs) which are areas of intervention that are needed to achieve sustainable development (Colglazier, 2015). It stresses the importance of sustainable management of natural resources and the functioning of ecosystems to maintain economic activities and well-being of local communities. Indeed, biodiversity and ecosystems predominate directly in many of the SDGs and their associated targets. For example, SDG 14 highlights the importance of protecting oceans, seas and marine resources to achieve sustainable development (Faivre et al., 2017).

To accomplish the 2030 Agenda, new initiatives and strategies aiming at enhancing and protecting ecosystems and their services have become the core of action to be developed, i.e. Ecosystem-based Adaptation, Green Infrastructure, Ecosystem-based Disaster-Risk Reduction or Natural Water Retention Measures (Faivre et al., 2017; Munang et al., 2013; Schäffler and Swilling, 2013; Cohen-Shacham et al., 2016). Among all these approaches, the concept of Nature Based Solutions (NBS) is increasingly seen as a key component in the mainstreaming of nature in development of policies and actions. The term NBS is often used as an umbrella concept, embedding a wide range of conservation and sustainability measures (Seddon et al., 2019). NBS are defined by the European Commission as:" …living solutions inspired by, continuously supported by and using nature, which are designed to address various societal challenges in a resource-efficient and adaptable manner and to simultaneously provide economic, social, and environmental benefits" (Maes and Jacobs, 2017). This definition highlights the importance of natural capital in the process of building a sustainable society supported by a green economic system. The key characteristic of NBS is their capability to be multi-functional, which means the ability to simultaneously perform multiple functions to deliver a set of associated ecosystem services (ES). The premise of the NBS approach is that enhancing and protecting certain ecosystems may buffer the unfavourable impacts of climate change while providing multiple environmental, economic and social co-benefits. For example, green alleys or tree planting have proven to be an effective approach to manage storm-water by retention and subsequent evaporation or infiltration while at the same time providing multiple co-benefits, such as groundwater recharge, urban heat island reduction, and expanded wildlife habitat (Newell et al., 2013). Socio-ecological systems, in which NBS are usually implemented, are dynamically complex, governed by non-linearities, feedback loops and multiple interconnections constantly changing over time (Nuno et al., 2014). Different policy interventions or management regimes may directly or indirectly affect different elements of the system causing trade-offs and synergies among co-benefits. For example, policies designed to protect a coastal ecosystem may improve its ecological status, but might also lead to a decrease of coastal livelihoods. Moreover, NBS may be altered over time as a result of the dynamic evolution of their natural component or due to responses to external pressures such as climate change. Consequently, the interconnections among co-benefits may also evolve over time. This means that trade-offs and synergies should be framed as an inter-temporal issue that manifest overtime (Qiao et al., 2019; Gómez Martín et al., 2020). The identification of synergies and trade-offs among co-benefits may reveal unconsidered consequences of diverse management strategies. This could support in finding the balance between social, economic and environmental targets (Calliari et al., 2019; Haase et al., 2012). In this paper, we argue that understanding the dynamic evolution of trade-offs and synergies across co-benefits may facilitate management to maintain synergies and thus, NBS multifunctionality may be enhanced and lead to increased adaptive capacity of NBS for addressing SDGs. To this aim, the complex structure of the system interested or impacted by NBS implementation is investigated and analysed.

Using the urban river restoration project in Copenhagen city as a means to demonstrate the framework of our analysis, we have assessed the trade-offs and synergies of the co-benefits associated with potential NBS implementation and thus with related SDGs. The urban river restoration project is a scenario for climate adaptation and greening the city of Copenhagen but not yet politically approved and implemented by the involved municipalities. We have adopted a system thinking approach to understand the main dynamics between NBS and their co-benefits to investigate the long-term effects on different SDGs. We have developed a Fuzzy Cognitive Map (FCM), a knowledge-based methodology developed to simulate and model dynamic systems (Kosko, 1986). In this case it was used to conceptualize and understand the social-ecological system where the scenario of a river restoration will be applied to analyse key relationships and feedback loops between the potential co-benefits that this NBS may deliver. The FCM was co-produced along with stakeholders and experts of the system where NBS could be applied. Participatory modelling was used to obtain relevant bottom-up information and to organize the collective knowledge of stakeholders in a Causal Loop Diagram (CLD) while promoting a constructive discussion among stakeholders. CLDs have been widely used as a graphical tool to represent the feedback structure of systems and to easily capture the causes of dynamics (Sterman, 2000). The CLD co-developed represents the shared vision of stakeholders of the system and it was used to set the basis for the FCM development. Although FCMs are not able to make quantitative predictions, they are suitable to easily indicate changes in the patterns of behaviour of the system due to changes in the relationships between factors. Therefore, FCMs allow the prediction of the effects of different policies taken under "what-if" scenarios. However, traditional vector-matrix operations typical from FCM assume that all the processes occur at the same time. It considers that the strength of the relationships between variables are constant over time. This structure limits the realistic description of the dynamics between co-benefits. To overcome this drawback and to improve the description of the non-linear behaviour of complex systems we implement the semi-dynamic FCM-based approach described in (Giordano et al., 2020). This work proposes the inclusion of time delays in the matrix-structure of FCM by allowing changes in the adjacency matrix, further explained in 2.3.

2. Research and methods

2.1. Case study

In December 2009, the fifteenth session of the Conference of the Parties (COP 15) was held in Copenhagen, Denmark. The objective of the COP 15 was to enter into a binding global climate agreement that includes as many countries as possible in order to reduce greenhouse emissions. As a result of COP 15, the City of Copenhagen developed the Copenhagen Climate Adaptation Plan in 2011. This plan established the framework needed for the implementation of climate adaptive measures in the city administration area. It is highly likely that the frequency and intensity of rainfall and cloudburst events in Denmark and Copenhagen will increase during fall and winter (City of Copenhagen, 2012; Liu and Jensen, 2017), thus contributing to the rise of shallow groundwater level and increase the risk for groundwater flooding causing economic and human costs. The catastrophic cloudburst event in July 2011 boosted the development of the Cloudburst Management Plan in 2012 making the Climate Adaptation Plan more explicit in this regard. This plan defines priority actions to reduce the negative impact of high-intensity rain.

Within the cloudburst management plan, different NBS were selected to mitigate the negative effects of pluvial flooding i.e. construction of green spaces and cloudburst channels, where the first include retention and detention areas to store excess rainwater for either infiltration or evaporation. The latter include channels that route excess water to open water recipients further downstream. In this paper, the focus is on the restoration of an urban river (the Ladegaardsaa) as a scenario for an NBS. According to the cloudburst management plan, NBS can be beneficial for drainage and for ensuring a sustainable river discharge. Currently, the Ladegaardsaa river is part of a larger piped river system (see Fig. 1) further upstream. The restoration of the river is a scenario which is part of a larger project including a traffic component, which consists of removing the present flyover motorway in combination with short and long tunnels to replace parts of existing roads further down the line. In addition to this, and considered in this paper, is the scenario of restoring the piped urban river and the further development into an open river park with both green and blue areas. The urban river scenario would restore the natural flow route towards the artificial lakes (shown in Fig. 1). The main objective of this NBS is to improve the drainage capacity of the city, thus mitigating groundwater flooding and subsequent damage to underground built infrastructure, notably cellars. Additionally, this NBS is expected to deliver a number of co-benefits (i.e. pollution reduction, heat island reduction, health and wellbeing, GHG reduction and green jobs creation) which could potentially contribute to the achievement of several SDGs.

2.2. Participatory modelling phase

Participatory modelling supports the decision-making process by enabling the integration of key stakeholders in the co-creation of conceptual models and co-design of actions and strategies. It also supports the active collaboration and the rigorous integration of different expertise and interdisciplinary skills, thus building greater trust in models (Zomorodian et al., 2018). The key advantage in the field of NBS analysis (with specific focus on decision support) relies in its potential for integration of variables (e.g. qualitative and quantitative), knowledge (e.g. expert and derived from models) and issues (e.g. social, environmental, economic, etc.). This is, indeed, highly relevant for describing the multi-dimensionality of NBS, and their capability to produce a multitude of

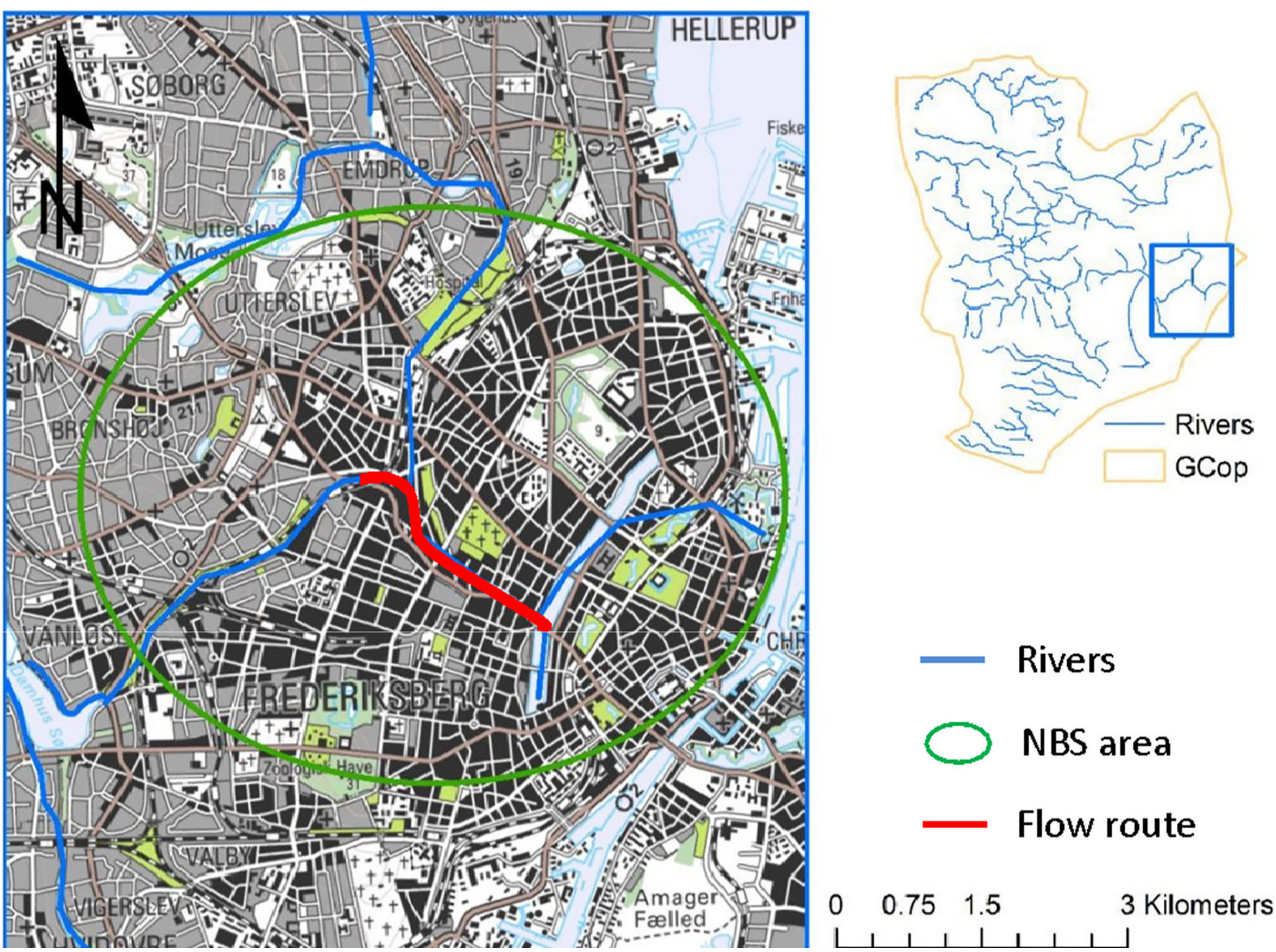

Fig. 1. NBS area: potential restored urban river (red) and its tributaries (blue) and surrounding catchment (to the right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

benefits over time. Participatory modelling is particularly well-suited for obtaining data coming from formal and non-formal sources. In this study, participatory modelling has been used to develop a comprehensive understanding of the scope of the system and to guide the actions undertaken, while showcasing advantages at both individual and collective levels. At the individual level, the approach improves the problem formulation and perception of participants. At the collective level, it allows their alignment, the achievement of a consensus with respect to decisions and the involvement of the group with respect to these decisions. We have divided the participatory process into two phases. During the first phase, a Causal Loop Diagram (CLD) defining relationships among the main variables of the system was developed using group model building techniques (Vennix, 1999). In the second phase, some quantitative elements of the FCM were assigned to the CLD by experts (i.e. link weights and time delays). To increase the effectiveness of NBS implementation and to assess the associated co-benefits, it is necessary to understand who is affected by the restoration scenario of the Ladegaardsaa urban river. It is also important to understand who has the power to influence the results obtained by executing the NBS, i.e. Danish Regions, municipalities, water utility companies, Danish Regions and others. The stakeholder group was representative for the different levels of governance and knowledge and has been carefully selected to avoid unnecessary overlap and missing elements. The selection was made in a way that the largest number of perceptions of the system was collected. The 'snowballing' technique was used to update the list, thus involving all the potentially relevant stakeholders that were cited or mentioned during the process. The number of stakeholders was chosen for having a realistic representation of the system and to allow for the active participation of individuals during the group model building exercise (See Appendix A of the supplementary material). In concordance with previous studies we estimated that the desired number of participants to successfully perform the group model building exercise ranged between 7 and 15 participants (Videira et al., 2014).

2.3. Group model building: Fuzzy cognitive maps development

Fuzzy Cognitive Maps (FCM) are based on graph theory and were introduced the first time by Bart Kosko (Kosko, 1986). They have been widely used to address complex problems from climate change adaptation to landscape or forest management (Martinez et al., 2018). FCM are graphical representations of causal relationships among concepts, also known as factors, variables or nodes in a system. The relationships are represented with links connecting the concepts. The direction of the causal relationship is represented with a positive or negative symbol. A positive sign (+) is used to represent positive causal relationships between two concepts or variables. This means that the decrease/increase of a variable V_i leads to a decrease/increase of variable V_j. A negative symbol (−) is used to represent negative causal relationships which indicates an inverse relationship (a raise in variable V_i will reduce variable V_j and vice versa). To indicate the strength of the causal relationship (weak, medium, strong) a weight that takes a normalised value between [−1,1] is assigned to each link (Sokar et al., 2011). This structure allows the propagation of the causality backward and forward allowing the knowledge base to increase when the concepts and links between them increase (Kontogianni et al., 2012).

FCMs are easy to build and easy to understand by non-technical experts, facilitating debate among stakeholders and the co-creation of shared knowledge. Additionally, its vector-matrix structure facilitates the aggregation of different experts and stakeholders' views. For this reason, FCMs have gained considerable interest in the research community to be combined with stakeholder's engagement and participatory modelling exercises (Gray et al., 2015). There are different participatory modelling approaches i.e. mediated modelling, shared vision planning, participatory simulation, companion modelling or participatory mapping among others (Chambers, 2006; Diehl, 1992; Simon and Etienne, 2010; Voinov and Bousquet, 2010; Williams et al., 2019). Unlike participatory processes carried out at the individual level (i.e. individual interviews) which are usually implemented to analyse differences in perception, Group Model Building (GMB) techniques pursue a shared understanding of the problem to be addressed. In this study, GMB was used to facilitate the consensus agreement process and to increase the communication and shared vision among stakeholders, as well as to enhance confidence among stakeholders in the use of system ideas. It was also used to conceptualize and understand the socio-environmental system in which the NBS will be applied. The GMB process was carried out in a two-hour workshop with key stakeholders of the system. During the process, stakeholders contributed to the identification of key factors and issues relevant for the modelling of the NBS. During the process, the moderator adapted the exercise to stimulate the exchange of relevant local knowledge among the participants. To facilitate the development of the Causal Loop Diagram (CLD), a syntactic rule was used to represent the key variables within the model. The participants were asked to use cards of different colours to represent the different variables and factors within the system. The variables representing natural resources and ecosystem services were marked in green, blue cards were used to identify socio-economic factors, yellow cards represented all the activities or actions. Finally, all the barriers, risks or challenges were marked in red. The stakeholders were also asked to represent and to mark the relationships between variables and their polarity (positive or negative). During the Group Model Building (GMB) session, discrepancies between participants or differences of opinion may arise. Whenever possible, consensus among participants was reached. For this, the role of the facilitator was crucial to favour the elucidation of knowledge within the group and to reveal hidden assumptions and differences among participants, thus facilitating a consensus view of the problem. In those occasions when it was not possible to reach an agreement, the final decision was taken by the expert group. To ease the post-processing of the Causal Loop Diagram, the resulting model was digitized using Vensim software.

The group model was analysed and post-processed by a group of experts who were involved in the GMB process and with experience in the system and in the FCM development. During the post-processing exercise, missing variables relevant for the co-benefit assessment were added into the model. The expert group was also in charge of indicating the strength of impacts of the elements composing the map. The weight assigned was used to describe the strength of the relationships (weak, medium, strong) between variables or nodes. The strength of a relationship was represented by changing the thickness of the links between concepts composing the FCM (See Fig. 2). The experts also suggested 'delays' (with a //) to represent processes or decisions that require some time to occur. This was made to allow a semi-quantitative analysis of the temporal dynamics. To ease the visualization of the causes-effects

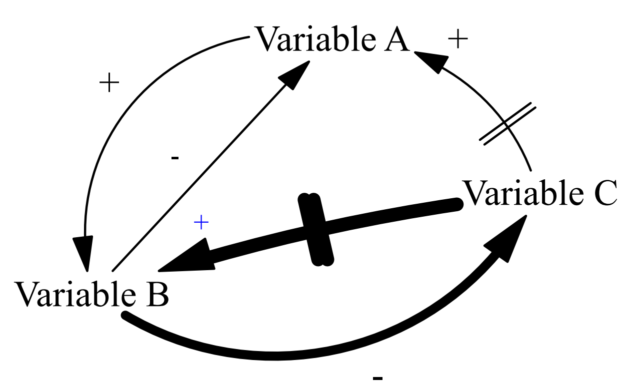

Fig. 2. Simple FCM. The thickness of the arrows indicates the strength in the relationship. Positive and negative symbols indicate the polarity of the relationship. Delays are indicated with two lines crossing the links (//).

of the processes occurring in the system, important feedback loops were identified within the system. The polarity of the loop is dependent on the polarity of the links composing the loop, in turn determining the behaviour of the variables within the loop. A reinforcing or positive loop (R) results when an action produces a result which influences the initial action. This type of loop results in exponential growth or decline. Alternatively, a balancing or negative loop (B) occurs when an action is taken to change the current state of a variable to a desired state. This type of loop tends to produce oscillations or movement towards equilibrium (Sterman, 2000).

After the participatory modelling phase, each fuzzy weight (weak, medium, strong) was translated into a numerical value. The weights ranged in an interval of {−1,0,1}. The value 1 represents a positive causality and the strongest relationship. The closer the values approach 0, the weaker the relationships are. For weak relationships, a value of 0.3 was assigned. For relationships of medium strength, a value of 0.6 was given. Finally, value 1 was used for the strongest links.

The first step to transform the Causal Loop Diagram into a Fuzzy Cognitive Map (FCM) was to translate the weights of the relationships into an adjacency matrix. This matrix defines the structure of the FCM and is needed to establish the dynamic inferences. The FCM is simulated using the mathematical formulation developed by Kosko (Kosko, 1986) and expressed in Eq.

$$x_i(t) = f\left(\sum_{\substack{j=1 \\ j\neq i}}^{n} x_j(t-1)w_{ij}\right) \quad (1)$$

where $x_i(t)$ is the value of variable V_i at time t, $x_j(t-1)$ is the value of variable V_j at time $t-1$ and w_{ji} is the weight of the relationship between the variable V_i and variable V_j. Finally, f represents a threshold function that is used to normalize the values of the FCM variables in an interval [−1,1].

As previously stated, traditional FCM does not allow for consideration of delays in the causality assuming that all the processes occur at the same time. The adjacency matrices produced are constant and assume that the polarity and the weights do not change over time (Papageorgiou and Salmeron, 2013). However, it should be considered that Nature Based Solutions (NBS) require time for becoming fully effective. Additionally, different co-benefits can be produced at different time steps (Giordano et al., 2020). To overcome this limitation and to describe the dynamics of the system to better represent "reality" we have introduced delays in the FCM allowing changes in the adjacency matrix and assuming that the weight can change over time. Following the work done by Giordano et al. (2020), we have developed three different adjacency matrices describing the strength of the casual connections at three different time steps (short term, medium term and long term). The FCM calculation described (Eq. 1) was sequentially implemented using the three adjacency matrices. The variable states resulting in the three-time steps were plotted in order to obtain the dynamic evolution of the FCM variables. For more information see Supplementary material in Appendix B.

2.4. FCM analysis

The analysis of the model has been carried out in two parts. First, the description of the qualitative model and the identification of feedback loops have been used to enhance the understanding of what drives the dynamic behaviour of the system. We assume that the dynamic behaviour of the system can be inferred from the structure and complex relationships of the diagram. Secondly, different "what-if" scenarios were simulated (Kok, 2009) to determine the state of the system under different conditions, such as e.g. the long-term effectiveness of NBS as well as the dynamic evolution of the co-benefits produced by different combinations. The simulation scenarios were defined and agreed among authors previously to the stakeholder workshop.

In this paper the following scenarios are considered: the restoration of the piped urban river combined with the creation of an urban green park (NBS1) and the creation of an urban green park without the river restoration (NBS2). Additionally, two soft measures combined with the above mentioned NBS were simulated. NBS1 with green space management (NBS1-GSM) and with strong institutional collaboration (NBS1-GSM and IC) and NBS2 with green space management (NBS2-GSM) and with strong institutional collaboration (NBS2-GSM and IC). Finally, a business as usual scenario without any measure applied has also been simulated (BAU).

To complete the study, the SDGs that could be potentially affected by NBS1 and NBS2 implementation have been identified. The co-benefits that are more likely to contribute to the achievement of each SDG have also been indicated. The long-term performance of each co-benefit under the 6 different NBS scenarios has also been highlighted (NBS1, NBS1-GSM, NBS1-GSM-IC, NBS2, NBS2-GSM and NBS2-GSM-IC). To ease the visualization of the results, a table describing which co-benefits affect each goal has been produced. For each scenario the long-term performance of each co-benefit has been indicated following a colour syntax. Red colour is used to indicate a weak contribution of the co-benefit to the achievement of a goal, orange is used when its contribution is moderate and green when the presence of a co-benefit significantly enhances the likelihood of achieving this goal.

3. Results

3.1. Qualitative analysis of the Fuzzy Cognitive Map (FCM)

In the following section, the system is presented as perceived by stakeholders, as well as the main patterns of behaviour which have been identified. Fig. 3 shows the FCM developed by stakeholders and experts. It is composed of key concepts (nodes) representing the economic, environmental and social factors of the system and their relationships. It describes system complexity and shows the multiplicity of interconnections among variables. To have a clearer representation of the loops, see Appendix C of the supplementary material.

The frequency and intensity of extreme weather events is highly influenced by climate change. An increase of the cloudburst events and prolonged rainfall in fall and winter will in the long-term, increase ground water level. This may increase the occurrence of groundwater flooding leading to an increase of water entering the sewer system. Stakeholders also perceived surface urban flooding as an important risk to consider. Surface flooding is aggravated by the water pushed up from the sewer system which cannot cope with excess water. Surface and groundwater flooding have a negative impact on Copenhagen wealth due to the damage caused by flooding and increased wastewater treatment. The re-connection of the river (which is currently piped) with groundwater is perceived to have a strong impact on groundwater flooding by increased drainage capacity. The re-naturalization of the river may reduce groundwater level and thus groundwater flooding. The restored urban river could receive water from cloudburst management plan associated NBS and thereby increasing the river discharge. Connecting the restored river would also improve the environmental quality of the connected lakes by maintaining an adequate water level which in turn, will contribute to reduce the urban heat island effect. We refer to NBS1 when the restoration of the river is combined with an adjacent urban green area in order to boost the delivery of ecosystem services. According to stakeholders, the green area on its own (NBS 2) may reduce surface urban flooding and provide a number of co-benefits such as biodiversity enhancement, reduction of the heat island effect or increase of the aesthetic value. However, the functionality of both NBS and thus, their effectiveness may be compromised by an

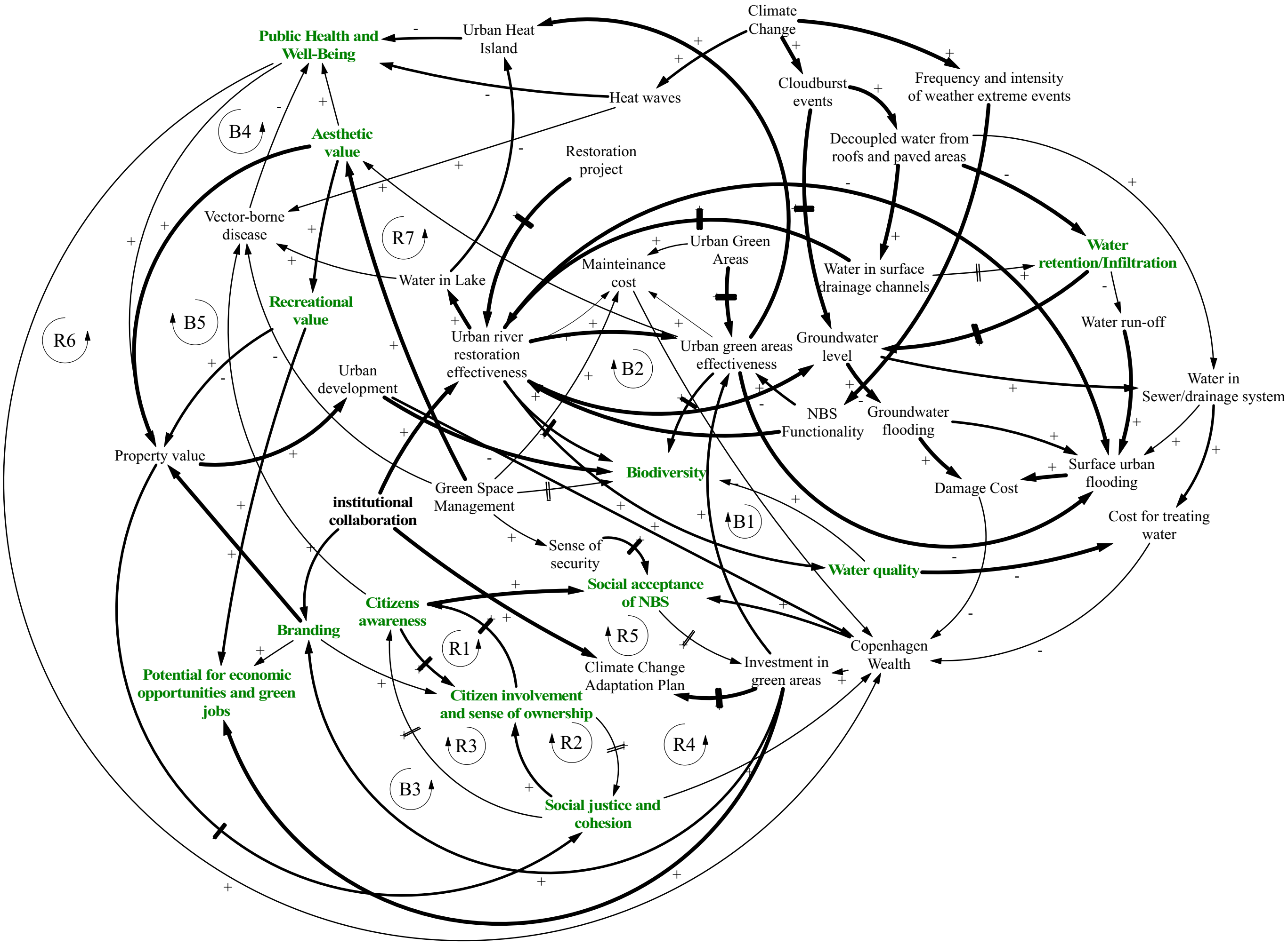

Fig. 3. Showing the final FCM integrating stakeholders and expert's knowledge. Note: Colour should be maintained when printed.

increase in the frequency and intensity of extreme weather events. Climate change may also increase the incidence of heat waves and thus the occurrence of vector-borne diseases.

Both NBS are perceived to have a positive impact on Copenhagen wealth. An effective river restoration would decrease the amount of water in the sewer system (by draining shallow groundwater) and therefore the economic cost associated with water treatment would decrease. Both NBS reduce damage cost associated with flooding and increase the potential for economic opportunities and green jobs in the area where the NBS is applied. To guarantee a continuous delivery of ecosystem services from the NBS, continuous management including maintenance and therefore, economic investments are required. This may have a negative effect on Copenhagen wealth (B1). Conducting a regular and appropriate management is perceived to be an important variable needed to support the social acceptance of NBS (B2). An increased acceptance of NBS may indirectly affect the aesthetic value of the area (B3) which in turn positively reinforces the delivery of other co-benefits such as public health and well-being or recreational value (R6, R7). Stakeholders also perceived institutional collaboration and investment in green areas as key factors to achieve the objectives established in the Copenhagen Climate Change Adaptation Plan. Finally, institutional collaboration involving key stakeholders, most notably municipalities and water utilities, and investment in green areas are needed to increase city branding, referring to local identity and the balance between human and nature. An enhancement in the branding the city's green image may increase citizen involvement and sense of ownership. Moreover, it could increase the potential for economic opportunities and green jobs by increasing the attractiveness of the city (R4 and R5).

According to the qualitative interpretation of the FCM co-benefits such as public health and well-being, aesthetic and recreational value may produce trade-offs with other co-benefits due to the causal connection that exists between these co-benefits and real estate property value. An increased value of the properties may support urban development which could negatively affect biodiversity. An increase in property value may also negatively affect social justice and cohesion (B4 and B5). Besides, social-justice and cohesion are strongly linked through reinforcing loops (R1, R2, R4 and R5) to other co-benefits such as citizen awareness, citizen involvement and sense of ownership and social acceptance of NBS. For this reason, a decrease of social justice may cause a chain reaction and reduce other associated co-benefits.

3.2. Semi-quantitative analysis of the dynamic behaviour of co-benefits

We only consider an NBS effective when the delivery of social, environmental and economic co-benefits is balanced. Therefore, we assume that an effective NBS implementation is based on reduction of trade-offs among co-benefits. From the modelling point of view, this means that if the increase of a certain co-benefit (i.e. aesthetic value) decreases the delivery of other co-benefits (i.e. social justice and cohesion) the effectiveness of this NBS will be reduced. A decrease in NBS effectiveness may have an impact on other co-benefits that are dependent on it.

Moreover, we have to consider that NBS may require time to be effective. This is well represented in Fig. 4 (A-B) which shows the dynamic behaviour of NBS effectiveness under different scenarios. When we compare the results of the scenarios, we observe that in the long term, NBS effectiveness is higher in scenarios NBS1 (river restoration combined with urban green park) and NBS1-GSM (river restoration combined with urban green park and good green space management), whereas NBS effectiveness is reached much earlier in scenarios NBS2-GSM-IC (urban green park with good green space management and strong institutional collaboration) and NBS1-GSM-IC (river restoration combined with an urban green park and with good green space management and strong institutional collaboration). This means that in order to accelerate the capability of NBS to deliver co-benefits, it is necessary to combine NBS with additional measures such as green space management or strong institutional collaboration. The results show that the restoration of the river combined with the urban green area (NBS1) is likely to reduce surface and groundwater flooding to a greater extent in the long term. However, the capability of NBS1 to reduce surface and groundwater flooding is very low in the first stages of NBS implementation. The implementation of the urban green area (NBS2) without green space management or institutional collaboration hardly has an impact on flood reduction. The results also show that when the NBS is combined with strong institutional collaboration, surface and groundwater flooding is reduced earlier (See Fig. 4 C-D). The capability of both NBS to reduce floods increases when the NBS is combined with strong institutional collaboration. Strong institutional collaboration does not directly influence the capability of NBS to cope with floods, but it does on the capability to deliver other co-benefits and thus, on its effectiveness.

Stakeholders perceived climate change as a limiting factor of NBS effectiveness. The results show that the frequency and intensity of extreme weather events are likely to reduce NBS functionality in the long term and thus NBS effectiveness, reducing the capability of NBS to cope with risk and to deliver co-benefits.

Climate change is expected to increase the occurrence of heat waves which may have direct consequences on public health and well-being. This could be aggravated by the urban heat island effect. The reduction of the latter was pointed out by the stakeholders as an important NBS co-benefit. The results of the simulation show that NBS1 is more effective in reducing urban heat island effect. However, the implementation of NBS1 with appropriate green space management and effective institutional collaboration accelerate the delivery of this co-benefit considerably. The results also show that the effectiveness of NBS2 in reducing heat island effect is highly dependent on green space management and institutional collaboration.

Fig. 5 shows four closely linked co-benefits; aesthetic value, recreational value, city branding and potential for economic opportunities and green jobs. The results of the simulation indicate that the implementation of NBS would rapidly increase the aesthetic value of the area and thus its recreational value.

In the long-term this would benefit the potential for economic opportunities and green jobs. The increase of the attractiveness of the city produced by the co-benefit of branding also has a positive impact on the potential for economic opportunities and green jobs. This is well illustrated in the similar patterns of behaviour that both co-benefits present. Once again, the results of the simulation demonstrate that the restoration of the urban river integrated with an adjacent green area (NBS1) is more effective in delivering these co-benefits. The simulations also demonstrate that green space management is essential to accelerate the delivery of aesthetic and recreational value co-benefits. If green space management is not applied, NBS requires more time to deliver these co-benefits.

The results of the simulation show a progressive decline in social justice and cohesion in scenarios NBS2-GSM-IC, NBS1-GSM-IC and NBS1-GSM (See Fig. 6 A).

This result exposes the trade-off that exists among social justice and cohesion, and aesthetic and recreational value. The increase of the

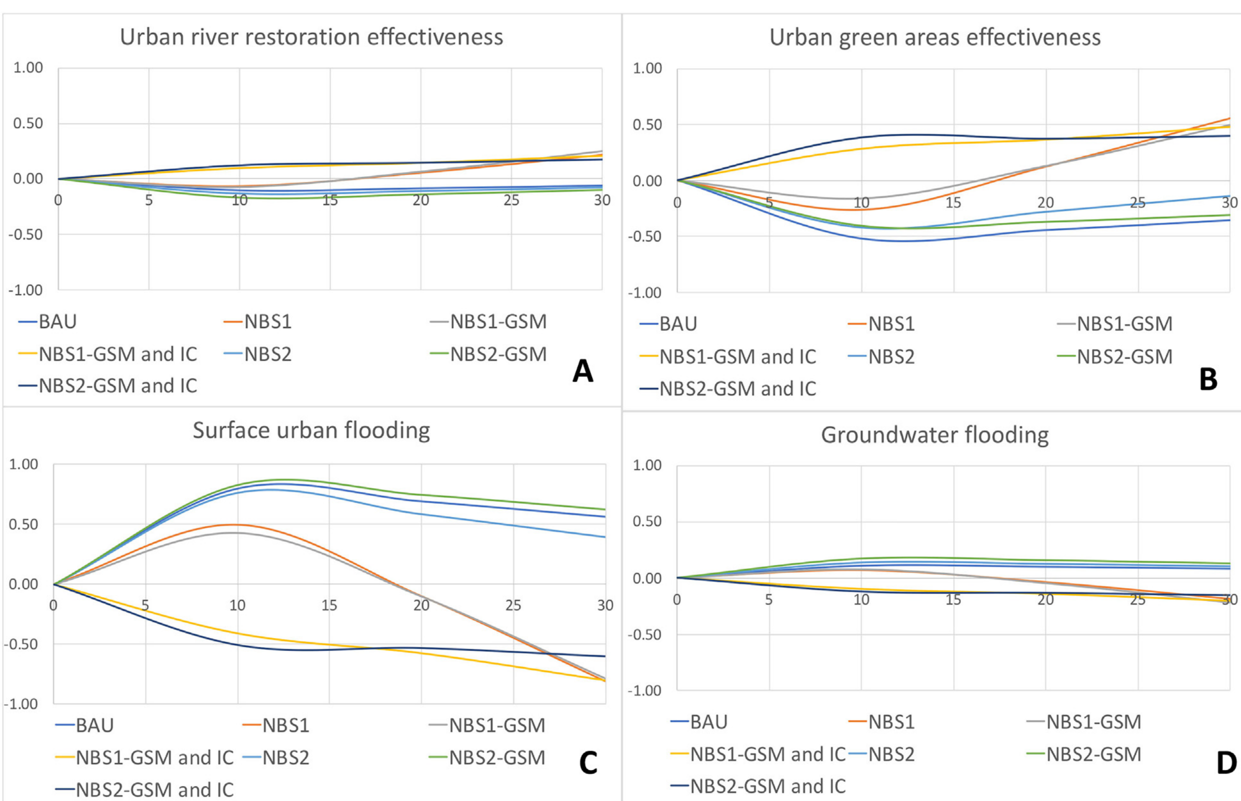

Fig. 4. Dynamic behaviour of NBS effectiveness (A-B) and surface and groundwater flooding (C-D). The x-axis represents time (in years) and the y-axis the value of the variables in each scenario.

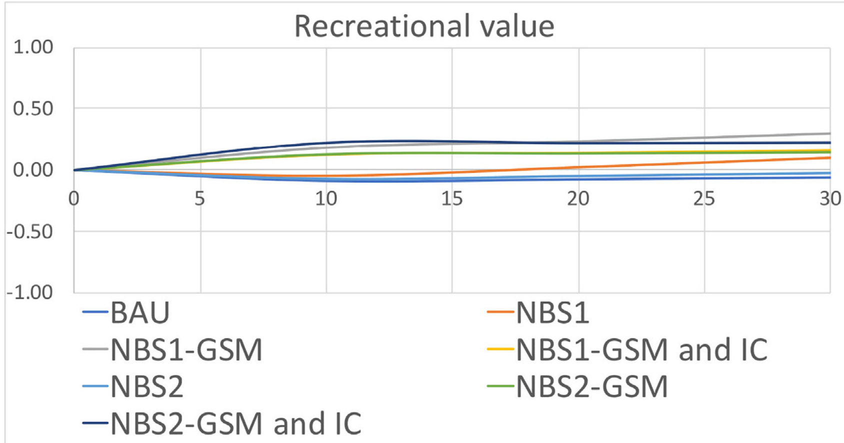

Fig. 5. Showing dynamic behaviour of co-benefits: Aesthetic value (A), Recreational value (B), Branding (C) and potential for economic opportunities and green jobs (D). The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

attractiveness of the city (branding co-benefit) has also a high impact on social justice. This occurs because these co-benefits help to increase property value. If the rise in prices is not controlled, a decrease in social-justice and cohesion follows. The increase of the real estate property value encourages urban development which, on the one hand increases Copenhagen wealth but on the other hand, decreases biodiversity. Firstly, scenarios NBS2-GSM-IC, NBS1-GSM-IC and NBS1-GSM encourage a higher delivery of aesthetic and recreational value co-benefits whereas biodiversity and social justice suffer a decrease in the same scenarios. As explained in Section 3.1, social justice is linked to other co-benefits (citizens awareness and citizens involvement and sense of ownership) through a series of self-reinforcing loops (R1, R2, R4 and R5). A decrease in social justice reinforces the decline of these other co-benefits. At the same time, this decrease negatively affects the social acceptance of NBS.

For more information of the results see Appendix D from supplementary material.

3.3. Sustainable development goals analysis

A list of SDGs that could be potentially influenced by NBS implementation for the case of Copenhagen is shown in this section. For a more complete list of these SDGs and their targets please see Appendix E.

We conclude that a minimum of 10 SDGs could potentially be affected by the implementation of NBS. The results reveal that the restoration of the urban river combined with an adjacent urban green area is more likely to produce a higher number of co-benefits in the long term and hence, a higher contribution to SDGs is expected (see Table 1). The results also expose that appropriate management regimes or measures designed to increase institutional collaboration increases

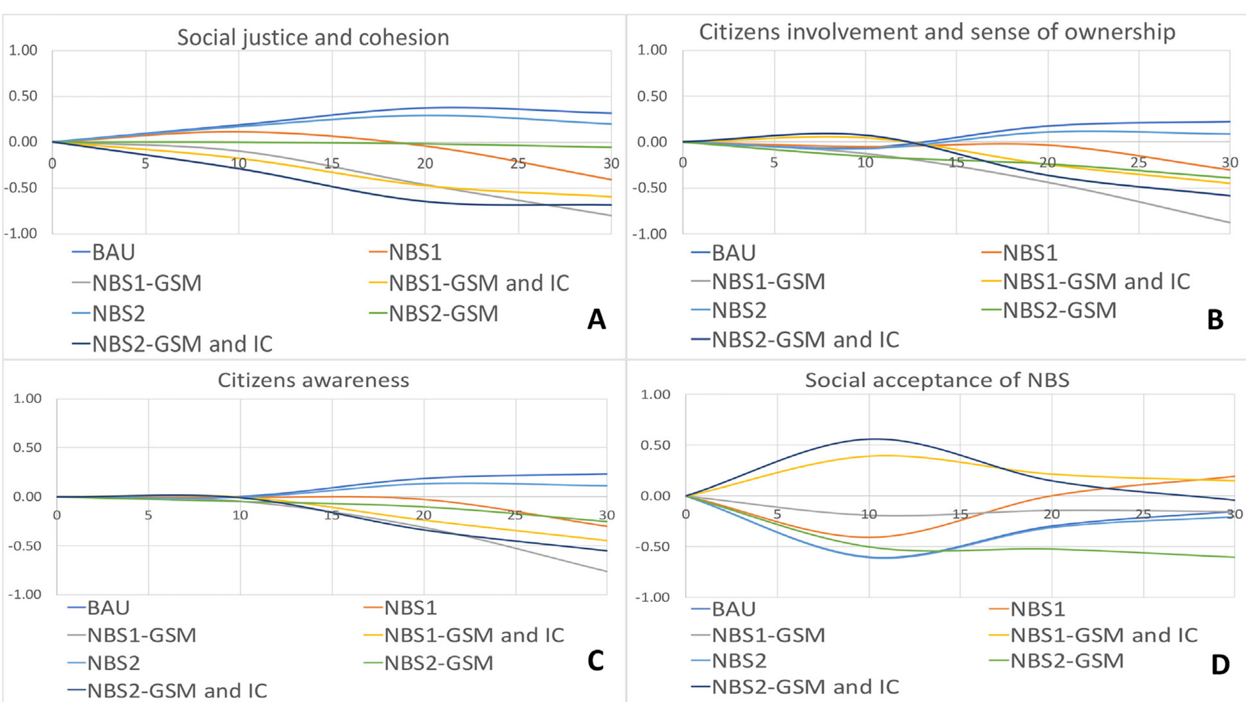

Fig. 6. Dynamic behaviour of co-benefits: Social justice and cohesion (A), citizens involvement and sense of ownership (B), citizens awareness (C) and social acceptance of NBS (D). The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

Table 1
Sustainable development goals linked with NBS co-benefits.

Sustainable development goal linked to NBS co-benefits

Goals (from the 2030 Agenda)	Co-benefits	NBS1	NBS1-GSM	NBS1-GSM-IC	NBS2	NBS2-GSM	NBS2-GSM-IC
Goal 1. End poverty in all its forms everywhere	Potential for economic opportunities and green jobs	[green]	[amber]	[green]	[red]	[red]	[green]
	Social justice and cohesion	[amber]	[red]	[amber]	[red]	[red]	[red]
Goal 3. Ensure healthy lives and promote well-being for all at all ages	Health and well being	[amber]	[amber]	[amber]	[red]	[red]	[amber]
	Water quality	[amber]	[amber]	[amber]	[red]	[red]	[amber]
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Social acceptance of NBS	[amber]	[red]	[amber]	[red]	[red]	[red]
	Social justice and cohesion	[amber]	[red]	[amber]	[red]	[red]	[red]
	Citizens awareness	[red]	[red]	[red]	[amber]	[red]	[red]
Goal 6. Ensure availability and sustainable management of water and sanitation for all	Water quality	[amber]	[amber]	[amber]	[red]	[red]	[amber]
Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	Potential for economic opportunities and green jobs	[green]	[amber]	[green]	[red]	[red]	[green]
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Potential for economic opportunities and green jobs	[green]	[amber]	[green]	[red]	[red]	[green]
	Investment in green infrastructure	[amber]	[amber]	[amber]	[red]	[red]	[amber]
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	Surface urban flooding reduction	[green]	[green]	[green]	[amber]	[red]	[green]
	Groundwater flooding reduction	[green]	[green]	[green]	[red]	[red]	[amber]
Goal 13. Take urgent action to combat climate change and its impacts[b]	Urban heat island reduction	[green]	[green]	[green]	[amber]	[amber]	[green]
	Surface urban flooding reduction	[green]	[green]	[green]	[amber]	[red]	[green]
	Groundwater flooding reduction	[green]	[green]	[green]	[red]	[red]	[amber]
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Biodiversity	[red]	[red]	[red]	[amber]	[red]	[red]
	Citizens awareness	[red]	[red]	[red]	[amber]	[red]	[red]
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Social justice and cohesion	[amber]	[red]	[amber]	[red]	[red]	[red]
	Citizens involvement and sense of ownership	[red]	[red]	[red]	[amber]	[red]	[red]

NBS effectiveness and boost the delivery of co-benefits. This implies that a higher influence on the SDGs is obtained. Trade-offs among co-benefits may limit the contribution of NBS to different SDGs. For example, SDGs 15, 16 and 4 will be weakly affected by NBS implementation due to the trade-off that exist between social justice and cohesion (and its related co-benefits) and those co-benefits that influence property value (i.e. aesthetic and recreational value, public health and well-being or city branding). In contrast, a higher contribution to SDGs 13, 11 and 8 is expected.

4. Discussion

In this paper, we assume that the capability of NBS for addressing SDGs may be enhanced by improving NBS multifunctionality and thus its effectiveness. NBS should be considered effective not only if they are capable of producing the expected co-benefits, but also if the production of co-benefits is balanced, which means, the capability of NBS to eliminate/reduce the level of trade-offs among different co-benefits. The long-term effectiveness of NBS depends not only on NBS design and implementation, but also on the socio-ecological context in which NBS are applied. For example, low level of institutional collaboration or lack of citizen awareness may hamper NBS effectiveness. External factors such as climate change may also influence NBS capability to deliver certain co-benefits over time. These issues need to be addressed prior to NBS design and implementation and requires a deep understanding of the complex relationships that exist among the social, economic and environmental factors of the considered system. We believe that trade-off identification in the prior stages of NBS implementation is crucial to enhance NBS multifunctionality and to pursue sustainable development. To this aim, system thinking modelling approach – i.e. Fuzzy Cognitive Mapping (FCM) – was adopted to explore the structural causes of the observed trends as well as to analyse and map the complex network of interactions among the components involved in NBS effectiveness. In this paper we have demonstrated that FCM combined with a participatory modelling phase is an appropriate methodology to handle the diversity in framing NBS complexity among the different stakeholders. FCM has provided different advantages in the process of analysing the river restoration NBS multifunctionality. It has allowed us to capture the essence of the whole system comprehensively, without making the model too complex to be used with the stakeholders. Compared to other methods for dynamic analysis, FCM demonstrated great potential in facilitating the interaction with stakeholders. FCM did not force the analysts to translate stakeholders' knowledge and narratives – which are mainly qualitative – into quantitative variables and equations, as already discussed in (Kok, 2009; Jetter and Kok, 2014). The FCM model for scenario simulation was built referring to the stakeholders' knowledge elicited during the early phases of anticipated project implementation. Therefore, participants were familiar with the causal connections described in the model and were able to understand the model. We learned that the adoption of a qualitative modelling approach, such as the FCM, positively affected the interaction with the stakeholders for both the model building phase and the scenario development.

This work is in line with the efforts already carried out aiming at developing integrated frameworks for assessing NBS effectiveness accounting for the production of co-benefits (see Raymond et al., 2017; Alves et al. (2019a, 2019b); Pagano et al., 2019). Compared to the above cited works, the approach described in this article introduced several novelties. Contrary to the works of (Pagano et al., 2019; Giordano et al., 2020), the activities carried out in the Copenhagen case study demonstrates the suitability of a group model building approach for developing the FCM model as the basis for the co-benefits and trade-off analysis. This approach has multiple elements of relevance. Firstly, it allows actors/stakeholders to share their knowledge/expertise. Secondly, it facilitates the creation of social capital among participants by providing a means for group identification of common problems and solutions, as well as the optimal way to test them. Finally, the group discussion reduced the biases introduced by the analyst during the aggregation phase. Nevertheless, trade-offs among co-benefits may arise due to differences among stakeholders' perceptions which means that co-benefits delivered by NBS may be valued differently depending on the stakeholder. Considering this, the adopted approach presents limitations concerning the lack of analysis of the differences between diverse kinds of stakeholders. Therefore, the analysis carried out accounted solely for the trade-offs among co-benefits, and not those between stakeholder's valuation.

The work also demonstrates the need to account for the time dimension in detecting and assessing trade-offs among different co-benefits. Importantly, the results of the FCM-based scenarios show that the same NBS can produce different co-benefits at different time steps. Thus, potential trade-offs might not appear because of the time delay. Conversely, the delays in co-benefits production could negatively affect the synergies between different co-benefits and NBS. For example, the results show that the implementation of NBS in Copenhagen (i.e. urban river restoration) is highly likely to produce a rapid increase of some co-benefits such as recreational and aesthetic value or city branding. However, the results also show that in the long term, the increase of these co-benefits may hamper the delivery of other co-benefits such as social justice and cohesion, social acceptance of NBS or citizens awareness. This is because urban green spaces usually correlate with an increase of properties and rent prices. This may displace groups of people that cannot afford the increase in real estate prices, consequently decreasing social justice and the social acceptability of NBS.

As highlighted by several authors, NBS have proven to be a cost-effective solution that can simultaneously contribute to several societal challenges. In the case of Copenhagen, the restoration of the urban river combined with an integrated urban green area is perceived by the stakeholders as an effective solution capable of delivering sets of benefits that contribute to a range of SDGs (i.e. SDG 5, 6, 4, 13, 11). The benefits delivered by NBS not only vary across spatial and temporal scales but also among societal groups. For this reason, new methods and approaches are needed to account for the real contribution of NBS to SDGs.

5. Conclusion

Assessing the dynamic behaviour of trade-offs and synergies among co-benefits could help to anticipate, identify and solve resistance to adopt policies and suitable strategies to implement NBS. The method proposed in this article has provided different advantages in the process of analysing the river restoration multifunctionality, and its capability to produce benefits over time. Firstly, it has supported the integration of quantitative and qualitative variables, knowledge and issues that are not well-defined or uncertain. Secondly, it has helped to show the complex interconnections and feedback processes within the system helping to infer intended and unintended consequences of NBS implementations. Lastly, besides the model, the whole process itself has promoted awareness and motivation of those taking part in decision- or policy-making processes, thus providing a platform for the joint-ownership of results. Despite all these advantages, new participative modelling tools focusing not only on a subset of impacts but on an integrated view of the system are needed to show the advantages of NBS over other adaptation strategies. Only this way could NBS be meaningfully and effectively integrated in national and international development policies.

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CRediT authorship contribution statement

Eulalia Gómez Martín: Conceptualization, Methodology, Writing - original draft.**Raffaele Giordano:**Conceptualization, Methodology, Writing - review & editing.**Alessandro Pagano:**Conceptualization, Methodology, Writing - review & editing.**Peter van der Keur:**Conceptualization, Writing - review & editing.**María Máñez Costa:**Conceptualization, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1. Identification of the main stakeholders involved in the participatory process and role.

Stakeholders	Rationale for selection
HOFOR	Greater Copenhagen Utility supplying 1.1 million customers in the Copenhagen metropolitan area with: Drinking water, District heating, District cooling, Town gas, Disposal of wastewater. Also, involved in climate proofing the metropolitan area against torrential downpours.
Region Hovedstaden	Region for Greater Copenhagen is concerned with public health and urban planning to ensure integrated solutions for environment, innovation and knowledge institutions.
City of Copenhagen (KK)	The Technical and Environmental management section is responsible for urban development with respect to urban use (e.g. compliance with environmental regulations), daily maintenance (cleaning etc), and urban development (e.g. infrastructure, built environment, climate proofing, resources management).
Insurance and Pensions (Forsikring og Pension)	Insurance & Pension Denmark (IPD) is the voice of the Danish insurance sector representing 92 insurance companies and pension funds operating in the Danish market.
KLIKOVAND	A cooperation between municipalities, utility services and the Capital Region of Denmark and supports efficient and sustainable climate adaptation solutions in the region, sharing knowledge and experience across municipal borders, and enabling mutual learning (Part of National Network for Climate Adaptation).
Gottlieb Paludan landscape / urban architects	An architect / landscape planner working with urban / landscape solutions for integrating climate change adaptation.
Call Copenhagen	Climate Adaptation Living Lab for Greater Copenhagen, to demonstrate, showcase and market integrated real-world climate adaptation solutions (part of National Network for Climate Adaptation).
De Danske Regioner (Danih Region)	Danish Regions have an interest in protecting public health and groundwater resources for drinking water purposes, as well as protecting surface water and natural resources.

Stakeholders	Rationale for selection
Miljøpunkt Nørrebro	The Environment Point is a non-governmental organization (NGO) promoting a better environment in the urban neighbourhood of Nørrebro and its close surroundings by executing practical environment and climate projects. Opportunities are challenged with regard to administrative rules and regulations in close collaboration with the local council who also provide economic support.

Appendix B

Introducing delays in the FCM

Traditional Fuzzy Cognitive Maps does not allow to consider delays in the causality assuming that that all the processes occur at the same time. This means that the polarity and the weight between variables are constant. To overcome this limitation, we have allowed changes in the adjacency matrices. For this we have developed three different adjacency matrices representing the system at three-time steps (short term, medium term and long term). To facilitate the understanding of the process, we will use the simple FCM described in figure B.1 as an example.

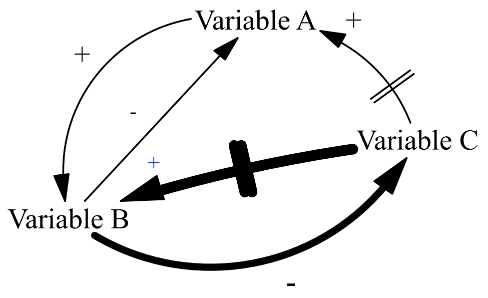

Figure B.1. Simple FCM. The thickness of the arrows indicates the strength in the relationship. Positive and negative symbols indicate the polarity of the relationship. Delays are indicated with two lines crossing the links (//).

Considering the FCM described in figure B.1, three were defined describing the system at three-time steps. The weights of the relationships that have delays (highlighted in red in the matrixes) change from the short-term matrix to the long-term matrix:

$$\text{Short term } E_s = \begin{pmatrix} 0.0 & -0.3 & 0.1 \\ 0.3 & 0.0 & 0.3 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

$$\text{Medium term } E_m = \begin{pmatrix} 0.0 & -0.3 & 0.2 \\ 0.3 & 0.0 & 0.6 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

$$\text{Long term } E_l = \begin{pmatrix} 0.0 & -0.3 & 0.3 \\ 0.3 & 0.0 & 1 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

To start the simulation, we implement the equation developed by Kosko in 1986. For this, the short-term matrix multiplied with an initial state vector which has one row and n (number of variables) columns. The initial state vector determines which scenario is simulated. The value 1 is used when the concept is activated and the value 0 when the concept is no-activated. In this case, the initial state vector is *A* = (1, 0, 0).

The multiplication between the initial state vector and the matrix leads to a new output vector. This output vector is then used as an initial vector for the second matrix (medium term). The same process is repeated with the long-term matrix.

State vector in the short term: $$V_s = A \times E_s = A \times \begin{pmatrix} 0.0 & -0.3 & 0.1 \\ 0.3 & 0.0 & 0.3 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

State vector in the medium term: $$V_m = V_s \times E_m = V_s \times \begin{pmatrix} 0.0 & -0.3 & 0.2 \\ 0.3 & 0.0 & 0.6 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

State vector in the long term: $$V_l = V_m \times E_l = V_m \times \begin{pmatrix} 0.0 & -0.3 & 0.3 \\ 0.3 & 0.0 & 1 \\ 0.0 & -0.6 & 0.0 \end{pmatrix}$$

To allow the comparison of the results, the three resulting vectors were aggregated and normalized with respect to the maximum absolute value to be within the range [-1,1]. The dynamic evolution of the FCM variables is obtained by plotting the state vector in the three-time steps.

The following tables shows the three FCM adjacency matrices developed for the case of Copenhagen case study.

Table B.1 Showing the short-term matrix. In red are cells are those which present delays. Therefore, the values of these cells change in each matrix

																							Short-term matrix																					
		INITIAL STATE VECTOR	**A0**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**	**A26**	**A27**	**A28**	**A29**	**A30**	**A31**	**A32**	**A33**	**A34**	**A35**	**A36**	**A37**	**A38**	**A39**	**A40**	**A41**
A0	NBS functionality	0.00	**0.00**	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A1	Frequency and intensity of weather extreme events	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A2	Mainteinance cost	0.00	0.00	0.00	**0.00**	0.30	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A3	**Urban Green Areas**	1.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A4	Social acceptance of NBS	0.00	0.00	0.00	0.00	0.00	**0.00**	0.60	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A5	Copenhagen Wealth	0.00	0.00	0.00	-0.30	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
A6	Aesthetic value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
A7	Biodiversity	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	-0.10	0.00	0.00	0.00	-1.00
A8	Urban river restoration effectiveness	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	1.00	0.00	0.00
A9	Surface urban flooding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	**0.00**	0.00	0.00	0.00	0.00	0.00	-1.00	0.60	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
A10	**Climate change**	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A11	Sense of security	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A12	Cost for treating water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00
A13	Water retention/infiltration	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	-1.00	0.00
A14	Potential for economic opportunities and green jobs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A15	Urban green areas affectiveness	0.00	1.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A16	Groundwater flooding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A17	Groundwater level	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A18	Water in Sewer/drainage system	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
A19	**Restoration project**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A20	Branding	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00
A21	Citizen involvement and sense of ownership	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	**0.00**	0.30	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A22	Citizens awareness	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	**0.00**	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A23	Climate Change Adaptation Plan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
A24	Property value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	**0.00**	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A25	Urban Heat Island	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A26	Public Health and Well-Being	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	**0.00**	0.00	-0.60	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A27	Social justice an cohesion	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	-0.30	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A28	Heat waves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A29	Vector-borne disease	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.30	**0.00**	0.00	0.00	0.00	0.00	0.30	0.00	0.00	-0.30	0.00	0.00	0.00	0.00
A30	Cloudburst events	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A31	Damage Cost	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A32	Investment in green areas	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A33	Recreational value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A34	Water in Lake	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A35	Water quality	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
A36	Water in surface drainage channels	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.30	0.00
A37	**Green Space Management**	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00
A38	Water run-off	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00
A39	**Institutional collaboration**	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00
A40	Decoupled water from roofs and paved areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00
A41	Urban development	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Table B.2 Showing the medium-term matrix. In red are cells are those which present delays. Therefore, the values of these cells change in each matrix

			Medium-term matrix																																									
		Initial state vector	**A0**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**	**A26**	**A27**	**A28**	**A29**	**A30**	**A31**	**A32**	**A33**	**A34**	**A35**	**A36**	**A37**	**A38**	**A39**	**A40**	**A41**
A0	NBS functionality	-0.60	**0.00**	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A1	Frequency and intensity of weather extreme events	1.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A2	Mainteinance cost	1.21	0.00	0.00	**0.00**	0.30	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A3	**Urban Green Areas**	**1.00**	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A4	Social acceptance of NBS	2.23	0.00	0.00	0.00	0.00	**0.00**	0.60	0.00	0.00	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A5	Copenhagen Wealth	3.62	0.00	0.00	-0.30	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
A6	Aesthetic value	1.46	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
A7	Biodiversity	-2.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	-0.30	0.00	0.00	0.00	-1.00
A8	Urban river restoration effectiveness	0.49	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	1.00	0.00	0.00
A9	Surface urban flooding	-2.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	**0.00**	0.00	0.00	0.00	0.00	0.00	-1.00	0.60	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
A10	**Climate change**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A11	Sense of security	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A12	Cost for treating water	-0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00
A13	Water retention/infiltration	-0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	-1.00	0.00
A14	Potential for economic opportunities and green jobs	2.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A15	Urban green areas affectiveness	1.54	1.00	0.00	0.00	0.80	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A16	Groundwater flooding	-0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A17	Groundwater level	-0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A18	Water in Sewer/drainage system	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
A19	**Restoration project**	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A20	Branding	1.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00
A21	Citizen involvement and sense of ownership	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	**0.00**	0.50	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A22	Citizens awareness	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	**0.00**	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A23	Climate Change Adaptation Plan	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
A24	Property value	3.99	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	**0.00**	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A25	Urban Heat Island	-1.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A26	Public Health and Well-Being	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	**0.00**	0.00	-0.60	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A27	Social justice an cohesion	-1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	-0.60	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A28	Heat waves	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A29	Vector-borne disease	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.30	**0.00**	0.00	0.00	0.00	0.00	0.30	0.00	0.00	-0.30	0.00	0.00	0.00	0.00
A30	Cloudburst events	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A31	Damage Cost	-2.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A32	Investment in green areas	1.75	0.00	0.00	0.00	0.00	0.50	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A33	Recreational value	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A34	Water in Lake	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A35	Water quality	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00
A36	Water in surgace drainage channels	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00	0.30	0.00
A37	**Green Space Management**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00	0.00	0.00
A38	Water run-off	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00	0.00	0.00
A39	**Institutional collaboration**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**1.00**	0.00	0.00
A40	Decoupled water from roofs and paved areas	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**	0.00
A41	Urban development	3.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**

Table B.3 Showing the long-term matrix. In red are cells are those which present delays. Therefore, the values of these cells change in each matrix

			Long-term matrix																																								
		Initial State Vector	**A0**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	**A14**	**A15**	**A16**	**A17**	**A18**	**A19**	**A20**	**A21**	**A22**	**A23**	**A24**	**A25**	**A26**	**A27**	**A28**	**A29**	**A30**	**A31**	**A32**	**A33**	**A34**	**A35**	**A36**	**A37**	**A38**	**A39**	**A40**	**A41**
A0	NBS functionality	-0.60	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A1	Frequency and intensity of weather extreme events	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A2	Mainteinance cost	1.22	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A3	**Urban Green Areas**	**1.00**	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A4	Social acceptance of NBS	0.58	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A5	Copenhagen Wealth	3.03	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.30	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60
A6	Aesthetic value	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
A7	Biodiversity	-2.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	-0.30	0.00	0.00	0.00	-1.00
A8	Urban river restoration effectiveness	0.58	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	1.00	0.00	0.00
A9	Surface urban flooding	-2.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.60	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
A10	**Climate change**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A11	Sense of security	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00
A12	Cost for treating water	-0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00
A13	Water retention/infiltration	-0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	-1.00	0.00
A14	Potential for economic opportunities and green jobs	2.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A15	Urban green areas effectiveness	1.50	1.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A16	Groundwater flooding	-0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A17	Groundwater level	-0.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A18	Water in Sewer/drainage system	-0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
A19	**Restoration project**	**0.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A20	Branding	1.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00
A21	Citizen involvement and sense of ownership	-1.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.60	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A22	Citizens awareness	-1.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A23	Climate Change Adaptation Plan	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
A24	Property value	3.60	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A25	Urban Heat Island	-1.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A26	Public Health and Well-Being	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.60	0.00	0.00	-0.60	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A27	Social justice an cohesion	-2.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	-0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A28	Heat waves	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A29	Vector-borne disease	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	-0.30	0.00	0.00	0.00	0.00
A30	Cloudburst events	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A31	Damage Cost	-2.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A32	Investment in green areas	1.20	0.00	0.00	0.00	0.00	0.60	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A33	Recreational value	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A34	Water in Lake	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A35	Water quality	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A36	Water in surgace drainage channels	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
A37	**Green Space Management**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00
A38	Water run-off	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A39	**Institutional collaboration**	**1.00**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
A40	Decoupled water from roofs and paved areas	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
A41	Urban development	3.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix C

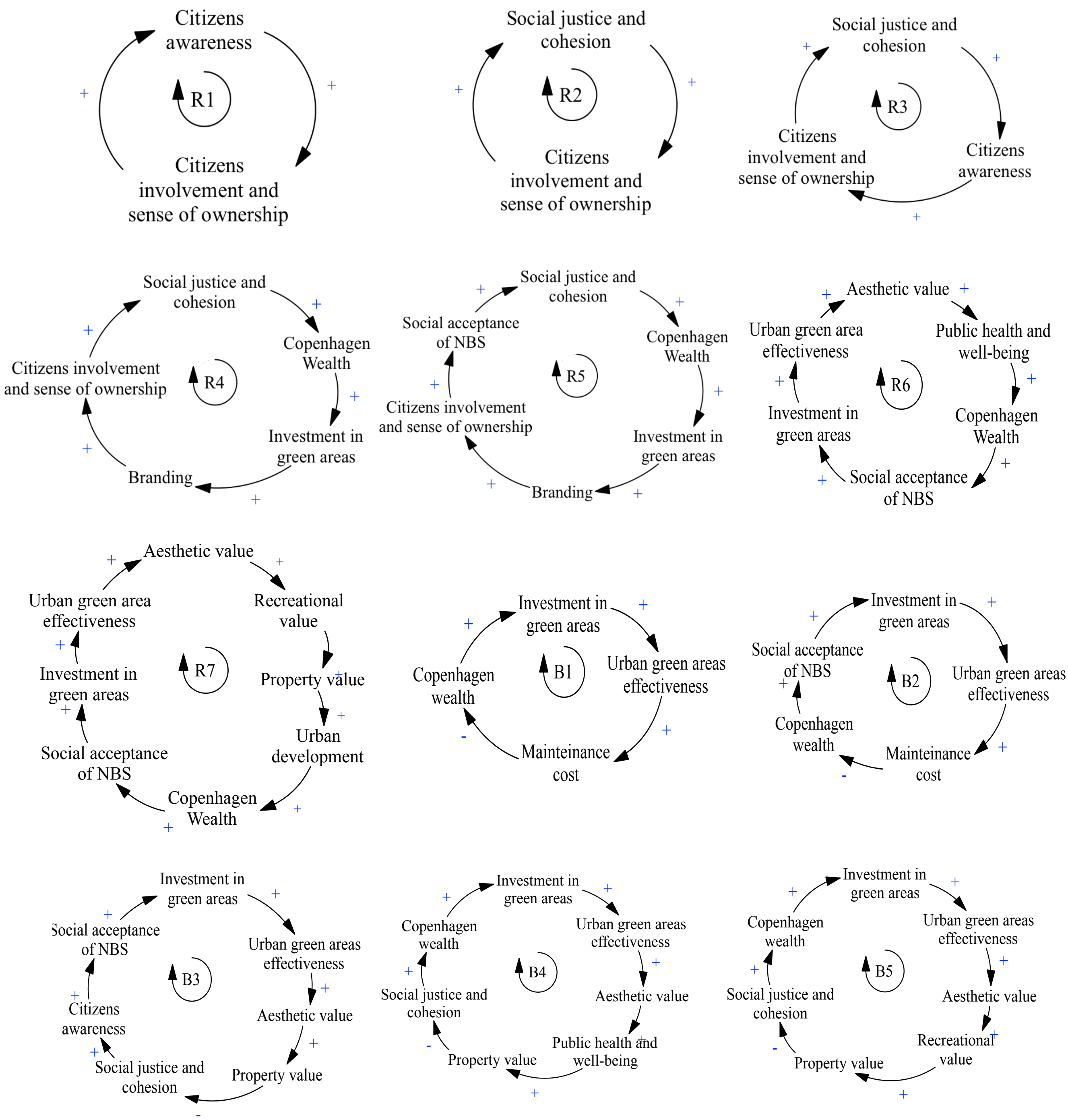

Figure C1. Important feedback loops. Balancing loops have been indicated with the letter "B" and reinforcing loops with the letter "R".

Appendix D

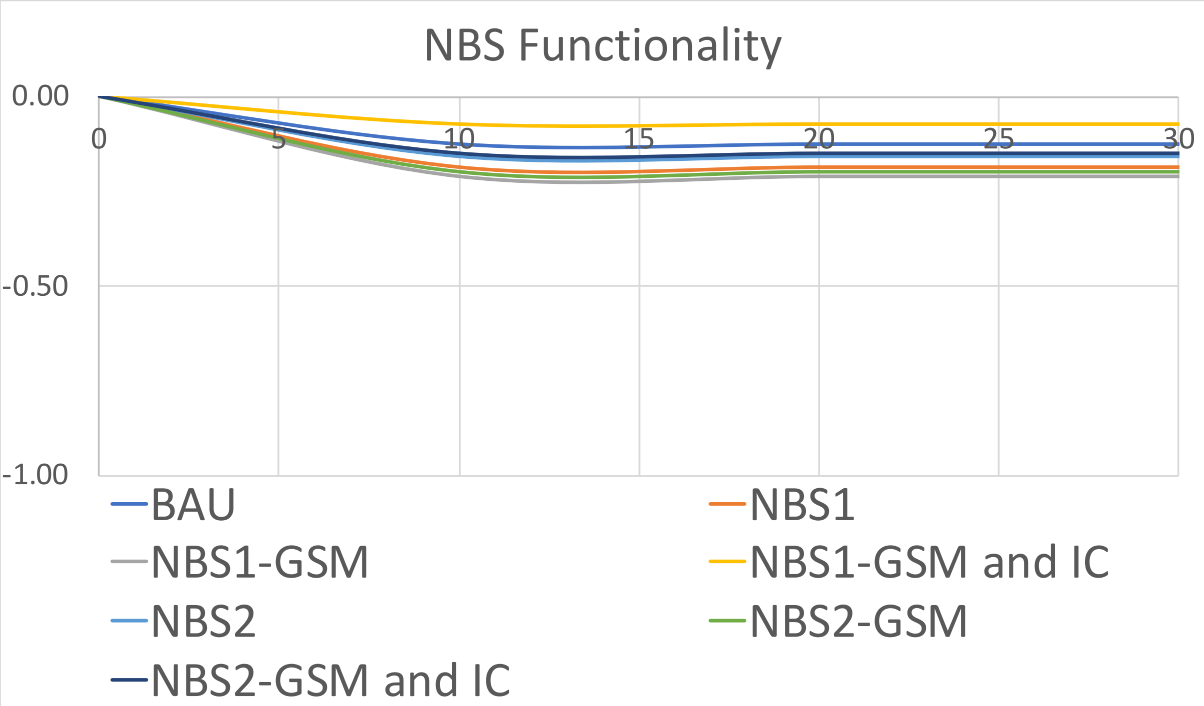

Figure D.1. Dynamic behaviour of groundwater flooding. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

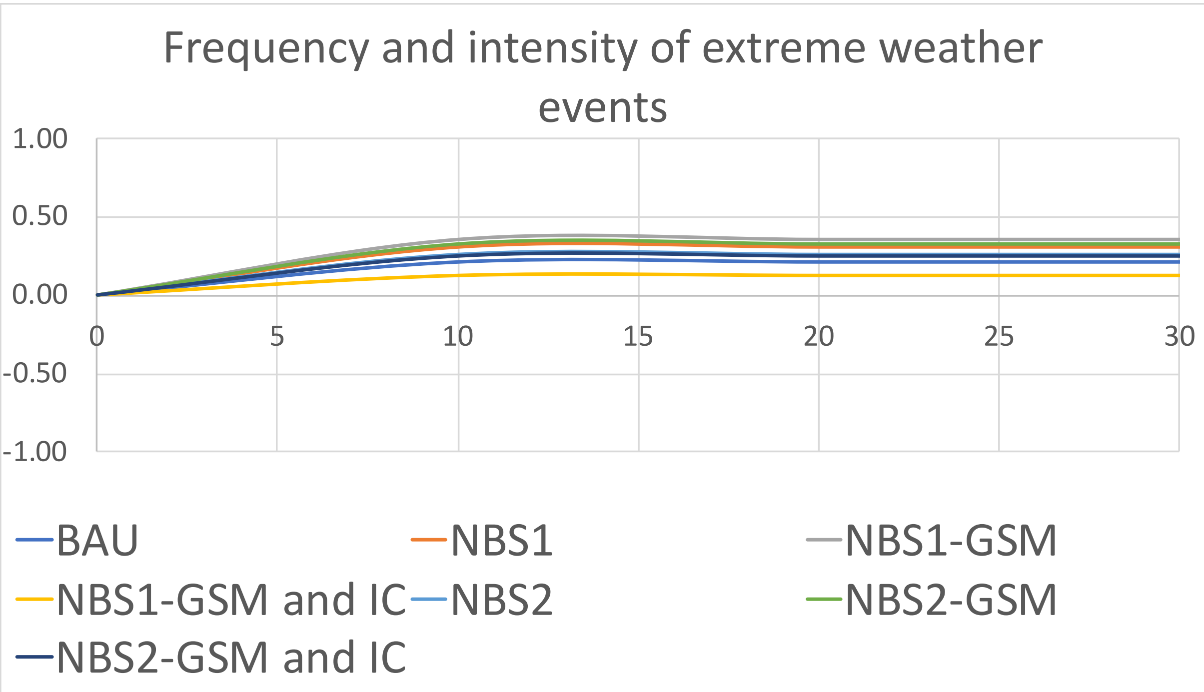

Figure D.2. Dynamic behaviour of frequency and intensity of extreme weather events variable. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

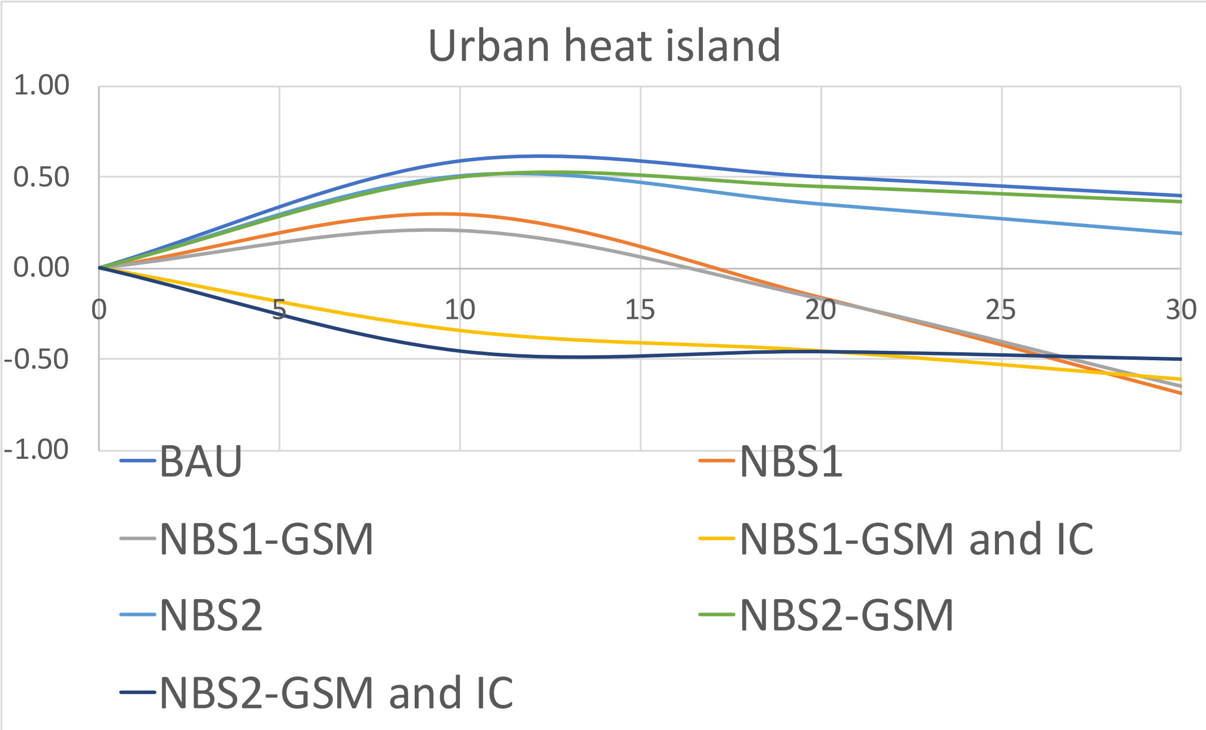

Figure D3. Dynamic behaviour of the urban heat island effects under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

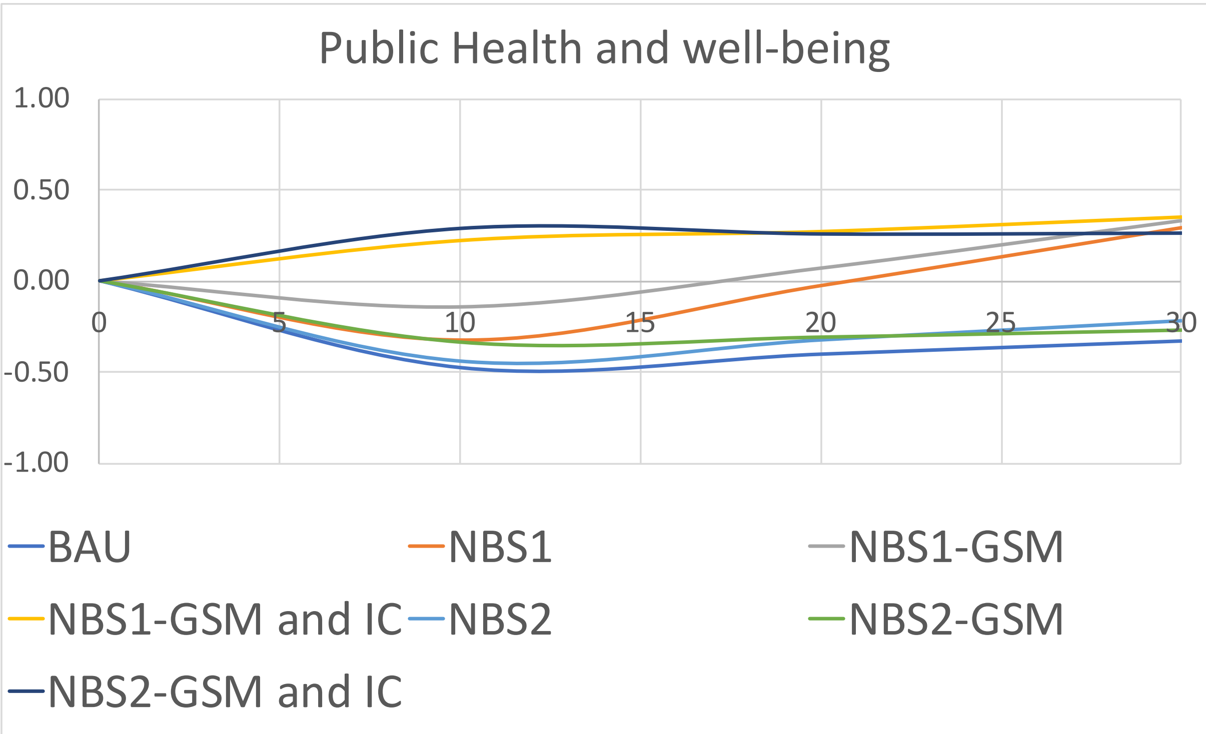

Figure D.4. Dynamic behaviour of public health and well-being co-benefit under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

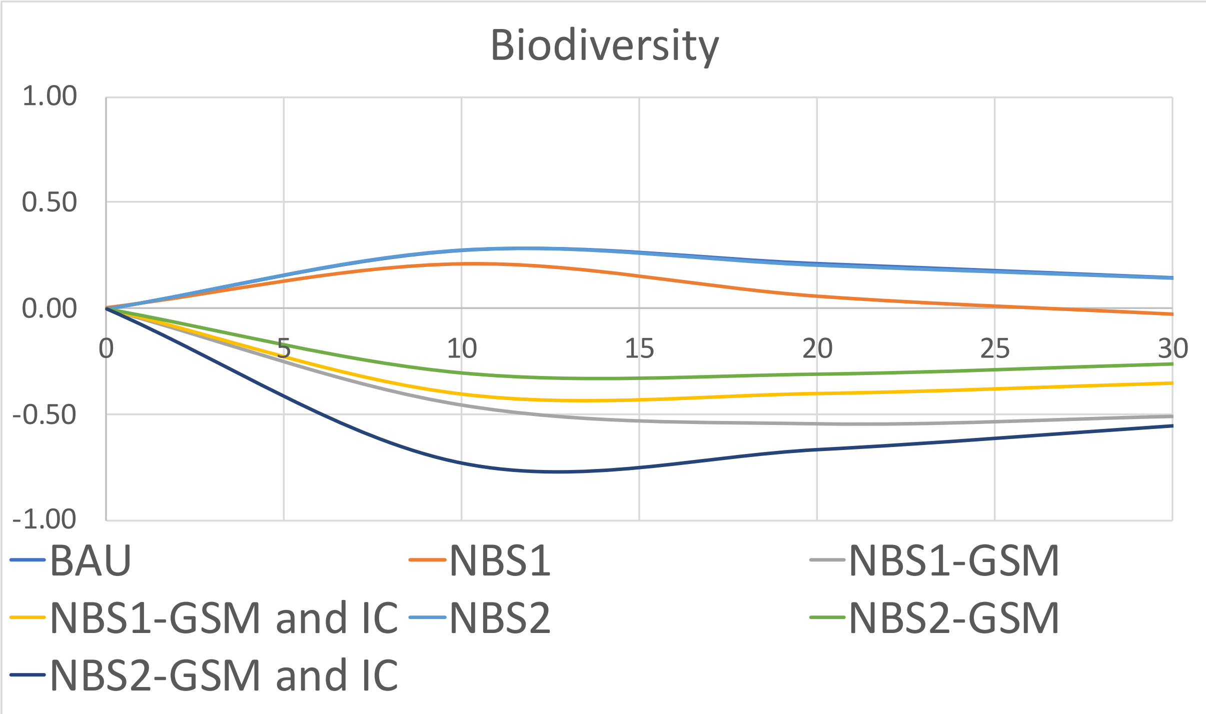

Figure D.5. Dynamic behaviour of biodiversity co-benefit under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

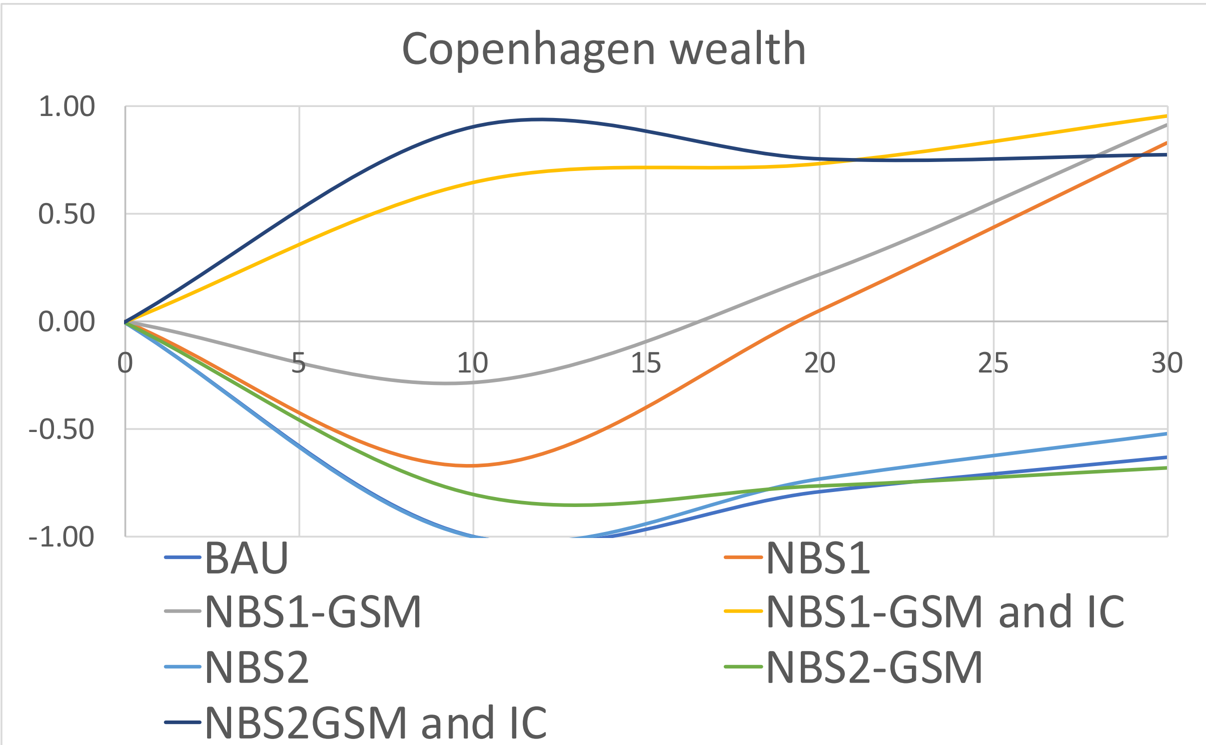

Figure D.6. Dynamic behaviour of Copenhagen wealth under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

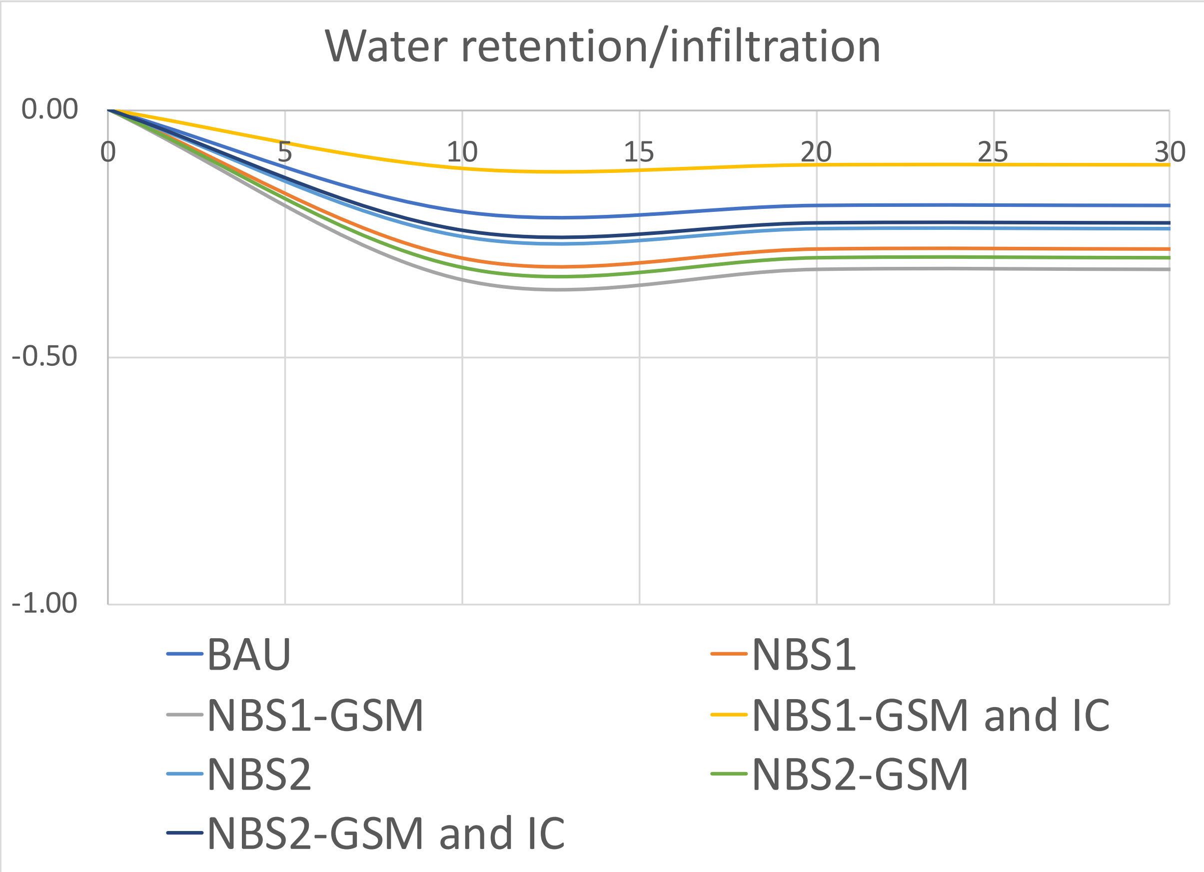

Figure D.9. Dynamic behaviour of water retention/infiltration under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

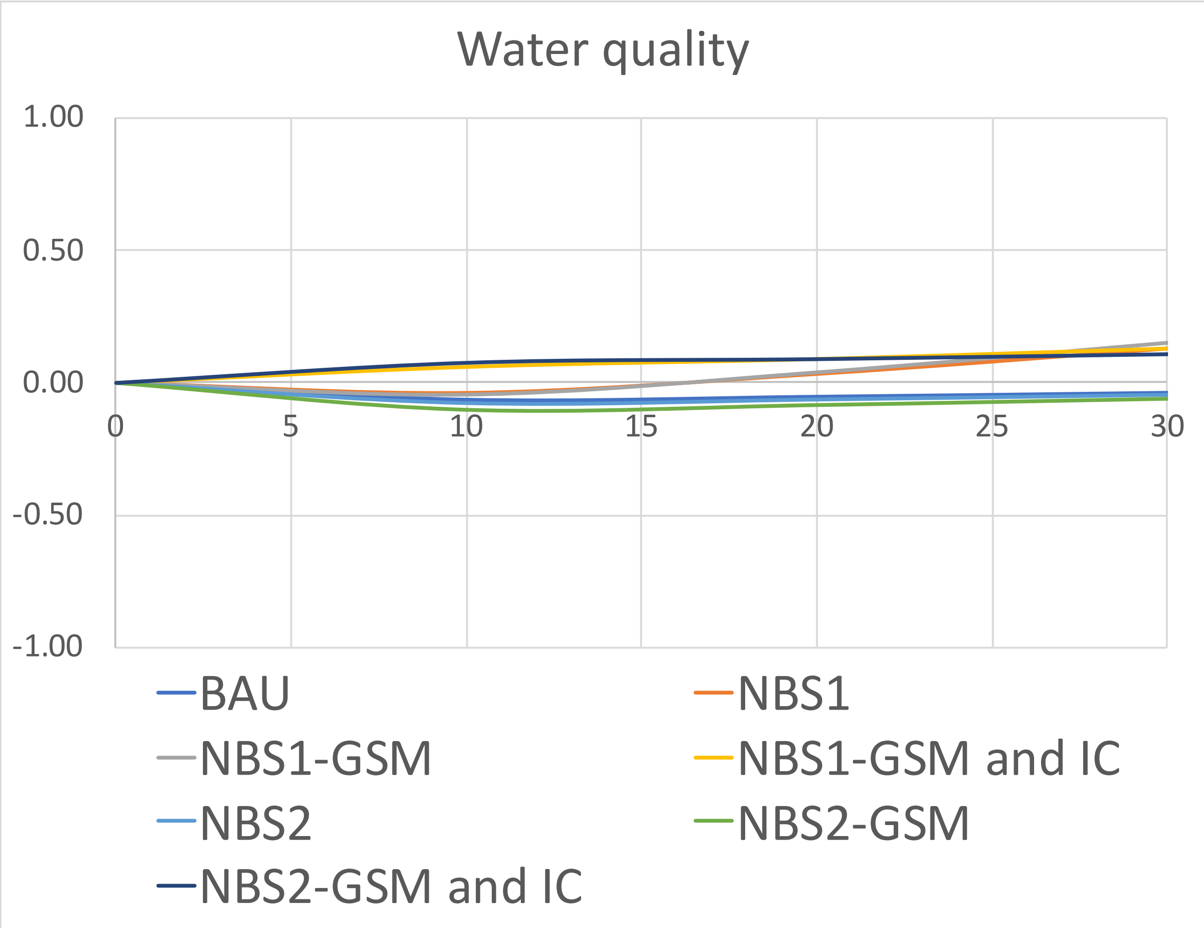

Figure D.10. Dynamic behaviour of water quality under different scenarios. The x-axis represents time (in years), and the y-axis the value of the FCM variables in each scenario.

Appendix E

Table E.1. Sustainable development goals and indicators with potential co-benefits that could support their achievement.

List of affected Sustainable Development Goal and indicators	
Goals and targets (from the 2030 Agenda)	*Co-Benefits*
Goal 1. End poverty in all its forms everywhere	
1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, as well as access to basic services, ownership and control over land and other forms of property, inheritance, natural resources, appropriate new technology and financial services, including microfinance	Potential for economic opportunities and green jobs Damage cost reduction Social justice and cohesion
1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters	
Goal 3. Ensure healthy lives and promote well-being for all at all ages	
3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being	Increase in health and well-being Increase in water quality Pollutants removal
3.9 By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination	
Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	
4.7 By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development	Social acceptance of NBS Social justice and cohesion Citizens awareness
Goal 6. Ensure availability and sustainable management of water and sanitation for all	
6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	River restoration Citizens awareness Reconnection between lake, river and groundwater
6.b Support and strengthen the participation of local communities in improving water and sanitation management	

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all	
8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors	Potential for economic opportunities and green jobs
8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services	
8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10-Year Framework of Programs on Sustainable Consumption and Production, with developed countries taking the lead	
8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products	
Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	
9.1 Develop quality, reliable, sustainable and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all	Investment in green infrastructures Potential for economic opportunities and green jobs
9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking-action in accordance with their respective capabilities	
Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable	
11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries	Reduce groundwater and surface flooding Pollutants removal River-lake reconnection Investment in green infrastructures Increase in NBS investment
11.a Support positive economic, social and environmental links between urban, peri-urban and rural areas by strengthening national and regional development planning	

Goal 13. Take urgent action to combat climate change and its impacts[b]	
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	Investment in green infrastructures Flood reduction CO_2 reduction Citizens awareness Increased responsibility and understanding and engagement of climate change
13.2 Integrate climate change measures into national policies, strategies and planning	
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	
Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	River restoration Citizens awareness Reconnection between lake river and groundwater Increase in biodiversity
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	
15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems	
Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	
16.7 Ensure responsive, inclusive, participatory and representative decision-making at all levels	Institutional cooperation Social justice and cohesion

Chapter 4:

Integrated analysis: A qualitative Systems Dynamic Model to understand the Medina del Campo system

Integrated analysis: A Qualitative Systems Dynamic Model to understand the Medina del Campo system

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Abstract

Nature-Based Solutions (NBS) are being implemented across Europe to reduce the economic and human cost of water-related hazards while addressing a range of societal challenges. However, the development and implementation of NBS is a complex process involving a variety of actors, from civil society members to policy makers and scientists. Adopting a bottom-up approach is a prerequisite to understanding how different knowledge is created and distributed among different stakeholders and governmental levels. The balanced distribution of co-benefits across different socio-economic sectors is key to achieve the full potential of NBS. Knowledge integration represents an opportunity to enhance decision making and facilitate the implementation of NBS. Integrating local and scientific knowledge increase the usability of local information and promotes the co-production of knowledge by facilitating community-based learning and reinforcing this way NBS effectiveness. In this chapter, it is suggested a knowledge integration approach to incorporate new and existing knowledge into a more efficient framework for NBS implementation. A qualitative system dynamics approach, starting with a participatory modelling phase, was used as a framework for analysis. This chapter presents the results from the case study of Medina del Campo groundwater body of the Duero River in central Spain.

Key words

Nature Based solutions, System Dynamics, participatory modelling, knowledge, co-production

1. Introduction

The correct implementation of Nature Based Solutions generates various social, economic and environmental co-benefits by delivering bundles of ecosystem services. The correct assessment of NBS effectiveness requires the combination of numerous heterogenous data and information that is usually fragmented across groups (Allen and Kilvington, 1999). For this reason, when it comes to implement and design NBS it is necessary to adopt a systemic and collaborative approach that integrates multiple perspectives and employs multiple sources of information (Allen and Kilvington, 1999). It has been recognized that adopting a bottom-up perspective increases the effectiveness of NBS implementation (European Commission, 2015). Participatory modelling is a valuable tool to obtain data coming from formal and non-formal sources. This approach supports the inclusion of transdisciplinary knowledge through the participation in the model creation process of stakeholders and researchers (Reed et al., 2009), Van den Belt, 2009). This makes this approach particularly well-suited to integrate different perspectives of socio-economic and ecological systems. Participatory Modelling activities have been used to develop a comprehensive understanding of the scope of the system and to guide the actions that are conducted, while giving advantages at both individual and collective levels. At the individual level, the approach improves the problem formulation and perception of participants. At the collective level, it facilitates the involvement of the group and the achievement of a consensus concerning a decision (Gómez et al., 2019).
Using the case study of Medina del Campo groundwater body, participative modelling was used to obtain relevant bottom-up information and to organize the collective knowledge of stakeholders in a graphical structure that captures the main dynamics of the system. In this chapter the participatory modelling framework is presented. The aim of the framework is to facilitate the co-design process of NBS, focusing on the stakeholder's perception on the main dynamics of the system, and on the related acceptability of measures and strategies.

2. Methodology

Participatory Modelling activities were used in Medina del Campo to develop a comprehensive understanding of the scope of the system as well as to promote a discussion among stakeholders that could lead to a shared vision of the system and of the main problems and barriers of NBS. This chapter focus on describing the participatory modelling framework implemented in Medina del Campo Groundwater Body (summarized in figure 1).

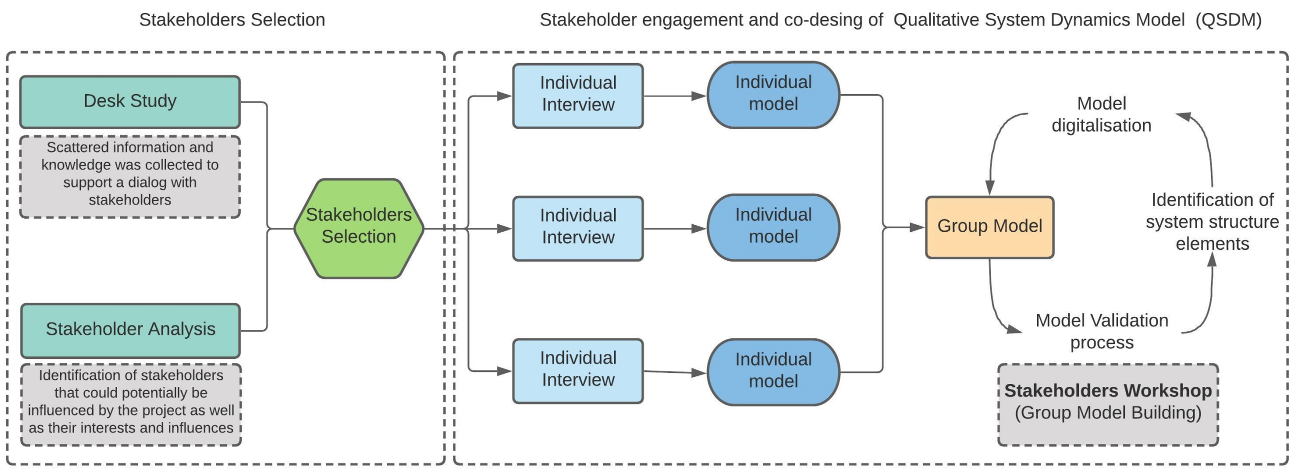

Figure 1. Participatory modelling framework implemented in Medina del Campo Ground Water Body for NBS decision making and planning.

2.1 Stakeholder's selection

Understanding who is affected by each decision and action (i.e. NBS implementation) is fundamental to increase the effectiveness of the decision-making process. It is also essential to understand which actor may have the authority to implement actions or decisions, thus influencing the results obtained (i.e. farmers associations, river basin authority) (Reed et al., 2009; Santoro et al., 2019). For this reason, before implementing the participatory modelling exercise, stakeholders representing different levels of governance and knowledge were selected. Before the stakeholder's selection, a desk study was carried out to understand the influences and responsibilities of each stakeholder. The desk study also allowed us to identify stakeholders that could potentially be affected by NBS implementation. The selection was made to collect the largest number of perceptions of the system. The list was updated using 'snowballing' techniques to involve all relevant stakeholders that were mentioned or cited during the individual interviews. The number of stakeholders was chosen to have a realistic representation of the system and to allow for the active participation of individuals during the final group model building exercise (See Appendix A[1]). In concordance with previous studies, we estimated that the desired number of participants to take part in the participatory modelling activities ranged between 7 and 15 participants (Gómez Martín et al., 2020; Videira et al., 2014).

2.2. Individual interviews

After stakeholder's identification, individual interviews were carried out. In each interview, individual conceptual models were created in a co-design process. The interviews used a semi-structured format designed to avoid straightforward questions and answers, maintaining an engaging debate among the stakeholder and the interviewer. Unlike interviews with fixed question, the semi-structured format allows more flexibility, and it is open to the new ideas that can arise during the interview based on the response of the stakeholder (Santoro et al., 2019). Before the interview, a series of questions and topics were prepared to guide the conversation. The guiding questionnaire was tailored, considering the information arising from the stakeholder analysis and desk study.

Stakeholder interviews were carried out along with cognitive mapping and diagramming techniques that were used to build a visual representation of stakeholder's perception of the system. A syntactic rule was used to differentiate the social, economic and environmental elements in order to facilitate the development of the conceptual model. The participants were asked to use cards of different colours to represent the different variables and factors within the system. The variables representing natural resources and ecosystem services were marked in green, blue cards were used to identify socio-economic factors; yellow cards represented all the activities or actions. Finally, all the barriers, risks or challenges were marked in red.

The interviewee answers the moderator's questions by constructing their causal model. The objective was to connect the elements needed to understand the socio-ecological system as well as barriers and issues associated with NBS implementation. During the process, the relationships were represented by arrows that represent the causal influences among variables (see table 1). The polarity of the relationship was represented by a positive (+) or negative (-) symbol. The polarity does not describe the behaviour of the variable but indicates the direction of the change. It is used to indicate how the dependent variable changes when the

[1] The individual models and their description will not be included in the published version of this book chapter.

independent variable changes. The processes or decisions that require some time to occur were indicated with a delay mark (//). Each interview was recorded in order to avoid loss of information. After the participatory process, the developed qualitative model was digitalised using Vensim software. The digitalisation enabled the post-process of the information and data. The individual models and their description can be found in Appendix B.

Table 1. Relationships described in the co-designed qualitative individual models

Type of relationship	Quotes from stakeholders	Translation into variables and relationships
Positive relationship	*"If there is no rain, there is no water infiltration"*	Rain + Water infiltration
Negative relationship	*"When there is water scarcity, the concertation of saline concentration increases, and the quality of water decreases "*	Water scarcity + Saline concentration - Water quality
Connection to the past	*"We use to use water from the aquifer for irrigation, but now, the level is too low and we use water from the river"*	Water in the aquifer + Agriculture
Connection to the future	*"From my point of view, in the future it is very likely that we not only have problems with the quantity (of water) but also with the cost"*	Water in the aquifer - Cost
Delay	*"The construction of small dams or water retention areas could retain water and thus, increase water infiltration"*	Water infiltration + Dams and water retention areas

2.3. Group Model Building

The information collected in all individual interviews was combined to develop a group model (GM). The GM is composed of all the variables and relationships that appeared in all individual models. Before the GM development, a language homogenisation phase was needed since some variables were described by stakeholders using different terminologies. For example, the groundwater level was named in the individual models using a variety of terms (i.e. aquifer, water in the aquifer, piezometric levels, water quantity). To avoid overcomplexity, the variables and relationships that were not repeated in the majority of the individual models were eliminated.

2.4. Group Exercise-Model Validation

The conceptual group model was presented and discussed with stakeholders in a one-day workshop. During the validation process, group model building techniques (GMB) were used to validate and improve the conceptual model. The GMB exercise promoted communication among stakeholders while facilitating the consensus agreement process and the shared vision among stakeholders. The GMB was carried out with all the stakeholders that participated previously in the individual interviews. In contrast to the individual interview, the system was analysed from a collective perspective. In contrast to the individual interview, the system was analysed from a collective perspective. The exercise was adequately moderate to stimulate the exchange of relevant information and knowledge among participants.

After the GMB, relevant feedback loops were identified to facilitate the visualisation and explanation of the causes-effect of the processes occurring within the system. The polarity of the loops is determined by the polarity of the links composing the loop. The polarity of the loops and the feedback structure determines the behaviour of the system. A reinforcing or positive loop (R) results when an action produces a result which influences the initial action, it results in exponential growth or decline behaviour. Alternatively, a balancing or negative loop (B) occurs when an action is taken to change the current state of a variable to the desired state. This type of loop tends to produce oscillations or movement towards equilibrium (Sterman, 2000). The resulting Qualitative System Dynamics Model (QSDM) was used as a graphical tool to represent the feedback structure responsible for the cause of dynamics of the Medina del Campo system.

3. Results

Figure 2 represents the co-developed Qualitative System Dynamics Model (QSDM) representing the Medina del Campo system (MCS). It describes the stakeholder’s perception of the complex cause-effect relationships that exist among the different social, economic and environmental elements of the system. The QSDM was used to infer the main dynamic hypothesis as well as to reveal important feedback structures responsible for the Medina del Campo systems behaviour.

Eighty-two feedback loops responsible for the MCS underlying behaviour were found in the QSDM. In order to improve the comprehension of the diagram and to facilitate finding strong leverage points, essential loops are highlighted. We identified nine positive loops (indicating self-reinforcement of a given change within the loop) and thirteen balancing loops (indicating self-regulation of a given change within the loop). Stakeholders selected 'water in the aquifer' variable as the core element of the system. According to stakeholder's perception, the principal elements influencing the aquifer are groundwater extractions (GWE), surface water and two climate components, precipitation and temperature. Agriculture and agriculture-based industry increase water extractions; this is further aggravated by the uncontrolled illegal extractions (R6, R5 and R9).

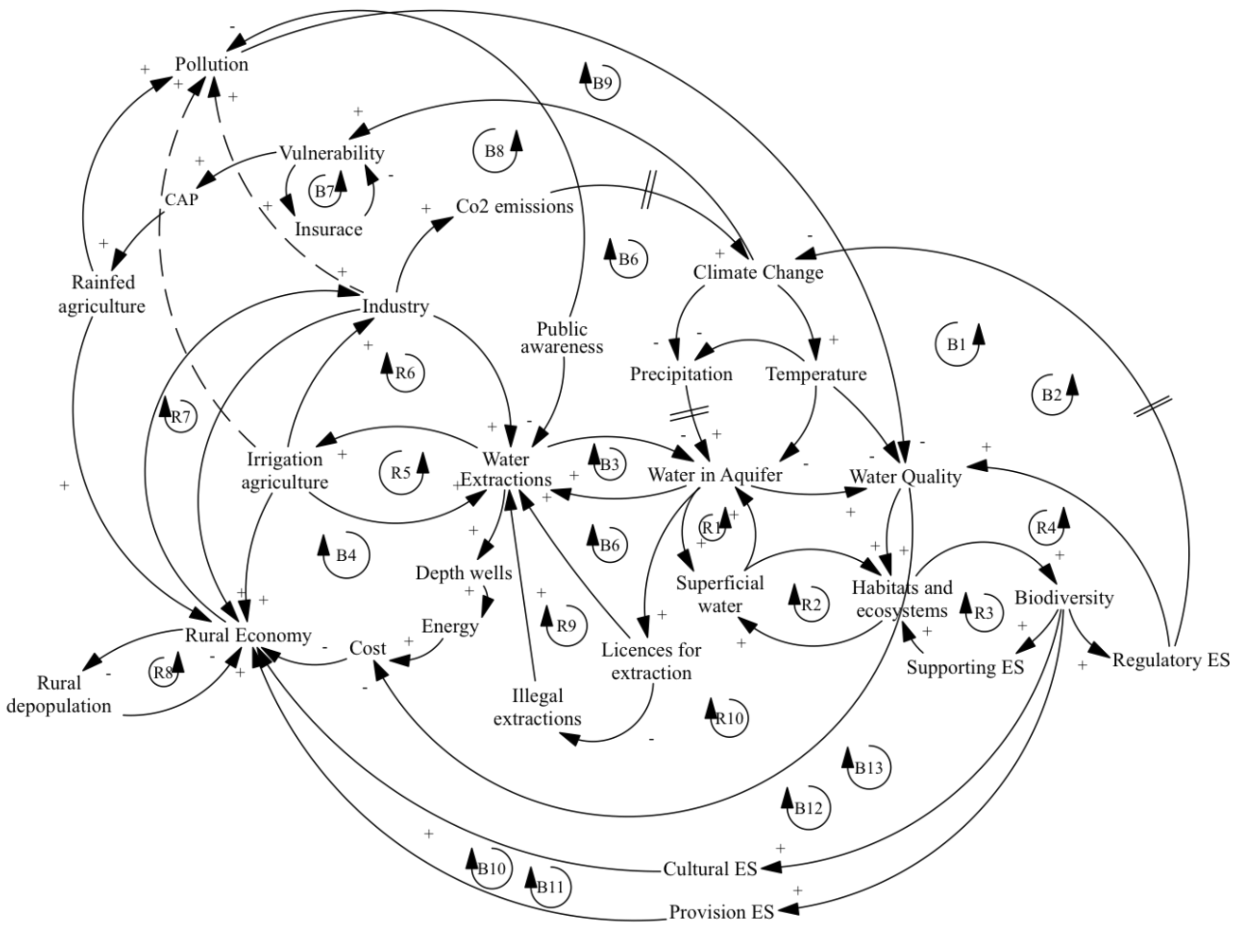

Figure 2. QSDM developed in Medina del Campo System. Balancing loops have been indicated with a B and its corresponding identification number; and reinforcing loops have been indicated with an R and their corresponding identification number. The polarity of the links has also been marked with a positive (+) or negative (-) symbol. Delays in the system have been indicated with a delay mark (//).

If the aquifer level reaches a level at which the cost of extracting water exceeds the economic productivity of extracted water, GWE start decreasing (B3). Water quality is negatively affected by the decrease of the piezometric aquifer levels; this is further aggravated by the pollution produced by industry and agriculture.

Superficial ecosystems delivering cultural, supporting, provision, and regulatory ecosystem services are highly dependent on the aquifer. When the aquifer level decrease, aquifer-dependent ecosystems degrade (R1, R2). As a result, local biodiversity and ecosystem services decrease due to the weakening of loops R1, R2, R3, R4. Stakeholders perceive rural depopulation as a severe problem in the area. Rural population is strongly influenced by the rural economy that at the same time, is dependent on water-dependent activities as well as on provision and cultural ecosystem services (B10, B11). Stakeholders perceived climate change as a potential risk. An increase in the frequency and intensity of droughts may threat the future environmental and economic recovery of the area.

4. Conclusion

Participatory modelling in the first stages of NBS design and implementation has multiple elements of relevance. Firstly, supports the organisation the collective knowledge of stakeholders in a graphical structure that promotes learning as well as constructive and targeted discussions to understand and conceptualise the socio-environmental context in which NBS are applied as well as the barriers and limitations of NBS implementation. Secondly, it supports active collaboration and the rigorous integration of different expertise and interdisciplinary skills, thus building greater trust in models (Zomorodian et al., 2018). Thirdly, it may contribute to show how the complex interconnections among system elements may lead to unexpected effects, thus helping to anticipate possible rebound effects or policy resistance as well as to identify suitable strategies to act on the systems. Lastly, besides the model, the whole process itself promotes awareness and motivation of those taking part in the decision- or policy-making processes, thus providing a platform for the joint-ownership of results (further details in Pagano et al. 2019). Participatory modelling has proven to be highly relevant for describing NBS multifunctionality and its capability to produce benefits over time. The main benefit of adopting a participatory modelling approach in the field of NBS relies on its potential for integrating qualitative and quantitative variables; local and expert knowledge; and knowledge coming from different disciplines. This is highly relevant for describing NBS multifunctionality and its capability to deliver benefits over time.

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6. Appendix A

Table 1. List of stakeholders involved in individual interviews and rationale for selection

Stakeholders	Rational for selection
Provincial Council of Ávila	Regional government of the area of study
Regional government of Castile and Leon (JCyL)	Regional government of the area of study
Municipal Council Valladolid	Local government of the area of study
Municipal Council Medina del Campo	Local government of the area of study
Municipal Council Horcajo de las Torres	Local government of the area of study
Municipal Council Rágama	Local government of the area of study
Irrigation Community Río Adaja	Farmers association in charge of the distribution of water in the irrigable area of the Adaja river.
UCCL: Association of Young Farmers (Jóvenes Agricultores)	Farmers association.
ACUAES (Aguas de las cuencas de España):	Public Company in hydraulic infrastructures.
University of de Salamanca. (Centro de Investigación y Desarrollo Tecnológico del Agua).	Academic/Research institution. They can provide information about the system from a scientific point of view.
L' ALHONDIGA de Arévalo	Cultural association with information about the socio-economic aspects of the area.
WWF Spain	NGO that can provide ecological information about the area, as well as different adaptation and conservation measures that have been implemented in the area.
SEOBirdlife	NGO with ecological information about the area.

7. Appendix B: Individual models Medina del Campo

Rágama municipality

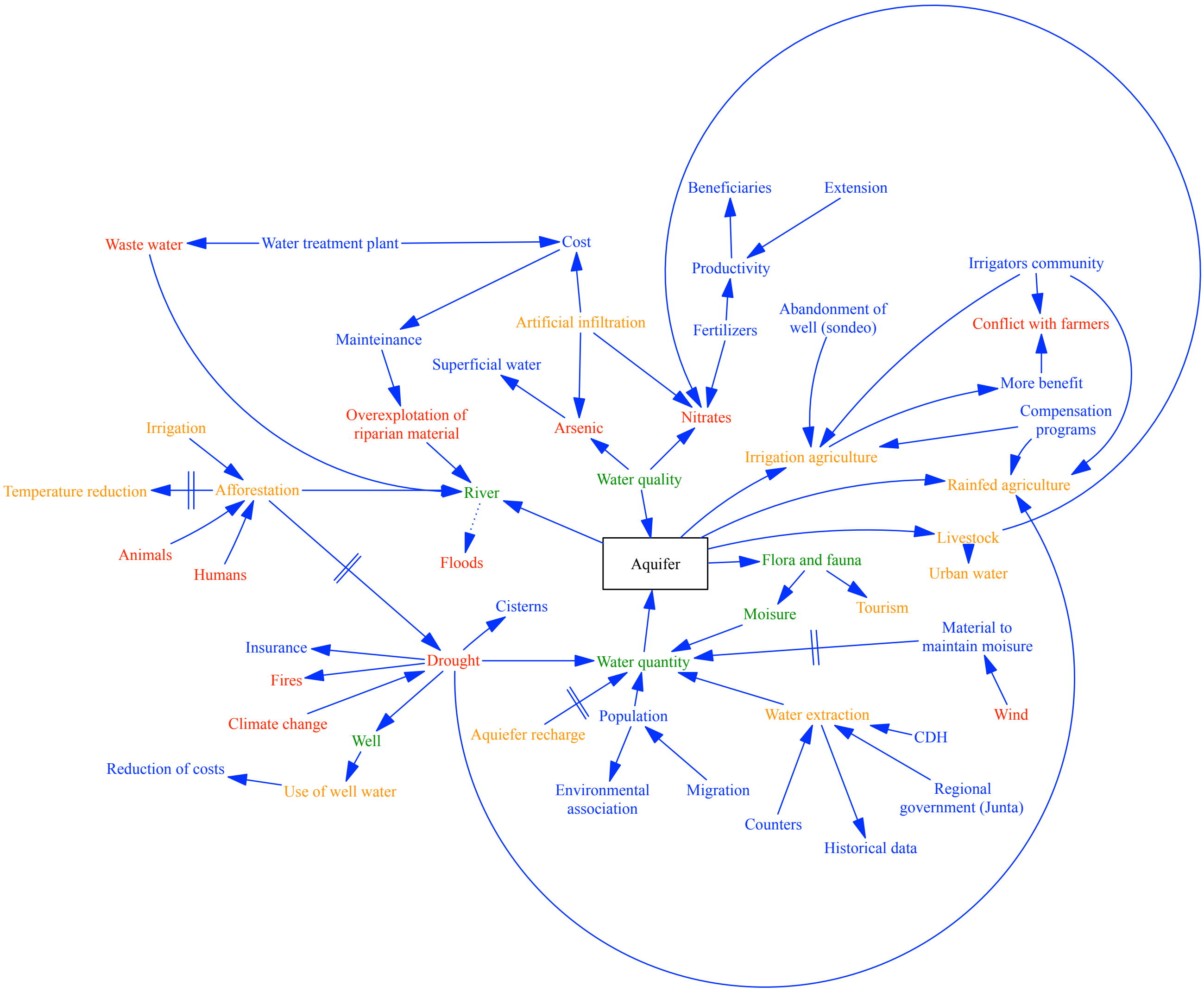

Figure B.1. Individual model Rágama municipality. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Rágama municipality has an extension of 32 m2 and has an aged population of 250 inhabitants. The lack of jobs in the area is creating a problem of depopulation in the region. The main livelihood is agriculture. Although the fraction of irrigation crops is small, the percentage of irrigation agriculture is increasing in the region.

The intensive extraction of water from the aquifer has reduced groundwater levels. Groundwater levels decrease caused several environmental and economic problem.

Groundwater level depletion has a direct effect on water quality. The arsenic that is naturally found in the soil is more concentrated in lower volumes of water.
To increase the productivity of crops, farmers are using fertilisers without an appropriate control (both in irrigation and rainfed crops). The uncontrolled use of fertilisers is reducing superficial water quality by increasing nitrates concentration.
In Rágama, the water used for agriculture is extracted from the aquifer and surface waters. Depending on the water quality, they alternate between superficial and groundwater intakes. If the arsenic levels are high, they use superficial water, if, on the contrary, the nitrates concentrations are high, groundwater is used.
Rainfed agriculture is not very profitable. In order to obtain benefits, it is necessary to have a considerable extension of crops. Rainfed crops are subsided by Common Agricultural Policies (CAP). CAP subsidies are essential to maintain the economy of the area.
Droughts further aggravate water quantity and quality problems. Climate Change is increasing the intensity of droughts. The decrease in precipitations directly affects the recharge of superficial and groundwater. Besides, the dryness of the soil is increasing fire risk.
In this region, the economy is highly dependent on irrigation agriculture. There are irrigation farmers associations such as the irrigators community (Comunidad de regantes). The purpose of the irrigators community is to distribute the water in an efficient, orderly and equitable way among its members. However, the distribution of irrigation water often causes conflicts among farmers.
The river basin authority (Confederacón Hidrograefica del Duero, CHD) manage groundwater. They control water extractions by limiting the permits to extract water. The CHD is planning to implement measures to recharge the aquifer artificially.
The decrease of the phreatic levels is threatening flora and fauna. The aquifer supports a variety of superficial groundwater-dependent ecosystems such as rivers and lagoons. Some lagoons close to Ragama municipality such as the Lavajares lagoon dries when the phreatic level is too low. This lagoon supports important migratory species of birds. Restoring the ecosystems of the area could potentially have a positive economic impact on economic sectors such as tourism.
In Rágama, some measures have been implemented to maintain soil moisture (i.e. mulching). However, this measure was not very effective because the wind dragged the material.
Afforestation programs have also been carried out in Rágama to cool the town. However, irrigation was needed, and animals ate young trees.

UCCL: Association of Young Farmers (Jóvenes Agricultores)

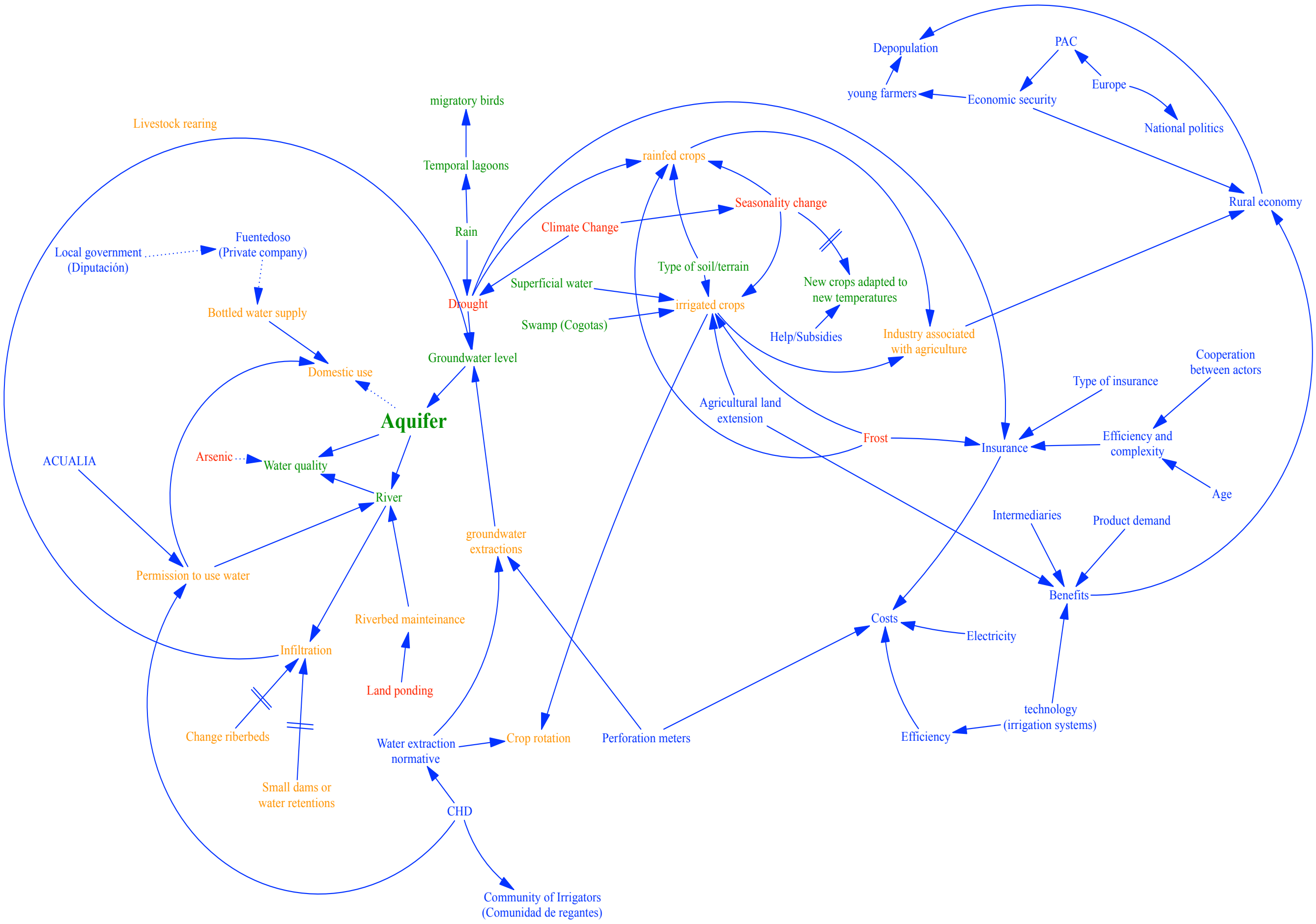

Figure B.2. Individual model UCCL. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Irrigation farmers extract water from the aquifer and the Cogotas artificial reservoir. In this area, the high levels of groundwater extractions have led to a reduction of the phreatic levels. The cost of extracting water from the aquifer is higher than from shallow water. The cost of groundwater extractions depends on the depth at which the well has to be dig. Depending on the zone, the depth of the intake is different. There are areas where they are extracting water at 50 meters, and others where the water is extracted at 200 meters.

Climate change is affecting the agricultural sector in two ways. Firstly, it has worsened droughts by increasing the temperature during dry periods and reducing precipitation.

Secondly, it has affected seasonality by advancing the summer and delaying the winter. Climate variability has reduced aquifer recharge and crops productivity.

In the past, there used to be water quality problems due to high levels of arsenic in groundwater. When they had this problem, small municipalities were supplied with water bottles. These bottles were supplied by the regional government (Diputación de Ávila).

In this area, the central part of the farmers has a larger area of rainfed crops and a small fraction of irrigated crops—this increases their economic security. 80% of the water used for irrigation comes from the aquifer, and the remaining 20% comes from shallow waters. The main rainfed crop is cereal. If the farmers have permission to irrigate, they also irrigate cereals. Cereals irrigation increases productivity and thus, the economic benefit.

In the past, the farmers use to cultivate only rainfed crops; this has changed in the last years due to the higher market price of irrigated crops. The shift from rainfed agriculture to irrigation agriculture required a high amount of economic investment as farmers have to invest in digging wells and irrigation machinery. Therefore, many farmers are reluctant to change again to rainfed crops.

The economic security of farmers is directly affected by the Common Agricultural Policy (CAP), which is the agricultural policy of the European Union. The CAP implements a system of agricultural subsidies to supplement the income of farmers. Changes in the European and National policy reduces economic security and affects the rural economy.

For example, the River Basin Authority (Confederación Hidrográfica del Duero) may limit the permits to extract water limiting irrigation agriculture. For this reason, farmers do not want to invest in modern and efficient irrigation systems if they are not confident that they will be able to amortise it.

To reduce economic losses due to droughts and frost, farmers hire agricultural insurances. However, the complexity of insurance contracts limits their efficiency.

As stated before, the economy of the area is highly dependent on water availability. For this reason, there is a need to invest in actions that help to recharge the aquifer. For example, building dikes in rivers such as Adaja, Arebalillo and Zafardiel can prevent water from flowing into the sea and thus, this water will infiltrate into the aquifer. The aquifer recharge will have a positive impact on the local economy and also on the ecosystems associated with the aquifer. This improvement of the natural habitat could potentially increase tourism.

In the area, they have not perceived problems with floods. They only have floods when the rivers are not well-maintained.

University of de Salamanca. (Center for Research and Technological Development of Water).

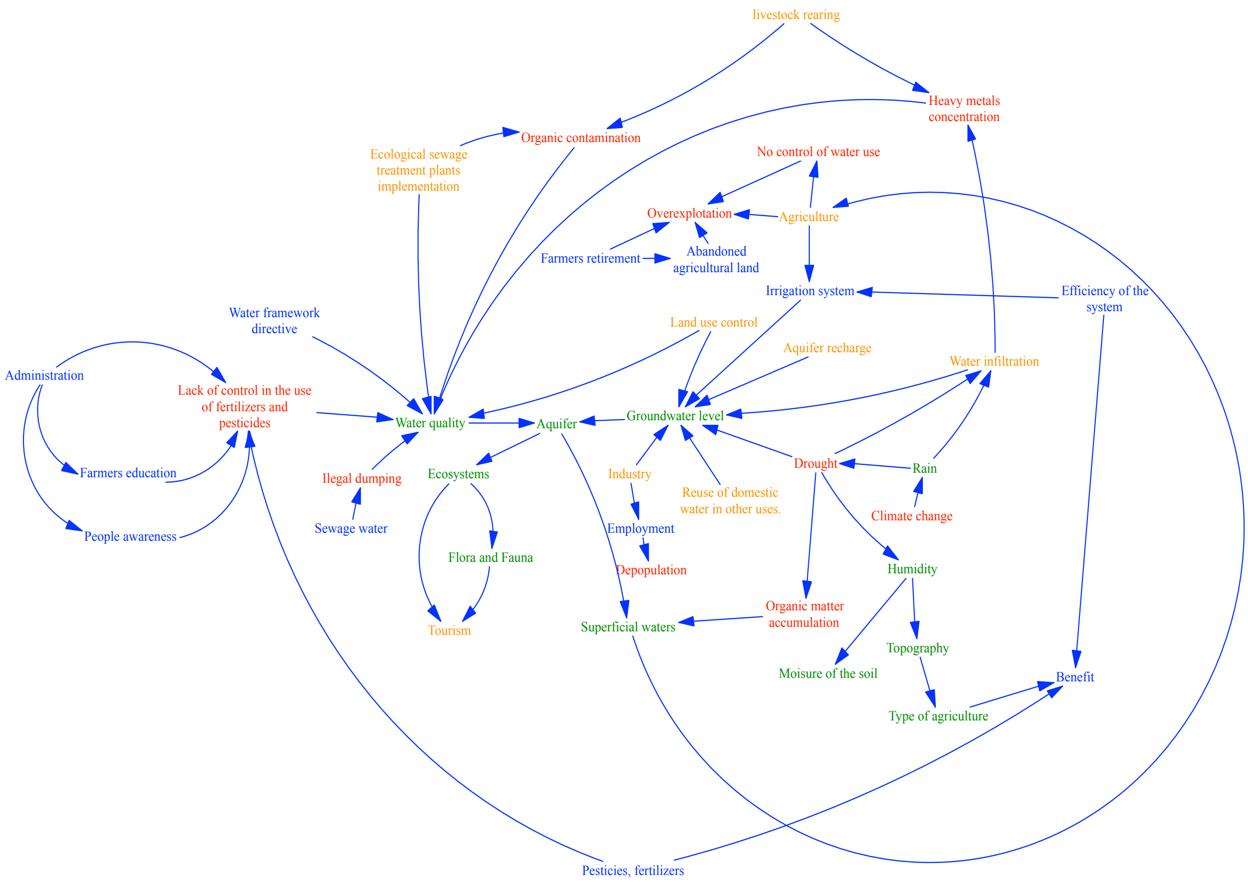

Figure B.3. Individual model University of Salamanca. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Flora and fauna of the area are highly dependent on the state of the aquifer since superficial and groundwater are connected. The rural economy of the area is highly dependent on agriculture. This sector uses 70-75% of the total freshwater.

Other livelihoods are livestock rearing, industry associated with agriculture and on a minor scale, rural tourism. The last one is positively related to the healthy state of the ecosystems. Degradation of these ecosystems will significantly affect this sector. Although tourism is not very well developed, there are regional plans to promote it.

The aquifer has quality and quantity problems. Lack of groundwater extractions control has led to a dramatic decrease in the phreatic levels of the aquifer and as a consequence, a decrease of the superficial water resources.

Climate change is reducing precipitations, affecting further groundwater level decrease. The decrease of groundwater has increased the concentration of arsenic that is naturally present in the soil. The quality of water is also being affected by illegal dumping of nitrates and pesticides coming from agriculture and livestock.

The water quality is not only affected by groundwater levels, but also by the mineralogy of the soil. For this reason, some areas have more concentration of arsenic than others. In many areas, the water used to irrigate and watering livestock has high concentrations of arsenic. High level or arsenic concentrations may cause health problems in the long term.

The River Basin Authority (Confederación Hidrográfica del Duero, CHD) is proposing to incentivise the shift to more efficient irrigation systems. However, this requires high amounts of economic investment by farmers. They are reluctant to make these investments because they do not have long-term security about whether they will be able to extract water in the future.

Different measures such as water re-use, illegal extractions control or artificial recharge by building artificial reservoirs could help to reduce the overexploitation of water.

Higher control of water extractions may affect irrigation agriculture and thus, the income of farmers. Increasing farmers income can potentially increase depopulation in rural areas.

To increase water quality in the area wastewater plants have been placed in many municipalities. However, the installation and maintenance of these plants are usually very costly. For this reason, many villages do not have wastewater plants and wastewater is dumped directly into the river.

Water quality is also affected by the lack of control of the use of fertilisers and pesticides. For this reason, some campaigns are being carried out to raise awareness between farmers and the rural population.

L' ALHONDIGA de Arévalo

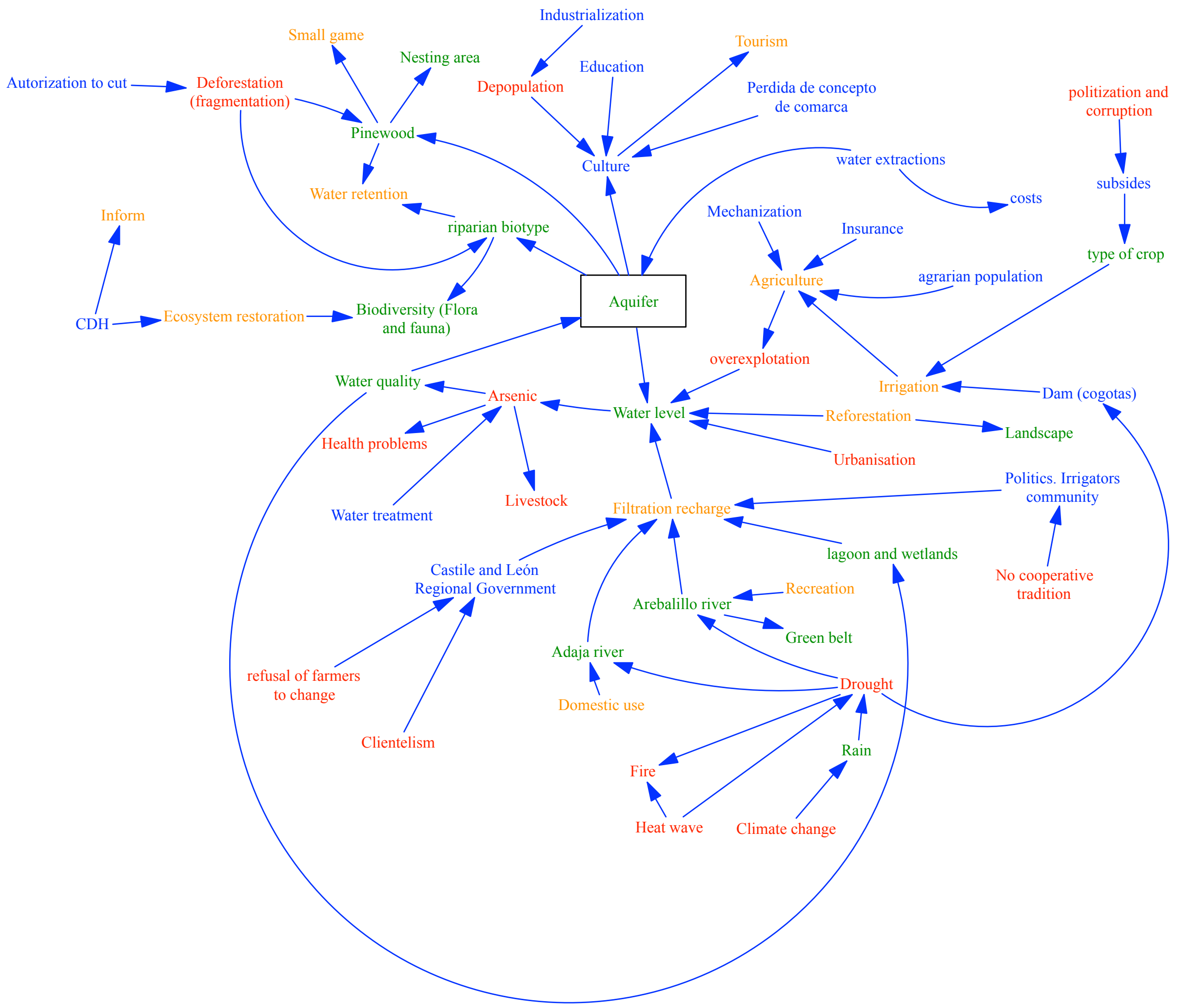

Figure B.4. Individual model L' Alhondriga de Arévalo. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The aquifer supports a wide range of important ecosystems such as riparian forests, lagoons, wetlands or pine forests. These ecosystems are the habitat of endemic species and provide essential ecosystem services such as climate regulation, water purification and water storage. These ecosystems also have significant cultural value for the region and support a variety of economic activities such as resin extraction, logging and tourism.

The lack of control of certain human activities is threatening these ecosystems. One of the main environmental problems in the area is the uncontrolled groundwater extraction. The dramatic decrease in the phreatic levels not only has affected the water quality of the aquifer but also of the superficial ecosystems that are dependent on it.

The central part of the extracted water is for agricultural reasons. Irrigated crops usually have higher market value. Habitually, the regions that have a higher percentage of irrigated crops have a better economy. There are irrigation crops that use water from the aquifer; others use water from shallow waters. Irrigation from surface waters has a positive impact on the aquifer recharge. When the phreatic level is low, extracting water from the aquifer is very costly.

Rainfed crops are subsided by Common Agricultural Policies (CAP). The CAP and the market price directly influence the type of crop that is grown in the area.

The decrease in the groundwater level has also reduced water quality. The concentration of arsenic has increased in areas where the water level is low. In some areas, the concentration of arsenic has reached levels unfit for human consumption, and bottled water has been supplied by the Regional government (Diputación de Ávila).

The quality of drinking water is controlled; however, water quality for irrigation and farming is not controlled. This uncontrol may have consequences in the health of the people who consume these products.

The decrease of the phreatic level has increased the desertification of the area, increasing the risk of natural fires. Climate change and the increased drought periods also play a fundamental role in the state of the aquifer.

Measures such as habitat restoration, awareness campaigns, water extraction control and activities to recharge the aquifer are needed to maintain the landscape, ecology and economy of the area. The implementation of measures to improve aquifer level is being limited by several barriers such as lack of institutional collaboration, conflict of interest among stakeholders or lack of awareness.

ACUACES (Aguas de las cuencas de España)

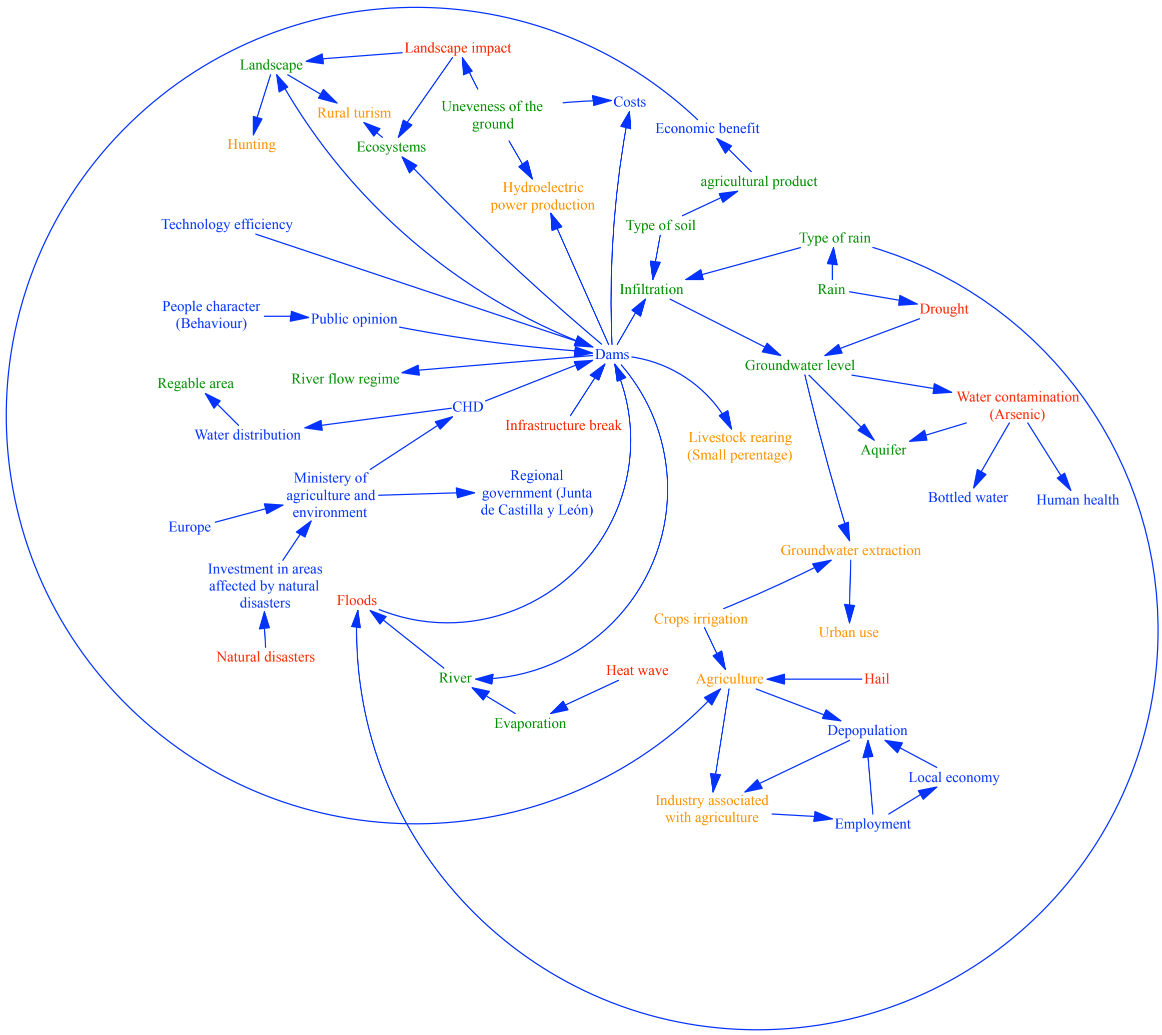

Figure B.5. Individual model Acuaces. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The construction of the Cogotas artificial water reservoir in 2002 had a positive impact on the aquifer. Firstly, it reduced the extraction of groundwater and secondly; it increased the aquifer recharge through the rivers. When there are high levels of precipitation and the water is not infiltrated, it is stored in the reservoir. The dam construction caused a change in the river flow regime, changing the landscape and ecosystems of the area. The construction of the reservoir has attracted several migratory birds that have settled in the area.

The primary economic sector in the area is agriculture which has benefit from the dam construction. There is 6500 ha of irrigation coming from the Cogotas reservoir. The River Basin Authority (CHD) manages the water distribution. The management of the CHD depends on the regional and national laws.

Agriculture is highly influenced by the weather. For this reason, farmers usually have agricultural insurance against hail and droughts.

The decrease of the phreatic levels directly affects the concentrations of arsenic in groundwater. In some municipalities, the quality of water was not good enough for human consumption. In these regions, bottled water has been supplied.

Climate change has increased dry periods; as a consequence, the groundwater level has decreased. Dry periods also affect river flows. However, it is essential to notice that although climate change affects water quantity, the main factor affecting river flows and groundwater levels is the overexploitation of water resources.

It is important to implement adaptation measures to regulate river flows, for example, with the construction of new dams. However, implementing any measure is very difficult because the administrative bureaucracy is convoluted, and it needs collaboration between local, regional and national government.

Although the main economic activity is agriculture, livestock rearing, and industry associated with agriculture play an essential role in the rural economy of the area. The construction of the dam has increased the economic activity in the region, and the depopulation problem is not very present. However, in other areas without irrigation from surface water reservoirs, depopulation represents a real threat.

Provincial Council of Ávila

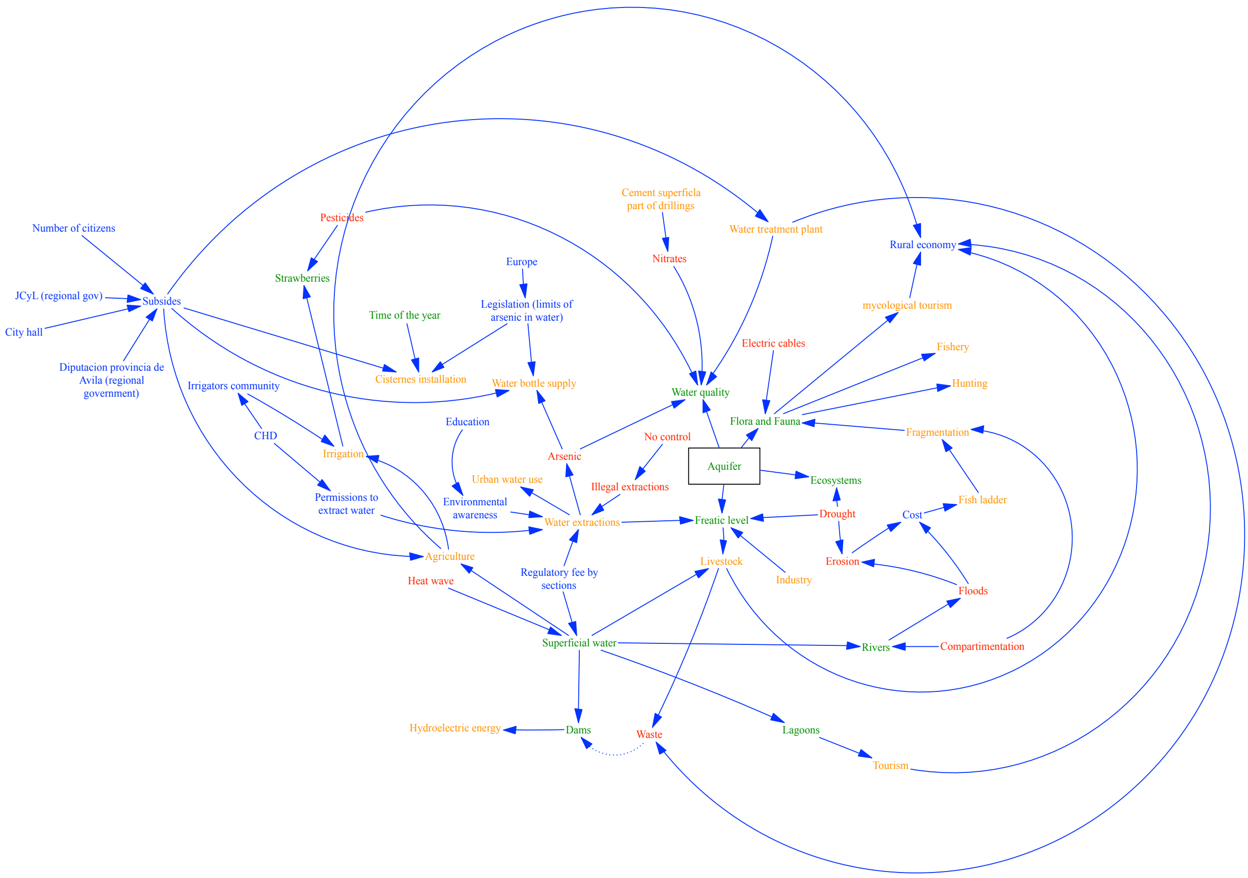

Figure B.5. Individual model Provincial Council of Ávila. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The function of the Avila regional government is to manage the subsidies, the financing of projects and the technical advice to projects. They also look for alternative intakes of water. If water quality is not good enough for drinking, they provide bottled water.

The region is highly dependent on the water reservoirs. The phreatic level of the aquifer has been reduced dramatically due to uncontrolled water extractions. The CHD provides the permissions for extracting water. They, along with the irrigators community, manage water resources. However, it is known that there are illegal extractions which are not controlled.

Draughts have also played a fundamental role in the reduction of groundwater.

The decrease in the levels of the aquifer has also led to an increase in the concentrations of arsenic. In some areas, the concentrations of arsenic have reached the levels where water is not suitable for drinking. In these areas, the Regional government (Diputacion de Avila and

Junta de Castilla y León) provide bottled water and subsides for cisterns installation and water treatment plants. The subsidies provided depends on the number of citizens in the municipality. In some villages with the lower population, there is no budget for installing water treatment plants. The lack of water treatment plants has led to the illegal dumping of wastewater into the rivers.

In some areas, there are also problems with Nitrates coming from pesticides and fertilisers. Contamination of Nitrates affects mainly shallow waters. In order to avoid the infiltration of nitrates into groundwater, the first 10-15 meter of the well is cemented.

Depending on the quality of the water municipalities alternate their water supply with the ground or shallow water. The Cogotas reservoir supplies Ávila municipalities with water quality problems.

In order to control water quality, different companies such as AQM, Aquimisa or Aqualia conduct water quality tests.

The aquifer supports superficial ecosystems that play an essential role in the rural economy of the area. The degradation of these ecosystems can threaten activities such as rural tourism, fishery or hunting. Many families have as an economical supplement the sale of mushrooms.

The regional government is promoting ornithological tourism as it is an activity that attracts high-income tourists. In the area, it is possible the sighting of endangered species of birds such as the Spanish imperial eagle (Aquila adalberti) or the black stork (Ciconia nigra). The ponds of the area are the habitats of endemic species of fish such as the Bemejuela (Achondrostoma arcasii) highly threatened by habitat fragmentation and drought. Important habitats have almost disappeared due to the lack of rain and the continuous decrease of groundwater level.

In some municipalities of the region, riverine floods have caused economic and human losses. Some of the rivers are compartmentalised; this has a direct impact of floods events. It is necessary to assess which infrastructures are needed and which infrastructures are not. Unneeded infrastructures are fragmenting rivers and, in some cases, can increase flood risk. Lack of vegetation increases water run-off, and thus, damages associated with floods increase.

Municipal Council Medina del Campo

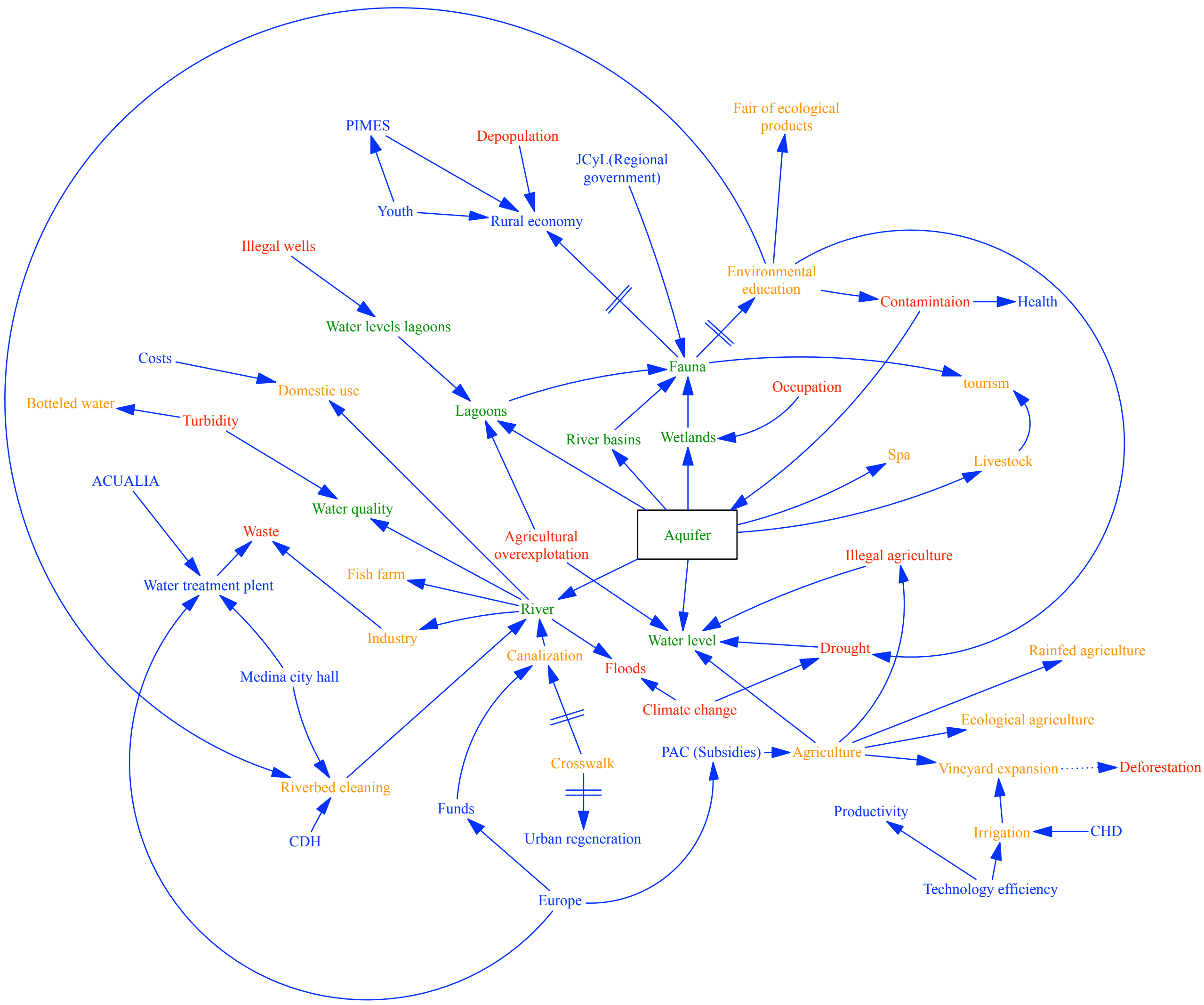

Figure B.6. Individual model Municipal Council Medina del Campo. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Medina del Campo is a town located in the province of Valladolid, Castilla y León autonomous region. Agriculture is one of the main economic sectors. In the past, agriculture was based on cereal farming; now, the cultivation of vineyards is growing. Five years ago, the vineyard occupied 5% of rural land; currently, it occupies 12% of the land. In the future, a more extensive area of the vineyard is expected. In the municipality of Medina is where the vineyards have been planted the most.

The plantation of vineyards not only has changed the landscape of the area but also the type of irrigation system. All vineyard crops are irrigated; many of these crops use efficient irrigation systems such as drip irrigation. However, many farmers manipulate the drip irrigation system to extract more water.

The CHD do not give more permissions to irrigate. For this reason, if a farmer wants to plant vineyards, it has to be in agricultural plots that have already water intakes.

In Medina, the traditional livestock has been sheep. The percentage of cattle is very low in the area. There are some farms of chicken and pigs.

The local government is promoting the expansion of rural tourism focused on vine, horses and ornithology.

The water for urban consumption is extracted from the Adaja river. Currently, the flow of the river is not very high; this has increased the turbidity of water.

In the past, when the phreatic level was higher, groundwater was used for urban purposes. Overexploitation and lack of rain have decreased groundwater levels; this has led to a deterioration of water quality in the region. Water quality is further aggravated by illegal dumping coming from agriculture and livestock. Medina city hall and private companies such as Aqualia have installed water treatment plants.

In Medina del Campo water quality is not perceived as a problem that affects the town.

The Zafardiel river that crosses Medina town was channelized in the 80s to reduce flash flood events. However, due to the lack of rain, the flow of the river has decreased and thus, flash floods events.

The decrease of the phreatic level has negatively affected superficial ecosystems that are connected with the aquifer. Several wetlands and lagoons that were associated with the aquifer are completely dry. The species that use to habit these ecosystems have been established in artificial reservoirs.

Different measures are needed to improve the estate of the aquifer and to reactivate the economy of the area. Increase control of illegal water extractions and campaigns to improve environmental awareness are being carried out. Conservation and restoration measures to improve natural heritage could potentially improve economic sectors such as tourism. Improving the tourism sector could increase the rural economy and reduce this way the depopulation of the area.

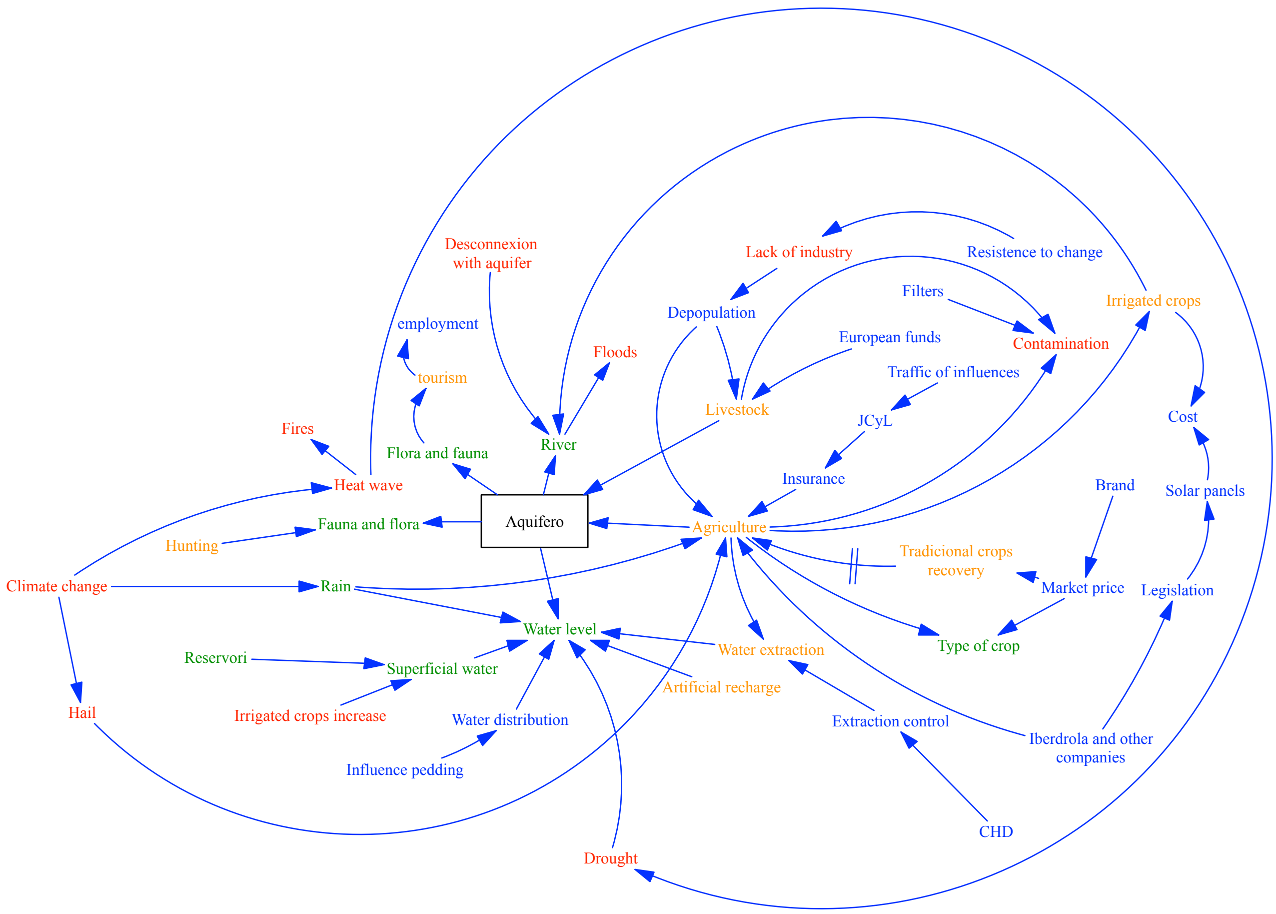

Figure B.7. Individual model Municipal Council Horcajo de las Torres. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The aquifer supports a variety of superficial ecosystems. A decrease in groundwater levels directly affects shallow water. Some of these ecosystems provide a range of ecosystems services such as biodiversity support or tourism.

The water used for irrigation comes from the aquifer. Rainfed agriculture is predominant in the area. However, irrigated crops are expanding because their products have a higher market price. In areas closed to artificial water reservoirs, the water used for agriculture comes from surface waters.

Climate change is increasing drought events. In the past years, an increase in heat waves has been perceived. The lack of rain is decreasing further groundwater levels, causing a disconnection between the aquifer and river. This disconnection affects the flow of the rivers as groundwater is not reaching saturation levels.

Another problem that agriculture faces is the increase of hail events. Climate change is likely to increase the frequency of these events.

Farmers hire insurances against droughts and heal to increase their economic security.

Water quality is being affected by the pollution produced by agriculture and livestock rearing.

The main livelihood in the area is agriculture and in minor scale livestock. There is also some industry associated with agriculture.

The lack of employment is encouraging young people to move to urban areas with more job opportunities. Emigration is causing a problem of depopulation.

Some measures need to be taken to improve the local economy and to improve the state of water resources. Projects are aiming to promote the growth of traditional rainfed crops in the area. However, the type of crops cultivated by farmers are highly influenced by the market price of products. For this reason, there are some projects focused on producing high-quality products able to have a designation of origin (Denominación de Origen). The designation of origin is a regulatory classification system to regulate the products according to their geographical origin and quality. This designation can increase the market price of products.

Increase the efficiency of the irrigation systems could potentially make irrigated agriculture more sustainable. However, the replacement of the irrigation system implies high amounts of economic investment. Some farms are starting to install solar panels. However, this is being limited by legislation and the cost of their installation.

Measures to increase water quality, such as filters or water treatment plants installation are also being implemented in the area.

SEO Birdlife

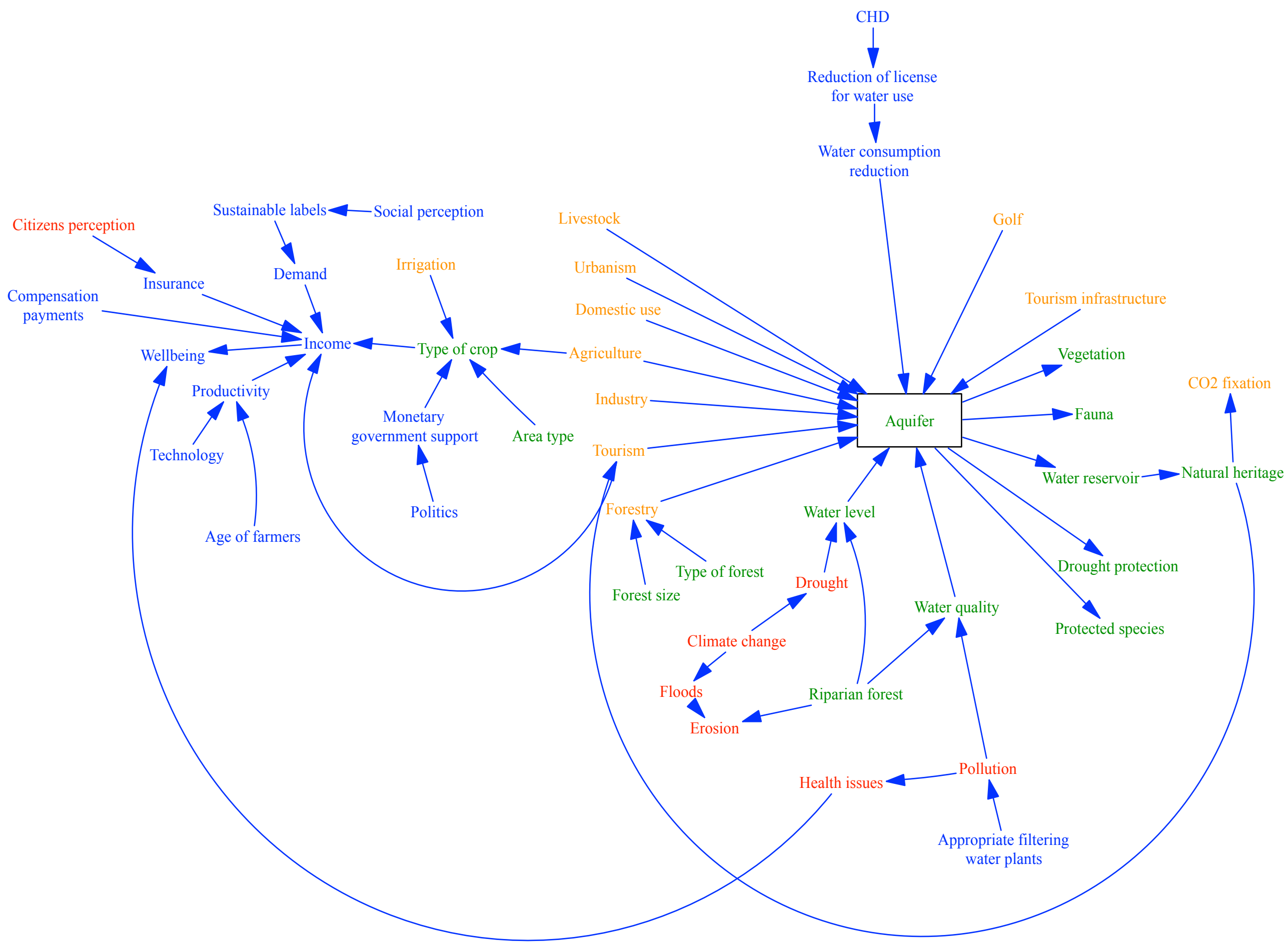

Figure B.8. Individual model SEO Birdlife. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Los Arenales aquifer supports a variety of superficial ecosystems such as riparian forest or wetlands. These ecosystems provide a wide range of ecosystems services such as flora and fauna support, wood provision, CO2 fixation, water filtration or flash flood protection. Many economic activities, such as rural and ornithological tourism are also dependent on the healthy state of these ecosystems.

The aquifer is a water reservoir that acts as an insurance against droughts. The aquifer supplies water for domestic use, industry, livestock rearing and agriculture.

The main economic activity of the region is agriculture. The type of crop grown by farmers depends on the market price of the product. Currently, irrigation crops have a higher market price that rainfed crops. For this reason, irrigation is increasing in the region. Traditional rainfed crops such as cereals are also being irrigated to increase their productivity. The efficiency of irrigation, as well as the productivity of arable lands, can increase if appropriate technology is used. However, it usually implies a high amount of economic investment.

European policies influence the types of cops that are grown with incentives and subsidies.

The productivity of crops is also highly dependent on the area where the crop is cultivated. Rainfed crops need an extensive area to generate income to the farmers.

The overexploitation of the aquifer, along with the increased drought caused by climate change, has decreased dramatically phreatic aquifer levels.

The decrease in the groundwater level has had a direct impact on water quality. A reduction in water quality may affect negatively human health.

In the region, there are some areas at risk of riverine floods. In these areas, a good state of ecosystems such as a riparian forest is essential to reduce the risk associated with floods.

The CHD controls the extractions of water from the aquifer. The CHD is reducing the permits to extract water in order to maintain groundwater levels and rivers flow in a good state.

There is an increasing demand for 'eco' products. In some municipalities, projects to cultivate sustainable crops are being carried out.

Water treatment plants are being installed in areas with a large population to increase water quality.

WWF Spain

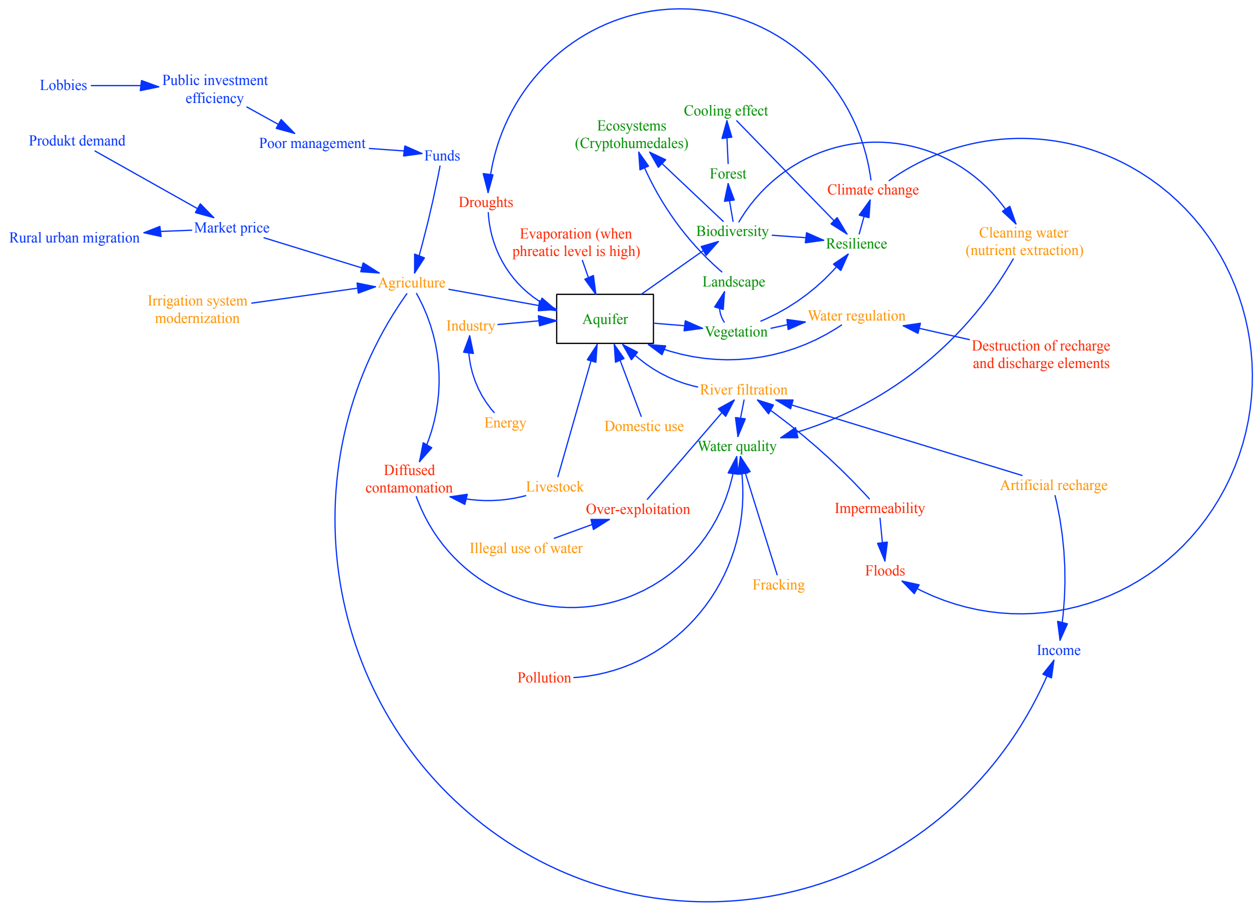

Figure B.9. Individual model WWF Spain. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The landscape and vegetation are highly dependent on groundwater levels. Some regulatory ecosystems such as lagoons, wetlands, rivers or riparian forest are connected with the aquifer. Some of these ecosystems have a regulatory function. For example, forests fix Co2 and reduce heatwave impacts by producing a cooling effect. Other ecosystems filtrate pollutants and organic matter, helping to maintain good water quality.

The destruction of some ecosystems that act as recharge and discharge elements also have a negative influence on the phreatic levels of the aquifer.

The exploitation of superficial water resources has also impacted groundwater levels because water infiltrates through sandy rivers.

Maintaining the structure and function of ecosystems also increases the resilience against water-related hazards such as drought and floods.

In the past, the channelization of urban rivers was very common in Spain. However, it has been proven that the destruction of riverbeds and riparian forest worsen further the flood risk.

The water from the aquifer is used for domestic use, livestock, industry and in the major scale, agriculture. Irrigated agriculture is increasing because irrigation crops are more productive and have a higher market price.

Incentives and subsidies have been created to incentivise rainfed agriculture. Ensure a source of income to farmers is essential to avoid rural migration to cities.

Another measure to reduce the overexploitation of water is the modernisation of the irrigation systems. However, this requires high amounts of economic investment.

The reduction of the phreatic levels has also impacted water quality. Some shallow waters have high concentrations of Nitrates coming from agriculture and livestock.

Municipal Council Valladolid

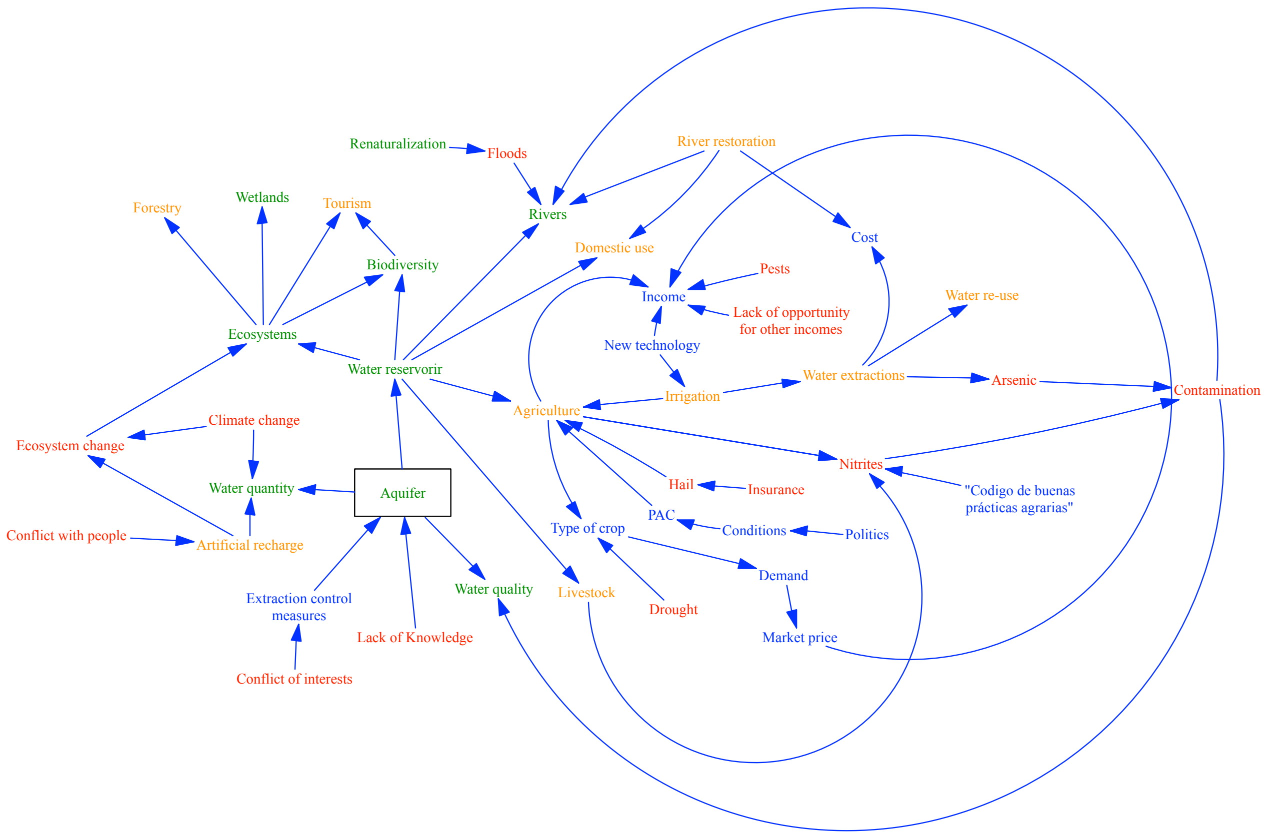

Figure B.10. Individual model Municipal Council Valladolid. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

The aquifer acts as a water reservoir supporting biodiversity and a wide range of superficial ecosystems such as wetlands and riparian forests. Some of these ecosystems support economic activities, such as forestry and rural tourism. However, the overexploitation of the aquifer has decrease groundwater levels in the last years directly affecting superficial ecosystems such as rivers and wetlands. Climate change is increasing the frequency and intensity of drought events, aggravating further this problem. The decrease of the phreatic level has also affected water quality as the arsenic that is naturally present in the soil is more concentrated. Some areas have problems with nitrates coming from agriculture and livestock rearing.

In the area, the main livelihood is agriculture. The type of crop cultivated in the area is highly influenced by European Common Agricultural Policies (CAP). The market prices of agricultural products also affect the type of crops that are cultivated in the region. Currently, irrigation crops are increasing because they have a better market price. Water to irrigate crops is extracted from the aquifer and surface waters. The decrease in aquifer levels has increased the depth of the wells; in turn, the costs of groundwater extractions has also increased. However, reducing water extraction in the area is complicated because the local economy is mainly based on agriculture.

In order to decrease water extractions, modern and efficient irrigation systems are needed. Other measures such as water re-use can positively affect the estate of the aquifer. Artificial recharge could potentially improve the estate of the aquifer is the artificial recharge. However, it is difficult to evaluate the effectiveness of this measure, as there is not enough information on the physical structure of the aquifer. There is no evidence of how artificial recharge will affect superficial ecosystems. The implementation of this measure is limited by the conflict of interests between different stakeholders.

There are regions with fluvial floods risk. River restoration and re-naturalisation measures can potentially help to reduce this problem.

Irrigation Community Adaja River

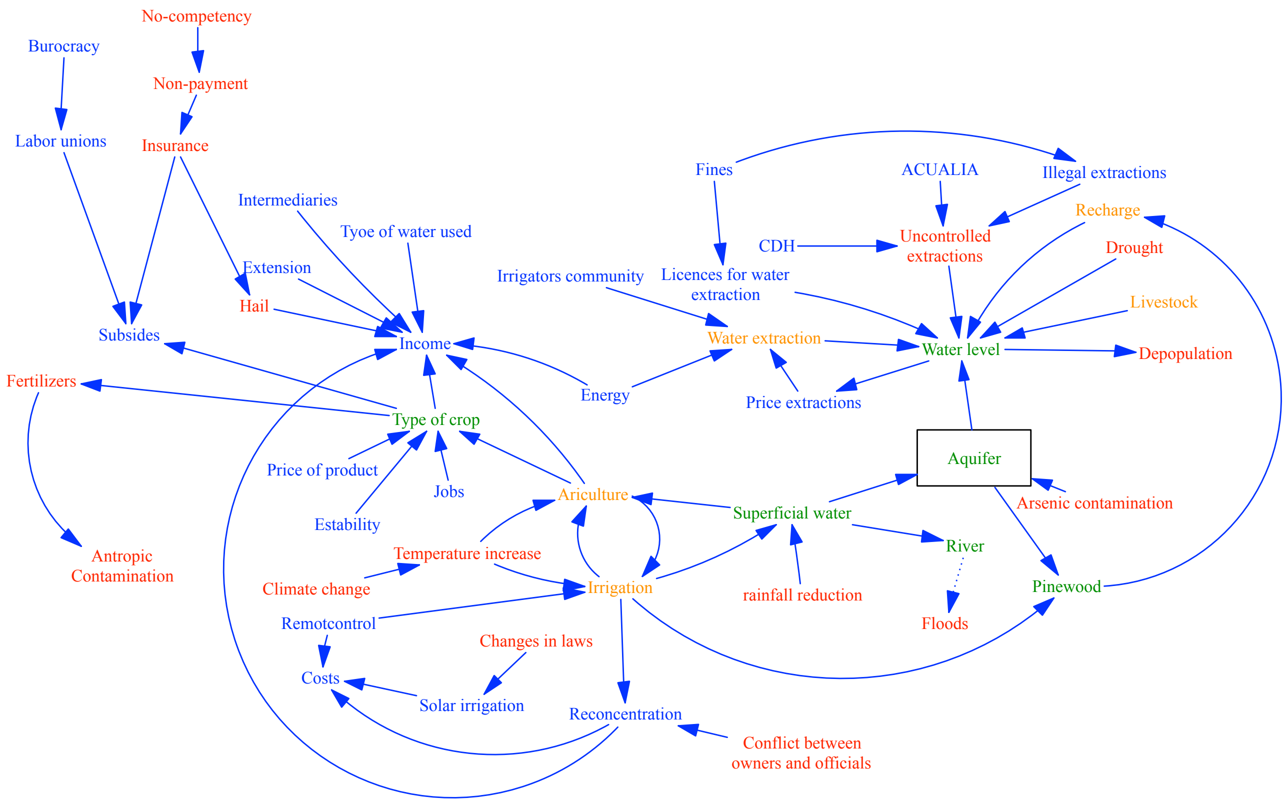

Figure B.11. Individual model Irrigation Community Adaja River. In green, environmental variables; in blue, socio-economic variables; in red, risks and barriers; in orange, activities. Delays have been marked with a delay mark (//).

Water resources from the aquifer have been extracted for agriculture and on a minor scale, for livestock. The aquifer is connected with superficial ecosystems such as rivers and pine forest. Some forests reduce water run-off and retain water into the soil, having a positive impact on natural aquifer recharge.

The amount of water extracted from the aquifer is higher than the amount of water that naturally infiltrates into the aquifer. The increase in water extractions has environmental and economic impacts. On the one hand, it degrades superficial ecosystems that are dependent on the aquifer. For example, if the phreatic level is too low, some rivers dry. Climate change is increasing temperatures and reducing precipitations; therefore, the amount of water that infiltrates into the aquifer is decreasing.

Additionally, the decrease in groundwater levels also has a direct impact on water quality. The arsenic (naturally present the soil) is more concentrated in lower volumes of water. Water quality is also affected by fertilisers.

On the other hand, the rapid depletion of groundwater levels is increasing the cost of extracting water from the aquifer increases when the depth of the wells increases. In some areas where they have access to rivers or artificial water reservoirs, farmers use shallow water to irrigate. The lack of water resources is affecting the agricultural sector by increasing the cost of irrigation and reducing farmers income. In order to make irrigation more sustainable and efficient, some farmers are investing in solar irrigation and remote-control systems. However, the installation of these systems requires an initial economic investment. Additionally, the profitability of investing in renewable energy (i.e. solar panels) is dependent on national laws. The economic insecurity of farmers supports the moving of people to urban areas with more job opportunities. In order to reduce their losses if a hail or drought event occurs, farmers hire insurance. Lack of competition between insurance companies leads to poor services delivery.

The River Basin Authority (Confederación hidrográfica del Duero, CHD) manage water resources from the Duero Basin. One of its function is to control groundwater extractions. However, illegal extractions are not managed or controlled. A system of fines is used to decrease the number of illegal extractions.

The irrigators community is responsible for organising the collective use of superficial and groundwater. The irrigations community aims to distribute irrigation water efficiently and equitably among its members.

Chapter 5:

Assessing the long-term effectiveness of Nature Based Solutions under different climate change scenarios

Assessing the long-term effectiveness of Nature Based Solutions under different climate change scenarios.

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Abstract:

Nature Based Solutions (NBS) have been gaining importance in many European cities for reducing the impacts of floods. However, evidence on their effectiveness in reducing the impacts of droughts in rural areas are scarce. Besides, climate change impacts on NBS are often overlooked in NBS studies and frameworks. The objective of this study is to analyse the long-term effectiveness of different NBS and management strategies in a climate change context. In order to contribute to the literature on NBS for rural areas, the Medina del Campo Ground Water Body system has been analysed. This article highlights the need to engage stakeholders in the model development process to obtain relevant bottom-up information and to organize the collective knowledge of stakeholders in a graphical structure that captures the main dynamics of the system. In this article, we propose a Participative System Dynamics Approach to analyse and understand the impacts of different NBS responding to climate change.

Highlights:

- Nature-Based Solutions are inherently multidimensional.
- Stakeholders knowledge and priorities should have a real (not just superficial) impact on the model.
- The implementation of NBS may not be sufficient to adapt to an intense climate change scenario.
- Climate services is an essential precondition to design adaptable and flexible NBS.

1. Introduction

The exponential population rise and the consequent growing demand for food in the next few decades are pressuring the agricultural sector into a more land-intense food production system (Panagopoulos and Dimitriou, 2020; Peter et al., 2017). The expected increase in agricultural land increases the exploitation of natural resources and threatens further degradation of ecosystems. Besides, rural communities are burdened by multiple socio-economic stressors such as rapid shifts in agriculture markets, low accessibility to services and job opportunities, lower human development, and the overlooking of policymakers (G J S Sonneveld et al., 2018; Masson-Delmotte et al., 2018)

Additionally, expected climatic pressures are likely to influence water supply, food security and agricultural incomes. For instance, higher incidences of extreme precipitation events will increase soil erosion therefore affecting soil productivity and water retention capacity of soils (Malhi et al., 2020). Additionally, climate change compromises several regulatory ecosystem services needed to maintain soil quality and water availability (IPCC, 2018). All these factors make rural communities particularly vulnerable. For this reason, migration patterns to cities are increasing, causing the abandonment of agricultural land and continuous loss of cultural landscapes (Pedroli et al., 2018).

Several governmental bodies have highlighted the need to shift to more sustainable food systems. New policy frameworks and climate adaptation actions are encouraged, which jointly address water and food security, preservation of agricultural and rural landscapes, mitigation of and adaptation to climate change, and conservation of ecosystems and biodiversity. (UN Climate Action Summit, 2019; Global Commission on Adaptation, 2019; UN-REDD Programme, 2008, European Commission, 2015 or European Green Deal, 2019). Among all the proposed strategies, the concept of Nature-Based Solutions (NBS) has occupied the EU political foreground in the past years (IUCN, 2016; Nesshöver et al., 2017;

Somarakis et al., 2019). NBS include all actions and management strategies aimed at maintaining and enhancing ecosystem function while providing social and economic benefits. NBS highlights the role of biodiversity and sustainable use of natural resources to address food security, poverty, water scarcity, climate change, or other societal challenges. NBS are increasingly seen as strategic opportunities to simultaneously address the climate and biodiversity crises. NBS have been applied worldwide to enhance the adaptive capacity of ecosystems and society to climate change while supporting the development of a more sustainable and resilient economy (Eggermont Hilde et al., 2015; Maes and Jacobs, 2017). Despite the growing evidence base for NBS to support climate change mitigation and adaptation, more research is needed to understand the challenges and limitations of NBS in the context of environmental change. The effectiveness of NBS in the future may be reduced by changes in species distribution, habitat fragmentation, biodiversity loss or increased climate variability (Seddon et al., 2020). Besides, the intensity of climate-related risks may increase in the next decade exceeding the capability of NBS to cope with these risks. Additionally, ignoring future climatic conditions or the specific socio-economic context in which NBS are applied could lead to 'maladaptive' practices (Seddon et al., 2019; Turner et al., 2020). For instance, afforestation projects that use fast-growing monocultures to increase carbon sequestration may be more vulnerable to climate change impacts, such as droughts, diseases, pests or fires. This could lead in turn to negative consequences, including stored carbon release into the atmosphere or water scarcity intensification in arid or semi-arid regions (Zhu et al., 2011).

Moreover, even though many biodiversity-based measures have been implemented in rural areas to support the development of sustainable agriculture, the concept of NBS has thus far been urban-centric (Nesshöver et al., 2017). For this reason, most of the indices and evidence developed to assess the long-term effectiveness of NBS are urban-specific. Besides, business models and financial instruments designed to encourage the mainstreaming of NBS into EU policies are also oriented for cities (Faivre et al., 2017).

In this paper, we want to assess the potential of NBS to conserve and enhance water resources management without compromising agricultural productivity. We have adopted a system perspective and a multi-sectoral approach to examine the socio-economic dynamics associated with the implementation of NBS in rural areas. Using the case study of Medina del Campo Groundwater body, located in North-West central Spain, we have developed a system dynamics model, which integrates hydrological, climatic and socio-economic data. System dynamics (SD) is a mathematical modelling technique to mimic and understand the non-linear behaviour of complex systems (Voinov and Bousquet, 2010). SD has been used worldwide to understand a variety of socio-economic problems and to study the effect of various policy interventions (Balali and Viaggi, 2015; Santos et al., 2019). SD depicts stocks, flows, feedback and delays, and other properties to describe and represent the dynamic performance of the simulated system over time (Sterman, 2000). If the initial conditions of a system are known, the conditions in future time can be projected. This way, the simulation of SD models allows the simulation of future scenarios from input data; this is useful to analyse different management measures and strategies. For example, different NBS or risk reduction strategies can be analysed by asking "what-if" questions to determine the state of the system under different conditions.

In this investigation, we use the model to analyse the long-term effectiveness of NBS strategies under different scenarios of climate change. For this study, SD provides several advantages. Firstly, it analyses complex interactions between physical, ecological and socio-economic factors affecting the NBS effectiveness and exposes the causes of different system behaviours. Secondly, climate change data was integrated into the model, allowing the simulation of different NBS strategies and climate scenarios. This has helped to anticipate possible rebound effects or policy resistance as well as to identify suitable NBS strategies to be implemented. Finally, it has facilitated the engagement of stakeholders in the model development process.

We believe that NBS should integrate scientific and local knowledge. Accordingly, NBS should be understood as an inter- and transdisciplinary approach that has a multi-stakeholder engagement at the very heart of NBS implementation (Sonneveld et al., 2018). For this reason, a participatory modelling approach has been used to co-design the SD model. The idea behind the work is that engaging with stakeholders at the very beginning of NBS implementation may increase NBS effectiveness by promoting awareness and motivation of those taking part in the decision-making processes, thus providing a platform for the joint-ownership of results.

2. Research, methods and model development

2.1. Case study

The Medina del Campo Groundwater body (MCGB), located in the Duero River Basin, north west-central Spain, forms the case-study for this region. The MCGB covers an area of 3.700 km^2 bordered by the Duero river to the east and the Sierra de Gredos and the Adaja and Trabancos rivers to the west. The rural development and the regional economy depend strongly on agriculture. Irrigated agriculture represents about 19% of the total agricultural land. Groundwater (GW) is the primary source of irrigation; 95% of total GW extractions are due to irrigation in agriculture. GW overexploitation has resulted in an uncontrolled decrease of the piezometric levels. Measurements show that GW levels have declined up to 20 m in some areas in the last 40 years. Simultaneously, the decrease of groundwater levels has increased their lithologic arsenic concentrations. Besides, excessive agricultural fertilization has spread nitrate pollution in the aquifer and superficial ecosystems.

These issues have caused a chain reaction resulting in severe deterioration of the main GW dependent ecosystems such as wetlands, rivers, riversides and streams. Many rivers and streams experience longer dry periods than before. More frequent and intense have altered the region's landscape and biodiversity.

Climate change impacts are likely to increase climate variability and extreme weather events such as heatwaves and heavy rainfalls (del Río et al., 2005). The continuing environmental degradation and consequent loss of essential ecosystem services may reduce the resilience of the whole socio-ecological system. Additionally, environmental deterioration has increased the vulnerability towards climate-related risks such as drought, floods or heat waves and has impacted livelihoods, human security and well-being.

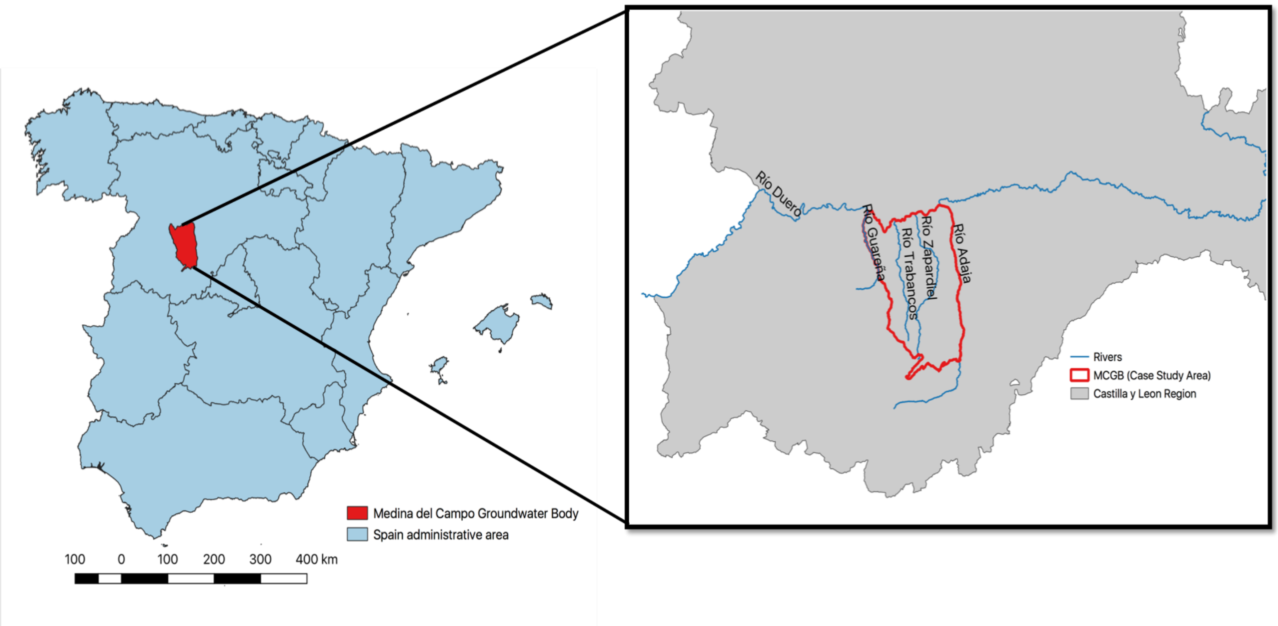

Figure 1. Groundwater body of Medina del Campo.

2.2. System Dynamics modelling approach

The System Dynamic approach was described for the first time in 1950 by Forrester and Cole (J.W.Forrester, 1958). Since then, it has been applied in several disciplines such as economics, environmental studies or social sciences. Several studies have used System Dynamics (SD) to address complex problems such as water scarcity (Stave, 2003; Sušnik et al., 2012), flood risk reduction (Pagano et al., 2019) or health care system management

(Homer and Hirsch, 2006). The theoretical concepts of system dynamics are grounded in systems theory, information science, organisational theory, control theory, tactical decision-making, cybernetics and military games. SD is a mathematical method that facilitates the description of systems behaviour by analysing the feedback structure of complex systems. The central aspect of this approach is the observation of the relationships between the different elements of the system (Sterman, 2000). Understanding the structure of these relationships can help to prevent undesirable consequences arising from various policies and actions. An essential premise in SD is that dynamic behaviour is a consequence of the system structure. Several interactions linked by feedback loops compose systems. The combination of feedback loops with delays and non-linear relationships produce a wide variety of behavioural characteristics.

Mathematically, the SD approach is based on linked first-order differential (or integral) equations that are represented in the simulation model in the form of stocks and flows. Stocks are accumulations within the system (i.e. amount of groundwater in the aquifer) and are represented by rectangles in the model. They represent the (observed) state of the system that can be changed by flows. Flows may be inflow to a stock or an outflow from stock. They are represented by pipes with valves controlling the rate of flow. In this study, the development of a simulation system dynamic model has provided several advantages. Firstly, it has allowed the integration of quantitative and qualitative data from different sources and spatial-temporal scales. Secondly, although SD is not an optimal tool to exactly predict future system states, it is an effective method to indicate how different policy interventions may alter the tendency to move towards any future state by simulating “what-if” scenarios (Simonovic, 2002). It was possible to observe how the implementation of different NBS strategies under different input conditions (i.e. climate change scenario) affected the behaviour of the system as a whole. Finally, the conceptual representation of the model in a graphical structure facilitated the engagement of stakeholders in the co-design of the SD model allowing the integration of knowledge of end-users and stakeholders within the model.

In this study, the development of the computer-simulated model started from a participatory modelling phase. Stakeholders input was used to develop a Qualitative System Dynamics Model (QSDM) representing key variables and relationships within the system. The qualitative model developed with stakeholders was used to develop the dynamic hypotheses before the quantitative stock-flow model was developed. The methodological process adopted is schematized in the following Fig. 2.

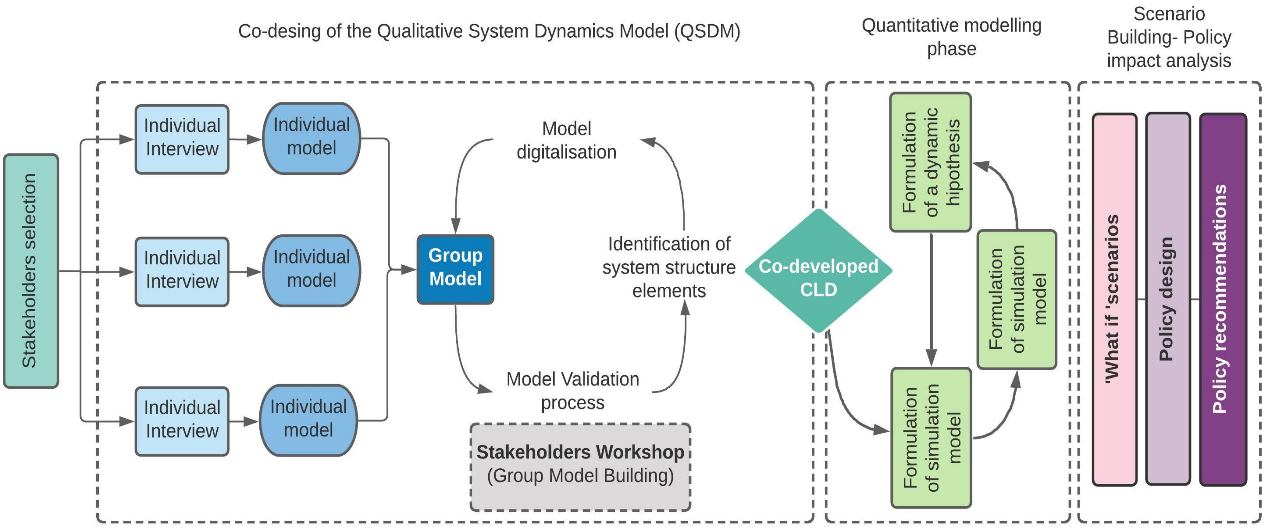

Figure 2.Overview of the modelling framework carried out in Medina del Campo Groundwater Body.

2.2.1. Participatory Modelling approach

The implementation of participatory modelling techniques allows for the integration of end-users and stakeholder's knowledge with scientific analysis, e.g. with development and application of scientific models. It has proven to be a suitable methodology to engage non-scientists with scientists as it introduces a new perspective for both the modeller and the stakeholder (Reed et al., 2009). Stakeholder's involvement from an early stage of the process increases their sense of ownership in the model. Furthermore, it enables participants to have a better understanding of the model, increasing their confidence in the outputs provided (van den Belt, 2004). Participatory modelling allowed us to obtain data coming from formal and non-formal sources as well as the analysis of multiple decision drivers and their interactions. Moreover, we were able to identify critical feedbacks and leverage points in order to support the process of NBS implementation (Voinov and Bousquet, 2010).

During the exercise, stakeholders identified essential factors and issues that were relevant for model the system. Additionally, modelling components needed to assess the long-term effectiveness of NBS were identified. The identification was carried out after analysing the causal connections and influences involving the multiple dimensions of NBS, ranging from economic, social and environmental factors.

The participatory modelling exercise was divided into two phases (see Fig.2). Firstly, individual semi-structured interviews were carried out along with conceptual mapping techniques. In each interview, individual conceptual models were created in a co-design process. The interviews used a semi-structured format designed to avoid straightforward questions and answers, maintaining an engaging debate among the stakeholder and the interviewer. A syntactic rule was used to differentiate the social, economic and environmental elements in order to facilitate the development of the conceptual model. The objective of the activity was to build a visual representation of stakeholder's perception of the system as well as identify the elements needed to understand the socio-ecological system and the barriers and issues associated with NBS implementation.

Secondly, the information collected in all individual interviews was combined to develop a group model (GM). This GM was validated in a group model exercise (GMB) which was carried out in a two-hour long workshop. The GMB exercise was used to increase the communication and to facilitate the consensus agreement process and the shared vision among stakeholders. During the validation process, the conceptual model was presented and discussed with stakeholders in a one-day workshop. In contrast to the individual interview, the system was analysed from a collective perspective.

The participatory modelling process resulted in the development of a Qualitative System Dynamics Model (QSDM) (see figure 3). The QSDM was used as a graphical tool to represent the feedback structure responsible for the cause of dynamics of the Medina del Campo system. The QSDM set the basis for the quantitative system dynamics model used to analyse the added value of nature-based solutions as well as their long-term effectiveness. It was used to define the model boundary as well as the elements that should be included in the model (elements that influence the system's behaviour).

For a more detailed description of the participatory modelling process carried out in Medina del Campo as well as for the qualitative analysis of the QSDM see Gomez et al., 2020.

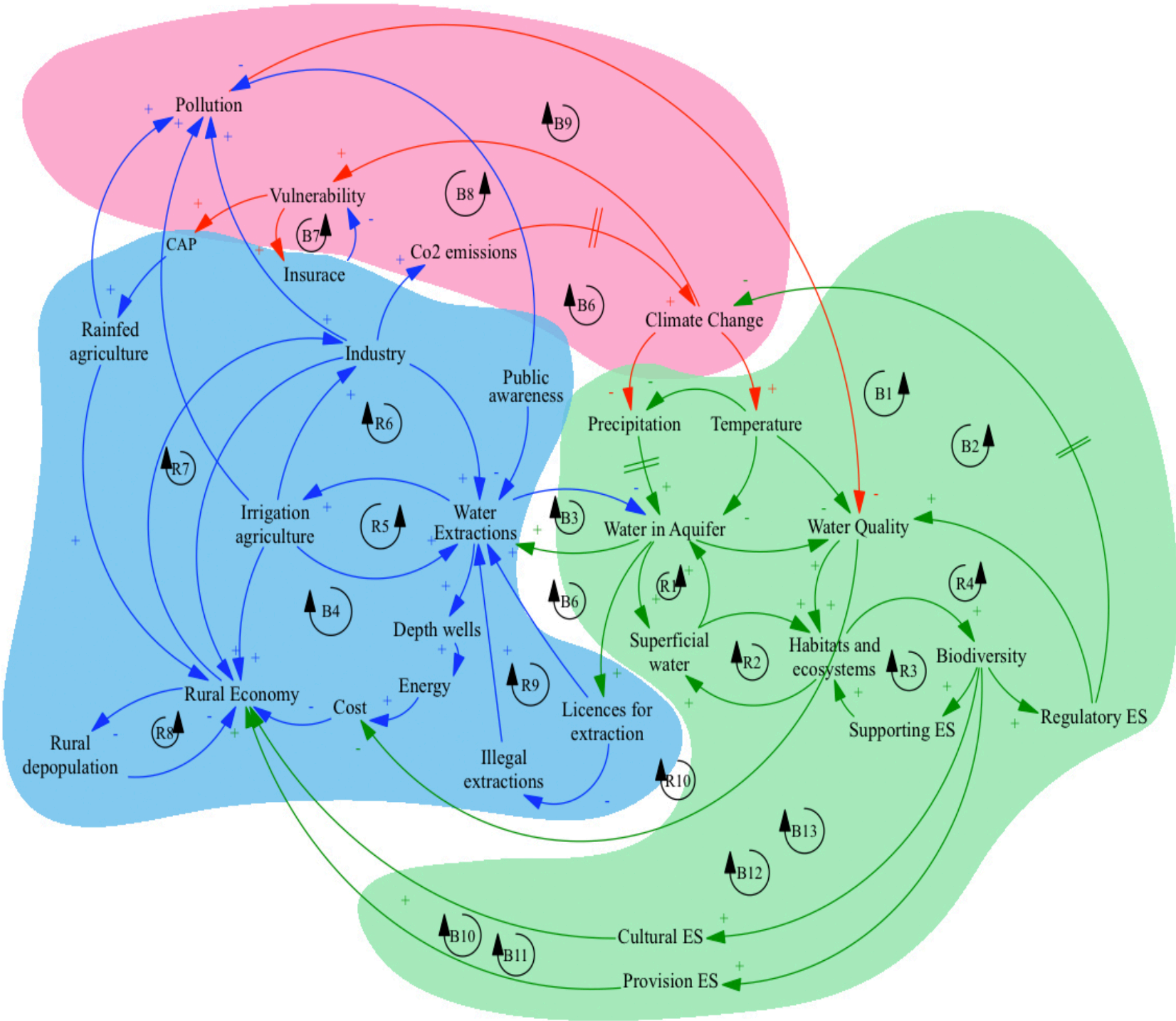

Figure 3. Qualitative System Dynamics Model co-developed with stakeholders. Highlighted in green the environmental variables and relationships, in blue the socio-economic elements are represented and in red the risks

2.2.3 Quantitative modelling phase

QSDMs do not distinguish between stocks and flows, meaning that the accumulation of resources in a system, as well as the rates of change that alter those resources, are not visible. A stock is a measurable accumulation of physical or non-physical resources (e.g. amount of water in aquifer or level of information/citizens awareness). It characterises the state of relevant variables in the system, storing the memory of their state at previous time steps, thus enabling description of their evolution. Flows affect the state of stocks via inflows and outflows, thus supporting interconnections among the variables within a system. For example, the change of the state of aquifer level depends on rain (inflow) or water extractions (outflow). Mathematically, stocks integrate their net flows; the net flows are the derivative of stocks. Identifying and modelling the behaviour of stocks is crucial to analyse the dynamic evolution of the essential variables and potential mutual influences (Sterman, 2000).

Given the interdisciplinary and complexity of NBS, a modular structure was adopted to quantify the SD model. Different modules coming from different disciplines were linked together by mutual feedbacks.

2.3. Description of the model

The system dynamics model represented in Fig 4 was developed using VENSIM [30] software. The Qualitative System Dynamics Model co-developed with stakeholders was used to define the overall structure of the model (see Fig 3). The grounds behind the individual sub-models and their fundamental dynamics are addressed in the manuscript. At the same time, the full list of equations and parameter values are included in Appendix A of the Supplementary Material.

The grey variables in the model describe the principal connections between different sub-models. These variables help to identify relationships and influences that are often difficult to recognize. The polarity of the relationship was represented by a green arrow (positive polarity) or red arrow (negative polarity). The polarity is used to indicate how the dependent variable changes when the independent variable changes.

The model is run for 100 years allowing the long-term assessment of NBS effectiveness under different projected climate change scenarios. The time step of the simulation is one month. The model assumes that water extractions are constant over the year. The main dynamic assumptions of each sub-model are summarised in the following:

2.3.1. Environmental sub-model

The environmental sub-model assumes that the water is stored in three different storage levels, soil water, groundwater and superficial ecosystems (Trabancos river, Guareña river, Adaja river, Zapardiel river and wetlands). The water entering into the soil moisture layer depends on the precipitation fraction that infiltrates into the soil (infiltration coefficient), the monthly retention of rainfall in the foliage (interception), and the fraction of irrigation water that returns into the system (irrigation return).

The infiltration coefficient is dependent on the slope, the vegetation cover and the basic soil infiltration (fc). The fc is a characteristic of the soil that corresponds to the permeability of the soil when is saturated. The model assumes that the lower the slope of the land and the more prominent the vegetation cover, the higher the percentage of rainwater which infiltrates. Soil conservation (SC) measures such as mulching, crop cover or no-till practices have proven to increase water infiltration up to 40%. The model assumes that increasing infiltration by a certain percentage (depending on the conservation measure), allows the estimation of the impact of SC in the system.

The vegetation leaves retain a portion of the rain, preventing water from reaching the soil. The interception is a function of the foliage coefficient which differs depending on the type of vegetation cover. For example, a forest may intercept 40% of rain while crops such as alfalfa can intercept between a range of 10 and 35% of the total rainfall.

The irrigation return is defined by the irrigation efficiency (percentage of irrigation returning) determined by the type of irrigation system used in agriculture—highly efficient irrigation methods such as drip irrigation use virtually 90% of the irrigated water. The model assumes that 10% of the remaining water constitutes the irrigation return into the system. This means that the higher the irrigation efficiency, the lower the irrigation return.

The monthly rain that is not retained by the vegetation foliage or infiltrated into the soil flows away in the form of surface run-off to the superficial ecosystems (in the model, wetlands and rivers).

The amount of water stored in the soil level (stock) depends on the amount of water that infiltrates (explained above) and the amount of water that evaporates and percolates into the aquifer. Both processes depend on the field capacity (maximum accumulation of water that an unsaturated soil can have) and the wilting point (minimum humidity to maintain vegetation). The model assumes that when the water stored in the soil equals the wilting point, the evapotranspiration stops, as it assumes that the plants close their stomas.

The percolation is described in the model as a function of saturation. The maximum percolation capacity occurs when the soil reaches its field capacity (100% saturated).

The total recharge (groundwater inflow) is determined by the amount of water that percolates, the underground run-off coming from other groundwater bodies (groundwater lateral movement in the model) and water drainage from superficial ecosystems (Trabanco and Zapardiel river). The model assumes that the groundwater lateral movement is constant over the year. It also implies that rivers drainage into the aquifer is a constant percentage of the monthly river flow.

The groundwater extractions and the discharge to superficial ecosystems constitute the outflow of the groundwater level. GW extractions include legal and illegal extractions. Legal extractions are regulated by the irrigation demand and the maximum volume of water allowed for extractions. Illegal extractions are a function of environmental awareness (defined in the socio-economic sub-model). An increase of environmental awareness results in a reduction of the illegal extractions.

The decrease of the piezometric level (level to which water is confined in an aquifer) occurs when the total recharge is lower than the GW extractions. If the piezometric level is less than a certain level, the surface ecosystems disconnect from the aquifer. On the contrary, if the piezometric level reaches a certain threshold, water flows to the surface ecosystems.

The superficial ecosystems are represented in the model with five stocks, the four most important rivers in the region (Adaja, Trabancos, Guareña and Zapardiel) and one stock representing the currently-dried wetlands.

The model assumes that the only waters that flow into these levels are the surface run-off and the groundwater discharge into superficial ecosystems. GW discharge depends on the piezometric level and the height at which the ecosystem is in the region. The total run-off entering into each of the ecosystems depends on the river/wetland catchment area. The model includes an additional inflow variable for Trabancos and Zapardiel river. This variable can be activated to simulate an artificial recharge of the aquifer through surface techniques. The model assumes that when the artificial recharge variable is activated an additional 0.77Hm3 of water will flow into the Zapardiel river and 0.6 Hm3 will frow into Trabancos. Evapotranspiration and drainage water into the aquifer are the only variables considered to calculate the outflow of water.

2.3.1.1. Climate data integrated in the environmental sub-model

The climate component has been highly relevant for this study as the intension is to analyse the performance of NBS strategies under different climate change scenarios. Therefore, climate projection information for three Representative Concentration Pathways scenarios (RCP 2.6, RCP 4.5 and RCP 8.5) has been integrated into the SD model. Specifically, monthly precipitation and monthly mean temperature were obtained from the EURO-CORDEX ensemble.

Climate simulations for past-time periods (hindcasts) from different models were compared with observational data. The comparison was made plotting both time series (for precipitation and temperature) and comparing the mean and the standard deviation. The objective was to select the model that most accurately represented the real-world climate system of MCGWB. Finally, the climate projections data used was generated by the driving model MOHC-HadGEM2-ES and downscaled with the Regional climate model (RCM), KNMI-RACMO22E. See supplementary material for more detailed information about the climate models that were compared.

After the appropriate model was selected, time series of precipitation and evapotranspiration (time-period 2019-2100) were integrated into the SD model.

Potential Evapotranspiration was calculated following the equation developed by Blaney & Criddle (ONU, 1972) and expressed in eq.1.

$$ETP = (8.10 + 0.46T) \times Ps. \quad (1)$$

Where ETP is potential evapotranspiration in units mm/month; T is mean monthly temperature (^{0}C/month), and Ps corresponds to the percentage of hours of monthly sunlight compared with the annual mean of sunlight.

Certain parameters of climate models carry considerable uncertainty depending on the climate model used. Thus, it is difficult to determine the actual effect that they have on the final results. It is necessary to use multi-model ensemble simulations to show the uncertainty range produced by climate models.

The main aim of the SD model presented in this article is to provide a valid description of the essential system structure and the resulting system dynamics; it does not intend to provide detailed quantitative results. For this reason, multi-model ensemble simulations were not carried out in all simulation scenarios.

However, a climate model-ensemble was used for the two climate variables (precipitation and evapotranspiration) in order to show the uncertainty range produced by climate models. This approach was also used for the variable “piezometric level” in the BAU scenario. Piezometric level was considered as the main indicator to describe the state of the aquifer. For this reason, a multi-model ensemble was used in this variable to highlight the need to consider climate uncertainty ranges in NBS decision-making.

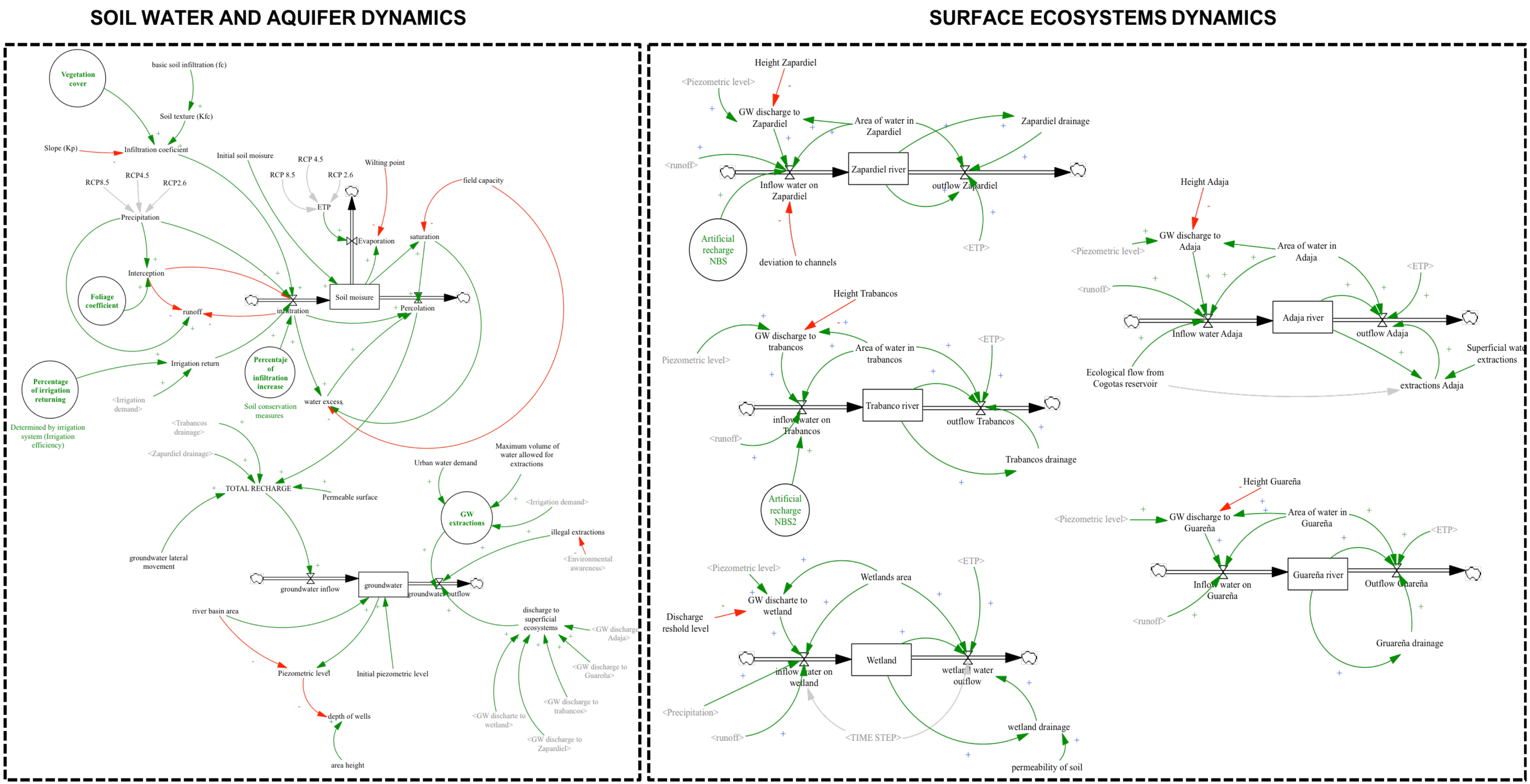

Figure 4. Environmental sub-model describing soil water and aquifer dynamics as well as surface ecosystems dynamics. Arrows in green representing positive polarity; red arrows representing negative polarity. Stocks are indicated with rectangular boxes. Green circles represent potential areas of intervention (NBS).

2.3.2. Socio-economic sub-model

This sub-model contains five state variables, environmental quality, tourists, new jobs and economic opportunities, infrastructure and services and rural population. These represent qualitative variables which are relative and dimensionless (ranging from 0 to 3) in order to understand the qualitative dynamics of this sub-system. The quality of the environment changes by natural regeneration and degradation of the environment. Natural regeneration increases when the quality of superficial ecosystems increases. The model assumes that the amount of water determines the level of ecosystems quality. However, it has been considered that the environment needs time to regenerate; for this reason, the model includes a delay in the regeneration rate. Environmental degradation occurs due to the environmental stress caused mainly by the increase of tourism in the area and by the rural population. The number of tourists decreases by tourist loss and increases by tourist gain. Tourist gain depends on the attractiveness of the area. Attractiveness is a function of environmental quality and advertisement (level of promotion to attract new tourists).

The model assumes that the higher the environmental quality and advertisement, the higher the gain in tourists. A delay function was included in the tourist gain rate to indicate a postponed effect from the increase in environmental quality to the increase in tourists.

The increase in tourists has a positive effect on the creation of new jobs and economic opportunities which, simultaneously, has a positive effect on income (money received by locals). The income is also produced with the use of the water extracted from the aquifer. Therefore, the more water is withdrawn from the aquifer, the higher the income. Income has a positive effect on profit which is a function of income, cost of investing in new infrastructures and cost of groundwater extractions—the cost of extractions increases as the depth of the wells increases (when the piezometric level declines).

It is considered that the economy of the area is a critical aspect to maintain the rural population. For this reason, the model assumes that an increase in profit leads to an increase in the rural population. The increase in services and infrastructure also positively affects the increase in the rural population. Environmental awareness can regulate the environmental stress caused by tourists and the local population. However, it is assumed that this regulation requires a specific time to produce effects on environmental stress. The model simulates this phenomenon using a delay function. The level of environmental awareness is defined by the level of information and citizens engagement as well as by the level of the economic growth.

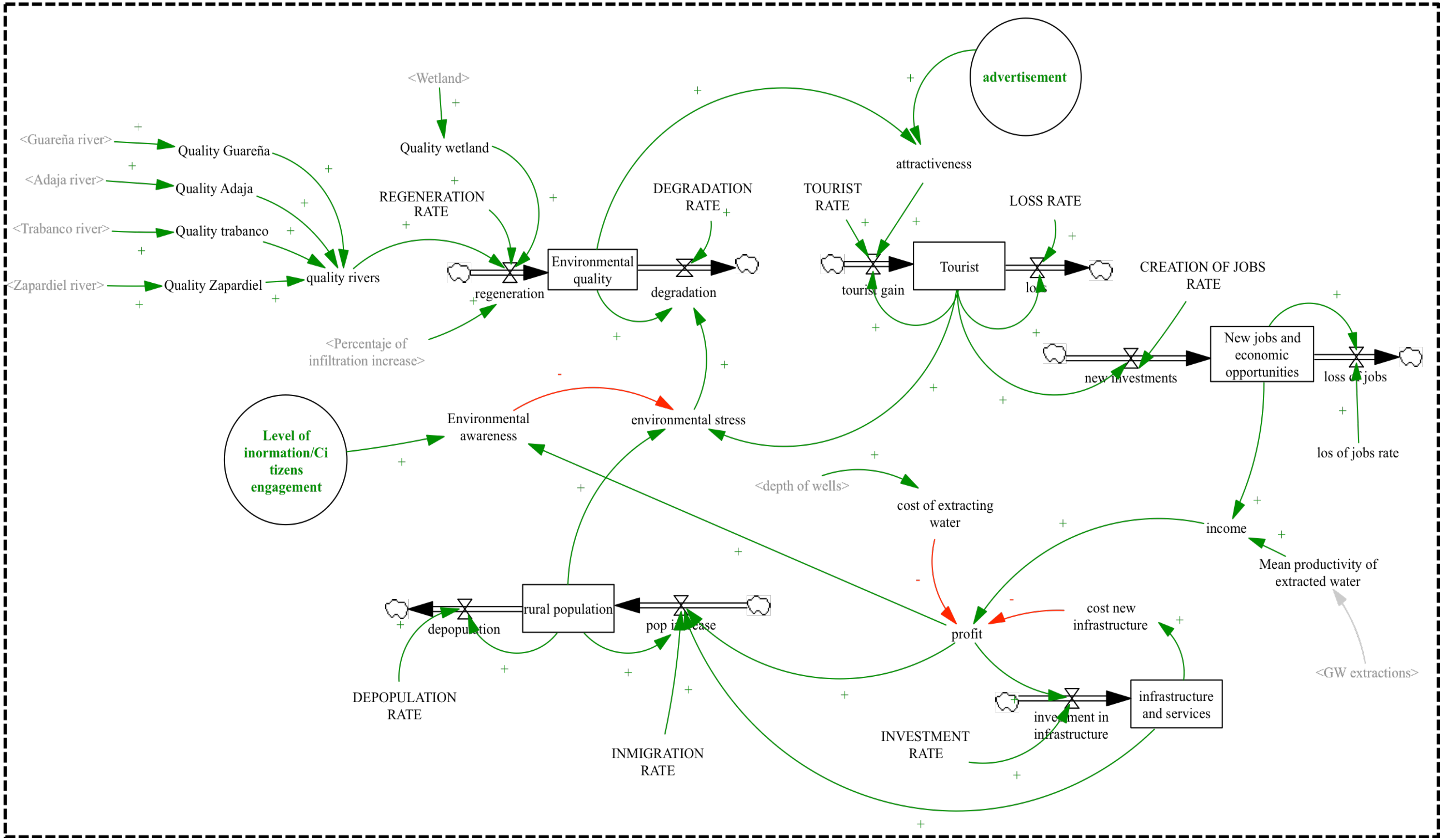

Figure 5.Socio-economic sub-model describing soil water and aquifer dynamics as well as surface ecosystems dynamics. Arrows in green representing positive polarity; red arrows representing negative polarity. Stocks are indicated with rectangular boxes. Green circles are potential areas of intervention.

2.3.3. Agricultural demand sub-model

This section of the model focuses on calculating the demand for irrigation water. The calculation was made using publicly-available official data from the regional government. On the one hand, the area of the main irrigation crops has been used to calculate the percentage of area occupied by the main irrigation crops. On the other hand, the average volume of irrigation water applied to the different crops was used. The model assumes that this volume is maintained constant over the year.

To facilitate the simulation process, the irrigated crops were grouped into five categories, cereals, industrial crops, forage crops, vegetables and other irrigation crops (those less present in the area).

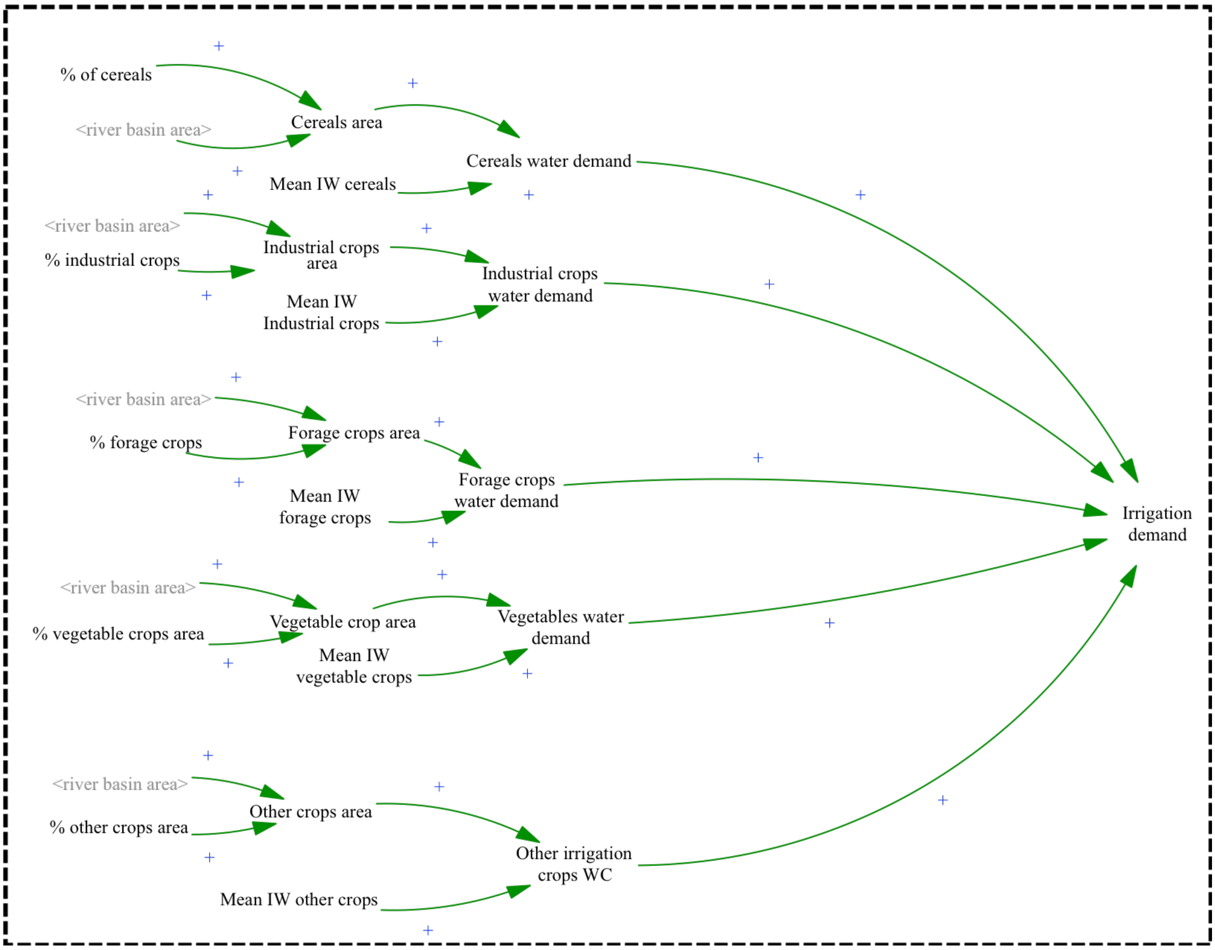

Figure 6. Irrigation demand sub-model. Green arrows represent positive polarity

2.4. Scenario building- Dynamic hypothesis

Five scenarios have been simulated to 'test' the effectiveness of diverse NBS and water resources management possibilities (summarised in table 1). In order to assess the long-term performance of these strategies under different climate change conditions, each management scenario has been simulated for three RCPs (RCP2.6, RCP4.5 and RCP 8.5). The initial dynamic hypothesis is that implementing NBS in the MCGW may provide benefits at both levels, environmental and socio-economic. Climate change may have impacts on ecosystems function, thus, compromising NBS capability to produce benefits (co-benefits). Therefore, NBS multifunctionality may be lower in scenarios where climate change is more intense (i.e. RCP4.5 and RCP8.5). Consequently, the long-term effectiveness of NBS may be compromised in a climate change context.

Table 1. Scenarios simulated under different management/NBS strategies and RCP scenarios

Management-NBS strategies / Climate scenarios	RCP2.6	RCP 4.5	RCP 8.5
BAU	• Extractions 21.7Hm3/month • No measure implemented • Tested in soils with medium Permeability	• Extractions 21.7Hm3/month • No measure implemented • Tested in soils with medium Permeability	• Extractions 21.7Hm3/month • No measure implemented • Tested in soils with medium Permeability
Moderate reductions of GW extractions	• Reduction of 20% of extractions (17.36Hm3/month) • Medium Permeability soils	• Reduction of 20% of extractions (17.36Hm3/month) • Medium Permeability soils	• Reduction of 20% of extractions (17.36Hm3/month) • Medium Permeability soils
NBS strategies implemented	• Soil conservation practices (increase of infiltration 20% • Vegetation Cover increase • Artificial recharge	• Soil conservation practices (increase of infiltration 20% • Vegetation Cover increase • Artificial recharge	• Soil conservation practices (increase of infiltration 20% • Vegetation Cover increase • Artificial recharge
NBS and high level of citizens awareness	• NBS implemented • Measures to increase the level of citizens awareness (i.e. stakeholders engagement)	• NBS implemented • Measures to increase the level of citizens awareness (i.e. stakeholders engagement)	• NBS implemented • Measures to increase the level of citizens awareness (i.e. stakeholders engagement)
NBS+ Extractions reduction	• Soil conservation practices • Vegetation Cover increase • Artificial recharge • Extractions reduction 20%	• Soil conservation practices • Vegetation Cover increase • Artificial recharge • Extractions reduction 20%	• Soil conservation practices • Vegetation Cover increase • Artificial recharge • Extractions reduction 20%

3. Results

The following section presents the main results and research findings. The analysis of the dynamic behaviour of four state variables (piezometric level, environmental quality, new jobs and green opportunities and rural population) has been used to analyse the long-term performance of NBS in the three sustainability dimensions.

Figure 7a, 7b and 7c show the dynamic behaviour of the piezometric level under five different management and climate change scenarios. The results show a continuous decrease in the aquifer levels for the BAU scenario (no-measures). The decrease shown in RCP 8.5 (fig. 7c) is more pronounced than scenario RCP2.6 (Fig. 7a). Although reducing GW withdrawals by 20% diminishes the tendency of aquifer levels to decrease, it is not enough to change the trend, and the levels continue to decrease for the three RCPs. The results show an improvement in the levels of the aquifer for RCP2.6. Contrarily, this improvement cannot be observed for the scenarios of RCP 4.5 and 8.5, where the levels continue to decrease. This decrease is slightly less significant than in scenarios where no NBS are applied.

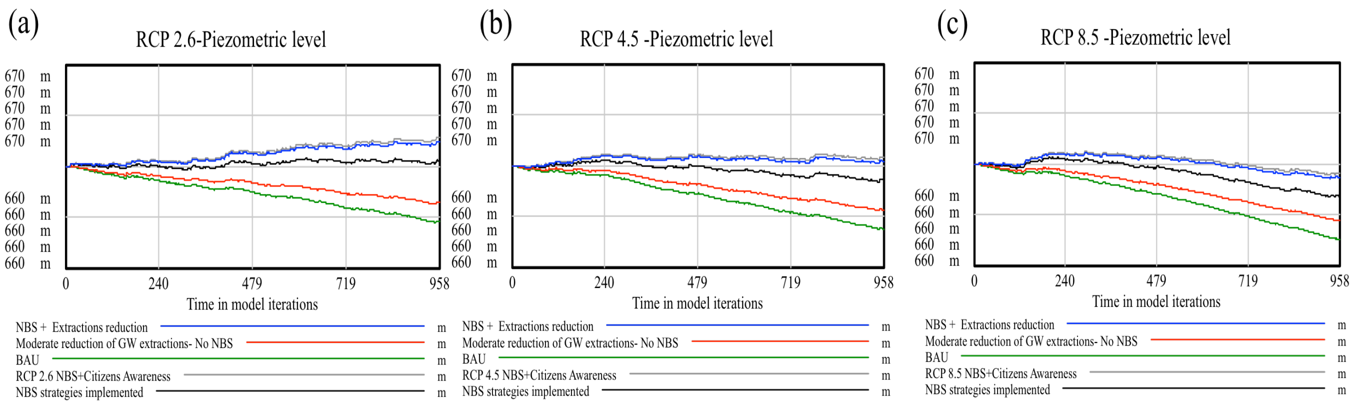

Figure 7. Dynamic behaviour of Piezometric level state variable under five different management scenarios and RCPs.

The most notable improvement of the aquifer level is shown when simultaneously applying NBS and groundwater extractions control. On the one hand, NBS measures focused on improving soils quality, increase the total recharge of the aquifer. On the other hand, measures such as limiting the maximum volume of GW extractions or changing the crop-type to other less-demanding crops, reduce total GW extractions. Although an increase of the piezometric level is observed for RCP2.6, the increase is not enough to reach the basin of the superficial ecosystems preventing the aquifer-superficial ecosystems reconnection.

This aquifer level improvement is maintained for the RCP4.5 scenario. However, the results show that in the long-term, these measures would not be sufficient in RCP 8.5, where more investments in adaptation measures will be required.

No significant difference is observed in aquifer levels in a scenario where NBS are apply along with measures focused on increasing environmental awareness.

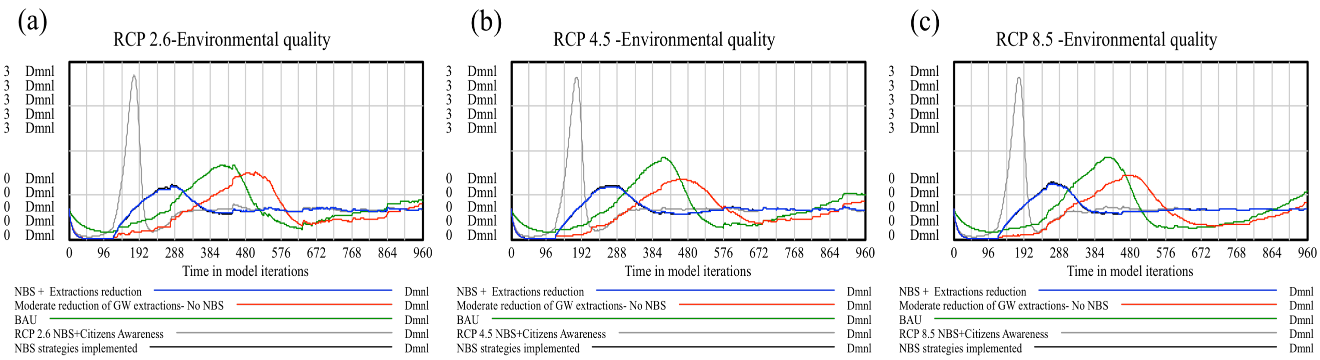

Figure 8. Environmental quality dynamic behaviour under different management scenarios and RCPs. The results are dimensionless and relative in a scale ranged from 0 to 3. Being 3 the higher level of environmental quality.

Figure 8 a, b and c show the dynamic behaviour or environmental quality (EQ) state variable under different management scenarios and for three RCPs. The results show no significant difference between the different RCP scenarios. The influence of several balancing loops present in the socio-economic sub-model strongly determines the behaviour of this variable. For example, the scenario in which NBS is combined with measures to increase environmental awareness shows a significant increase in EQ in the area. However, even though the initial condition describes a strong level of citizen engagement, environmental quality reduces drastically due to the pressure suffered by the increase in tourists and rural population. As the environmental quality diminishes, so does the environmental pressure produced by tourists, since the area is less attractive.

Combining NBS with extractions reduction produces an increase in environmental quality. However, this increase is less pronounced than in the aforementioned scenario (NBS and citizens awareness). Additionally, the positive effect of NBS in EQ requires more time to become visible. The initial increase in EQ produced by these measures (NBS+GW reduction) follows an EQ decrease. Reducing GW extractions may have a negative effect on the economic profit in the area as it is highly dependent on irrigated agriculture. A decrease in profit leads to a decrease in environmental awareness and thus, on EQ.

The same pattern of behaviour is followed by BAU and NBS-NCA (NBS without citizens awareness) scenarios.

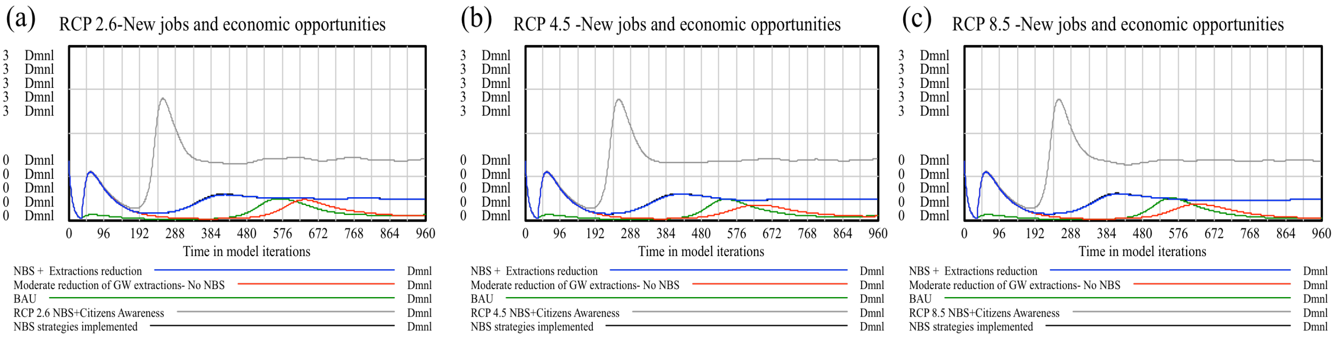

Figure 9. New jobs and economic opportunities dynamic behaviour under different management and RCP scenarios. The results are dimensionless and relative in a scale ranged from 0 to 3. Being 3 the higher level of new jobs and economic opportunities achieved.

Figure 9 shows the dynamic behaviour of new jobs and economic opportunities state variable (NJEO). The model results do not provide evidence showing a real influence of climate change on the creation of new NJEO. As observed in the graphs presented in figure 8, there are no variations in behaviour among the three RCPs. However, different patterns can be observed within the management scenarios. The implementation of NBS along with measures focused on improving citizen awareness (i.e. stakeholder's engagement, increasing level of information) manifests to be the most effective strategy to achieve higher levels of NJEO. Although implementing NBS along with extraction control measures produces an initial increase of this state variable, a rapid decrease is produced in the following years. Therefore, it indicates a positive causal connection between environmental quality and the creation of new jobs and economic opportunities. The same pattern of behaviour is observed in the scenario where NBS are applied without any additional measures; thus, indicating a general positive effect of NBS on NJEO.

BAU and GW extractions reductions scenarios do not show any significant improvement in NJEO levels.

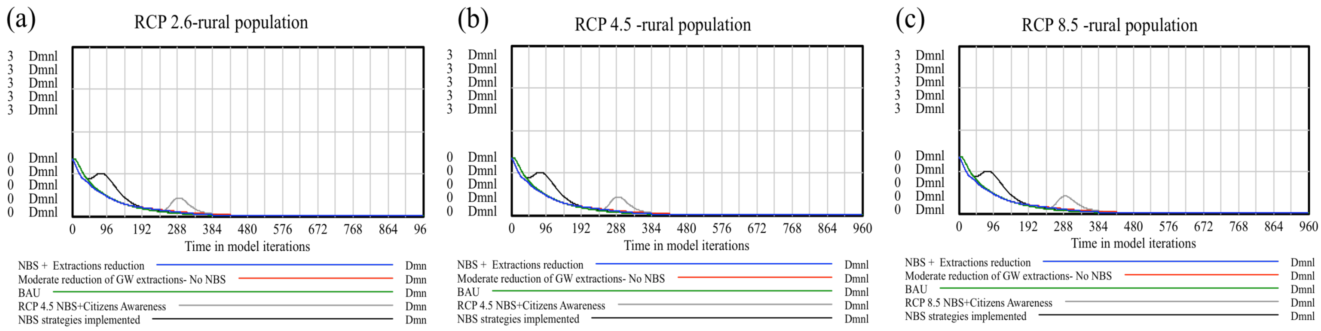

Figure 10. Rural population state variable under different management and RCP scenarios. The results are dimensionless and relative in a scale ranged from 0 to 3. Being 3 the higher level of rural population achieved.

The results of the model simulation show a decrease of rural population on all management and climate change scenarios (fig. 10). Scenarios where NBS are present (NBS and NBS and citizens awareness) show two peaks of increase followed by a rapid decline of rural population levels. The influence of NBS on environmental quality and the economy of the area (NJEO) is not sufficient to maintain the rural population.

Additional simulations were carried out to assess, for example, the impact of different soil conservation strategies in the system or the effect of shifting to a more efficient irrigation system (these results can be found in annex 2 of the supplementary material).

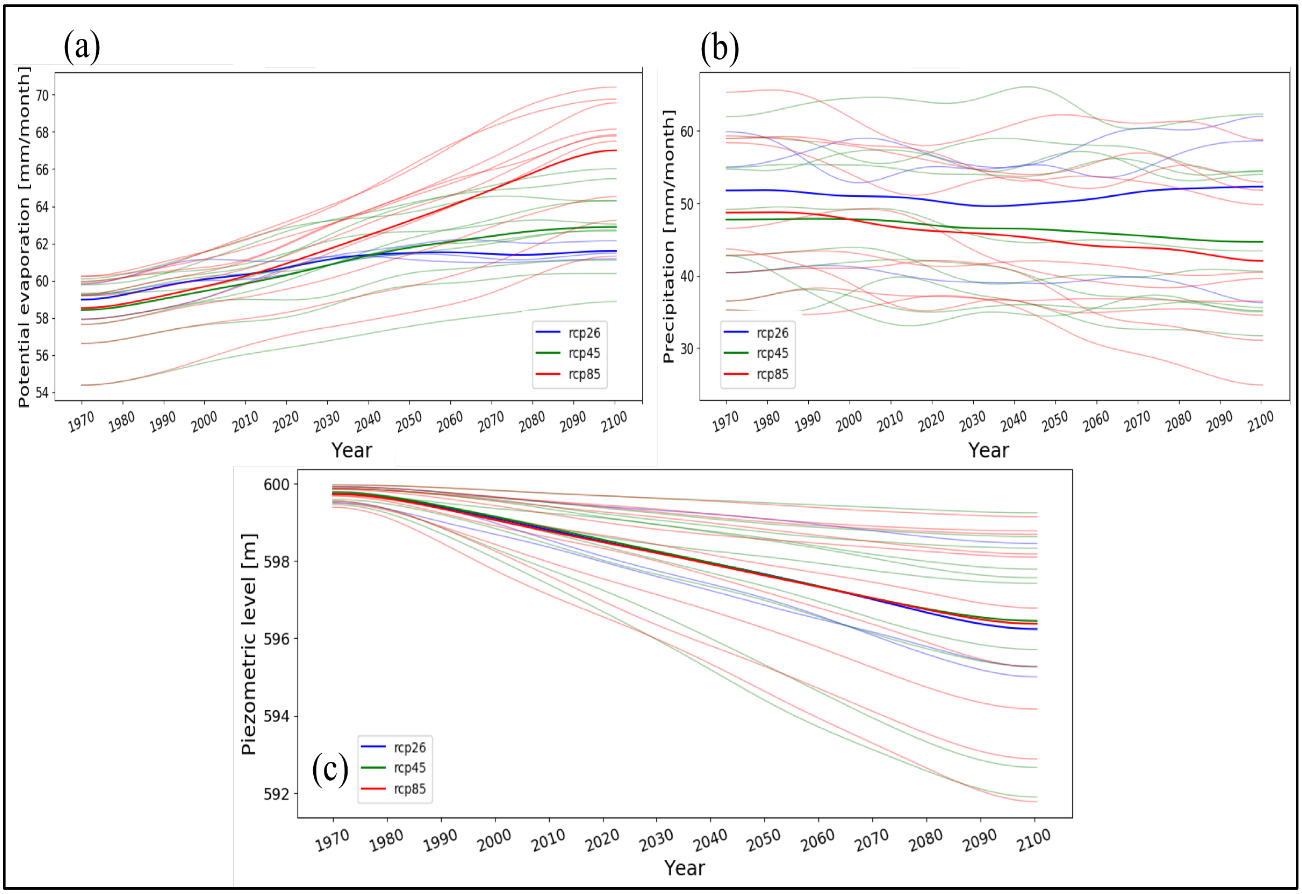

Figure 11. Multi-model simulation with two climate components of the system dynamic model (Potential Evapotranspiration and precipitation) and one auxiliary variable (piezometric level). The curves where smoothened using a Gaussian filter. Thin lines indicate the specific climate models, whereas thick lines show the model ensemble mean.

Figure 11a and 11b show the multi-model simulation results for the two climate components that were included in the SD model, precipitation and potential evapotranspiration. Figure 11c shows the multi-model simulation results for the piezometric level state variable (in the BAU scenario). The results show higher evapotranspiration in RCP 8.5 compared with RCP 4.5 and RCP2.6. A reduction of precipitation is also observed in RCP 8.5 and RCP 4.5. Although lower levels of piezometric levels are shown for RCP 8.5, the difference between the different RCPs is not significant. However, the results reveal a high uncertainty among the different climate models.

4. Discussion

Adaptation strategies, such as Nature-Based Solutions are inherently multidimensional. However, NBS complexity is not often captured in research studies and frameworks as they are frequently framed in a reductionist way, focusing only on a subset of impacts. Besides, a significant part of the NBS research studies has been contextualised in cities. Usually, the urban-centred evidence on NBS effectiveness cannot be transferred to rural contexts. Rural areas are affected by different pressures and socio-economic circumstances. This research seeks to contribute to assess the impact of NBS in rural areas by analysing the Medina del Campo Ground Water Body system.

This article also highlights the need to engage stakeholders in the model development process by contributing to model assumptions and parameters. Stakeholder knowledge and priorities should have a real (not just superficial) impact on the model. In this article, we applied a Participative System Dynamics Approach to analyse and understand the main dynamics behind NBS. Engaging stakeholders in the co-design of the SDM has provided multiple advantages. Firstly, it has supported constructive and targeted discussions relevant to the identification of barriers and limitations of NBS implementation. Secondly, it has allowed for the integration of local knowledge in a graphical structure that was used to set the basis of the quantitative SD model supporting the integration of qualitative and quantitative data. Thirdly, complex interconnections among system elements were revealed, helping to anticipate possible policy resistances or rebound effects as well as suitable potential strategies to act on the system. Finally, the process itself has promoted awareness and collective learning of those taking part in the participatory modelling process.

This paper explores a diversity of management alternatives to improve aquifer levels while delivering additional benefits (i.e. creation of new job opportunities, improvement of environmental quality or reduction of depopulation) in the Medina del Campo system. This research has focused mainly on NBS and water management performance. Special attention has been given to the long-term effectiveness of these measures under different climate change scenarios. The modelling approach implemented does not intend to provide detailed predictions on water level (piezometric level) changes due to NBS implementation. The intention was to a) analyse the main dynamics of the system; b) see the pathways of development of the system depending on different policy measures and c) Assess the effect of different climate change scenarios.

Climate change impacts are frequently overlooked in NBS assessments and frameworks. However, it is known that changes in mean temperature, species distribution or precipitation patterns are highly likely to alter ecosystem functions and thus, NBS functionality. Besides, the long-term capability of NBS to deal with extreme weather events such as droughts may not be sufficient in a climate change context.

The results of this study demonstrate that the implementation of NBS is not sufficient to adapt to a Business as Usual climate change scenario (RCP8.5).

The main limitation of this study is that changes in evaporation and rain patterns have been the only climate change impacts considered. Soil degradation, plant pathogens, pests, or increase of ground-level ozone are just a few of many climate change impacts that could ultimately compromise the effectiveness of NBS in rural areas.

Ignoring uncertainty ranges, for example, by only using one climate model, does not allow informed decision-making. In this paper, we stress the importance of accounting for this model uncertainty by using multi-model ensemble simulations in NBS assessments.

Developing scientifically based and customised information on the impacts of climate change by assessing uncertainty ranges (known as climate services) is an essential precondition to design and implement long-term effective and flexible NBS.

The results show that the socio-economic context in which NBS are applied significantly influence the performance of NBS. The benefits delivered by NBS may be compromised if a balance between nature, economic growth and social justice is not found. NBS should not be considered as a single action to protect or restore nature but as a process that engages with society to merge natural and human systems into a wholly unique system.

Acknowledgements

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Appendix A

Table A.1. List of equations and parameter values

Variable Name	Variable Type and Sub-type	Units	Variable Description
Basic soil infiltration (fc)	Constant-Normal	mm/day	*The value of fc corresponds to the permeability of the saturated soil in the first 30 centimetres of depth, considering that this is the soil layer that is in direct contact with rainwater- characteristic values of each type of soil.* **Value:** High permeability (i.e. Sand) 1200; Medium Permeability (i.e. Sandy Loam) 600 *[1]; Low permeability (i.e. Clay) 12 • Presented in View 1 • Used by "Soil texture (Kfc)" **Reference: [2], [6], [13]**
Vegetation fraction (Kv)	Constant-Normal	Dmnl	*Fraction of rain that infiltrates due to vegetation cover.* **Value:** Pastures <50%, Kv = 0.09; Cultivated land, Kv = 0.10 *[1]; Grassland coverage, Kv = 0.18; Forests, Kv=0.20; Pasture coverage more than 75% = 0.21 • Presented in View 1 • Used by "Infiltration coefficient" **Reference: [13]**
Slope (Kp)	Constant-Normal	Dmnl	*Infiltration fraction due to slope effect.* **Value:** Very flat (0.02% - 0.06%), Kp = 0.3; Flat (0.3% - 0.4%), Kp = 0.2; Flat (1% - 2%), Kp = 0.15; Average (2% -7%), Kp = 0.10 *[1]; Strong (> 7%), Kp = 0.06 • Presented in View 1 • Used by "Infiltration coefficient" **Reference: [4], [13]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Soil texture (Kfc)	Auxiliary-Normal	Dmnl	*Fraction that infiltrates due to soil texture. To apply this equation, the range of basic soil infiltration (fc) has to be between 16 to 1568 mm / day. For values of fc less than 16 mm / day, Kfc = 0.0148fc / 16. For values of fc greater than 1568 mm / day, Kfc = 1.* **Equation:** IF THEN ELSE ("basic soil infiltration (fc)">=16: AND: "basic soil infiltration (fc)" <=1568, (0.267*LN (“basic soil infiltration (fc)”)) -(0.000154*"basic soil infiltration (fc)")-0.723, IF THEN ELSE (“basic soil infiltration (fc)"<16, (0.0148*"basic soil infiltration (fc)")/16, 1)) • Presented in View 1 • Used by “Infiltration coefficient” **Reference: [2], [4], [6], [9], [13]**
Infiltration coefficient	Auxiliary-Normal	Dmnl	*The infiltration coefficient is the factor used to calculate the water that is infiltrated monthly to the ground. The infiltration is higher in areas with low slope and high vegetative cover.* **Equation** Infiltration coefficient= IF THEN ELSE (("Slope (Kp)"+"Soil texture (Kfc)"+"Vegetation fraction (Kv)")>1, 1, "Slope (Kp)"+"Soil texture (Kfc)"+"Vegetation fraction (Kv)”) • Presented in View 1 • Used by” Infiltration” **Reference: [13]**
RCP2.6	Data-Equation	mm/month	*Representative Concentration Pathway (RCP) is a greenhouse gas concentration trajectory adopted by the IPCC. The RCP2.6 mitigation scenarios aiming to limit the increase of global mean temperature to 2°C. RCP 2.6 requires that carbon dioxide (CO_2) emissions start declining by 2020 and go to zero by 2100.* **Equation:** "RCP2.6”: = GET XLS DATA (‘? SDclima’, 'RCP2.6’, 'P’, 'R3’) • Presented in View 1 • Used by “precipitation”

Variable Name	Variable Type and Sub-type	Units	Variable Description
Rcp4.5	Data-Equation	mm/ month	*Intermediate stabilisation pathways in which radiative forcing is stabilised at approximately 4.5 W m^{-2} and 6.0 W m^{-2} after 2100.* **Equation:** RCP4.5": INTERPOLATE: = GET XLS DATA ('? SDclima', 'RCP4.5', 'K', 'D3') • Presented in View 1 • Used by "precipitation"
RCP8.5	Data-Equation	mm/ month	*One high pathway for which radiative forcing reaches greater than 8.5 W m^{-2} by 2100 and continues to rise for some amount of time (the corresponding ECP assuming constant emissions after 2100 and constant concentrations after 2250).* **Equation:** "RCP8.5": INTERPOLATE: = GET XLS DATA ('?SDclima' , 'RCP8.5' , 'L' , 'D3') • Presented in View 1 • Used by "precipitation"
Precipitation	Data-Equation	mm/ month	*Projected precipitation in Medina del Campo under three different climate change scenarios* **Equation:** Precipitation: INTERPOLATE: = ("RCP2.6"*0) +("RCP4.5"*0) +("RCP8.5"*1) • Presented in View 1 • Used by "infiltration", "interception" and "runoff"
Interception	Auxiliary-Normal	mm/ month	*Monthly precipitation intercepted by foliage.* **Equation:** Interception= IF THEN ELSE (Precipitation<=5, Precipitation, IF THEN ELSE (Precipitation>=5: AND: (Foliage coefficient*Precipitation)>=5, Foliage coefficient *Precipitation, 5)) • Presented in View 1 • Used by "Infiltration" and "runoff" **Reference: [13}**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Foliage coefficient	Constant-Normal	Dmnl	*Percentage of monthly rainfall that is retained in the foliage.* **Value:** 0.12 in cultivated area • Presented in View 1 • Used by “interception”. **Reference: [13]**
Runoff	Auxiliary-Normal	mm/ month	*Flow of water occurring on the ground surface when excess rainwater is not sufficiently infiltrated into the soil.* **Equation:** runoff= MAX (Precipitation-infiltration-Interception, 0) • Presented in View 1 • Used by “Inflow water Adaja”, “Inflow water Guareña”, “Inflow water Trabancos”, “Inflow water Zapardiel”, “Inflow water Wetland” **Reference: [13], [19]**
Infiltration	Auxiliary-Normal	mm/ month	*Monthly precipitation that enters into the soil.* **Equation:** infiltration= (Infiltration coefficient*((Precipitation + Artificial recharge)-Interception)) + ((Infiltration coefficient *((Precipitation + Artificial recharge)-Interception) *Soil conservation practices)) • Presented in View 1 • Used by “Soil moisture”, “Percolation”, “Runoff” and “water excess” **Reference: [2], [4],[5],[8],[13]**
Initial soil moisture	Constant-Normal	mm	*Soil moisture at Time step 0* **Value:** 50 • Presented in View 1 • Used by “soil moisture” **Reference: [2], [4],[5]**
Soil moisture	Level-Normal	mm	*Amount of water stored in the soil* **Equation:** Soil moisture= INTEG (infiltration-Evaporation-Percolation, initial soil moisture) • Presented in View 1 • Used by “evaporation” and “saturation”.

Variable Name	Variable Type and Sub-type	Units	Variable Description
Percolation	Auxiliary-Normal	mm/ month	*Water that moves from soil storage to groundwater per month.* **Equation:** Percolation= water excess+(POWER((saturation/100), exponent)) *infiltration*percolation factor • Presented in View 1 • Used by “total recharge” **Reference: [13], [19]**
Percolation factor	Constant-Normal	Dmnl	**Value**: 0.03 • Hidden variable • Used by “percolation”
Exponent	Constant-Normal	Dmnl	**Value:** 2 • Hidden variable • Used by “percolation”
Evaporation	Auxiliary-Normal	mm/ month	*Quantity of soil water that is transpired and retained in plant tissues, and evaporated from surrounding soil surfaces. It is assumed that when soil moisture is lower than the wilting point, the plants close their stoma. Consequently, the evapotranspiration stops.* **Equation:** Evaporation= IF THEN ELSE (Soil moisture>Wilting point, ETP, 0) • Presented in view 1 • Used by “soil moisture”, “Percolation”, “Runoff” and “water excess”
ETP	Data-Equation	mm/ month	*Potential evapotranspiration under three different climate change scenarios.* **Equation:** ETP: INTERPOLATE: = ("RCP 2.6"*0) +("RCP 4.5"*0) +("RCP 8.5"*1) The ETP was calculated in Excel and integrated in the SD model using GET EXL DATA function. The following equation was used: ETP=(8.10+0.46*T)*Ps where, T= Mean monthly temperature in C^0. P= Percentage of monthly sunlight with respect to the year [%]. • Presented in View 1 • Used by “evapotranspiration”

Variable Name	Variable Type and Sub-type	Units	Variable Description
RCP 2.6	Data-Equation	mm/ month	*Evapotranspiration calculated using temperature in scenario RCP 2.6* **Equation:** RCP 2.6: = GET XLS DATA (‘?SDclima' , 'RCP2.6' , 'P' , 'Q3') • Presented in View 1 • Used by “ETP”
RCP 4.5	Data-Equation	mm/ month	*Evapotranspiration calculated using temperature in scenario RCP 4.5* **Equation:** "RCP 4.5”: = GET XLS DATA (‘?SDclima' , 'RCP4.5' , 'K' , 'M3') • Presented in View 1 • Used by “ETP”
RCP 8.5	Data-Equation	mm/ month	*Evapotranspiration calculated using temperature in scenario RCP 8.5* **Equation:** "RCP 8.5”: = GET XLS DATA(‘?SDclima' , 'RCP8.5' , 'L' , 'N3') • Presented in View 1 • Used by” ETP”
Wilting point	Constant-Normal	mm	*Point of minimum humidity at which a plant cannot continue to extract water from the soil and cannot recover from water loss even if the ambient humidity is saturated. In the model an estimation of the wilting point was used (17% of the root zone).* **Value used in the model:** Wilting point: 103 mm • Presented in view 1 • Used by “Evapotranspiration” **Reference: [4], [13]**
Saturation	Auxiliary-Normal	Dmnl	*Amount of soil pores that are filled with water. The soil is saturated when it reaches the field capacity. When the soil is saturated the percolation is higher.* **Equation:** saturation= (Soil moisture/field capacity) *100 • Presented in View 1 • Used by “percolation” and “water excess”

Variable Name	Variable Type and Sub-type	Units	Variable Description
Field Capacity	Constant-Normal	mm	*Soil moisture condition at which the soil contains the maximum amount of water that can hold before it percolates. In other words, it is the maximum water storage in soil. It has been estimated that the Field capacity in Medina del Campo corresponds to the 35% of the root zone.* **Value used in the model:** 210mm • Presented in View 1 • Used by "saturation" and "water excess" **Reference: [4]**
Water excess	Auxiliary-Normal	mm/ month	*Difference between the maximum amount of water in the soil (on its saturated point) and the water that percolates.* **Equation:** water excess=MAX(((saturation/100) *(field capacity/TIME STEP) +infiltration-(field capacity/TIME STEP)), 0) • Presented in View 1 • Used by "percolation"
Percentage of infiltration increase	Constant-Normal	Dmnl	*Percentage of infiltration increase due to soil conservation practices. Techniques to improve soil quality by preventing soil degradation and building organic matter. These practices include crop rotation, tillage reduction, mulching or cover cropping. A number of studies have estimated that conservation practices may increase soil infiltration up to 30%.* **Value in the model**: 0.20 • Presented in View 1 • Used by "infiltration" and "regeneration" **Reference: [1], [3], [14],[16],[17]**
Irrigation return	Auxiliary-Normal	mm/ month	*Fraction of irrigation water that returns to the system.* **Equation:** Irrigation return= (((Irrigation demand*conversion factor*Factor mm)/river basin area) *Percentage of irrigation returning)/TIME STEP • Presented in View 1 • Used by "infiltration" **Reference: [7], [9]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Percentage of irrigation returning	Constant-Normal	Dmnl	*Percentage of water that returns into the system. It is assumed that this percentage reduces when efficient irrigation systems are implemented. It has been estimated that 35% of the water used by agriculture returns into the system.* **Value:** 0.35 • Presented in View 1 • Used by irrigation return **References: [7], [9], [15]**
Irrigation demand	Auxiliary-Normal	Hm*Hm *Hm	*Water used by irrigation crops in the area of Medina del Campo* **Equation:** Irrigation demand=Cereals water demand + Forage crops water demand + Industrial crops water demand +Other irrigation crops WC + Vegetables water demand • Presented in View 4 • Used by “GW extractions” and “irrigation demand”
River Basin Area	Constant-Normal	m*m	*Area of Medina del Campo Groundwater body* **Value:** 3700000000 m2 • Presented in View 1 • Used by “Cereals area”, “Forage crops area”, “Industrial crops area”, “Vegetable crops area”, “Other crops area”, “Piezometric level”, “Irrigation return”, “Groundwater”
Factor mm	Constant-Normal	mm	*Factor to covert units to convert (m*m*/m*m) into mm* **Value: 1** Hidden variable
Conversion factor	Constant-Normal	m*m/ (Hm*Hm *Hm)	*Factor to convert to Hm3 into litters* **Value:** 1000000 Hidden variable
Artificial recharge NBS	Constant-Normal	Hm*Hm *Hm	*The recharge will take place by means of a surface technique, by pouring into the channel (in Trabancos and Zapardiel river).* **Value** of monthly recharge volume in Zapardiel: 0.77 • Presented in view 2 • Used by "inflow water in Zapardiel" **Reference: [4], [19]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Artificial recharge NBS2	Constant-Normal	Hm*Hm *Hm	*The recharge will take place by means of a surface technique, by pouring into the channel (in Trabancos and Zapardiel river).* **Value** of monthly recharge volume in Trabancos: 0.6 • Presented in view 2 • Used by "Inflow water in Trabancos" **Reference: [4], [19]**
Total recharge	Auxiliary-Normal	Hm*Hm *Hm/ month	*Amount of water that recharges the aquifer.* **Equation:** TOTAL RECHARGE= (factor*Percolation*Permeable surface) +groundwater lateral movement + Zapardiel drainage +Trabancos • Presented in view 1 • Used by "groundwater"
factor	Constant-Normal	(Hm*Hm *Hm)/ (m*m* mm)	*Units converting factor (From mm/month to hm3). Precipitation is in mm/month. This means that each mm is one litre per m2. For example, if it rains 380 mm/month. This means that each month it rains 380 litres of water per m2.* **Value:** 1e-09
groundwater lateral movement	Constant-Normal	Hm*Hm *Hm/ month	*Water coming from other GW bodies.* **Value**: 0.75 • Presented in View 1 • Used by "total recharge"
Permeable surface	Auxiliary-Normal	m*m	*Area of basin that is permeable* **Value**: 3184*1e+06 • Presented in view 1 • Used by "TOTAL RECHARGE"
Trabancos drainage	auxiliary-Normal	Hm*Hm *Hm	*Amount of water that drains into the aquifer from Trabancos river* **Equation:** IF THEN ELSE (Trabancos river<=0, 0, 0.0275*Trabancos river) • Presented in View 1 • Used by "total recharge" **Reference: [8], [6], [12]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Zapardiel drainage	auxiliary-Normal	Hm*Hm *Hm	*Amount of water that drains into the aquifer from Zapardiel river.* **Equation:** Zapardiel drainage= IF THEN ELSE (Zapardiel river<=0, 0, 0.112) • Presented in View 2 • Used by "outflow Trabancos" and "Total recharge" **Reference: [8], [6], [12]**
groundwater inflow	auxiliary-Normal	Hm*Hm *Hm/ month	*Amount of water that goes into the aquifer, corresponds to total recharge.* • Presented in View 1 • Used by "groundwater"
Groundwater	Level-Normal	Hm*Hm *Hm	*Amount of water in the aquifer at time t.* **Equation:** groundwater= INTEG (groundwater inflow-groundwater outflow, river basin area*factor de conversion m3 a Hm3*Initial piezometric level) • Presented in View 1 • Used by "Piezometric level"
Groundwater outflow	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that goes out of the aquifer.* **Equation:** groundwater outflow= (discharge to superficial ecosystems + GW extractions + illegal extractions)/TIME STEP • Presented in view 1 • Used by "groundwater"
GW extractions	auxiliary-Normal	Hm*Hm *Hm	*Amount of water extracted from the aquifer.* **Equation:** GW extractions=MIN (Urban water demand + Irrigation demand, Maximum volume of water allowed for extractions) • Presented in view 1 • Used by "groundwater outflow"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Urban water demand	constant-Normal	Hm*Hm *Hm	*Urban* water demand per month. **Value:** 0.27 • Presented in View 1 • Used by "GW extractions" **Reference: [4], [5], [9]**
Maximum volume of water allowed for extractions	constant-Normal	Hm*Hm *Hm	*Maximum volume of water that the river basin authority allows extracting. It is assumed that the maximum volume of water allowed for extractions equals to the current demand for water.* **Value:** In BAU scenario: 21.7; In scenario with GW extractions restrictions: 17.3 • Presented in View 1 • Used by "GW extractions"
Illegal extractions	Auxiliary with Lookup	Hm*Hm *Hm	*Volume of water extracted from the aquifer without permission. The model assumes that illegal extractions reduce when the environmental awareness increase.* **Equation:** illegal extractions= WITH LOOKUP (Environmental awareness, ([(0,0(10,10)], (0,1), (0.2,0.8), (0.3,0.7), (0.4,0.5), (0.5,0.12), (0.6,0.15), (0.7,0.1), (0.8,0.08), (0.9,0.05), (1,0))) • Presented in View 1 • Used by "GW extractions"
Environmental awareness	Auxiliary-Normal	Dmnl	*The level at which the rural population and tourists are aware of the impacts that their behaviour impacts the environment and the level of commitments to make changes.* **Equation:** DELAY1I ((3*"Level of information/Citizens engagement") +profit, 24, 0.1) • Presented in view 3 • Used by "environmental stress" and "illegal extractions"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Discharge to superficial ecosystems	Auxiliary-Normal	Hm*Hm *Hm	*Amount of water that is discharged to superficial ecosystems. The discharge happens when the piezometric level is height enough to reach the basin of superficial ecosystems.* **Equation:** discharge to superficial ecosystems= GW discharge to Adaja + GW discharge to Guareña + GW discharge to trabancos + GW discharge to Zapardiel + GW discharge to wetland • Presented in View 1 • Used by" groundwater outflow"
GW discharge to Adaja	Auxiliary-Normal	Hm*Hm *Hm	*Amount of groundwater that is discharged to Adaja river.* **Equation:** GW discharge to Adaja =IF THEN ELSE (Piezometric level>Height Adaja, (Piezometric level-Height Adaja). *Area of water in Adaja*factor de conversion m3 a Hm3, 0) • Presented in view 2 • Used by "discharge to superficial ecosystems" and "Inflow Adaja"
GW discharge to Guareña	Auxiliary-Normal	Hm*Hm *Hm	*Amount of groundwater that is discharged to Guareña river.* **Equation:** GW discharge to Guareña =IF THEN ELSE (Piezometric level>Height Guareña , (Piezometric level-Height Guareña)*Area of water in Guareña*factor de conversion m3 a Hm3 , 0) • Presented in view 2 • Used by "discharge to superficial ecosystems" and "Inflow Guareña"
GW discharge to Trabancos	Auxiliary-Normal	Hm*Hm *Hm	*Amount of groundwater that is discharged to Trabancos river.* **Equation:** GW discharge to Trabancos =IF THEN ELSE (Piezometric level>Height Trabancos, (Piezometric level-Height Trabancos) *Area of water in Trabancos*factor de conversion m3 a Hm3, 0) • Presented in view 2 • Used by "discharge to superficial ecosystems" and "Inflow Trabancos"

Variable Name	Variable Type and Sub-type	Units	Variable Description
GW discharge to Zapardiel	Auxiliary-Normal	Hm*Hm *Hm	*Amount of groundwater that is discharged to Zapardiel river.* **Equation:** GW discharge to Zapardiel =IF THEN ELSE (Piezometric level>Height Zapardiel, (Piezometric level-Height Zapardiel) *Area of water in Zapardiel*factor de conversion m3 a Hm3, 0) • Presented in view 2 • Used by "discharge to superficial ecosystems" and "Inflow Zapardiel
GW discharge to wetland	Auxiliary-Normal	Hm*Hm *Hm	*Amount of groundwater that is discharged to the wetlands.* **Equation:** GW discharte to wetland=IF THEN ELSE (Piezometric level>=Discharge treshold level, ((Piezometric level -Discharge treshold level) *Wetlands area*factor de conversion m3 a Hm3), 0) • Presented in view 2 • Used by "discharge to superficial ecosystems" and "Inflow Wetland"
Piezometric level	Auxiliary-Normal	m	*Water levels of the aquifer's basin* **Equation:** Piezometric level= (groundwater*units' factor)/river basin area • Presented in view 1 • Used by "Depth of wells", " GW dischafge to Adaja", "GW discharge to Guareña","GW discharge to trabancos", "GW discharge to Zapardiel" and "GW discharge to wetland"
Initial piezometric level	Constant-Normal	m	*Groundwater level at the beginning of the simulation. Value measured for height 730m.* **Value**: 665 • Presented in View 1 • Used by "groundwater" **Reference: [4], [5], [6]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
depth of wells	Auxiliary-Normal	m	*Depth of wells used to extract groundwater.* **Equation:** depth of wells=area height-Piezometric level • Presented in View 1 • Used by “cost of extracting water”
area height	constant-Normal	m	*Height of the Basin (Metres Above Sea Level)* **Value**: 740 • Presented in view 1 • Used by "depth of wells" **Reference: [4], [6]**
Height Adaja	Constant-Normal	m	*Source of river at 1490m, Mouth of the river at 680m* **Value:** For the simulation a height of 800m has been chosen • Presented in view 2 • Used by “GW discharge to Adaja”
Area of water in Adaja	constant-Normal	m*m	*River basin area* **Value:** 5.304e+09 • Presented in view 2 • Used by "Inflow water Adaja" and "Outflow water Adaja"
Adaja river	Level-Normal	Hm*Hm *Hm	*Amount of water in Adaja river at time t. Initial value: 34.375 (Average flow in a month)* **Equation:** Adaja river = INTEG (Inflow water Adaja-outflow Adaja, 34.375) • Presented in view 2 • Used by "Extractions Adaja", "Outflow Adaja" and "Quality Adaja" **Reference: [12]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Ecological flow from Cogotas reservoir	constant-Normal	Hm*Hm *Hm	*The River Basin Authority (Confederación hidrological del Duero) has allowed an ecological flow from the Cogotas dam to the Adaja river of 13.08 cubic hectometres per year in normal periods and 8.23 hm3 in periods of drought.* *The ecological flow varies from month to month. The model assumes that the ecological flow from the Cogotas dam is constant over the year.* **Value:** 0.9 • Presented in View 2 • Used by "Inflow water in Adaja" and "Extractions Adaja" **Reference: [12], [7], [8]**
Outflow Adaja	auxiliary-Normal	Hm*Hm *Hm /month	*Water that goes out of the Adaja river. The model assumes that the only variables affecting the outflow are Evapotranspiration and superficial extractions. It does not consider the flow to other rivers or streams.* **Equation:** MIN(((Area of water in Adaja*ETP*factor) + (extractions Adaja/TIME STEP)),Adaja river/TIMESTEP) • Presented in View 2 • Used by “Adaja river”
Extractions Adaja	auxiliary-Normal	Hm*Hm *Hm	*Water extracted for irrigation. The model assumes that an ecological flow is maintained over the year. For this reason, extractions from Adaja will be produced if there is enough water to maintain this ecological flow.* **Equation:** extractions Adaja=IF THEN ELSE(Adaja river <= Superficial water extractions , 0 , Adaja river -Ecological flow from Cogotas reservoir) • Presented in view 2 • Used by "Outflow Adaja"
Superficial water extractions	constant-Normal	Hm*Hm *Hm	*Monthly water extractions from Adaja river* **Value:** 3.54 • Presented in View 2 • Used by "Extractions Adaja" **Reference: [10]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Height Zapardiel	Constant-Normal	m	*Source of river at 1150m, Mouth of the river at 675m* **Value:** For the simulation a height of 700m has been chosen • Presented in view 2 • Used by "GW discharge to Zapardiel"
Inflow water on Zapardiel	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that flows into Zapardiel river. Water from runoff or artificial recharge NBS (If the variable is activated).* **Equation:** Inflow water on Zapardiel=MAX (((Area of water in Zapardiel*factor*runoff) +(((Artificial recharge NBS)+GW discharge to Zapardiel-deviation to channels)/TIME STEP)) , 0) • Presented in view 2 • Used by "Zapardiel river"
Deviation channels	constant-Normal	Hm*Hm *Hm	*Amount of water that is deviated through channels. There is a network of canalizations and diversions that extract the waters of torrential episodes.* **Value:** 5.2 • Presented in view 2 • Used by "Inflow water on Zapardiel" **Reference: [8]**
outflow Zapardiel	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that goes out of the Zapardiel river. The model only considers Evapotranspiration and Zapardiel drainage. It does not consider the flow to other rivers or streams.* **Equation:** outflow Zapardiel= MIN ((factor*ETP*Area of water in Zapardiel+(Zapardiel drainage/TIME STEP)) , Zapardiel river/TIME STEP) • Presented in View 2 • Used by Zapardiel river
Height Guareña	Constant-Normal	m	*Source of river at 932m, Mouth of the river at 700m* **Value:** For the simulation a height of 720m has been chosen • Presented in view 2 • Used by "GW discharge to Guareña"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Area of Water in Guareña	constant-Normal	m*m	River basin area **Value:** 1.007e+09 Presented in view 2 Used by "Inflow water Guareña" and "Outflow water Guareña"
Inflow water on Guareña	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that flows into Guareña river. Water from runoff and GW discarge to Guareña.* **Equation:** Inflow water on Guareña= (Area of water in Guareña*factor*runoff) +((GW discharge to Guareña)/TIME STEP) • Presented in view 2 • Used by "Guareña river"
Guareña river	Level-Normal	Hm*Hm *Hm	*Amount of water in Guareña river at time t. Initial value: 5.3 (Average flow in a month)* **Equation:** Guareña river = INTEG (Inflow water on Guareña-Outflow Guareña, 5.3) • Presented in view 2 • Used by "Guareña drainage", "Outflow Guareña" and "Quality Guareña" **Reference: [12]**
Outflow Guareña	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that goes out of the Guareña river. The model assumes that the only variables affecting the outflow are Evapotranspiration and Guareña drainage. It does not consider the flow to other rivers or streams.* **Equation:** Outflow Guareña=MIN (((factor*ETP*Area of water in Guareña+(Gruareña drainage/TIME STEP))) , (Guareña river/TIME STEP)) • Presented in view 2 • Used by "Guareña river"
Guareña drainage	auxiliary-Normal	Hm*Hm *Hm	*Amount of water that drains from Guareña river.* **Equation:** Gruareña drainage=IF THEN ELSE (Guareña river<=0, 0 , 0.1255*Guareña river) • Presented in view 2 • Used by "Gruareña outflow"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Height Trabancos	Constant-Normal	m	*Source of river at 1120m, Mouth of the river at 657m* **Value:** For the simulation a height of 720m has been chosen • Presented in view 2 • Used by "GW discharge to Trabancos"
Inflow water on Trabancos	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that flows into Trabancos river. Coming from runoff, GW discharge to Trabancos or artificial recharge NBS (If the variable is activated).* **Equation:** Inflow water on Trabancos=MAX (((Area of water in Trabancos*factor*runoff) + (((Artificial recharge NBS2) +GW discharge to Trabancos)/TIME STEP)), 0) • Presented in view 2 • Used by "Zapardiel river"
Trabancos river	Level-Normal	Hm*Hm *Hm	*Amount of water in Trabancos river at time t. Initial value: 6.425 (Average flow in a month).* **Equation:** Trabancos river = INTEG (inflow water on Trabancos-outflow Trabancos, 6.425) • Presented in view 2 • Used by "Trabancos river"
Outflow Trabancos	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that goes out of the Trabancos river. The model assumes that the only variables affecting river outflow are Evapotranspiration and Trabancos drainage. It does not consider the flow to other rivers or streams.* **Equation:** outflow Trabancos= MIN ((factor*ETP*Area of water in Trabancos+ (Trabancos drainage/TIME STEP)), Trabancos river/TIME STEP) • Presented in View 2 • Used by "Trabancos river"
Discharge threshold level	Constant-Normal	m	*Height at which the aquifer discharges to the wetland.* **Value:** 720m • Presented in view 2 • Used by "GW discharge to Wetland"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Inflow water on wetland	auxiliary-Normal	Hm*Hm *Hm/ month	*Water that flows into Wetland. Water from runoff and GW discharge to Wetland.* **Equation:** inflow water on wetland=(GW discharge to wetland/TIME STEP)+(factor*Precipitation*Wetlands area)+(factor*Wetlands area*runoff) • Presented in view 2 • Used by "Wetland"
Wetland	Level-Normal	Hm*Hm *Hm	*Amount of water in Wetland at time t. Initial value: 0.122* **Equation:** Wetland= INTEG (inflow water on wetland-wetland water outflow, 0.122) • Presented in View 1 • Used by "Quality Wetland", "Wetland drainage" and "wetland water outflow"
Wetland water outflow	auxiliary-Normal	Hm*Hm *Hm/ month	*Amount of water that is lost due to Evapotranspiration or drainage to GW aquifer.* **Equation:** wetland water outflow=MIN ((ETP*Wetlands area*factor) + (wetland drainage/TIME STEP) , (Wetland/TIME STEP)) • Presented in view 1 • Used by "Wetland"
wetland drainage	auxiliary-Normal	Hm*Hm *Hm	*Percentage of wetland water that drains into the aquifer.* **Equation:** wetland drainage =IF THEN ELSE (Wetland<=0 , 0 , permeability of soil*Wetland) • Presented in View 1 • Used by "Wetland outflow"
Wetland area	constant-Normal	m*m	*Wetland area* **Value:** 1.22e+06 • Presented in view 2 • Used by "Inflow water on Wetland" and "Outflow water on Wetland"

Variable Name	Variable Type and Sub-type	Units	Variable Description
% of Cereals	constant-Normal	dmnl	*Percentage of cereals occupying the area of Medina del Campo.* **Value:** 7.89 • Presented in View 4 • Used by "Cereal crops area" **Reference: [10], [11]**
% of Industrial crops	constant-Normal	dmnl	*Percentage of Industrial crops occupying the area of Medina del Campo.* **Value:** 2.13 • Presented in View 4 • Used by "Industrial crops area" **Reference: [10], [11]**
% forage crops	constant-Normal	dmnl	*Percentage of forage crops occupying the area of Medina del Campo.* **Value:** 0.45 • Presented in View 4 • Used by "Forage crops area" **Reference: [10], [11]**
% Vegetable crops area	constant-Normal	dmnl	*Percentage of Vegetable crops occupying the area of Medina del Campo.* **Value:** 1.1 • Presented in View 4 • Used by "Vegetable crops area" **Reference: [10], [11]**
% other crops area	constant-Normal	dmnl	*Percentage of other crops occupying the area of Medina del Campo.* **Value:** 3.21 • Presented in View 4 • Used by "other crops area" **Reference: [10], [11]**
Cereals area	auxiliary-Normal	m*m	*Area of cereals in Medina del Campo* **Equation:** Cereals area= ("% of cereals"*river basin area)/100 • Presented in View 4 • Used by "Cereals water demand"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Industrial crops area	auxiliary-Normal	m*m	*Area of Industrial crops in Medina del Campo* **Equation:** Industrial crops area= ("% of industrial crops"*river basin area)/100 • Presented in View 4 • Used by "Industrial crops water demand"
Forage crops area	auxiliary-Normal	m*m	*Area of Forage crops in Medina del Campo* **Equation:** Forage crops area= ("% of Forage crops"*river basin area)/100 • Presented in View 4 • Used by "Forage crops water demand"
Vegetable crop area	auxiliary-Normal	m*m	*Area of Vegetable crops in Medina del Campo* **Equation:** Vegetable crops area= ("% of cereals"*river basin area)/100 • Presented in View 4 • Used by "Vegetable crops water demand"
Oher crops area	auxiliary-Normal	m*m	*Area of other crops in Medina del Campo* **Equation:** Other crops area= ("% of cereals"*river basin area)/100 • Presented in View 4 • Used by "Other crops water demand"
Mean IW cereals	auxiliary-Normal	Hm*Hm*Hm/m*m	*Amount of water used by cereals per m2. Main cereals: Barley, Common Wheat, Maize, Oat and other cereals* **Value**: 3.3e-8 • Presented in View 4 • Used by "cereals water demand" **Reference: [10], [11]**
Mean IW industrial crops	auxiliary-Normal	Hm*Hm*Hm/m*m	Amount of water used by Industrial crops per m2. Main industrial crops: Rape, sunflower and Sugar Beat **Value:** 6.1e-8 • Presented in View 4 • Used by "Industrial crops water demand" **Reference: [10], [11]**

Variable Name	Variable Type and Sub-type	Units	Variable Description
Mean IW forage crops	auxiliary-Normal	Hm*Hm *Hm/ m*m	*Amount of water used by Forage crops per m2. Main forage crop: Alfalfa* **Value**: 2.2e-8 • Presented in View 4 • Used by " Forage crops water demand" **Reference: [10], [11]**
Mean IW vegetable crops	auxiliary-Normal	Hm*Hm *Hm/ m*m	*Amount of water used by vegetable crops per m2. Main vegetable crops: Onion, green pea, carrot and others.* **Value:** 6.6e-8 • Presented in View 4 • Used by "vegetable crops water demand" **Reference: [10], [11]**
Mean IW other crops	auxiliary-Normal	Hm*Hm *Hm/ m*m	Amount of water used by other crops per m2. Main crops considered: Legumes, Tuber, Vineyards and others **Value:** 2.3e-8 • Presented in View 4 • Used by "other crops water demand" **Reference: [10], [11]**
Cereals water demand	auxiliary-Normal	Hm*Hm *Hm	*Total water used by cereals per month* **Equation:** Cereals water demand=Cereals area*Mean IW cereals • Presented in View 4 • Used by "irrigation demand"
Industrial crops water demand	auxiliary-Normal	Hm*Hm *Hm	*Total water used by industrial crops per month* **Equation:** Industrial crops water demand=Industrial crops area*Mean IW Industrial crops • Presented in View 4 • Used by "irrigation demand"
Forage crops water demand	auxiliary-Normal	Hm*Hm *Hm	*Total water used by forage crops per month* **Equation:** Forage crops water demand=Forage crops area*Mean IW forage crops • Presented in View 4 • Used by "irrigation demand"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Other irrigation crops water demand	auxiliary-Normal	Hm*Hm *Hm	*Total water used by other crops per month* **Equation:** other crops water demand=other crops area*Mean IW other crops • Presented in View 4 • Used by "irrigation demand"
Quality Guareña	auxiliary-Normal	dmnl	*Quality status of Guareña river. The only criteria used to define the quality of the river is the amount of water in the river. A lookup table has been used. The model assumes that the higher the amount of water in the river the higher is the quality of the river.* **Equation:** Quality Guareña= WITH LOOKUP (Guareña river, ([(0,0)(100,10)],(0,0),(0.5,0),(1,0),(2,0.1),(2.5,0.15),(3,0.2),(3.5,0.25),(4,0.3),(4.5,0.4),(5,0.5),(5.5,0.6),(6,0.7),(7,0.8),(8,0.9),(9,1))) • Presented in view 3 • Used by "Quality of rivers"
Quality Adaja	auxiliary-Normal	dmnl	*Quality status of Adaja river. The only criteria used to define the quality of the river is the amount of water in the river. A lookup table has been used. The model assumes that the higher the amount of water in the river the higher is the quality of the river.* **Equation:** Quality Adaja= WITH LOOKUP (Adaja river,([(0,0)-(150,10)],(0,0),(6.8,0.1),(7.5,0.15),(9.5,0.2),(10.5,0.25),(11.5,0.3),(14,0.35),(16,0.4),(18,0.45),(20,0.5),(25,0.6),(30,0.7),(35,0.8),(40,1))) • Presented in view 3 • Used by "Quality of rivers"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Quality Trabancos	auxiliary-Normal	dmnl	*Quality status of Trabanco river. The only criteria used to define the quality of the river is the amount of water in the river. A lookup table has been used. The model assumes that the higher the amount of water in the river the higher is the quality of the river.* **Equation:** Quality trabanco= WITH LOOKUP (Trabanco river, ([(0,0)(100,10)],(0,0),(1.28,0.1),(2,0.2),(3,0.3),(4,0.4),(5,0.45),(6,0.5),(7,0.6),(8,0.65),(9,0.7),(10,0.75),(11,0.8),(12,0.85),(13,1))) • Presented in view 3 • Used by "Quality of rivers"
Quality Zapardiel	auxiliary-Normal	dmnl	*Quality status of Zapardiel river. The only criteria used to define the quality of the river is the amount of water in the river. A lookup table has been used. The model assumes that the higher the amount of water in the river the higher is the quality of the river.* **Equation:** Quality Zapardiel= WITH LOOKUP (Zapardiel river, ([(0,0)(50,10)],(0,0),(0.8,0.1),(1,0.15),(1.5,0.2),(2,0.3),(2.5,0.4),(3,0.45),(4,0.5),(5,0.55),(6,0.6),(7,0.7),(8,0.8),(10,1))) • Presented in view 3 • Used by "Quality of rivers"
Quality river	auxiliary-Normal	dmnl	*Quality status of all rivers. The only criteria used to define the quality of the rivers is the amount of water in the river. A lookup table has been used. The model assumes that the higher the amount of water in the rivers the higher is the quality of the rivers.* **Equation:** quality rivers= WITH LOOKUP ((Quality Adaja+Quality Guareña+Quality trabanco+Quality Zapardiel) *Units correction,([(0,0)(10,10)],(0,0),(0.6,0.1),(1,0.3),(2,0.5),(2.5,0.6),(3,0.7),(3.5,0.85),(4,1))) • Presented in view 3 • Used by "Regeneration"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Quality wetland	auxiliary-Normal	dmnl	*Quality status of wetland. The only criteria used to define the quality of the wetlands is the amount of water in the wetland. A lookup table has been used. The model assumes that the higher the amount of water in the wetland the higher is the quality of the wetland.* **Equation:** Quality wetland= WITH LOOKUP (Wetland*Units correction,([(0,0)(100,10)],(0,0),(0.05,0),(0.1,0),(0.15,0.2),(0.2,0.3),(0.25,0.5),(0.3,0.6),(0.35,0.7),(0.4,1),(4.45,1),(5,1),(100,1))) • Presented in view 3 • Used by "regeneration"
regeneration rate	constant-Normal	dmnl	*Rate at which ecosystems regenerates or recover their quality.* **Value:** 0.05 • Presented in view 3 • Used by "regeneration"
regeneration	auxiliary-Normal	dmnl/ month	*Ecosystems recovery per month. It is assumed that the ecosystems need some time to recover. Based on literature, we assume that they need 10 years.* **Equation:** regeneration= DELAY FIXED (((quality rivers + Quality wetland + Percentage of infiltration increase) *REGENERATION RATE) ,120, 0) • Presented in view 3 • Used by "Environmental quality"
Environmental quality	Level-Normal	dmnl	*Quality of Ecosystems at time t* **Equation:** Environmental quality= INTEG ((regeneration-degradation)/1, 0.5) • Presented in view 3 • Used by " degradation" and "attractiveness"
Degradation Rate	constant-Normal	dmnl	*Rate at which ecosystems degrade naturally.* **Value:** 0.02 • Presented in view 3 • Used by "degradation"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Degradation	auxiliary-Normal	dmnl/ month	*Degradation of environmental quality per month* **Equation:** degradation=DEGRADATION RATE*environmental stress*Environmental quality • Presented in view 3 • Used by "Environmental quality"
Advertise-ment	constant-Normal	dmnl	*Level of promotion to attract new tourists* **Value:** 0-2 The simulations on this study have use a value of 2 • Presented in view 3 • Used by "Attractiveness"
attractiveness	auxiliary-Normal	dmnl	*Landscape appraisal level* **Equation:** attractiveness=advertisement*Environmental quality • Presented in view 3 • Used by "tourist gain"
TOURIST RATE	constant-Normal	dmnl	*Rate at which tourist arrive to the area* **Value:** 0.5 • Presented in view 3 • Used by "tourist gain"
tourist gain	auxiliary-Normal	dmnl/ month	*Gain of tourists per month.* **Equation:** DELAY1(attractiveness*TOURIST RATE*Tourist, 60) • Presented in view 3 • Used by "Tourists"
Tourist	Level-Normal	dmnl	*Number of tourists at time t* **Equation:** Tourist= INTEG ((tourist gain-loss), 1) • Presented in view 3 • Used by "Environmental stress" and "new investments"
Loss Rate	constant-Normal	dmnl	*Rate of tourist loss* **Value**: 0.5 • Presented in view 3 • Used by "Loss"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Loss	constant-Normal	dmnl/month	*Loss of tourists per month* **Equation:** Tourist*LOSS RATE • Presented in view 3 • Used by "tourists"
Investment rate	constant-Normal	dmnl	*Rate at which investments are produced* Value: 0.1 • Presented in view 3 • Used by "New investments"
New investments	auxiliary-Normal	dmnl/month	*Investment to create new jobs and economic opportunities per month* **Equation:** new investments= DELAY FIXED (Tourist*INVESTMENT RATE, 36, 0) • Presented in view 3 • Used by "New jobs and economic opportunities"
New jobs and economic opportunities	level-Normal	dmnl	*New jobs and economic opportunities at time t* **Equation:** New jobs and economic opportunities= INTEG (new investments-loss of jobs, 1) • Presented in view 3 • Used by "profit" and "loss of jobs"
loss of jobs	auxiliary-Normal	dmnl/month	Loss of jobs and economic opportunities per month **Equation:** Loss of jobs= New jobs and economic opportunities*loss of jobs rate • Presented in view 3 • Used by "New jobs and economic opportunities"
Loss of jobs rate	constant-Normal	dmnl	*Rate at which jobs and economic opportunities are lost* **Value:** 0.1 • Presented in view 3 • Used by "loss of jobs"

Variable Name	Variable Type and Sub-type	Units	Variable Description
Income	auxiliary-Normal	dmnl	*Economic benefit produced by new jobs and economic opportunities and agriculture.* **Equation:** Income= New jobs and economic opportunities+ (Mean productivity of extracted water*Units correction) • Presented in view 3 • Used by "profit"
Mean productivity of extracted water	Auxiliary with Lookup	dmnl	*Productivity of extracted water (economic benefit produced by the exploitation of water resources).* **Equation:** Mean productivity of extracted water= WITH LOOKUP (GW extractions,([(0,0 (20,10)],(0,0),(1,0.2),(2,0.4),(3,0.6),(4,0.8),(5,1),(6,1.2),(7,1.4),(8,1.6),(9,1.8),(10,2),(11,2.2),(12,2.4),(13,2.6),(14,2.8),(15,3),(16,3.2),(17,3.4),(18,3.6),(19,3.8),(20,4))) • Presented in view 3 • Used by "Income"
Profit	auxiliary-Normal	dmnl	*Economic profit produced by new jobs and economic opportunities and agriculture.* **Equation:** Profit= income-(cost new infrastructure+(cost of extracting water*Units correction 2)) • Presented in view 3 • Used by "pop increase" and "Environmental awareness"
Investment in infrastructure	auxiliary-Normal	dmnl/ month	*Investment in new infrastructures and services per month* **Equation** Investment in infrastructure= INVESTMENT RATE*profit • Presented in view 3 • Used by "Infrastructure and services"
Infrastructure and services	level-Normal	dmnl	*Infrastructure and services at time t* **Equation:** infrastructure and services= INTEG (investment in infrastructure, 1) • Presented in view 3 • Used by "cost of new infrastructure" and "pop increase"

Variable Name	Variable Type and Sub-type	Units	Variable Description
cost of new infrastructure	auxiliary-Normal	dmnl	*Economic cost produced by the creation and maintenance of new infrastructures* **Equation** cost of new infrastructure=infrastructure and services*0.2 • Presented in view 3 • Used by "Profit"
Cost of extracting water	Auxiliary with Lookup	dmnl	*Cost of extracting water from the aquifer. If the aquifer level is low, the cost of extracting water is higher.* **Equation** cost of extracting water= WITH LOOKUP (depth of wells,([(0,0)(39,10)],(0,0),(1,0.1),(2,0.2),(3,0.3),(4,0.4),(5,0.6),(6,0.7),(7,0.8),(8,0.9),(9,1),(10,1.1),(11,1.2),(12,1.3),(13,1.4),(14,1.5),(15,1.6),(16,1.7),(17,1.8),(18,1.9),(19,2),(20,2.1),(21,2.2),(22,2.3),(23,2.4),(24,2.5),(25,2.6),(26,2.7),(27,2.8),(28,2.9),(29,3),(30,3.1),(31,3.2),(32,3.3),(33,3.4),(34,3.5),(35,3.6),(36,3.7),(37,3.8),(38,3.9),(39,4))) • Presented in view 3 • Used by "Profit"
pop increase	auxiliary-Normal	dmnl/ month	*Increase in rural population per month.* **Equation** Pop increase=infrastructure and services*profit*INMIGRATION RATE*rural population • Presented in view 3 • Used by "rural population"
Rural population	level-Normal	dmnl	*Rural population at time t* **Equation** rural population= INTEG (pop increase-depopulation,1) • Presented in view 3 • Used by "pop increase", "depopulation" and "environmental degradation"
depopulation	auxiliary-Normal	dmnl/ month	*Loss of rural population per month* **Equation** depopulation=DEPOPULATION RATE*rural population • Presented in view 3 • Used by "Rural population"

Variable Name	Variable Type and Sub-type	Units	Variable Description
depopulation rate	constant-Normal	dmnl	*Rate at which rural population decrease* Value: 0.01 • Presented in view 3 • Used by "depopulation"
environmental stress	auxiliary-Normal	dmnl	*Environmental response to potential stressors such as noise, pollution and crowding that are exacerbated by the increase in tourist local population. The environmental stress could be reduced with high level of environmental awareness.* **Equation** Environmental stress= (rural population+4*Tourist)-Environmental awareness • Presented in view 3 • Used by "degradation"
Level of information/ Citizens engagement	constant-Normal	dmnl	*Level of public information that is available for rural citizens and tourists. Civil engagement includes communities working together or individuals working alone in both political and non-political actions to protect nature.* **Value:** 0.1 (low level of information/citizens engagement)-1(high level of information/citizens engagement) • Presented in view 3 • Used by "Environmental awareness"

*[1] *Value Used in the model*

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Appendix B

Table 1B. List of climate model used in the evaluation and multi-model simulations

Driving Model	Run type	Regional climate model (RCM)
ICHEC-EC-EARTH	simulation rcp26	SMHI-RCA4
MOHC-HadGEM2-ES	simulation rcp26	KNMI-RACMO22E
MPI-M-MPI-ESM-L	simulation rcp26	MPI-CSC-REMO2009
MPI-M-MPI-ESM-LR	simulation rcp26	MPI-CSC-REMO2009
ICHEC-EC-EARTH	simulation rcp45	DMI-HIRHAM5
ICHEC-EC-EARTH	simulation rcp45	CLMcom-CCLM4-8-17
ICHEC-EC-EARTH	simulation rcp45	SMHI-RCA4
IPSL-IPSL-CM5A-MR	simulation rcp45	SMHI-RCA4_v1
MOHC-HadGEM2-ES	simulation rcp45	CLMcom-CCLM4-8-17
MOHC-HadGEM2-ES	simulation rcp45	KNMI-RACMO22E
MOHC-HadGEM2-ES	simulation rcp45	SMHI-RCA4
MPI-M-MPI-ESM-LR	simulation rcp45	CLMcom-CCLM4-8-17
MPI-M-MPI-ESM-LR	simulation rcp45	MPI-CSC-REMO2009
MPI-M-MPI-ESM-LR	simulation rcp45	SMHI-RCA4
MPI-M-MPI-ESM-LR	simulation rcp45	MPI-CSC-REMO2009
ICHEC-EC-EARTH	simulation rcp85	KNMI-RACMO22E
ICHEC-EC-EARTH	simulation rcp85	DMI-HIRHAM5
ICHEC-EC-EARTH	simulation rcp85	CLMcom-CCLM4
ICHEC-EC-EARTH	simulation rcp85	SMHI-RCA4
IPSL-IPSL-CM5A-MR	simulation rcp85	SMHI-RCA4
MOHC-HadGEM2-ES	simulation rcp85	CLMcom-CCLM4-8-17
MOHC-HadGEM2-ES	simulation rcp85	KNMI-RACMO22E
MOHC-HadGEM2-ES	simulation rcp85	SMHI-RCA4
MPI-M-MPI-ESM-LR	simulation rcp85	CLMcom-CCLM4-8-17
MPI-M-MPI-ESM-LR	simulation rcp85	MPI-CSC-REMO2009
MPI-M-MPI-ESM-LR	simulation rcp85	SMHI-RCA4
MPI-M-MPI-ESM-LR	simulation rcp85	MPI-CSC-REMO2009

Chapter 6:

Conclusions, limitations and future research

6. Conclusions, limitations and future research

Nature Based Solutions (NBS) are increasingly considered as a suitable approach to address biodiversity alongside the climate change crisis. NBS are based on the principle that protecting and enhancing ecosystem functions may provide multiple socio-economic and environmental co-benefits. The main advantage of this management strategy over other adaptation strategies is their capability to deliver multiple benefits (so-called co-benefits) simultaneously. Despite their potential, several barriers and the lack of evidence on NBS effectiveness are limiting the total uptake of the concept into national development policies and adaptation actions. Additionally, the NBS concept has been predominantly oriented for cities. Rural areas are affected by different pressures and socio-economic contexts, meaning that the major part of the urban-centred evidence on NBS effectiveness gathered in existing frameworks and assessments cannot be transferred to rural contexts. Thus, the overall research aim of this study is to contribute to the science-based knowledge on NBS effectiveness for adaptive planning in both, urban and rural scales.

This thesis has critically assessed the NBS concept as well as the main limitations of its applicability and long-term performance. Different methods and tools have been proposed to improve the decision-making process, and the flexible adaptation capacity of NBS.

The study is divided in four consecutive chapters that explore different aspects relevant to the design and implementation of NBS. Multi-stakeholder participation has been the core of action of this research. For this reason, the conceptual and methodological assessment of NBS carried out has been “road tested” and validated by end-users and stakeholders in two case studies, an urban-based case, Copenhagen (Denmark) and rural-based case, Medina Del Campo Groundwater Body (Spain).

Table 1.1. Answer to research questions

Research Questions	Results
RQ1: Which criteria need to be considered prior to NBS design and implementation?	An extensive literature review revealed several factors that were not sufficiently considered in previous NBS design and assessments: • **Type of risk:** Identifying the origin and the spatial and temporal dimensions of the analysed risk is essential to assess their impacts, potential damages, and related costs. • **Area:** Considering socio-economic differences between rural, urban and peri-urban areas is critical to design adaptive and efficient NBS. • **Impact scale:** Understanding NBS at different scales is key to ensure a balanced distribution of benefits. • **Co-benefits:** Identifying NBS co-benefits and their interactions is essential to exploit NBS multifunctionality. • **Disservices:** Identifying potential disservices is necessary to evaluate the life cycle cost of NBS as well as to avoid NBS malfunctioning. • **Climate change:** Its impacts on NBS are of utmost relevance to ensure that NBS effects will last in the long term.
RQ2: How can the capability of NBS to contribute to the achievement of different SDGs be enhanced?	NBS should be considered effective not only if they are capable of producing the expected co-benefits, but also if the production of co-benefits is balanced, which means, the capability of NBS to eliminate/reduce the level of trade-offs among different co-benefits. Assessing the dynamic behaviour of trade-offs and synergies among co-benefits could help to anticipate, identify and solve resistance to adopt policies and suitable strategies to implement NBS. The capability of NBS for addressing SDGs may be enhanced by improving NBS multifunctionality and thus its effectiveness.
RQ3: To what extent will Climate Change affect the long-term effectiveness of NBS?	Climate change impacts on NBS are frequently overlooked in assessments and frameworks. The capability of NBS to buffer the adverse impacts of extreme weather events such as droughts may not be enough in a climate change context. The results of this study demonstrate that the implementation of NBS (Soil conservation practices and artificial aquifer recharge in Medina del Campo) is not sufficient to adapt to a Business as Usual climate change scenario. Developing scientifically-based and customised information on the impacts of climate change (climate services) should be understood as an essential precondition to design and implement adaptable and long-term effective NBS.

Research Questions	Results
RQ4: How can local and scientific knowledge be better integrated to facilitate NBS implementation?	Engaging stakeholders in the co-design of NBS assessment methods has provided multiple elements of relevance. Adopting a bottom-up approach has proven to be a prerequisite to understanding how different knowledge is created and distributed among different stakeholders and governmental levels. The balanced distribution of co-benefits across different socio-economic sectors is key to achieve the full potential of NBS. Knowledge integration through participatory modelling exercises represents an opportunity to enhance decision making and facilitate the implementation of NBS. Integrating local and scientific knowledge increase the usability of local information and promotes the co-production of knowledge by facilitating community-based learning and enhancing this way NBS effectiveness.

6.1 Conclusions

NBS definitions in literature are deliberately vague in order to include a wide range of adaptation measures, from the conservation of existing natural ecosystems to the creation of new artificial ecosystems. However, the ambiguity and flexibility of the term challenge the differentiation between NBS other practices. This study highlights the NBS capability to deliver bundles of ecosystems services together as the principal distinguishing criterion. NBS multifunctionality should be balanced; thus, finding an equilibrium between social, economic and environmental targets. This thesis identified critical elements that, if ignored, can produce an imbalance in NBS multifunctionality in the long term.

The first chapter of this dissertation aimed to develop a comprehensive and easy-to-use classification scheme as a basis for assessing and evaluating NBS under different socio-economic and climatic scenarios. The innovative aspect of this framework is

the development of an easy-to-use tool that includes, in a matrix structure, relevant elements that are often overlooked in NBS studies and assessments.

These elements include the potential impacts of climate change on NBS performance and trade-offs and synergies among NBS co-benefits and disservices. Proactive involvement at all societal levels was also recognised as an essential component to enhance and maintain ecosystems resilience and therefore, NBS effectiveness. For this reason, stakeholder's engagement and participatory modelling exercises were carefully described and implemented in the following field-based empirical chapters.

NBS are usually implemented in dynamically complex socio-ecological systems continually changing over time. Therefore, NBS may be altered due to responses to external socio-economic or environmental pressures, causing trade-offs between co-benefits and disservices. Identifying trade-offs among co-benefits may reveal the unintended consequences of NBS implementation, providing an opportunity to support the balance between social, economic and environmental targets. Consequently, the second chapter of this thesis aimed to develop a methodology to enhance NBS multifunctionality through the identification of trade-offs and synergies among co-benefits.

The innovative aspect of this research work is

the co-development of semi-dynamic Fuzzy Cognitive Maps to simulate and analyse the dynamic network of interactions among the different components involved in NBS effectiveness.

The results of this study show the importance of considering the socio-ecological context in which NBS are applied. External factors such as lack of citizens awareness, low level of institutional collaboration or climate change may hamper the capability of NBS to deliver certain co-benefits. For this reason, understanding the relationships, governance structure and dynamism that exist among the different elements of the system may contribute to maintaining NBS effectiveness in the long-term. The work also demonstrates the need to account for the time dimension in detecting and assessing trade-offs among different co-benefits. Notably, the results show that the same NBS can produce different co-benefits at different time steps. Thus, potential trade-offs might not appear because of the time delay.

Stakeholders engagement and participatory modelling methods have been the cornerstone of the modelling approaches implemented in this dissertation. Using the case study of Medina del Campo as a framework for analysis, chapter three aimed to present and describe in detail the participatory modelling approach implemented.

The innovative aspect of the proposed methodology is

the enhancement of NBS effectiveness through the integration of transdisciplinary knowledge (local and scientific) in a community-learning process that promotes awareness and motivation of those taking part in the decision-or policy-making process.

The results of both field-based studies demonstrate that participatory modelling is a suitable method to examine the diversity in framing NBS complexity among the different stakeholders. It is demonstrated that adopting a bottom-up approach supports the balanced distribution of co-benefits across socio-economic levels and sectors, therefore improving NBS performance.

NBS may be altered over time as a result of the dynamic evolution of their natural component or due to responses to external pressures such as climate change. However, climate change impacts on NBS performance are frequently overlooked in NBS assessments and frameworks. Therefore, the fifth and last chapter of this thesis aimed to analyse the long-term effectiveness of NBS strategies under different scenarios of climate change.

For that, a quantitative system dynamic model was co-developed with stakeholders. The SDM was used to explore the long-term performance of different management alternatives, including NBS, to improve aquifer levels in the Medina del Campo system.

The innovative aspect of this research is

the integration of regional downscaled climate ensembles for three RCP scenarios into a quantitative system dynamic model that was used to analyse the long-term effectiveness of different NBS strategies.

The results of this study demonstrate that climate change is likely to exceed the capability of NBS to deal with climate-related risks, meaning that NBS may not be sufficient to adapt entirely to climate change. Besides, the high level of uncertainty surrounding climate change projections increases the complexity of NBS decision-making. Therefore, chapter five highlights the need for developing scientifically-based and customised information on the impacts of climate change (so-called climate services) as enablers for NBS implementation. Additionally, chapter five seeks to contribute to assess the impacts of NBS in rural areas by analysing the Medina del Campo Ground Water Body system.

6.2. Limitations

The innovations presented previously show promising improvements when it comes to the planning of NBS implementation and critical features to keep in mind. However, this research has clear limitations. Firstly, the implementation of the methodologies has been limited to the two case studies presented. Additionally, this research has been primarily focused on assessing and evaluating the NBS capability to cope with extreme hydrological events (droughts and floods). Other climate-related risks, although mentioned, have not been carefully analysed. Therefore, only the possible up scalability of the results to other areas with similar concerns could be considered. Besides, participatory techniques were implemented to support the design and implementation of NBS, monitoring and evaluation of NBS are out of the scope of this research.

Secondly, the NBS classification scheme presented in this dissertation has two potential limitations. On the first hand, the presented framework distinguishes between three types of NBS depending on the level of human intervention required. Nevertheless, this differentiation may be too narrow and difficult to implement due to the ambiguity produced by the lack of criteria to define what is high or low human intervention. On the other hand, it does not consider the economic cost associated with NBS maintenance and management in the long-run. However, it is assumed that the cost increases in those measures that require a higher level of engineering or management (high level of human intervention). In this sense, a detailed, cost-effective analysis should be carried out before implementing any NBS.

Thirdly, the methodology used to analyse NBS multifunctionality accounted solely for the trade-offs among co-benefits, and not those between stakeholder's valuation. However, trade-offs among co-benefits may arise due to differences among stakeholders' perceptions which means that co-benefits delivered by NBS may be valued differently depending on the stakeholder.

Fourthly, although regional downscaled climate projections were used to analyse the long-term effectiveness of different NBS strategies, evaporation and changes in rain patterns have been the only climate change impacts considered. Nonetheless, other impacts such as changes in species distribution or soil degradation may also alter ecosystems function and thus, the capability of NBS to deliver co-benefits. Therefore, new modelling approaches focusing not only on a subset of impacts but on an integrated view of different CC influences should be carried out to assess NBS long-term performance.

Finally, although the integration of climate projection data into a Dynamic System model has been an essential component in the preliminary evaluation of climate change impacts on NBS, there is a high uncertainty surrounding climate projections. Even though this research has stressed the importance of accounting for this uncertainty, more research is needed to understand the potential contribution of climate projections in NBS assessments.

6.3. Future research

Future research is oriented to overcome the limitations of this research presented in the previous section and, thus to improve the evaluation and assessment of NBS effectiveness. This study has provided an exhaustive evaluation of different NBS strategies to address different societal challenges, with special attention to hydrological extreme events. The benefits delivered by NBS vary across spatial and temporal scales but also among societal groups. For this reason, new participatory modelling methods and tools focusing not only on a subset of impacts but on an integrated view of the system are needed. Only this way, NBS could be meaningfully and effectively integrated into national and international development policies and adaptation actions.

Additionally, new methods and tools supporting the integration of climate change data with other socio-economic elements may contribute to the decision-making process of NBS design and implementation. The uncertainty associated with climate projections has several implications on NBS assessments that, if not correctly understood, may complicate and jeopardise the correct assessment of NBS performance.

Climate uncertainty is difficult to quantify and calculate. However, the proper communication and management of this uncertainty represent an opportunity to NBS decision-making. Therefore, new research strategies focusing on how to transform climate data (and its associated uncertainty) into a customised and tailored information to be used in NBS assessments and evaluations are needed.