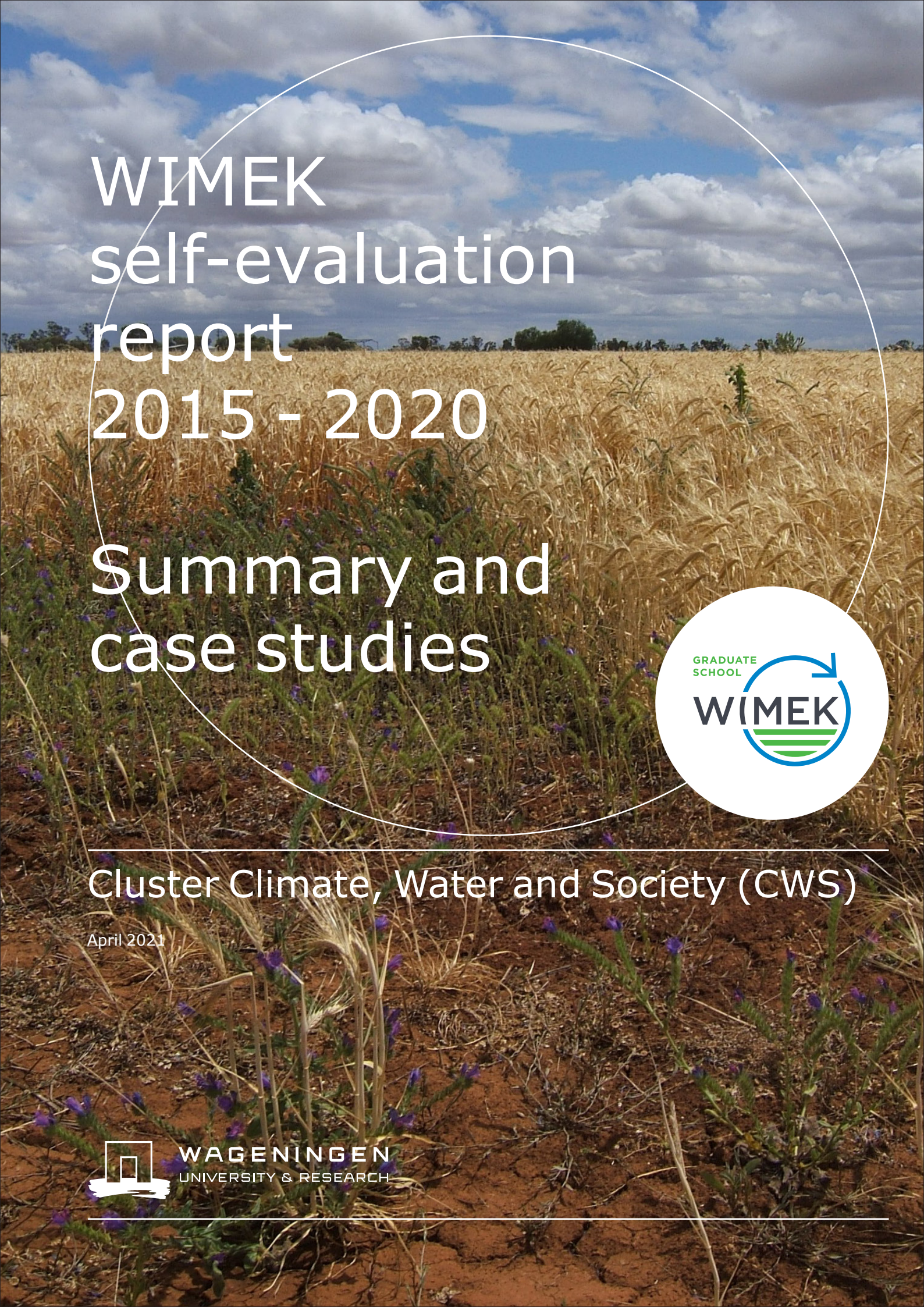

WIMEK self-evaluation report 2015 - 2020

Summary and case studies

GRADUATE SCHOOL WIMEK

Cluster Climate, Water and Society (CWS)

April 2021

WAGENINGEN UNIVERSITY & RESEARCH

Summary Climate, Water and Society

The WIMEK Cluster Climate, Water and Society (CWS) is a multidisciplinary research cluster studying environmental systems, with a focus on challenges related to water and climate (Figure 1). The **mission** of the CWS cluster is to improve our understanding and ability to represent natural and human dimensions of climate and water resources in a changing global environment. We aim for excellent disciplinary research in the atmospheric, hydrological, and ecological sciences combined with innovative multidisciplinary, interdisciplinary and transdisciplinary approaches related to climate, water and society. We develop new and novel solutions for a more sustainable world with sufficient, clean, equitably distributed and climate-proof water resources for people, food production and natural ecosystems. Our solutions aim to limit the impact on the environment by reducing greenhouse gas emissions, preserving biodiversity, increasing resilience against natural hazards, and improving environmental quality. Within CWS we thus generate **new knowledge** that improves our understanding of the impact of interventions across scales and disciplines, and link our research to capacity building, community action and policy initiatives aiming to generate a broad **impact on society**.

The research contributes to all **three grand challenges** defined by WIMEK. In terms of *Climate action* our science stimulates and enables mitigation and adaptation. In terms of *Managing our future biosphere* we develop strategies for sustainable use of water, the atmosphere, and ecosystems. In terms of *Advancing circular systems,* the CWS cluster investigates innovation towards closed water and nutrient flows and co-creating water-food-energy-environment and climate solutions. We highlight CWS research by presenting several case studies: Plastics in Nature and Society, Circular water systems, Climate Information Services, Sustainable Nutrient Management, Longitudinal dams, Water Justice, Weather Extremes.

The CWS groups employ in total 22 full professors, 25 associate professors and 30 assistant professors. In addition the cluster employs 26 post-docs and a total of 209 PhD candidates are associated with the cluster. The number of staff, our research capacity and number of PhD students have grown by about 10 to 20% over the last 6 years. Most of the growth has occurred over the last 3 years. Also for the coming years we expect to grow as a result of a combination of higher student numbers and successful acquisition of funding.

The accomplishments of CWS over the last six years include more than 1900 articles in peer reviewed scientific journals. More than 6% of the publications are highly cited (top 1%) and almost 30% belong to the 10% most cited articles. This implies that our publications have more impact than average (Field Weighted Citation Impact 2.4-3). The excellence in science is also shown by a large number of prestigious personal grants: over the last six years eleven NWO-Talent Programme grants and three ERC grants were awarded to CWS scientists. The fact that a large number of our early career scientists received these personal grants shows the capacity of the cluster to create an inspiring and fruitful environment, and the future potential. About 70% of our research capacity is funded by research grants and projects. Almost all of our PhD candidates are funded by external partners and funding bodies. The variety of funding sources guarantees a robust and future proof acquisition strategy. This includes capacity building initiatives through which a substantial number of African and Asian PhD students are funded. Our research has an important impact on society through (1) direct involvement of stakeholders, (2) contributions to science-policy assessments, (3) scientific advice to governments, water user federations, indigenous and farmer organizations, businesses and NGOs, (4) informing the general public, (5) co-creation of water and climate knowledge, and (6) the development of water and climate information services.

The CWS **strategy for the coming six years** is first of all to perform excellent research in the domain of climate, water and society. The strength of our cluster is in the quality of the research as well as in the societal impact. The opportunities for CWS lie in the increasing interest from the public and private sector for climate, water and society related problems. These problems ask for a transdisciplinary approach. Our cluster will take up this challenge by bringing together researchers from different disciplines. Identified topics that we aim to evaluate across different scales (landscapes, water basins, countries, continents and world) include, for instance (1) understanding of our future climate, and how to adapt to a more variable and extreme climate, (2) water scarcity in relation to climate change, (3) sustainable nutrient management in relation to the increasing demand for food while reducing environmental impacts. The cluster is well-situated and with a large capacity to respond to the demand of society for knowledge-based adaptation.

Case study: Longitudinal training dams in the river Waal

Summary

Longitudinal training dams with accompanying shore channels form an innovative way of controlling the channel geometry of the river, replacing traditional groynes. During an extensive pilot study in the River Waal, research was carried out into the effects on flow patterns, bed morphology and their management. This was investigated with a combination of an extensive field campaign and physical scale experiments in the Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics at Wageningen UR. The results reveal how the complex flow pattern at the entrance to the side channel behind the longitudinal dam depends on geometrical properties of the inlet section. In a participatory process where water managers and researchers work together with representatives of the inland shipping sector and the Royal Dutch Angling Association, important advantages are obtained for various stakeholders. These include an increase in the water depth during periods with a low water level, facilitating shipping, and a reduction of peak water levels, yielding higher safety against flooding.

Case Description

Background

Our large rivers have been extensively controlled by infrastructure that avoids bank erosion and sand accretion, by which the main channel has been reduced to a constant width. Traditionally, this has been realised by the construction of groynes. Longitudinal training dams (LTDs) with accompanying side channels form an innovative alternative measure of control (Figures 1 and 2). The aim of such LTDs is to reduce as much as possible the problems in the river network by splitting the river into a fairway, used for commercial shipping, and a side channel where recreation takes place and biodiversity increases. The concept addresses all the functions and interests: not only liveability and safety problems related to high water levels, biodiversity, water management and low water levels, but also the transport of goods, recreation in the floodplains, pleasure cruising and sport fishing.

Research Approach

To evaluate the potential of LTDs as an alternative for groynes, a pilot was set up in 2015 by Rijkswaterstaat, over a length of ten kilometres in the river Waal near Tiel. This pilot was monitored extensively. To be able to use LTDs as effectively as possible, attention was also paid to the dynamic equilibrium of the sandy river bed. As part of collaborative research with stakeholders and research institutions, knowledge was developed about the dominant physical processes for flow and sediment dynamics in the vicinity of the inflow of a shore channel, which resulted in developing handles for managing the river. In this context, WIMEK researchers have conducted field measurements and physical scale experiment at the Kraijenhoff van de Leur laboratory for Water and Sediment Dynamics.

Generic scientific knowledge was gained to optimize the design and management of LTDs in terms of navigation, flood protection and ecological rehabilitation. The physical scale model in a laboratory setting successfully mimicked the river bed morphodynamics observed in the field (Figure 3). Using the model, alternative designs of the subaqueous inlet geometry were tested, showing how geometrical properties influence the exchange of water and sediment at low and high water stages. At low water stages, the penetration of ship-induced waves and flow is reduced such that the disturbing influence of navigation on the flora and fauna in the riparian zone is minimized without disconnecting the side channel completely. At high water stages, flow may impinge on the banks of the river, behind the LTD, which either requires bank protection or an adjustment of the inlet geometry. A number of WIMEK projects have offered thorough understanding of the transport processes associated with an LTD based on field monitoring and laboratory experiments.

Stakeholder involvement

The work on hydrology and quantitative water management within WIMEK enhances the involvement of civil society in water management, for example through the participatory process called *WaalSamen* (WaalTogether). *WaalSamen* was initiated by the **Department of Waterways and Public Works** (Rijkswaterstaat) to promote sustainable and integrated river management by combining improvements for flood safety, inland shipping, nature development, discharge conveyance capacity, maintenance costs and public engagement in water management. Biannual stakeholder meetings are organized with the aim to explore opportunities, risks and uncertainties when monitoring the effects of the LTDs, which are attended by representatives of Rijkswaterstaat, Royal BLN-Schuttevaer, representing professional inland shipping sector, the Royal Dutch Angling Association and various research institutes. Partners within *WaalSamen* have all formally signed a cooperation agreement, which facilitates rapid data and knowledge exchange.

Link to education

WIMEK provides several courses related to understanding river flow processes, sediment transport and river bed morphodynamics. The ongoing rigorous changes the Dutch river landscape related to the introduction of LTDs offer inspiration for updating educational material. Students apply physical concepts and approaches that are used to describe and interpret phenomena of flow, sediment transport, bedform dynamics and regional scale channel morphology. Such phenomena are being illustrated and explained during lectures, working classes, and in practical experiments at the Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics. Students use numerical modelling tools to simulate and gain understanding of the physical processes at different scales.

Research Highlights

To monitor the active bed in physical scale experiments, a new monitoring system was developed using a laser line scanner that scans the entire bed of the laboratory flume from a computer controlled measurement carriage[1]. The flume experiments revealed the emergence of a sand bar where the flow diverges at the LTD inlet, and where the flow curves into the side channel[2]. A simple theoretical flow model was developed that can be instrumental in minimizing the occurrence of sand bars causing hindrance for shipping[3]. From a detailed analysis of repeated scans of the river bed, the interaction between migrating river dunes with the static bars was investigated, which explains flow resistance[4].

Impact

The pilot project has a positive impact on the ecosystem services of the river, including safety against flooding and the facilitation of navigation, recreational boating and sport fishing. The development of innovative measures to manage rivers helps Dutch consultancy companies to maintain their frontrunner position in river engineering. Through user committees, established by the Domain Applied and Engineering Sciences of the Dutch Scient Foundation (NWO), WIMEK researchers interact with consultancy companies such as Royal HaskoningDHV, Arcadis, Witteveen & Bos and HKV Consultants, and knowledge institutes such as Deltares. Knowledge transfer also takes place through dual appointments of PhD candidates and Postdocs, which emerge when research programmes align with longer term consultancy projects.

[1] De Ruijsscher, T. V., Hoitink, A. J. F., Dinnissen, S., Vermeulen, B., & Hazenberg, P. (2018). Application of a line laser scanner for bed form tracking in a laboratory flume. *Water resources research*, *54*(3), 2078-2094.

[2] De Ruijsscher, T. V., Hoitink, A. J. F., Naqshband, S., & Paarlberg, A. J. (2019). Bed morphodynamics at the intake of a side channel controlled by sill geometry. *Advances in Water Resources*, *134*, 103452.

[3] De Ruijsscher, T. V., Vermeulen, B., & Hoitink, A. J. F. (2020). Diversion of flow and sediment toward a side channel separated from a river by a longitudinal training dam. *Water Resources Research*, *56*(6), e2019WR026750.

[4] De Ruijsscher, T. V., Naqshband, S., & Hoitink, A. J. F. (2020). Effect of non-migrating bars on dune dynamics in a lowland river. *Earth Surface Processes and Landforms*, *45*(6), 1361-1375.

Illustrations

Figure 1: Aerial view on a longitudinal training dam in the River Waal.

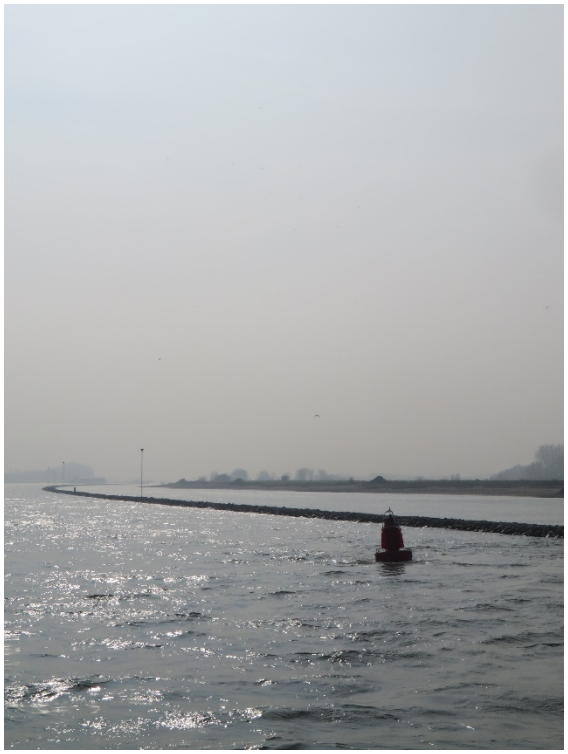

Figure 2: A longitudinal training dam seen from the fairway, where the buoy indicates the foot of the slope.

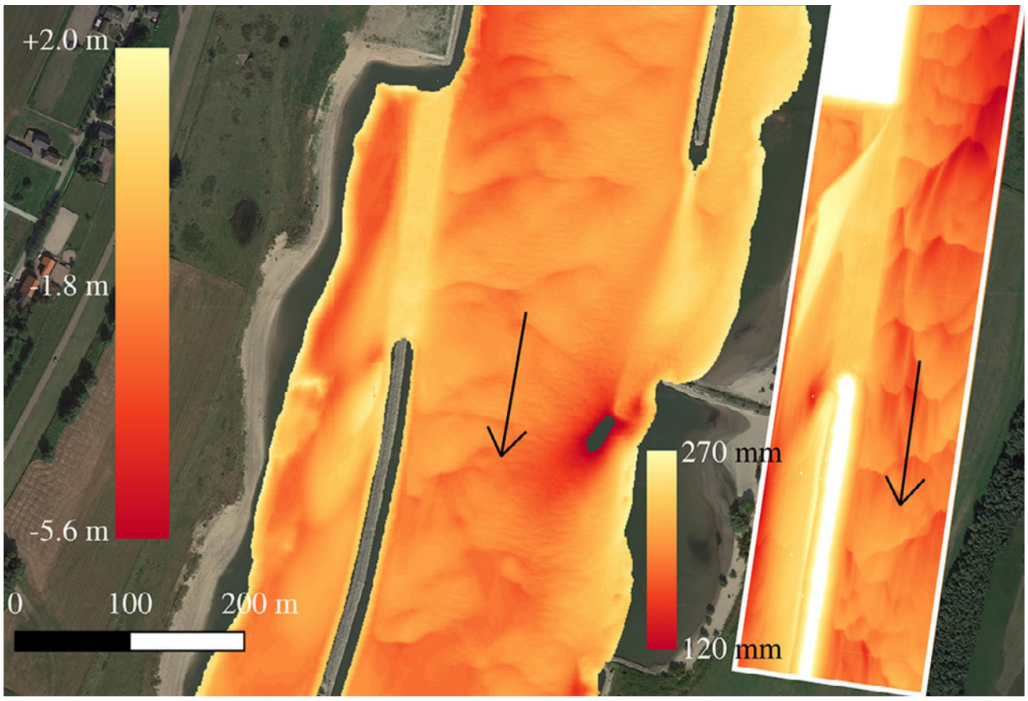

Figure 3: River bed morphology observed at the inlet area of the pilot study in the River Waal (left) and the corresponding physical scale model in a 2.6 m x 14 m current flume of the Kraijenhoff van de Leur Laboratory for Water and Sediment Dynamics, where sediment is being recirculated (right).

Case study: Water justice

Summary

Water resources management, today, primarily is about the interdisciplinary question of how to conserve, allocate and organize water among competing uses and users. Water's decreasing availability and quality, and its unequal distribution, lead to growing pressures on society and nature, threatening future availability and intensifying conflicts. At the same time, the water pollution problem is growing and, partly triggered by climate change, vulnerability to flood risks is increasing. This all raises new questions about differential and deeply unequal access to socio-environmental health, protection and security. To tackle such fundamental issues, the Water Resources Management (WRM) chair group has set up and coordinates the Water Justice / Justicia Hídrica Alliance. This worldwide network departs from the notion that in water governance issues, the questions of sustainability and ecological integrity cannot be dealt with in separation from questions of fairness, solidarity and justice. Combining these requires original and creative analyses that acknowledge that 'water' is as much a biophysical, as an engineering, as a social, symbolic and political issue.

An intercontinental network

The Water Justice alliance is a research, training and action network that brings together academic, policy-making and civil society institutions, and comprises of numerous scholars, professionals, students and grass-root leaders – in Latin America, North-America and Europe and expanding towards Africa and Asia. Since over a decade, beyond isolated projects, the alliance combines theoretical with comparative empirical research, with societal action in training and policy advocacy.

Based on a political ecology approach (Boelens et al., 2018), its research, education and action focuses on the pressing societal problem of how water rights and water-related decision-making are importantly distributed along lines of class, gender, cast and ethnicity -- in the global South, but often also in the North. In many countries contemporary water policies and legislative measures have tended to aggravate historically rooted inequalities rather than solving them. Small-holder irrigator communities, indigenous territories, or local drinking water committees -- often with context-based water practices -- are constantly overruled by bureaucratic water administrations, market-driven water policies, desk-invented legislation and top-down project intervention practices. Given such contradictions and complexities, water science, policy-making, and development interventions face the need to look for new, innovative strategies.

Combining multiple actions and projects (funded by NWO, USA-NSF, EU-ERC, and national governments and NGOs) through Water Justice we have organized research, congresses, as well as yearly courses for many hundreds of students, leaders and young water researchers, in the global South and North, bridging the two cross-culturally and stimulating transdisciplinary collaboration. To illustrate the content that is at the heart of the matter, below we copy one declaration out of many (Crow et al., 2014; resulting from the Water Justice congress that we organized at University of California at Santa Cruz). It triggered large scholarly and societal debate and new research and action projects on water-based inequities, and the ways to confront these.

Santa Cruz Declaration on the Global Water Crisis

At least one billion people around the world struggle with insufficient access to water. However, the global water crisis is not, as some suggest, primarily driven by water scarcity. Although limited water supply and inadequate institutions are indeed part of the problem, we assert that the global water crisis is fundamentally one of injustice and inequality. This declaration expresses our understanding of water injustice and how it can be addressed.

Crisis manifested *The global water crisis has multiple causes, dimensions and manifestations. One can observe the crisis in rural and urban areas across the global South. We have, for example, observed the following in our fieldwork:*

- *Peasants impelled to draw water from a spring, when large nearby pipes carry water to a mine in Peru*
- *People in Lesotho lacking access to clean drinking water as the government exports water to South Africa*
- *Community water managers excluded from the Nicaraguan water law*
- *Young girls in rural Nepal carrying water barrels up long mountain trails at night because climate change and hydroelectric projects have made village taps intermittent*
- *People bathing in a toxic river in Cambodia*
- *Residents of Dar es Salaam lacking access to water because the pipes fail to reach the informal settlements where most residents live*
- *Multinational agribusiness companies growing asparagus for export to the industrialized world, in the desert of Peru, with water taken from indigenous communities in the Andes*

Environmental injustices are not limited to the global South. They are also manifested in the global North where marginalized communities live in similar conditions. For instance, in California's Central Valley, running from Sacramento to Bakersfield, residents in low-income communities pay high prices for contaminated water for domestic and garden uses, and then have to buy bottled water to drink. Clean water from the Sacramento Delta travels in canals, bypassing these communities, for the benefit particularly of large-scale agriculture in Southern California.

These are a few of the ironies and inequities that make up the global water crisis. They are inequities of access, illustrations of exclusion and misuse, not the consequences of water shortage. They arise from the tendency of water to flow to the powerful and privileged, and often result from larger processes, including those highlighted in the full online declaration text.

***Remedies for injustice** We, the undersigned scholars, community members, activists, officials and citizens, declare that the principal form of the water crisis is not a shortage of water, nor failures of government, but the many injustices in access to, the allocation of, and the quality of water. The global water crisis is not likely to be resolved by the provision of more water. Redressing injustice is a more promising approach. That requires a critical rethinking and transformation in how water, water rights and authority are distributed. We recognize and build upon work that has gone before, including notably the work of the Justicia Hídrica/ Water Justice Alliance, and the work to implement the human right to water and to include water in corporate social responsibility certification initiatives.*

An understanding of the multidimensional causes of injustice, including historical decisions about infrastructure, unnoticed aspects of technologies, the diversity of ecological constraints, and the use of water to accumulate wealth and power, may each suggest possible openings for the redemption of inequities.

We suggest that this work can be furthered through some of the following portfolio of measures to mitigate inequities and to seek a wider water justice.

Policy dialogue could be instigated with diverse stakeholders to examine persistent water inequities. There could be harmonizing mechanisms to redress imbalances of power. This mode of action has been pioneered on a range of questions by community-based organizations in several countries. The object of such dialogues on water justice would be to open up long-ignored injustices for collective action by government, judicial process and social protest. Active and conscious efforts to include those who most directly experience injustices are important here.

Local actions, multi-scalar mobilizations and democratic assessment. Mobilizations by marginalized household members, water user families, environmental justice organizations, and grass-roots communities and federations often raise significant questions of water equity. Resistance to large hydroelectric and irrigation structures, for example, has sometimes led to multi-stakeholder and democratic discussion. On a global scale, the World Commission on Dams is perhaps the most substantive example of such discussion. Comparable initiatives are required to evaluate the influence of new combinations of physical infrastructure and the social and environmental choices they embody.

Academic and reportorial investigations. Both scholarly and journalistic investigations, in a wide range of academic disciplines and by those in the media specializing in questions of poverty or the environment, could examine the implications of established as well as new infrastructure and institutional boundaries. Water access could be understood under this framework but expanded to include multi-scalar processes and situations where boundaries are complicated by the politics of space.

Santa Cruz, California, 15 February 2014

The UCSC Declaration, as one illustrative action of a permanent series of collective research, training, education and policy actions by the Water Justice Alliance, fostered worldwide attention to and debate on water injustice questions and evidences. These point at the need to revisit prevailing water management and allocation practices, and reframe distributive issues regarding water quantity and quality. They show the need to transform the rationale and patterns of 'established' water knowledge development and 'institutionalized' intervention policies. They provide concrete inputs for working with a broader, more diverse, transdisciplinary and literally pluri-cultural water-vision and water-interest arena.

Thereby, the alliance examines how understanding, in particular, on-the-ground, 'living water rights' and 'water justice frameworks' are key to comprehending the diverse rationalities of water management, conflicts and solutions. The respective conceptual frameworks that the network has developed provide insight in the diverse ways in which water rights and governance systems are given substance, the complex ways in which sociolegal, cultural-political and technological systems interact, and how they materialize injustice or support greater fairness and democracy.

In the forthcoming five years, the Water Justice Alliance will deepen such academic questions and societal action with partners in North and South through two new, large projects: the ERC Consolidator Grant project Riverhood, and the INREF-funded project River Commons. In a WASS-WIMEK-WIAS collaboration among the CWS chair groups WRM (lead), HWM, and AEW; and other chair groups at Wageningen University including ELS, GEO, and AFI, together with local, national and global partner institutes, 13 PhD and 40 Master projects will investigate societal co-governance of rivers in Europe, Africa, Asia and Latin America. The projects aim to learn from grassroots experiences in situ and translocally, and build new conceptual and methodological tools for research, education and stakeholder interaction. They foresee supporting river co-governance initiatives at multiple scales through combining scientific excellence and societal co-learning.

References

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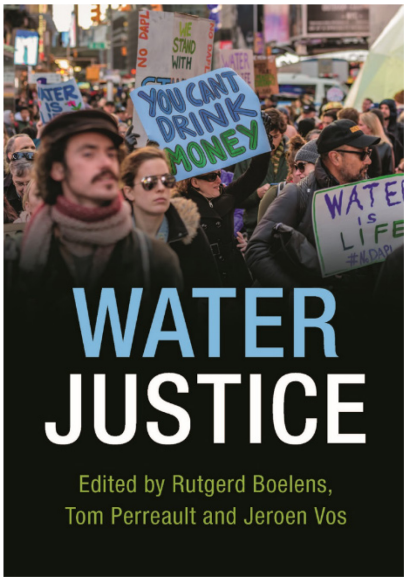
Crow, B., R. Boelens et al. (2014) Santa Cruz Declaration on the Global Water Crisis, *Water International* 39(2):246-261.



Cambridge University Press, 2018

CAMBRIDGE UNIVERSITY PRESS

Water Justice

Rutgerd Boelens, Tom Perreault and Jeroen Vos (Editors)

The Water Justice alliance (alianza Justicia Hidrica) has published a new book, with *Cambridge University Press*. Edited by Rutgerd Boelens, Tom Perreault and Jeroen Vos, the book *Water Justice* has contributions from renowned scholars worldwide. The book lays new ground for challenging current water governance forms and unequal power structures. It also provides inspiration for building alternative water realities. *Water Justice* is directed at students, researchers, and policy makers interested in water governance, environmental policy and law, political geography, and cultural anthropology.

About the book: Water justice is becoming an ever- more pressing issue in times of increasing water- based inequalities and discrimination. Megacities, mining, forestry, industry, and agribusiness claim an increasingly large share of available surface and groundwater reserves. Water grabbing and pollution generate poverty and endanger ecosystems' sustainability. Beyond large, visible injustices, the book also unfolds the many "hidden" water world injustices, subtly masked as "rational," "equitable," and "democratic." It features critical conceptual approaches, including analysis of environmental, social, cultural, and legal issues surrounding the distribution and management of water. *Water Justice* is illustrated with case studies of historic and contemporary water injustices and contestations around the world.

Case study: Weather Extremes

Summary

The Climate, Water and Society (CWS) cluster investigates and teaches challenging topics related to climate change and their adaptation. *Extreme Weather* case study involves multiple fields represented within CWS, ranging from monodisciplinary studies to research that requires crossing disciplines. Our research aim is to gain detailed understanding of the fundamental coupled processes that lead to extreme weather under climate change conditions. By advancing in this understanding, we are in a position to improve representations of key processes in the hydrological cycle, such as evaporation, clouds and precipitation, and the subsequent reduction of uncertainties in the projections of weather extremes calculated by regional and global climate models.

Potential impacts of extreme weather encompass, among others, fire, floods, air pollution, and impacts of renewable energy. Here, we present three examples of CWS studies to extreme weather that act at different time scales: days (clouds, precipitation, flooding), weeks (heatwaves) and months (droughts) (see infographics). The first example is on cloud spatial organization, and its potential impact on precipitation. The second example is on the role of land-atmosphere interactions occurring at the local scale that appear to be a key factor in enhancing the intensity of heatwaves and droughts. The final example shows how we transfer this knowledge in an interdisciplinary MSc course. In all these examples, active interaction of the various CWS groups has been key. We foresee that the case study "Extreme Weather" will play a role in the cooperation between the different CWS disciplines in the coming years, both in research and in education.

Case Description

Background

Extreme weather poses major challenges for society. These challenges include understanding and predicting its severity, frequency and impacts. Within the cluster for Climate, Water and Society (CWS), fundamental understanding of the link between climate change and extreme weather plays an important role in research and education. The new "Extreme Weather" initiative stimulates multidisciplinary collaboration among CWS groups, by setting up PhD projects involving multiple chair groups and joint MSc courses. The general approach starts with the recognition that there is a need to integrate natural science disciplines and to study various time-scales to understand and represent extreme weather in models. We present here three examples that are currently carried out at CWS. Related to intense precipitation, occurring at time scales of hours and days, the research aims to identify changes of cloud organization that may be triggered by climate change. In researching heatwave extremes, happening on timescales of days to weeks, we focus on analysing how the enhancement of heatwaves is driven by abnormal phenomena occurring in the atmosphere and on the land. This connects to droughts, with typical time scales of weeks to months. By selecting droughts as a central theme in the starting course of the master program Earth and Environment, MSc students learn that hydrological, meteorological and soil processes need to be integrated in order to understand and quantify long and short-term changes in the exchange of energy, water and carbon between the pedosphere, hydrosphere, biosphere and atmosphere.

Concrete Collaborations

Within the CWS cluster, there are active collaborations among groups on poorly understood processes in the global and regional hydrological cycle. A first collaboration is on the largest uncertainty in climate projections: the role of clouds in regulating climate. In a joint PhD project, the Aquatic Ecology and Water Quality Management (AEW) and Meteorology and Air Quality (MAQ) groups investigate how clouds organize in the trade wind (sub-tropics) region, which is highly sensitive to climate change. Here, we combine the expertise of AEW in studding complex system using a dynamic system approach to the expertise of MAQ on physical processes associated to clouds.

The main aims are to analyse whether there are multiple states of cloud organization and whether critical transitions between these states can be expected in a warming climate. A second collaboration between the Hydrology and

Quantitative Water Management group (HWM) and MAQ, studies enhancements of heatwaves due to processes acting at a *local scale* and the role of *large-scale* atmospheric circulation in these enhancements. It was shown that accumulation of heat in the lower layer of the atmosphere leads to enhanced land desiccation. In joint publications by the HWM, MAQ, and WSG groups in 2018 and 2020 it is shown that mid-latitude heatwaves in early spring impact summer droughts, while tropical wet season droughts impact consecutive dry season heat. These studies attempt to quantify links between heatwaves and droughts, and place emphasis on the multi-scale and multi-process character of extreme weather. In all these studies, the outcome is a quantification of the main relevant processes and an improvement of their representations in weather, hydrological and climate models.

Joint Research Approach

What links the studies presented above is a combination of comprehensive observations collected at global and regional scales and of a hierarchy of weather and climate models coupled to the land surface, that include hydrological and plant physiological processes. In the project on cloud organization, we make use of a large amount of remote sensing data to design an effective and objective method to quantify cloud organization. This innovative method based on principle analysis could be used in the future to analyse the degree to which weather and climate models manage to reproduce similar states of cloud organization as observed in nature (digital twin approach). Within the project of enhancement of heatwaves by local land-atmosphere couplings, we employ surface and atmospheric observations and conceptual models. The drought studies rely on long remote sensing and operational ecosystem/surface networks that sample fluxes between land and atmosphere. CWS groups actively cooperate within these networks, e.g. with the Loobos temperate forest site managed by MAQ.

Stakeholder involvement

The improved representation of extreme weather in operational weather, climate and hydrological models is of prime importance for short-term predictions of extreme weather (where can damage be expected?) and long-term predictions related to climate change (e.g. relevant for insurance companies). Our research is at the forefront of representing important *coupled processes* in these models. Our main stakeholders are international research institutes that develop and operationalize weather, hydrological, and climate models. Active collaborations exist with the European Centre for Medium-Range Weather Forecast (ECMWF, https://www.ecmwf.int/), the KNMI in the Netherlands, commercial weather and sustainable energy companies like DTM and Whiffle, and applied research institutes working in the field of water cycles and subsurface, i.e. DELTARES (https://www.deltares.nl/en/).

Link to education

At CWS, special emphasis is placed on transferring research methods to students. A representative example is the course *Interdisciplinary Topics in Earth and Environment*. This course, which is taught in the first year of the MSc programme Earth and Environment, devotes a large amount of time to why, when and how droughts are controlled by processes in the pedosphere, hydrosphere, biosphere and atmosphere. Through a combination of theoretical lectures, practical tutorials and discussion sessions, students learn about interactions between these different spheres. The students compile all this information into a portfolio, including critical reviews of peer-published papers. As a final assignment, they are required to draft a research proposal that places emphasis on the multi-scale and multi-disciplinary aspects of the research on droughts.

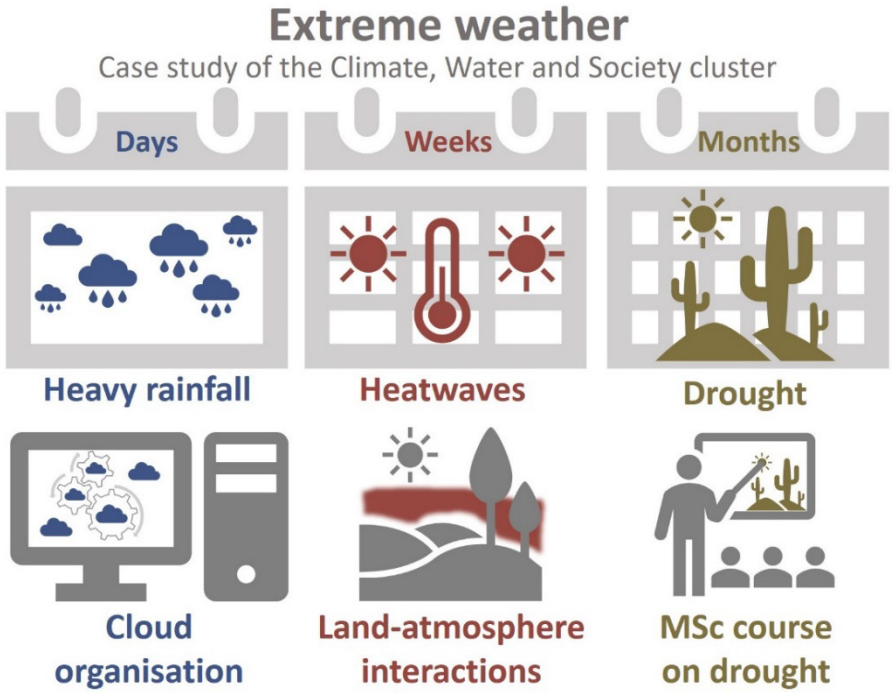
Research Highlights

The most representative papers of our research[1] show the relevance of our approach. We have selected papers in which three groups of the CWS are actively involved: Aquatic Ecology and Water Quality Management (AEW), Hydrology and Quantitative Water Management (HWM) and Meteorology and Air Quality (MAQ). These papers illustrate the richness in methods that emanate from collaboration and the joint use of observations and models. For instance, in the paper of Janssens et al. (2020) system dynamic theory (AEW) is used to extract information on the cloud fields (MAQ). Other papers show the role of hydrology in controlling desiccation and evapotranspiration (HWM). Understanding these hydrological processes appears crucial to study atmospheric feedbacks that enhance heatwaves and droughts.

Impact

Human society is highly impacted by extreme weather with dramatic effects on natural and urban ecosystems. Among the most important impacts, water scarcity and flooding, disruptions in the food chain, enhancing of human stress by worsening of the air quality and fires are in direct relation with the current research and education activities carried out at the CWS cluster. By improving our understanding of the causes of heavy precipitation, heatwaves and droughts we improve the predictability of extreme weather in climate and weather models coupled to hydrological and land conditions. By so doing, decision makers can base their decisions on better data which will subsequently improve planning and reduce the economic costs associated to extreme weather.

Infographic of the case study on extreme weather at the CWS cluster



Main extreme weather studies carry out within the CWS cluster (upper panel) and their characterization as a function of the time scales. The specific investigations focus on specific attributions to extreme weather like cloud organization and land-atmosphere interactions, or the education link to the MSc course are show below.

[1]

- **Benedict I, van Heerwaarden C.C. van er Linden E., Weerts A. H. Hazeleger W. (2018)** Anomalous moisture sources of the Rhine basin during the extremely dry summers of 2003 and 2018. Weather and Climate extremes
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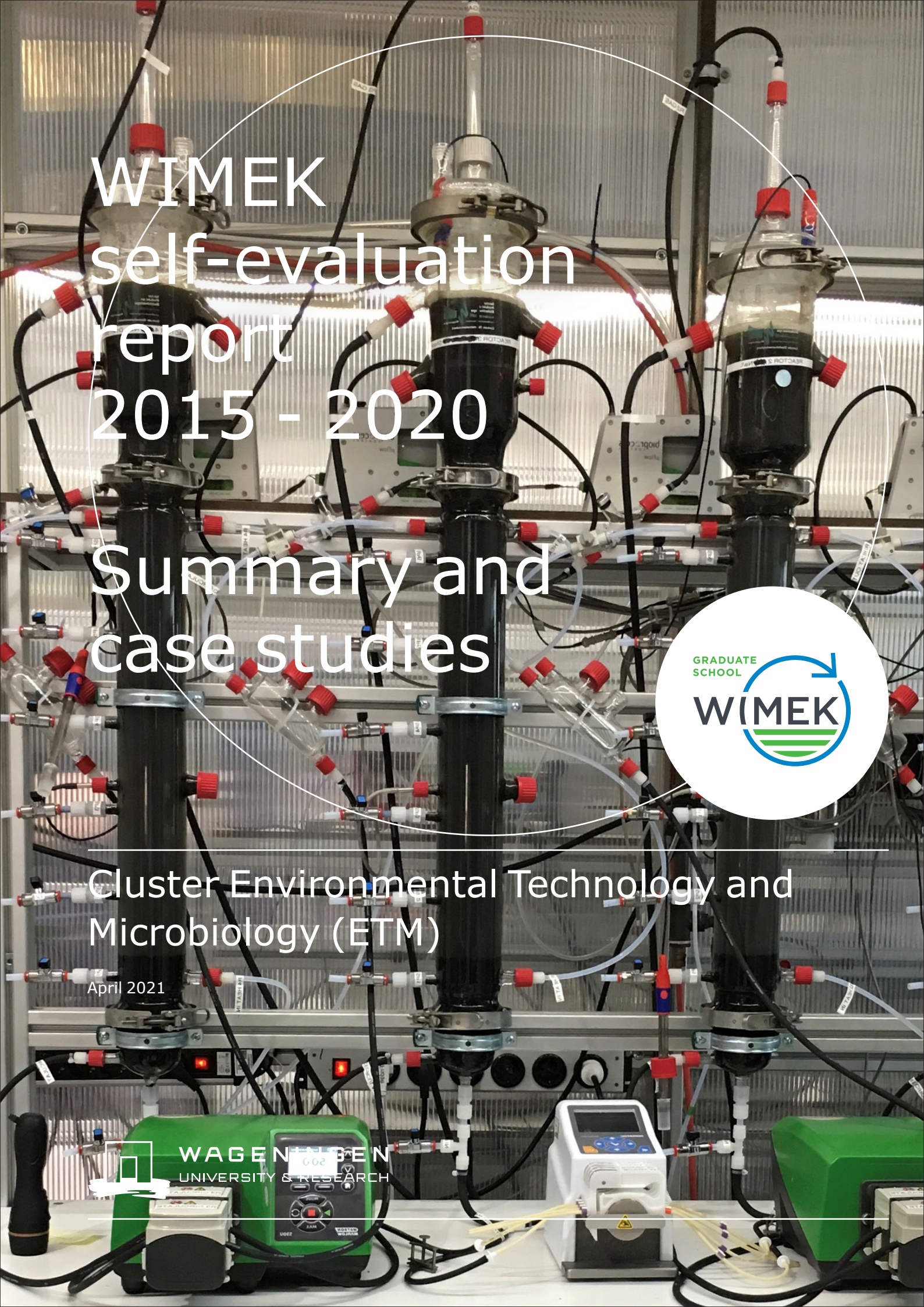

WIMEK self-evaluation report 2015 - 2020

Summary and case studies

GRADUATE SCHOOL WIMEK

Cluster Environmental Technology and Microbiology (ETM)

April 2021

WAGENINGEN UNIVERSITY & RESEARCH

Summary Environmental Technology and Microbiology

The mission of the cluster **Environmental Technology and Microbiology (ETM)**[3] is to combine fundamental and applied research to find solutions for a more sustainable society. ETM focuses on understanding and developing processes to supply the world's growing population with sustainable water, platform chemicals, minerals, and nutrients. ETMs' prime focus is on the societal challenge *Advancing circular systems: Inclusive innovation towards closed water, nutrient, and material flows*. In our vision this includes the focus points of the green deal policy of the Netherlands and EU: climate change, water quality, and circular economy.

The team of ETM comprises three chair groups combining scientific excellence in fundamental, technological, and engineering research. The chair of microbiology (MIB) is led by prof. Thijs Ettema as the successor of Prof. Willem de Vos per January 2019, the chair in Biorecovery (BRC) is led by prof. Cees Buisman, and Environment and Water Technology (EWT) is the chair of prof. Huub Rijnaarts. The past six years ETM has expanded, due to increased interest of society in circularity and increasing popularity among students. The expansion includes research, education, and infrastructure thanks to combined subsidiary and societal partner funds. ETM currently has 30 staff members, and 85 PhD's and Post Docs. ETM is balanced in diversity (discipline, gender, age, and cultural background) and has adopted values as integrity, cooperativity, creativity, and originality, while providing a safe working environment.

The research infrastructure of ETM is a great asset that includes the ModuTech Physical-Chemical, Biological and Nature Based Technology Centre, and the Microbiome Centre. These were established by investments through multiple internal and external funding sources. Currently a new facility is being built for defined and open system microbial culturing and biotechnology development (UNLOCK) and will soon be available for ETM and (inter)national visiting researchers. The SIAM program enabled ETM to train a new generation of microbiologists and anaerobic biotechnologists.

The accomplishments of ETM include an output of 100 peer reviewed papers a year, providing the scientific foundation for effective and occasionally game changing environmental solutions in society. Collaboration with private and public partners, such as drinking water companies, water authorities and companies, including spin offs, that focus on commercialization of ETM's technologies, has ensured societal impact. WETSUS and NWO programs provided important focus in such collaborations. ETM works in three research themes. *Theme 1: Renewable Chemicals*. Here ETM develops new biotechnological processes which allow transformation of waste streams into compounds with added value. At the base of this lies new fundamental knowledge on microbial interactions in 'synthetic co-cultures' and enriched open microbial systems. One result is Chaincraft, the only company producing at large scale medium chain fatty acids from organic waste. *Theme 2: Quality of Water*. Here ETM developed technologies to remove organic contaminants, such as pharmaceuticals and pesticides, and salts from water, ensuring environmental and human health, as well as increasing circularity in water and nutrient cycles. Understanding and application of natural and synthetic microbiomes in nature-based technologies, and physical-chemical principles for electro-membrane technologies offered resilient powerhouses for sustainable technologies. Various pilot projects for domestic and industrial water treatment have been established. *Theme 3: Rural-Urban Balances*. This is studied by the Urban System Engineering team as a link between the developed technologies and the societal demand by a suite of modelling tools for mapping resource flows and identifying opportunities for technology implementation in urban-industrial-agricultural settings and connections. Herein we include social and economic sciences, and relevant stakeholders within society. A strong collaboration exists with the Amsterdam Institute of advanced metropolitan solutions – AMS. Insight from this group gives new impulses to innovations of the technology groups of themes 1 and 2.

The strategy for the coming six years. The coming decades, our field will remain important to support society to cope with multiple environmental crises. ETM will build on its strong team and infrastructure with a policy to further develop diversity the coming six years at higher staff levels. The existing three themes of research are at the centre of our field and will be continued, interconnected, and deepened, and no new themes are planned for sake of keeping focus. Smart and selective collaboration in the Netherlands, EU and the global south is foreseen to enhance ETM knowledge and societal impact further to provide sustainable solutions for society.

[3] In the WIMEK SER the cluster is named ETE-MIB, which is the same as ETM used here in the cluster report.

Case study: Renewable resources for a circular economy

Waste and wastewater systems were initially designed and implemented to protect humans and the environment from pollutants. Nowadays, circularity is an additional design criterion for systems that convey materials in our society. This new criterion implies that, after use, materials should remain available for societal reuse and that there should be minimal value destruction. This striving for circularity is driven amongst others, by the rising awareness that natural resources cannot endlessly be drained from the earth without jeopardizing planetary health, regardless of the timing of specific scarcity threats. Both societal and ecosystem stability are depending on establishing a circular economy. Phosphorous is an element for which scarcity and related geopolitical issues are widely known, but exhaustion of other elements, such as copper and zinc, is also a threat. Furthermore, circular material cycling can prevent environmental impacts often associated with the current linear material use.

We evaluate the options to restore the cycling of resources (water, carbon, nutrients, minerals), especially their recovery from waste streams, by combining microbiology and physical-chemical processes.

An important waste stream in our society is domestic wastewater. Current wastewater collection and treatment systems were primarily designed to protect humans and the environment from potential harmful effects of sewage. They were not primarily aimed, and are not well suited, for the recovery of the valuable resources sewage contains. Organic matter in wastewaters is often removed via the activity of aerobic microorganisms, resulting in carbon release to the air in the form of CO_2. The forced aeration taking place at the treatment plants consumes large amounts of energy, whereas the organic matter itself is a potential source of energy. Additionally, the nitrogen and phosphorous are traditionally regarded as pollutants and not as resources - a vice not a virtue. A lot of effort is spent on removing these compounds from sewage, whereby the nitrogen is released as N_2 to the air. At the same time society is producing artificial N-fertiliser from the air through the energy-intensive Haber-Bosch process. Municipal wastewaters also contain the other nutrient elements present in human excreta like potassium, magnesium, selenium, boron, etc. Last but not least, sewage contains the most essential resource for all life on earth: water.

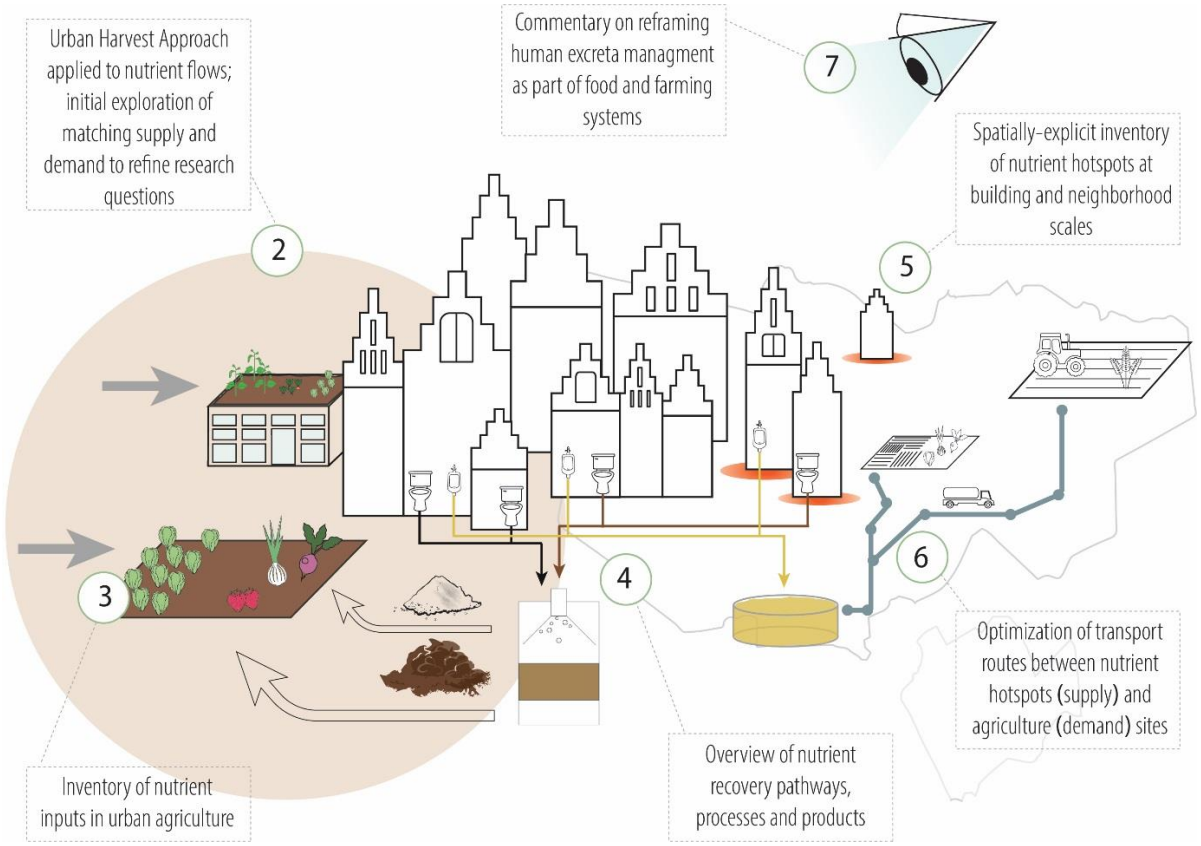

Figure 1: Overview of new sanitation concepts connected to agriculture

Since about 20 years, we work on new concepts with circularity as a prime design criterion besides environmental and hygienic safety. This has led to various new overall sewage system concepts, with the common characteristic that dilution of resources is prevented as much as possible by separating human excreta (black water), which carry the bulk of organic matter and nutrients, from dilute grey water originating from the remainder of household activities such as showering and laundry (Figure 1). In the Netherlands, this concept is known as Novel Sanitation. In these systems, industrial wastewaters are also separately managed. Separation at source has the added advantage that excreta – containing the nutrients originating from food - are not mixed with pollutants from other streams, such as personal care products, industrial heavy metals, flame retardants and microplastics. Thus, the challenges to make micropollutant-free nutrient products from the concentrated flow of excreta, containing the nutrients originating from food, are fewer. Compared to sewage, blackwater flows are at least 10 times smaller. Recovery of resources from this concentrated flow is much more efficient, as well as the removal of unwanted compounds such as the mentioned micropollutants. In a new breakthrough concept developed by us, highly concentrated blackwater is digested at high temperature to simultaneously produce biogas and inactivate pathogens, a step toward reuse of the resulting stream as an organic fertiliser product. The high temperature anaerobic digestion is currently being further developed and demonstrated in the framework of Horizon 2020 project Run4Life in which we are a partner.

In Europe, Novel Sanitation systems are currently implemented in new residential areas of up to 2000 inhabitants. At these sites state-of-the-art and innovative technological solutions are integrated, aiming at integrated optimal resource recovery while ensuring human and environmental safety. Countries with executed and planned projects include Canada, Sweden, Germany, Belgium and the Netherlands. Figure 2 shows the four demonstration sites of the Run4Life project. In this project Novel Sanitation is demonstrated at full scale, showing that the concept is mature.

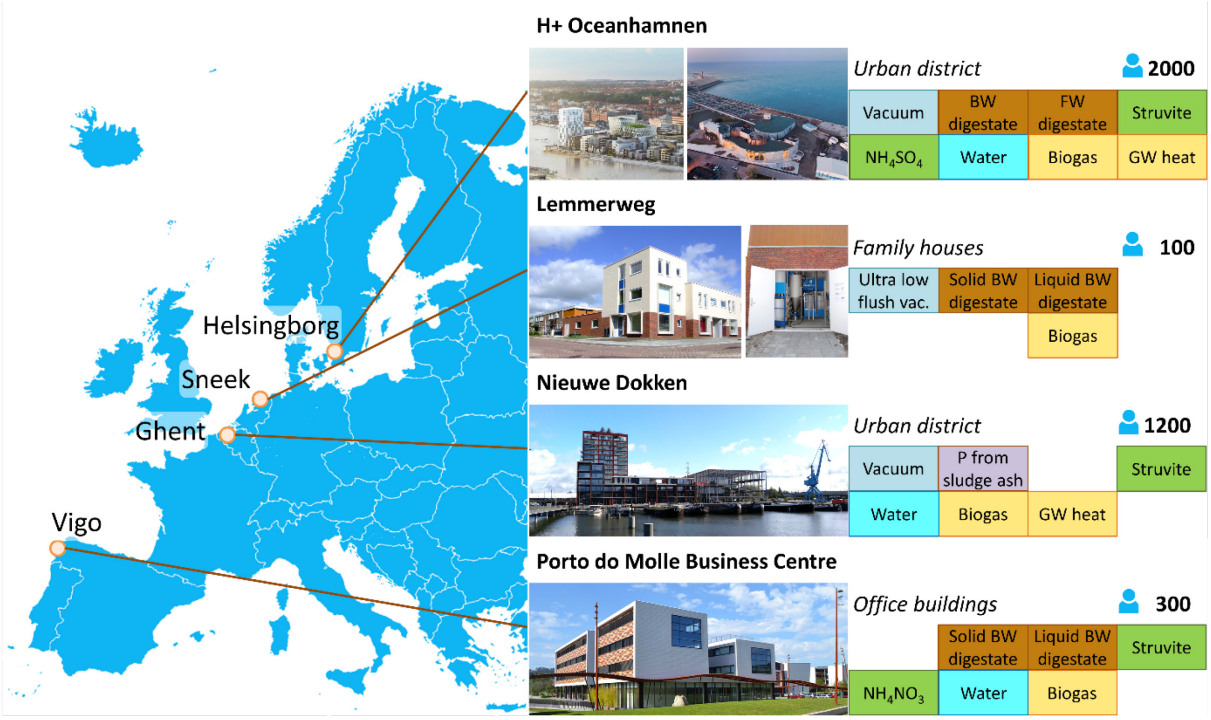

Figure 2: Overview of the four demonstration sites of the Horizon 2020 project Run4Life and the resources recovered at each site (www.run4life-project.eu).

The realization of a circular economy also entails finding alternative sources for a wide range of carbon-based chemicals that currently originate from fossil sources or environment-degrading agricultures such as palm oil industries. Microbial chain elongation is an alternative method developed by us to produce 'oily' carbon-based chemicals. It can be employed to recycle organic waste streams and to sequester CO_2 to form products such as isobutyric acid, n-caproic acid and n-hexanol. More recalcitrant wastes can also be valorised by introducing a gasification step – a high-temperature process that transforms any type of carbon material into syngas, a mixture of CO, H_2 and CO_2. Syngas can further be fermented to several products, including n-caproic acid and n-hexanol. Further development of these technologies facilitates a sustainable transition towards a more circular economy. Microbial chain elongation

fermentation from organic waste streams is currently undergoing its first full-scale implementation at a demonstration factory in Amsterdam by ChainCraft B.V., an ETM spin-off company.

More stringent legislation on both wastewater discharge and waste storing facilities and an increasing scarcity of resources leading to higher metal prices creates a need for improved metal removal and recovery technologies. The clusters sulphur reducing technology is applied in the Dominican republic to recover copper. In order to extend the potential of this technology, we are currently studying the biological reduction of sulphur by extremophilic microorganisms, growing at low pH and high temperature. Microorganisms that reduce sulphate and elemental sulphur to produce sulphide are promising for solving circularity challenges in several industries such as viscose production, tanneries, and the mining and metallurgical industries. Sulphide precipitates heavy metals, which can thereby be separated from the liquid and recovered. Such a microbial process is for instance successfully applied at the zinc smelter plant of Nyrstar (Budel-Dorplein, the Netherlands) to avoid zinc pollution and minimise zinc losses.

Figure 3: Left: the zinc factory in Budel, the Netherlands where metal recovery has been implemented. Right: the shore of the Rio Tinto in Spain, where gold, silver, copper and other metals have been mined for centuries. The river's red colour is due to the high amounts of dissolved metals and its high acidity (pH=2).

The possibilities for biorecovery concepts to contribute to recovery of resources, upgrade of materials, production of chemicals, protection of water sources, reduction of energy and use of chemicals are as diverse as the bacteria that are employed in such processes (Figure 3). The possibilities nature has to offer are abundant and have far from dried up. As previous results have demonstrated, biorecovery concepts we created have now developed into full-scale technological solutions, and others will be realised in the future.

Case study: Salt and urban water as a resource

Summary

Shortage of fresh water is increasingly damaging industrial, agricultural, and drinking water sectors and ecosystems, especially in delta areas suffering from climate change driven droughts. Industrial companies consume large amounts of fresh water, and have adopted sustainability policies aiming at reducing their fresh water footprints. ETM researchers led the past five years the Water Nexus consortium of industries, research institutes, technology developers, consultancies, governing institutions and universities, to help industry to use treated salt wastewater and brackish groundwater as a resource, instead of fresh water. Various examples from practice were provided by industrial stakeholders as a starting point for the development of modelling tools and technological treatment trains to enable salt water (re)use. Modelling tools were designed to support circular water management in industries and the sustainable extraction of brackish water from the subsurface for industrial use. One treatment train was developed for highly saline industrial effluent rich in organic material, and another for treating moderately saline wastewater and reusing the treated water in industry, i.e. for cooling towers, or in agriculture. Seven ETM PhD and Postdoc researchers joined this co-creative environment and while co-designing efficient and scalable solutions, they obtained new scientific insights in the mechanisms underlying a variety of water treatment technologies and water grid models. This practice-science connectivity yielded technological and modelling outcomes that are now used in practice, 30 scientific publications, inclusion of new scientific modelling and technological principles and practical examples in student courses and 40 BSc/MSc graduation theses.

Background

Urbanized delta's around the world, such as the Netherlands, Southern Vietnam and Bangladesh, experience increasing fresh water scarcity problems. This is the result of increased water consumption, climate change related droughts and saltwater intrusion. This results in seasonal fresh water shortages for ecosystems, agriculture, industry and even municipalities, leading to increasing economic and ecological damage. We aimed to evoke a paradigm shift in water sourcing and use, i.e. to consider saline (waste) water no longer as a threat but as an alternative water source, alleviating the pressure on fresh water resources. (Re)using saline water, and other alternative water resources such as rainwater or wastewater treatment plan effluents requires innovative technological solutions and strong collaboration with industries, consultancy companies, drinking water companies, technology developers and government. In a co-creative way, this group of stakeholders and scientists selected three domains that demand new knowledge and tools to enable the use and reuse of salt water and other alternative waters as a resource:

1. **Modelling tools for use of salt water and other alternative water resources** were identified as lacking, and these are needed to support salt water reuse and circular water management.

Technologies for treatment of saline industrial wastewaters with

2. **high amounts of organics**. These are often encountered in dairy, leather, and textile industries.
3. **low amounts of organics**. These are often found in cooling tower draw down and produced waters in chemical and petrochemical industries.

Research objectives

The research objective of Water Nexus was to provide blueprints for future water management based on the use of saline water in fresh water stressed delta-areas using situations from practice provided by the consortium partners as living lab studies. These blueprints integrated new models, tools and combined water treatment technologies (technology trains) that allow matching the demand and supply of water between water users and water producers, in quantity and quality.

Research approach

Various examples from practice from industrial sectors consuming large volumes of water with different characteristics formed the basis for the development of new technologies for saline water treatment and re-use management. The providers of the examples from practice, and Water Nexus partners grouped together to co-create innovative technologies for saline water treatment and modelling tools for circular water management, on three main topics:

***1. Modelling tools for use of salt water and other alternative water resources**:* In these studies, the fresh water scarce region of Zeeuws-Vlaanderen (The Netherlands) is taken as the practical example. Currently, millions of m^3 of fresh water per year are imported to this region but this supply has become uncertain due to increasing droughts occurring in the whole Rhine-Meuse-Scheldt delta region. Alternative resources such as brackish groundwater and collected residential rainwater can ensure, at least partially, the provision of water to local water users, such as industries as DOW Benelux, or agriculture. Therefor a toolbox was developed to model and design such alternative resource based water grids. One tool connects available water sources, including brackish groundwater, with water users, considering both water quantity and quality requirements. Herein limits for extraction were taken into account to prevent damage to nature and salt water intrusion from the sea. Local decentralized water supply networks were designed using the model, connecting users with fresh and brackish groundwater sources (Fig. 1).

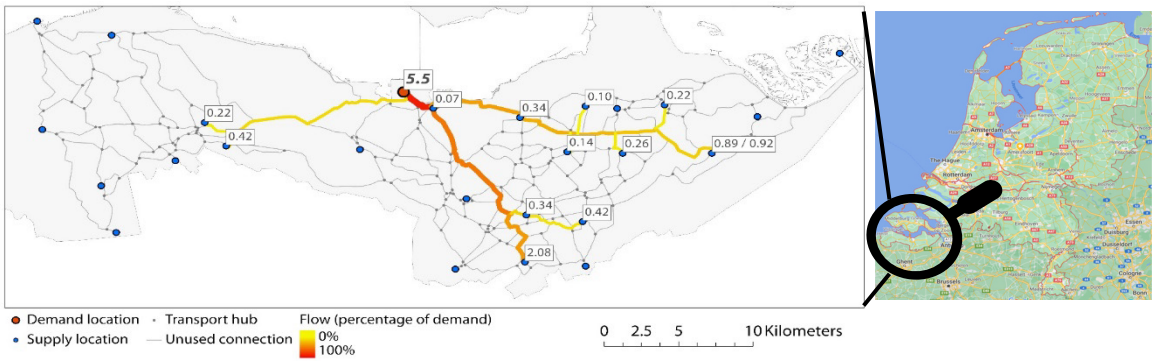

Figure 1: Regional water supply network (smart water grid). The model selects available water sources, considering available water quantity and quality and regional landscape characteristics, and calculates the required pipeline infrastructure for the lowest costs.

The second tool designs water treatment trains, based on water quality requirements of the users, and the quality of available sources. These trains are receiving increased interest for their potential to meet water standards while minimizing negative externalities. However, determining which technologies to combine and predicting their performance is both difficult and situation/context specific. We developed a tool to compare desalination treatment trains based on the same input requirements.

***2. Technology train for saline industrial wastewaters with high amounts of organics**.* The wastewaters generated by many agro-industrial sectors often contain high concentrations of both salt and dissolved organic materials. To consider these streams for further re-use, firstly the organic pollutant level needs to be decreased. Typically for highly saline wastewaters this is done via physical-chemical and/or aerobic biological processes that are disadvantageous since these require high amounts of energy and/or chemicals. A more sustainable alternative would be the application of compact anaerobic bioreactors, as first step in a treatment train. In this process microorganisms convert the organic pollutants into an energy rich biogas consisting mainly of methane (CH_4) and carbon dioxide (CO_2) and little amount of energy is required for operation. However, salts negatively impact microorganisms activity and granulation, hampering anaerobic treatment of saline waters. The ETM team proved that these two problems can be resolved, which was achieved by tuning the process conditions of lab-scale reactors at ETE and linking the reactor performance with a thorough analysis of microbial communities developing in them by MIB (Fig. 2).

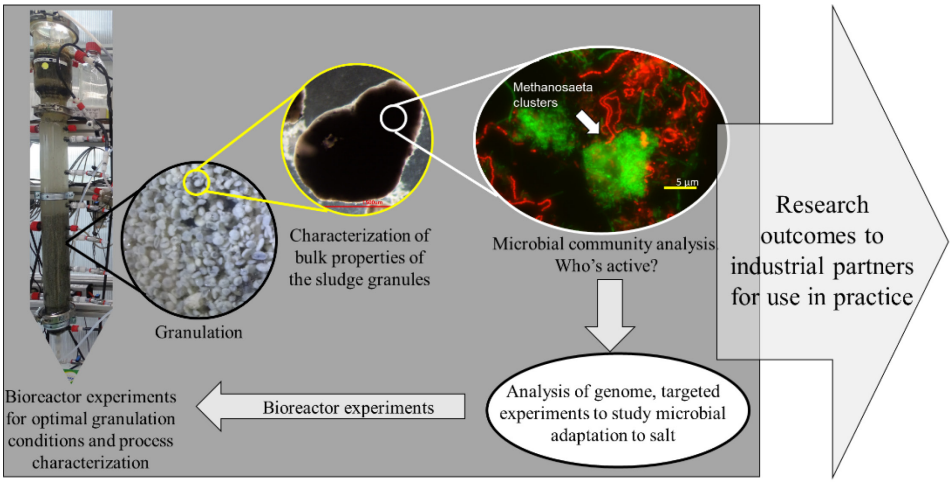

Figure 2: Research that made anaerobic granular sludge technology work for waters with high salinity.

Successful granulation, together with mechanistic insights into microbial adaptation to salt, allowed to improve two full-scale treatment plants in operation in cooperation with technology developers Paques, Nijhuis Industrial Technologies and Royal Haskoning-DHV. An energy efficient technology train of a set of Anaerobic-Aerobic granular sludge reactors was designed in collaboration with Delft University of Technology, one of the other university partners of Water Nexus.

3. Technology train for saline industrial waste waters with low amounts of organics. During cooling, water is sprayed at the top of a cooling tower and largely evaporates; the water that remains at the bottom is enriched in salt. To make this wastewater reusable, industrial conditioning chemicals and natural organic compounds need to be removed and followed by desalination. The optimal set of technologies for such a treatment train was not available at the start of the project. Therefore various technologies were tested by the ETM team of researchers, in collaboration with Dow Benelux, Evides Industrial Water, Plant-E, Magneto and Wageningen Food & Biobased Research. The first technology tested was a constructed wetland to remove conditioning chemicals from the cooling tower wastewater. Various different conditions and configurations were investigated in the ModuTech facility of ETM in Wageningen, using artificial wastewater, and effective removal of conditioning chemicals was demonstrated. This led to the design of a constructed wetland pilot, that was installed and operated on-site next to the cooling tower of DOW Benelux in Terneuzen, and which was tested for its ability to remove organic conditioning chemicals from the cooling tower wastewater in practice (Fig 3).

Figure 3: Constructed wetland pilot in Terneuzen, the Netherlands, effectively removing conditioning chemicals from cooling tower wastewater.

Further steps in the treatment of the cooling tower wastewater are needed to make reuse possible. Many investigations at ETE and with other Water Nexus partners resulted in a coupling of different processes and the design of a treatment

train, using newly developed nanofiltration membranes (Fig. 4). The concentrate stream of the nanofiltration was subjected to electrochemical oxidation to remove organic carbon, and the permeate was fed to a reverse osmosis process to desalinate the water and make it ready for reuse in the cooling tower.

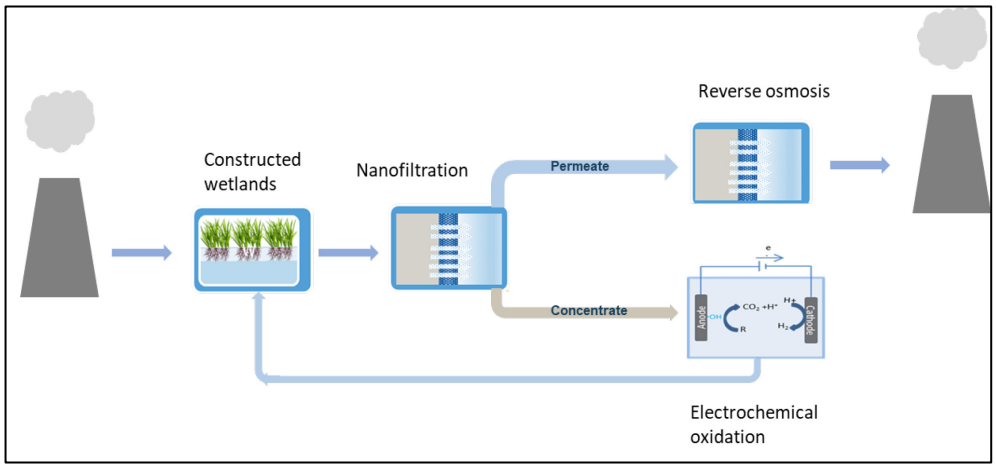

Figure 4: Technology train developed with and tested for Dow Benelux, to make cooling tower wastewater reusable.

This integrated set of technology studies provided essential insights in relevant process parameters of the different steps of treatment. Such a process scheme can be used for making cooling tower wastewater reusable, as was demonstrated in practice at the site of DOW Benelux. A technology set of a similar scheme can make water streams from petrochemical (and other) industries suitable, for instance, for irrigation in (non-food) agriculture. This is currently further investigated for "greening the desert" programs in the Middle East in collaboration with Shell and local universities.

Stakeholder involvement

Solving water scarcity challenges requires close interaction with stakeholders to ensure that the solutions designed by our ETM researchers match the needs of society. Input at the start of research, feedback during the research, and demonstration of research outcomes of the newly developed models, tools and technologies, is essential for conducting high level science as well as realizing societal impact. In our approach, we took the water footprint reduction and water reuse needs of the large industrial water users, such as Dow Benelux and Shell, and drinking water companies, such as Evides Industrial Water and Oasen, as starting point. The development of water treatment technologies was done in collaboration with technology providers, such as Paques, Nijhuis Technologies, Magneto and Plant-E. The translation of scientific insights to broader application of the modelling and blueprint concepts was facilitated by consultancy companies, such as Witteveen&Bos and RoyalHaskoning-DHV, and research institutes, such as Deltares, TNO and KWR-Water. Governmental organizations, such as the Ministry of Infrastructure and Water Management, provinces and water authorities provided insight in the legal and administrative boundaries for implementing the newly developed technologies in blueprints for future water management.

Link to education

Central to fighting water scarcity, is educating future water practitioners on how to perform academic research on societally relevant challenges. We aim to educate PhDs, MSc, and BSc students on how to execute high-level academic research in conjunction with stakeholders in order to make high societal impact. In line with this vision, we organised so-called design studio workshops with PhD's, Postdocs and relevant stakeholders. These workshops were held at several places and occasions, including the offices of the local Water Authority "ScheldeStromen" in Terneuzen and the main office of Shell in Amsterdam. In this way PhD students learn how to interact with their societal counterparts, to understand and listen to them and take their suggestions into consideration, while at the same time holding on to scientific and integrity principles. These stakeholder aspects are also incorporated in the education programs of Environmental and Biobased Sciences at WUR at BSc and MSc level.

Research Highlights

Currently the Water Nexus research has resulted in 19 peer-reviewed scientific publications involving ETM researchers (Appendix 1a), while a dozen more publications is expected in the coming year. An important research highlight is that

both the modelling tool box (1) for designing smart water grids using alternative water resources, and the physical-chemical treatment trains (2), were recognized by 37 stakeholders as very important instruments for making the Netherlands resilient against drought. This recognition appeared in their support for the new and awarded NWO grant AquaConnect (with a budget of 6.5 M€). A second highlight is the Anaerobic Granular Sludge technology (3) for treating salt water with high loads of organics bringing groundbreaking new scientific insights on how the granular sludge microorganisms protect themselves against salinity, awarding researcher Dainis Sudmalis the prize for best presentation at the renowned 'IWA Granular Sludge' conference in 2018. A third highlight are the emerging worldwide possibilities for reuse of alternative water resources with lower amounts of organics (4) after treatment. Especially constructed wetlands combined with other technologies have proven to be very cost-effective in cleaning water containing harmful and difficult to degrade chemicals.

Societal Impact

Water Nexus stakeholder interactive research has broadened the spectrum for the application of various water treatment technologies towards more saline effluent streams, and delivered new models and tools that allow regional water self-sufficiency. The enhanced understanding of salt-adapted granular sludge applications has led to the full-scale application of these developments by providers of technology for industrial wastewaters with high amounts of organic pollutants. Newly developed technologies for cooling tower water treatment are currently being considered for use in actual cooling tower water treatment trains, and similar treatments for making such water streams suitable for irrigative agriculture. The value of nature-based water treatment by constructed wetlands has been acknowledged by large industrial water users, which are currently looking into new locations with different wastewater streams for implementation. The decision-making frameworks for regional water extraction, transport and local treatment in Zeeuws-Vlaanderen are now being adopted by the local stakeholders, while also stakeholders from other regions in the Netherlands and worldwide have shown great interest in applying these elsewhere. Via various global outreach projects (Appendix 1b), technology trains with wetland components are now being developed to make water suitable for reuse in industry or for irrigative agriculture. Currently we investigate with local stakeholders such treatments for industrial zones in Vietnam, for the Barapullah drain in New Delhi, India, for the greening the desert programs in Oman and Qatar, and for the city of Khulna in Bangladesh (Fig. 5).

Figure 5: Rice paddy field near Khulna City Bangladesh, threatened by salt water intrusion, that could greatly benefit from treated urban grey water as a fresh water resource.

Appendix 1a *Peer-reviewed* scientific publications involving ETM researchers resulting from the program Water Nexus

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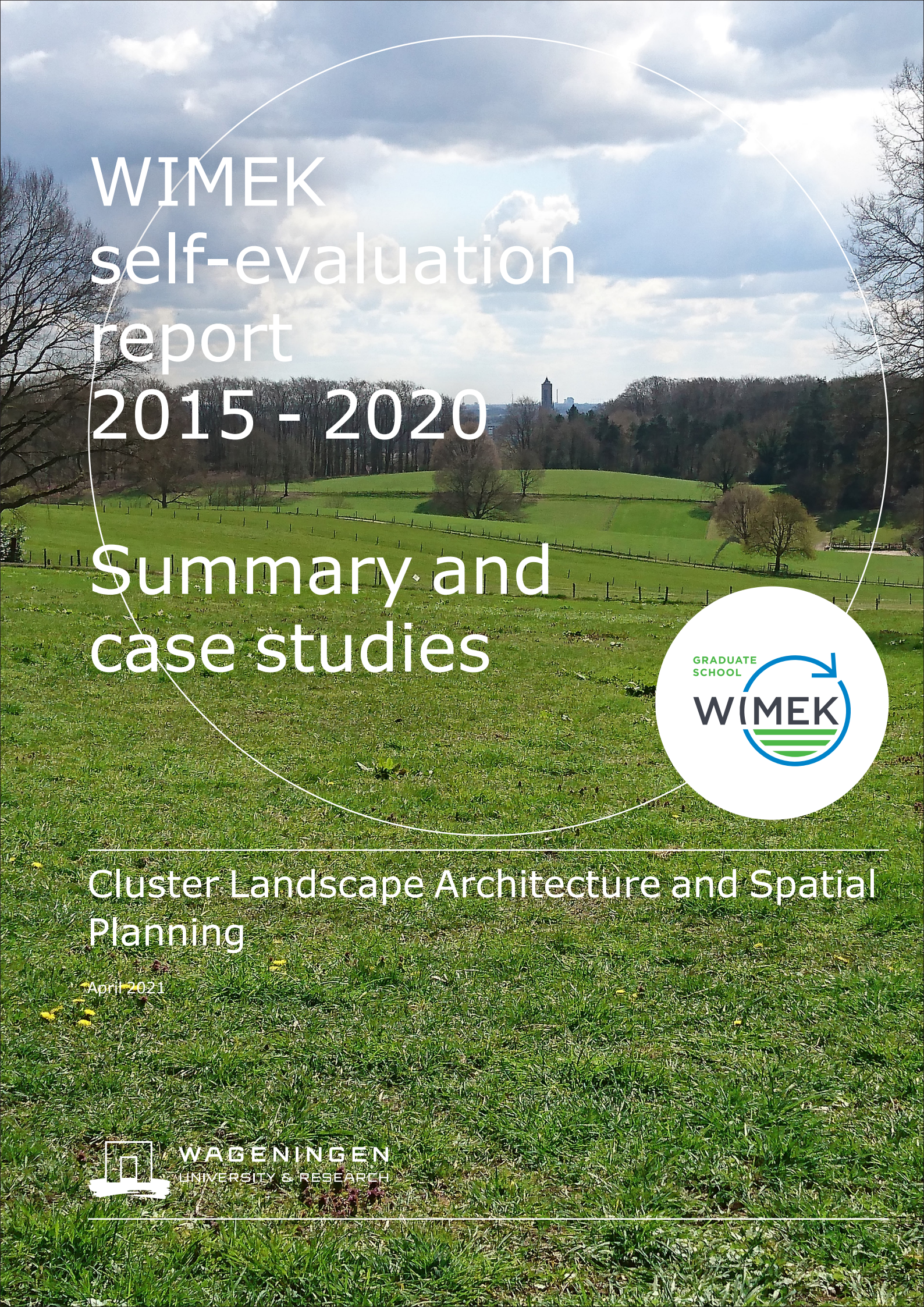
Appendix 1b Global outreach projects where technology trains with wetland components are developed

- Water Nexus (https://waternexus.nl/)
- Entire (https://www.nwo.nl/en/projects/w-0769202)
- LOTUSHR (https://lotushr.org/)
- Water2Rice project of Kamonishish Haldar (https://www.wur.nl/en/Research-Results/Research-programmes/International-programmes/Asia/Bangladesh.htm)
- Greening the Desert (https://www.shell.com/about-us/major-projects/pearl-gtl/producing-water-in-the-desert.html; https://www.shell.com/inside-energy/oman-reed-beds-nature.html#vanity-aHR0cHM6Ly93d3cuc2hlbGwuY29tL3N1c3RhaW5hYmlsaXR5L2Vudmlyb25tZW50L3dhdGVyL2EtbmF0dXJhbC1maWx0ZXItZm9yLXdhdGVyLXRoZS1uaW1yLXJlZWQtYmVkcy5odG1s
- AquaConnect >> NWO/Min EZ website 10th of March



WIMEK self-evaluation report 2015 - 2020

Summary and case studies

GRADUATE SCHOOL WIMEK

Cluster Landscape Architecture and Spatial Planning

April 2021

WAGENINGEN UNIVERSITY & RESEARCH

Summary Landscape Architecture and Spatial Planning

The mission of the LSP cluster is to study how deliberate modifications to landscape features or processes can contribute to the quality of life. To respond to the great challenges of our times such as climate change, transitions in the countryside and urban developments, LSP focuses its research on physical transformations of landscapes through spatial planning and landscape architectural design interventions. We devise sound and creative solutions, based on empirical analyses, model-based simulations, and ethical and esthetical considerations. Both chairs (Landscape Architecture and Land Use Planning) cultivate an open and transdisciplinary academic culture in order to integrate knowledge from multiple into projects that serve understanding or contribute to transformations in real-world situations.

The work of the cluster focuses on creation of evidence-based, technically and societally viable solutions. Spatial designs, design guidelines, policy recommendations or actual spatial plans are outcomes of such research, as well as analysis of and reflections on such designs, policies, and plans. The group's research covers three main dimensions: i) the interdisciplinary analysis of the landscape and environmental an societal problems at stake, ii) the reflection and evaluation of value systems, to explore how desirable futures can or should be assessed, and iii) the transformative dimension, covering the concepts, methods, and instruments to arrive at desirable futures.

The work of the LSP cluster is prominent in different ways: in the field of landscape architecture, the chair group excels in scientific impact within the discipline as the group ranks at the world's top of landscape architecture schools. In the field of spatial planning, the chair group sits in the heart of the societal debate about securing environmental quality of the countryside while all new land use claims are to be accommodated in it. The products of the LSP cluster have clear societal impact. Co-creation of knowledge and planning/ design solutions together with stakeholders from the quadruple helix characterize the cluster's work. Methods such as Research Through Design and Agent-Based modelling in which various solutions are developed and then tested with scientifically sound methods play a crucial role.

In the future, the LSP cluster aims at developing more integrated solutions for the grand challenges that await us in landscapes and in cities. The quest is for integrated solutions that deal with closing the cycles of nutrients, more efficient water and energy streams, resilience to climate change, and improve environmental quality. Emerging topics or interest are the changes in traffic modes (e.g. electric/ autonomous, less cars) and public health issues. The Netherlands, with its scarcity of space, and its large number of landscape stakeholders, form an excellent study area. Challenges lie in capitalizing on the integrated nature of our activities: our bridging of mono- and interdisciplinary work, of teaching and research, of fundamental and applied sciences and of creative and analytical approaches.

Case study: SPLENDID Spatial PLanning for ENvironmentally Diverse cIrcular Development

Summary

When conceiving plans for environmentally friendly agriculture, policy makers and scientists often overlook a key element: the spatial organization of land use. Specifically for circular agriculture, the spatial organization is important, as the closer the source and destination of residues are located, the better loops can be closed at minimum risk and cost. SPLENDID provides policy makers with a scientific valid methodology to assess the spatial implications of implementing circular agricultural practices. It also looks at barriers and solutions to overcome these. This allows policy makers to realize circularity visions with a clear attention for all important landscape values. SPLENDID investigates how circular options match with their surroundings and what ecosystem services they yield in their geographical context. In Noord-Brabant – a Dutch province which exemplifies a range of agriculture-related sustainability issues – SPLENDID assesses three types of circular agriculture (nature-based, technology-based and transport-based), their spatial organization and the ES they deliver. Circular agriculture probably requires a rigorous reorganization of the land use pattern, leading to farmers adjusting their farming practices, swapping land with other land owners or even relocating the entire farm to achieve geographical zones with farming and processing facilities ideally located to optimize the benefits of food production and related ES like animal welfare, preservation of biodiversity, landscape quality and water retention. SPLENDID is funded by NWO and allows one postdoc and three PhD students to produce clear policy guidelines for realizing these objectives.

Case Description

Background

When contemplating ways to achieve more sustainable agriculture – be it circular, nature-inclusive, or regenerative agriculture – policymakers and scientists often overlook a crucial aspect: that of the spatial organization of land use. Spatial organization is important for achieving circularity, because the closer the source and destination of residues, the lower the costs and risks of transport, and thus the more viable the exchange of residues and the closing of cycles. Without an efficient spatial organization of land use, any attempt to convert to sustainable practices tends to remain at the level of pin pricks: flower strips surrounded by biocide-treated fields do not increase biodiversity; ecosystem restoration near ammonia-emitting farms is doomed to fail; attempts to improve soil-water retention in agricultural soils will run afoul of intensifying farmers; and so on. Moreover, spatial fragmentation of sustainable practices hampers the potential synergies that could be achieved with a more consolidated and clever spatial organization. This often leads to adopters of sustainable practices remaining at a disadvantage compared to those who stick to conventional practices that rely on existing, efficient and therefore cheap infrastructures.

We expect that a breakthrough towards the massive adoption of sustainable practices, including the partial closure of nutrient and carbon cycles, can be achieved by a rigorous reorganization of the land use pattern. We envision a diversity in variants of circularity, derived from three different circularity archetypes, which all have a role to play in the overall circular system. The degree to which the different variants can achieve circularity may vary, but so will the delivery of other important values such as landscape quality and biodiversity. In any case, a crucial success factor for the plurality of variants will be their spatial coherence and match with their surroundings. We therefore take a landscape / ecosystem services (ES) approach to investigate how circularity can take shape, which ES are delivered by what circularity variant, and what spatial organization results in the highest environmental quality.

Research objectives

SPLENDID hypothesizes that circular agriculture can be grouped into three types of implementation: the nature-based implementation, that aims at restoring natural cycles and makes use of so-called regenerative farming; the technology-based implementation, where complementary types of non-land-based farms (livestock, horticulture, etc.) are

combined in fully closed systems, to maximally re-use waste streams; and the transport-based implementation, where farmers make an effort to either capture and upgrade their own waste for re-use by others, or by replacing of their input by the upgraded waste of others. Each type has a specific ecosystem service delivery profile, and only in combination with each other we can achieve the societally-desired palette.

Part of the SPLENDID research questions focus on the (diversity of) circularity variants, and how they should be spatially organized to strike a good balance between all desired ecosystem services (ES):

- Which variants of the three circularity archetypes can be distinguished, and what is their general performance in terms of ES delivery?
- How is the actual ES delivery of each variant affected by how it is located and shaped?
- Which overall mix of circularity variants is needed – and how should they be organized in space – in order to meet society's need for a wide range of ES?

And part of our questions focus on how the desired spatial organization can be realized:

- Which instruments of land policy exist to implement the desired spatial organization of the various circularity variants?
- How effective are these instruments, given the institutional (property and user rights), societal (public support), and financial (available budgets) constraints?
- Will the new spatial organization be viable? How to redirect gains in ES to farmers, and what supporting institutional regime is required to secure the clusters?

Research approach

This project will follow a research-through-design approach (RTD). The RTD process starts with a creative, inspiring vision, derived from a participatory process with a wide range of stakeholders and experts. In this case this vision will concern the spatial distribution of the various circularity variants throughout the research area (i.e. the spatial designs; see Figure 1 for an illustration). What follows is a systematic iteration between (a) the use of scientific methods to answer the questions brought about by the vision, and (b) re-imagining the vision based on the outcomes of the scientific research. RTD is highly suitable for real-world situations in which a multitude of related, yet ill-defined problems (so-called 'wicked problems') are at play. RTD is participatory, area-based, and make use of visualisation techniques to involve a wide range of stakeholders (ensuring transdisciplinarity).

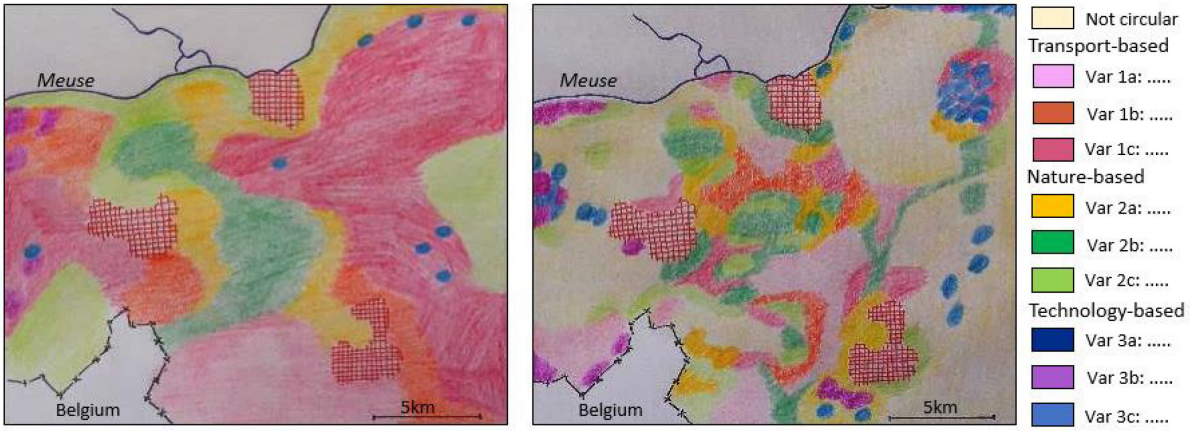


Figure 1: An illustration of what spatial designs could look like (at the largest scale level).

Our research area is larger than in most area-based approaches (>200 km2), which is necessary to evaluate the holistic effect of having all circularity variants in one spatially coherent design (i.e. a landscape approach, bridging the scale-gap between national strategies and local implementation).

For this reason, research in-between the design workshops is model based. Model studies can simulate effects of large-scale implementation of circular agriculture, replace costly or risky real-world experiments, and are highly complementary to pilots and living labs (which are embedded in the research area, and which we will tap into). The effects and experiments which we expect to make a real difference, and which require a modelling approach, are the following:

1. The strategic implementation of instruments such as land consolidation schemes, tradeable development rights, payment schemes for ecosystem services, and land banking;
2. The experimentation with other modes of governance (e.g. top-down versus bottom-up);
3. The effect of the plurality of the circularity variants, so that there will be a place for each farmer type and trade-offs can be managed so that overall ES provision remains high;
4. The agglomeration benefits that follow from large-scale implementation;
5. The effects of a long-term spatial land-use policy, so that farmers can make investments;
6. The synergistic effect of implementing all measures at the same time.

To evaluate these effects three PhD students will conduct scenario studies using (1) environmental models that predict ES delivery for each spatial design (and that allow to systematically investigate effects of location, scale and shape of circularity variants on ES delivery); (2) a land regime analysis to map constraints and opportunities from legislative and economic perspectives; and (3) an agent-based model (ABM) that explores how farmers will respond to instruments, new business models, and long-term spatial policy. All models will be spatially-explicit and cover the entire research area (minus the urban areas).

Stakeholder involvement

There will be three integration and design workshops. Preparation for the first workshop entails system analysis; stakeholder analysis; collection of GIS data; preparing a short documentary to present circularity variants, including a provisionally ES profile; and prepare interactive software environment. In the workshop, circularity variants are discussed and adjusted based on stakeholder knowledge; we establish which ES to include and assess their minimal delivery; smaller groups of participants are asked to distribute variants over the research area (i.e. a spatial design).

At the second workshop, stakeholders receive feedback on their spatial designs in the form of overall ES delivery. Groups may try to improve their design and receive on the spot information of the ES performance of their adjusted design; stakeholders are asked to reflect on (a) the longlists of potential measures and define a coherent strategy and (b) on the Agent Based Model prototype.

At the final workshop researchers present the final outcomes to stakeholders and illustrate effects of location, size and shape on ES delivery. Stakeholders explore, using the metamodel of PhD1, how they can improve their designs based on these insights. PhD3 presents the extent to which the various designs are feasible given the ambitions of farmers in the area. PhD2 presents the most successful policy strategies for achieving spatial designs: one from the point of view of maximizing ES delivery; one from the point of view of achieving the largest societal support.

Research Highlights

The SPLENDID project has only recently started and therefore most results still need to be generated. Nevertheless, one important result was already produced: a map of The Netherlands where the three circularity archetypes could be located, based on a number of environmental variables. The main result is displayed in Figure 2, which is published in a Dutch professional journal for environmental scientists (Milieu). The map is currently being reproduced to feature in an advice to the new government, written by a formally appointed governmental advice committee.

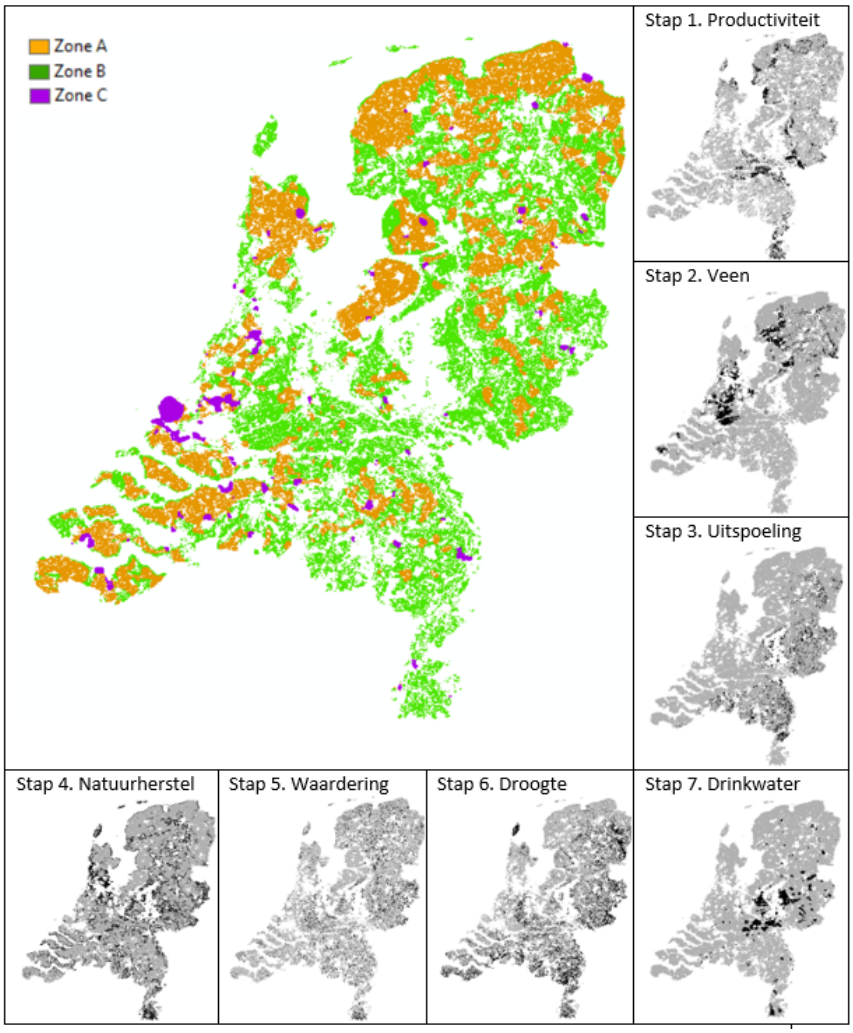


Figure 2: A provisionary map of the three circular agriculture variants, based on a number of environmental constraints

Impact

This research forms a crucial contribution to the actual implementation of circular agriculture. The concept of circular agriculture has been received with great enthusiasm by many societal partners, but it is entirely unclear how to implement it at a scale that exceeds the individual farm or cooperative. Without a clear implementation strategy, also the Circular Agriculture vision published by the Ministry of Agriculture, Nature and Food Quality tends to get stuck at the level of good intentions and propositions. We will provide this implementation strategy by delivering:

- an overview of different variants of circular agriculture, accompanied by an ES delivery profile. Provincial planners can use this to make strategic zoning plans for the rural area;
- design principles for each circularity variant that allows selecting the appropriate location, optimizing scale benefits, and minimizing negative externalities;
- guidelines for redirecting ES gains back to land owners supplying them, hence ensuring viability of circular agriculture, including its less economically competitive forms;
- coherent policy strategies to implement circular agriculture and prevent undesired developments (including guidelines for using the New Environmental Act and integration of the Rural Areas Development Act);
- a detailed reflection on pros and cons of a suite of land policy instruments for achieving the desired zonation.

Case study: REALCOOL ‘Really cooling water bodies in cities’

Summary

The ‘Really cooling water bodies in cities’ (REALCOOL) was a Research Through Design (RTD) project exploring the most effective combinations of shading, water vaporisation and natural ventilation around small urban water bodies. Small urban water bodies, such as ponds or canals, were commonly believed to solve urban heat problems but recent research showed that this might be a misconception. At the same time, there were indications that shading, vaporising water and ventilation can help to keep urban water bodies and their surroundings cooler. Yet, it was necessary to explore combinations of these strategies in urban designs and how to communicate the resulting design guidelines to design professionals. The REALCOOL project catered for this demand by designing virtual prototypes of the most cooling combinations of shading, water vaporisation and ventilation around small urban water bodies. We tested the designs on their microclimate effects with simulations, on their applicability with a broad triple helix stakeholder group and aesthetical perception with the public. Our extensive urban climate simulation studies showed that small urban water bodies do not have a relevant cooling effect. The prototypes we developed proved to be useful in practice as conceptual design guidelines. A final evaluation of REALCOOL’s advanced RTD methodology with the stakeholder group indicated that RTD is a reliable method to combine scientific knowledge and design knowledge into robust and widely applicable new spatial design guidelines.

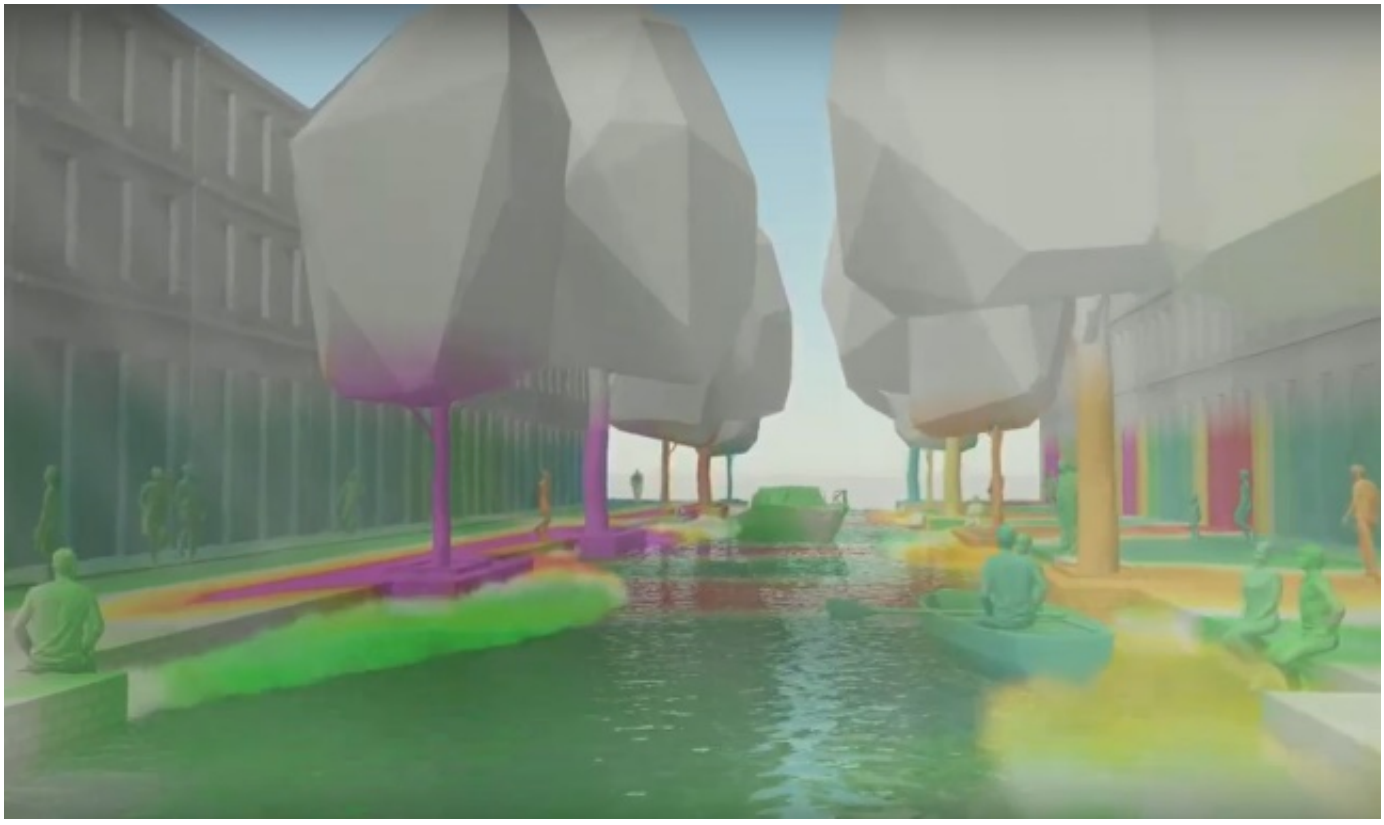


Figure 1: Still from the final animations that depict the spatial prototypes of the new water environments

Case Description

Background

Many assertions could be found in the urban design literature about urban water bodies having a cooling effect on their surroundings. However, recent research on larger water bodies showed that these may be quite limited over day and may lead to a night time warming. So the question arose if smaller urban water would show similar effects. At the same time, there are indications that shading water, vaporising water and proper ventilation might help to keep urban water bodies and their surroundings cooler. Yet, it was unknown how these strategies can be optimally combined in urban design and also effectively communicated to design professionals.

Research objectives

The REALCOOL project aimed at understanding the micrometeorological effects of smaller urban water bodies and accordingly designing prototypical solutions combining cooling strategies like shading, water vaporisation and ventilation around small urban water bodies. The prototypes to be developed were virtual 3D scenes depicting the spatial layout and biometeorological effects of these combinations, that design professionals can use as design guidelines. These design guidelines were to convey the information about the spatial configurations and their biometeorological effects in an understandable way for urban design practitioners.

Research approach

To answer understand the micrometeorological effects of small urban water bodies, simulations in the micrometeorology simulation software Envi-met with a new plug-in for water evaporation, were employed. We found that the cooling effect of such smaller water bodies is rather limited as well and that they cannot be used to effectively cool the environment. Based on this finding we started with the main part of the project: developing the design guidelines.

This main part was based on a 'Research through Design' (RTD), methodology, introducing an approach in which design and testing designs with scientifically robust methods was implemented (See Fig. 2). The project team consisted of experts in the areas of bio-climatological urban design, urban meteorology, water-atmosphere interactions, and 3D-visualisations from Wageningen University and the Amsterdam University of Applied Sciences. The project team closely cooperated with an advisory team from engineering consultancies, the national health institute, municipalities, water boards and design offices that assessed the design solutions we developed.

The RTD started with defining the environments into which the different design experiments could be projected: 'testbeds'. They are 3D spatial representations of typical Dutch urban water bodies such as different types of canals, ditches and ponds. After this preparatory work, the REALCOOL RTD process started, where each iteration had designing and testing components. The designing involved experimenting with different combinations of shading, vaporisation and ventilation strategies around water to reduce people's thermal load, but also took into account practical criteria.

Testing was done on different kinds of expected performance of the design solutions: biometeorological effects, through Envi-met simulations, hydrological functionality, combination with other urban functions (e.g. boat and road traffic), costs of implementation, maintenance requirements, and public health effects by evaluations of the advisory board. Design refinement principles for each subsequent iteration were directly retrieved from these assessments. Testing also included an online visual inquiry aimed at knowing how the general public would perceive hypothetical environments resulting from the application of the prototypes (photorealistic images). More than 1200 persons participated in the online questionnaire.

After this iteration, a set of final prototypes could be developed for each testbed. These were now tested in a 'reality check' where they were got applied by practitioners in 'real-world' projects. As the prototypes were evaluated positively by the practitioners we were able to finalize the RTD process. Subsequently we generated animated design guidelines, based on our prototypes, that visually communicate the 3D settings of the prototypes and the invisible microclimate science behind the designs

The last part of the project dealt with the visualization strategy to bring the new information across to the target group, being urban design professionals, in an understandable and inspiring way. The team's visualization specialist developed

different types of visualisations and tested these with the project and the advisory team. These animations can be found via: http://climatelier.net/projects/research/realcool-really-cooling-water-bodies-in-cities/.

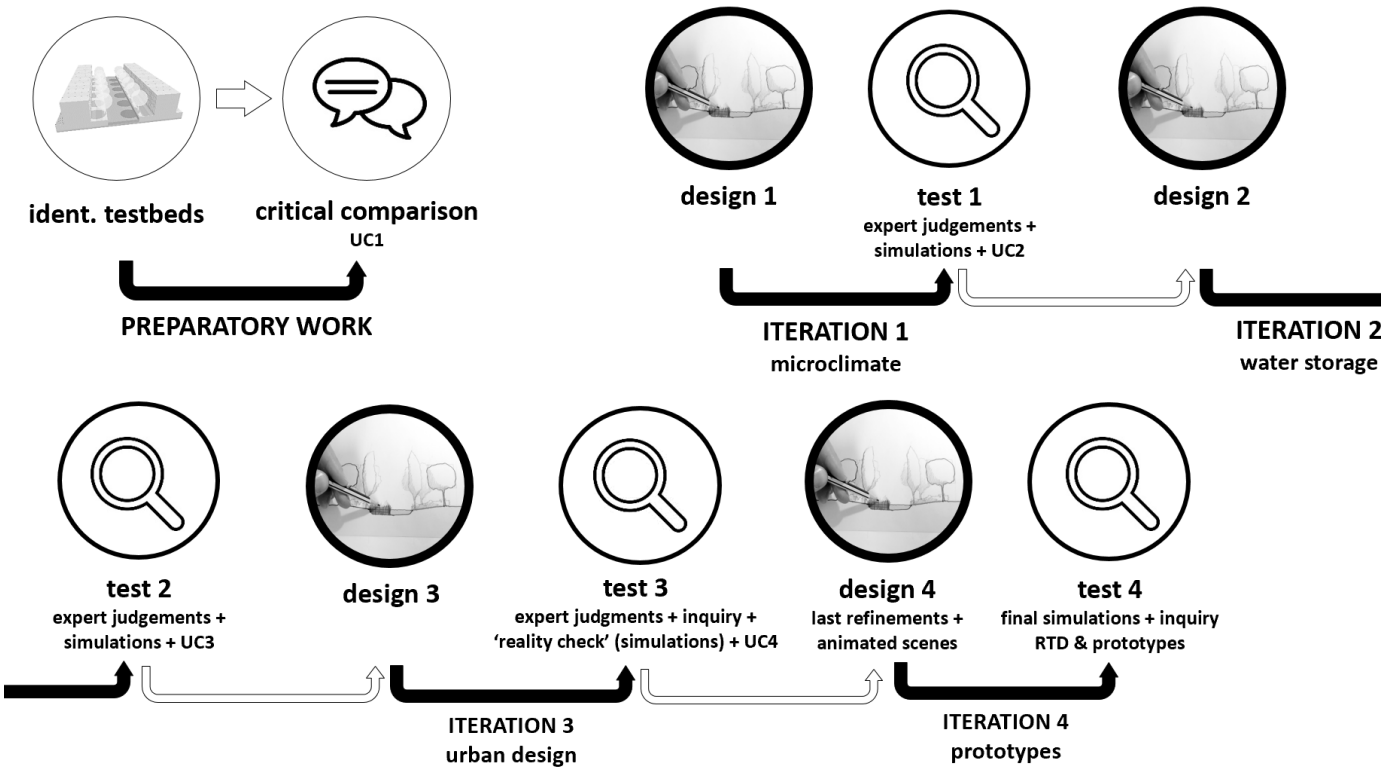


Figure 2: The method of Research Through Design in REALCOOL

Main findings

Biometeorology and hydrology
According to the micrometeorological simulations the cooling (and also warming) effects of small urban water bodies on air temperature are quite small and often negligible — about 0.8 °C or less in air temperature and 2 °C or less in PET at 1.5 m above the water surface. In adjacent pedestrian areas, like quays, cooling effects were found to be even smaller, in particular during the night. Warming effects during the night were also very small and it appeared that little can be done through urban design to cool down water and to make it cool its surroundings.

Hence, the focus of the cooling water environments lies on implementing cooling strategies that cool people near the water but not the water body itself. The combination of these strategies across the different prototypes led to very significant local reductions in thermal sensation levels.

The prototypes increased rainwater storage capacity of current situations from 15% (meaning an increase of around 275 m^3 per 50 m) to 160% (meaning an increase of around 160 m^3 per 50 m).

The results from the online visual inquiry show that the majority of new water environments we had designed were perceived as more attractive than the current situations.

Applicability in practice
The interim consultations with the practitioner's advisory team, as well the 'reality check' showed that it was possible to easily and quickly apply the REALCOOL designs into site-specific projects; and there were no concerns about the relevance and usefulness of the conveyed principles.

Aesthetical appeal of prototypes
The results from the online visual inquiry show that the majority of depicted environments (12) were perceived as more attractive than the current situations. The remaining designs (4) were perceived as attractive as the current situations. Beauty, harmony and excitement were the main reasons for the perceived attractiveness of the designs.

Visual communication of prototypes
The consultations with the practitioner's advisory team, indicated that the visualisation of the prototypes as 3D animations worked well and that crucial criteria for effective visual communication of climate knowledge, being visual clarity, trustworthiness and raising interest, were met.

Stakeholder involvement
REALCOOL had an intensive cooperation with the advisory team with which we met at least twice a year to discuss the outcomes of the different design iterations and asked them for their assessments of the designs. This helped us to generate results that are well-applicable in practice. The involvement of the broad public through the online inquiry about of the new urban environments was valuable to understand the future effects on citizen's perceptions.

Without the involvement of the entire quadruple helix, the REALCOOL project would not have been as successful and without such impact.

Research Highlights

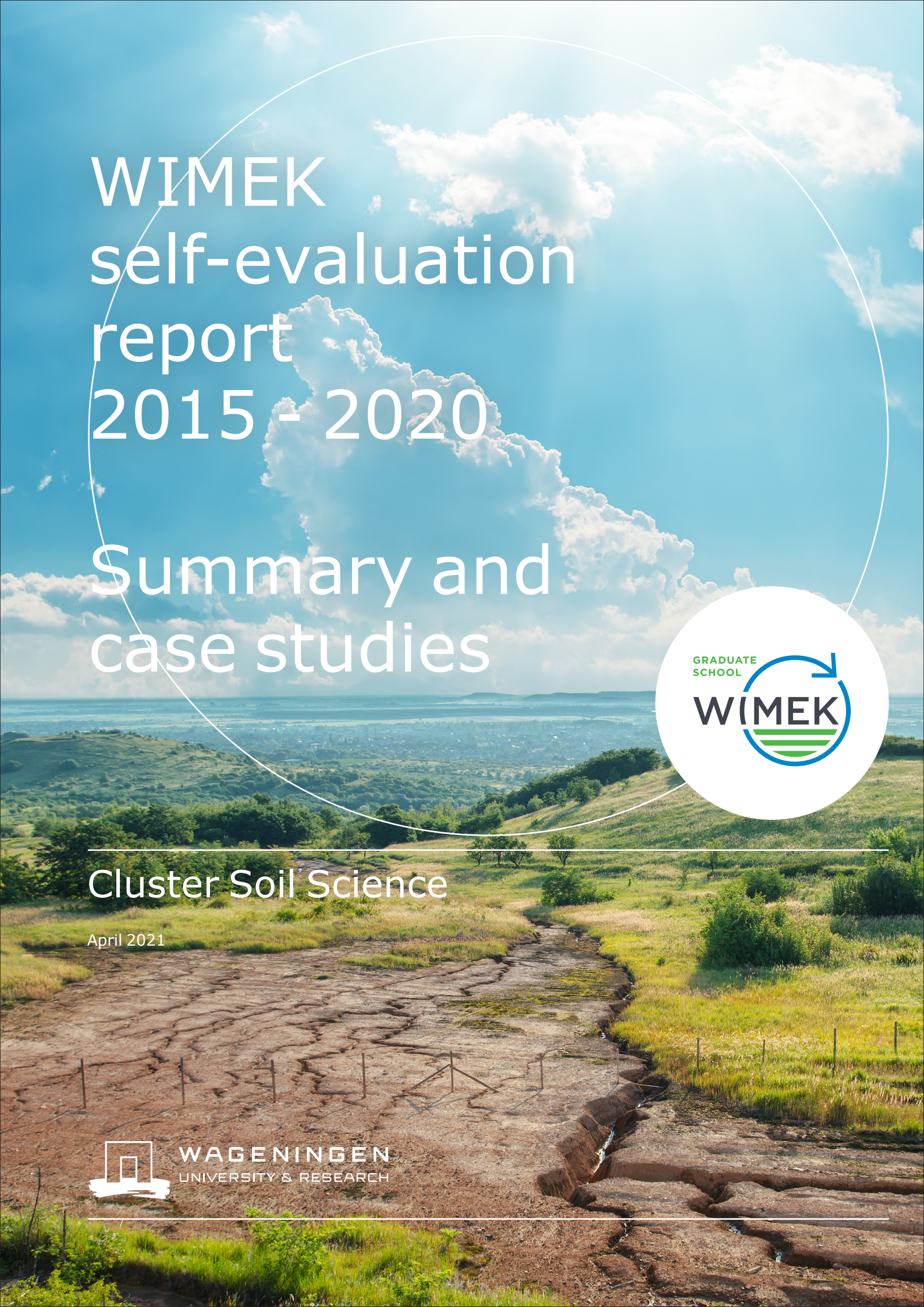
One of the main findings relevant for both urban climatology as well as urban design is the finding that smaller urban water bodies are not really cooling, proving earlier conceptions being incorrect. The recent paper about this finding is already cited quite frequently and researchers have been invited to give lectures about these results. (LIT nog invoegen!).

REALCOOL also brought about an extension of the Envi-met simulation software that was supplemented with input from the 'cool-water-tool' to predict evaporation processes more precisely.

Furthermore, REALCOOL brought about a methodological shift in landscape architectural RTD approaches as it employed more rigid testing of design proposals than other design-related research did. It was a 'proof of concept' of earlier, rather theoretical work on this matter that has now been employed in a research project successfully. The success of this project has led to many invitations for invited talks and keynote lectures.

Impact
The REALCOOL project had impact at an early stage already as it actively engaged with the professional community and later also with a broad societal public, which increased the visibility of the project and led to many invitations to present the project, amongst the urban design community in design offices and municipalities but also at the TTW applied science festival and the Dutch Design week. The REALCOOL team was also invited to present the project in professional magazines and online outlets. The project also was mentioned in a state secretrary's letter to the parliament (kamerbrief).

The main outcomes of the project: the design prototypes are much valued in urban design practice and have already led to follow-up projects in which parts of the REALCOOL team work on implementing the knowledge from REALCOOL in other projects where urban water bodies are (re-)designed and get built (Nieuwe Mark Breda and GreenQuays).



WIMEK self-evaluation report 2015 - 2020

Summary and case studies

GRADUATE SCHOOL WIMEK

Cluster Soil Science

April 2021

WAGENINGEN UNIVERSITY & RESEARCH

Summary Soil Science

The WU Soil Science cluster was established in 2018. The cluster consists of four chair groups: Soil Physics and Land Management (SLM), Soil Chemistry and Chemical Soil Quality (SOC), Soil Biology Group (SBL) and Soil Geography and Landscape (SGL) (Appendix 1A). The unit is interdisciplinary, increasingly multicultural and quite gender-balanced.

The main aims of the soil science cluster include:

i) To be a world-leading academic group for high-impact research in the domain of our mission,
ii) To generate and openly communicate science-based knowledge on sustainable soil/land management, serving multiple stakeholders from local to global,
iii) To provide a world-renowned platform for research development through a range of global knowledge networks and state of the art research facilities, and
iv) To develop the skills of new and current soil scientists (particularly graduate and early career) who will further enhance our mission and our contribution world-wide.

The Soil Science cluster research strategy for the last six years, which particularly supports our first three aims, has included development of Research Lines to contribute to more sustainable soil and land use for future generations, and the overarching themes within the programmes of both the WIMEK and PE&RC research schools. The Research Lines are: **Soil-water interactions**, **Multi-functional land evaluation, Bio-diverse agroecosystems**, **Nutrient cycling and contaminant mitigation** and **Soil carbon management and climate change**.

The Soil Science cluster combines fundamental and applied **research** at different spatial and temporal scale in different soil sciences disciplines, and includes socio-economic aspects to enable a more holistic understanding of the systems. The research focusses on environmental problems where soils play a major role and on related sustainable nature-based solutions, from local to global scales. Therefore, the Soil Science cluster has an important role and significant impact not only in the soil sciences research domain, but also on society through close interactions with a wide range of stakeholders.

The Soil Science cluster is a strong unit with inspired and productive staff, Postdocs and PhD candidates, good inter-cluster collaboration and sufficient financing. The unit provides continuing support and **training** to these different groups. The strategy during the past years has been to direct pro-active attention to wider collaboration in order to build the identity of the Soil Science cluster and further strengthen our capabilities and output. Part of this strategy included appointing of the soil cluster coordinator, and the creation of Research Line working groups composed of researchers and staff from different chair groups to support and further develop the Research Lines.

The Soil Science cluster **publications** over the past six years are well cited. The average Field Weighted Citation **Impact** is 2.53, which is well over two times the world average. Of all publications, 30% belong to the top 10% most cited publications (field weighted). Soil Science cluster publications were frequently mentioned in the news and in policy documents, and contribute to the public debate on planetary boundaries, sustainable food production, ecosystem services, climate mitigation and adaptation, and clean healthy soil and water systems. In the period 2015-2020 a number of Soil Science cluster researchers received prestigious grants, namely for NWO VENI (1 researcher), VIDI (1), and Marie Curie (2) grants. Furthermore, a wide spectrum of large international research projects have been initiated and acquired by staff members of the cluster, amounting to a total of more than 70 M€.

For the coming six years the Soil Science cluster's **outlook** is to further advance its high quality and high relevance research and its scientific and societal impact, and to address the weaknesses identified in the SWOT analysis of this review. The cluster aims to maintain and increase collaborations with societal stakeholders, and to address challenges and opportunities occurring in society. An important point that the Soil Science cluster will address is to strengthen the unit further and increase the opportunities for collaboration and co-creation within the cross-cutting Research Lines to build strong links among the soil chair groups and with external collaborators. The Soil Science cluster will place particular attention on maintaining a highly reputable scientific staff, developing skills of new and current soil scientists, and to support the research with proper funding.

Case study: Soil quality at your fingertips

Two projects led by the Soil Science Cluster developed tools for land users and managers to get a better grip on soil quality, and understand the consequences of management decisions: iSQAPER (http://isqaper-project.eu/) and LANDMARK (http://landmark2020.eu/). They illustrate many of the clusters' strategies in action and their societal relevance.

Summary

Intensive agriculture has maximised production of food and fibre at often significant expense of soil quality, undermining resilience and future productivity. Farmers and other land managers must hence balance the societal need for food and fibre with the increasing need and demand for sustainability. However, there are barriers to implementing new sustainable practices, one of which is the lack of comprehensive tools for land managers to understand the consequences of management practices on soil health or quality. Two EU-funded projects led by the Soil Science Cluster developed tools for land users and managers to get a better grip on soil quality and impacts of management decisions: iSQAPER and LANDMARK. The two projects followed different innovative approaches, combining established methodologies and state of the art technology with heavy involvement of final stakeholders. The projects also put substantial efforts into communicating scientific results with the broader public, for greater impact.

Case Description

Background

We rely on soils for the production of almost all agricultural products. However, conventional agricultural practices come with significant environmental consequences (Tilman et al., 2001). This presents challenges for farmers and other land managers who must balance the societal need for food and fibre with the ever-growing need and demand for sustainability. The number of organically managed farms has been slowly increasing, underlining the societal interest in sustainable practices and a willingness to adopt them (Willer and Lernoud, 2019). However, there are barriers to implementing new practices, one of which is the lack of tools that can help land managers understand the consequences of management practices on soil health or quality (Schröder et al., 2020). In fact, the concept of soil quality itself is challenging. Historically, and due to society's focus on producing food, soil quality has been closely bound to soil fertility. In recent years, however, the notion of soil quality has moved to include aspects related to other ecosystem services that are delivered by the soil, such as water quality and supply, carbon storage and climate regulation (Bünemann et al., 2018). Some researchers refer to this rearticulated concept of soil quality as soil health. As with human health, a healthy soil must be able to perform multiple functions simultaneously, i.e., be multifunctional.

Research objectives

Amongst the core objectives of both projects was the development of a tool that could be used by interested parties to understand soil quality and aid decision making. More specifically, the iSQAPER project, coordinated by the SLM group of the soil cluster, aimed to develop and provide an Interactive Soil Quality Assessment app, based on data existing in the academic domain in conjunction with available data at the farm level, to provide land users targeted recommendations for improved soil management at the field level to increase soil quality. LANDMARK, coordinated by the SBL group of the cluster, aimed to quantify the current and potential supply of soil functions (and therefore assess soil quality) across the EU and Brazil, using a collection of input variables that include soil and environmental properties as well as information regarding soil management.

Research approaches - Two sides of the same coin

While the research objectives of these projects were closely linked, they each followed different approaches. These approaches have been both diverse and innovative, combining established and new methodologies and inclusion of state-of –the-art technology.

iSQAPER

iSQAPER was funded by the European Union, the Chinese Ministry of Science and Technology and the Swiss State Secretariat for Education, Research and Innovation, and brought together 26 partner organizations including universities, research institutes, foundations, and small and medium-sized enterprises from all over Europe and China. Four research institutes from China participated in the project, showcasing the international role of the Soil Science cluster in soil quality research. The iSQAPER project analysed soil quality and locally appropriate agricultural management practices in different farming systems and pedoclimatic zones underpinning the creation of the soil quality assessment app – SQAPP (Fleskens et al., 2020; Figure 1).

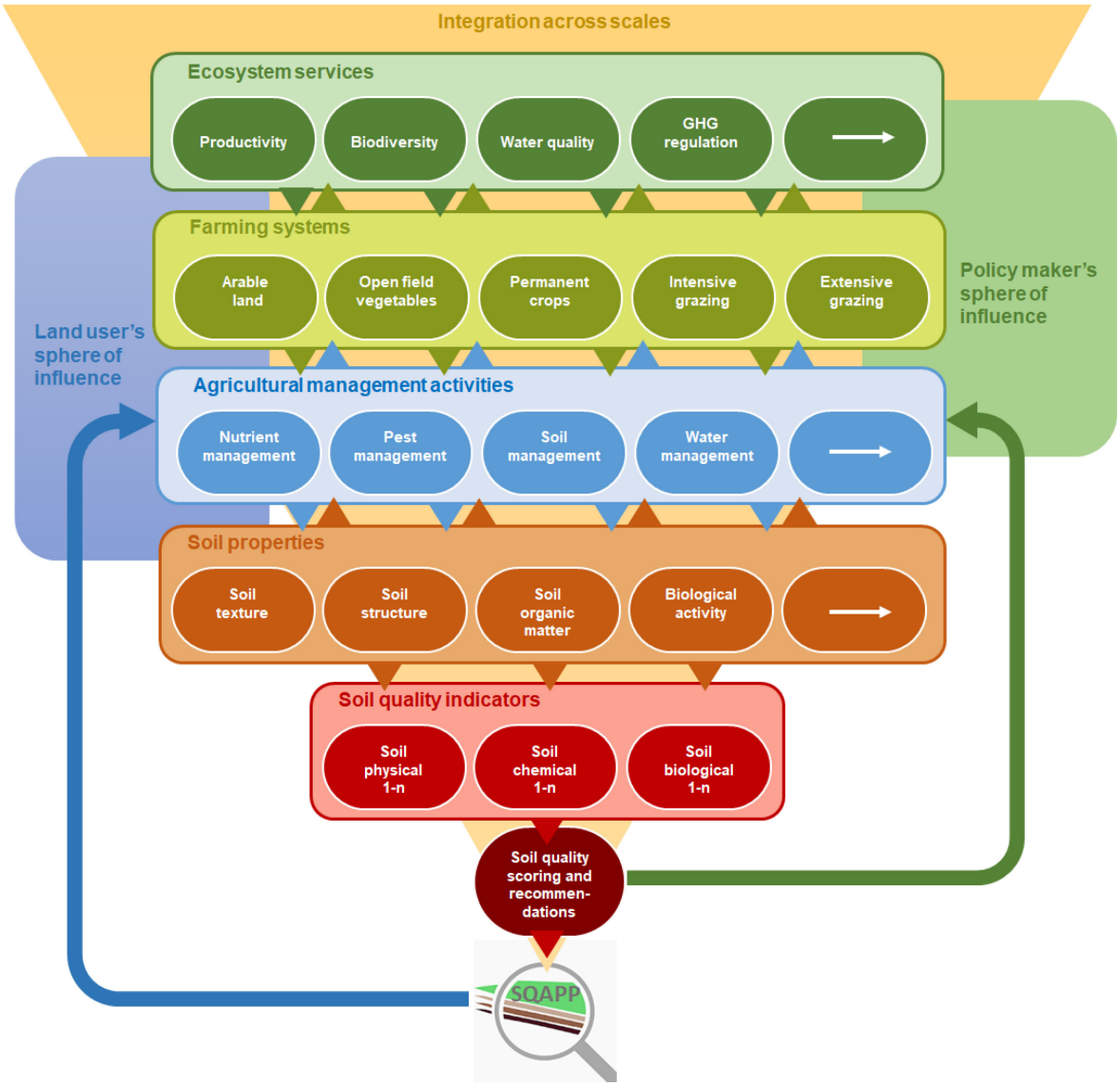


Figure 1: iSQAPER approach to soil quality assessment converging in the soil quality assessment app - SQAPP

The project started with a comprehensive review of soil quality (Bünemann et al., 2018), a valuable task, given that the publication has already received more than 400 citations. Thereafter, the project explored cost-effective and novel biological methods for assessing it (Bongiorno et al., 2019a-c; 2020). Soil quality information was gathered from experimental fields and case studies on operating farms all over Europe (Zai et al., 2018; Alaoui et al., 2020). The goal was to explore the effects of management practices on soil quality, across climatic zones and under different soil textures and farming systems. This allowed addressing questions such as: Is the effect of tillage on nutrient cycling significant despite differences in pedoclimatic zones? Effects that are observable in a variety of systems and conditions are of particular importance when developing suggestions for more sustainable farming practices.

These studies led to the development of the SQAPP, an app that uses global or European soil property and soil threat indicator maps as a base to find site-specific scores for diverse variables, whose values can also be refined by the users. These are then put into perspective, by comparing them with scores observed in other locations in the same pedo-climatic zone and land use type. In this way a score is obtained for each indicator and the SQAPP recommends alternative agricultural land management practices (AMPs) to increase overall soil quality by addressing those indicators that scored low. To put the analysis into a broader societal perspective, the iSQAPER project examined the consequences of widespread implementation of land management practices, providing recommendations for integrating and promoting soil quality and sustainable land management in farming practices and policy recommendations (Figure 1).

As SQAPP was intended for independent use by different end users, a multi-actor approach underpinned its development. The app was developed, tested, evaluated and improved by farmers, scientists, practitioners, agricultural service providers and policy makers. SQAPP[1] is freely available for download on mobile devices, can be used anywhere in the world and can be deployed in education and citizen science initiatives.

LANDMARK

The LANDMARK project, coordinated by SBL, was a collaboration between experts from 14 European countries belonging to a total of 21 research institutes, universities and governmental agencies, and Brazil and China. To quantify soil multifunctionality, LANDMARK built upon the framework of Functional Land Management (Schulte et al., 2014). This framework is based on the idea that while one soil cannot perform *all* soil functions at a high level, it can provide a number of them at a medium to high level. This could result in landscapes with varied soils providing, overall, all soil functions (Schulte et al., 2014).

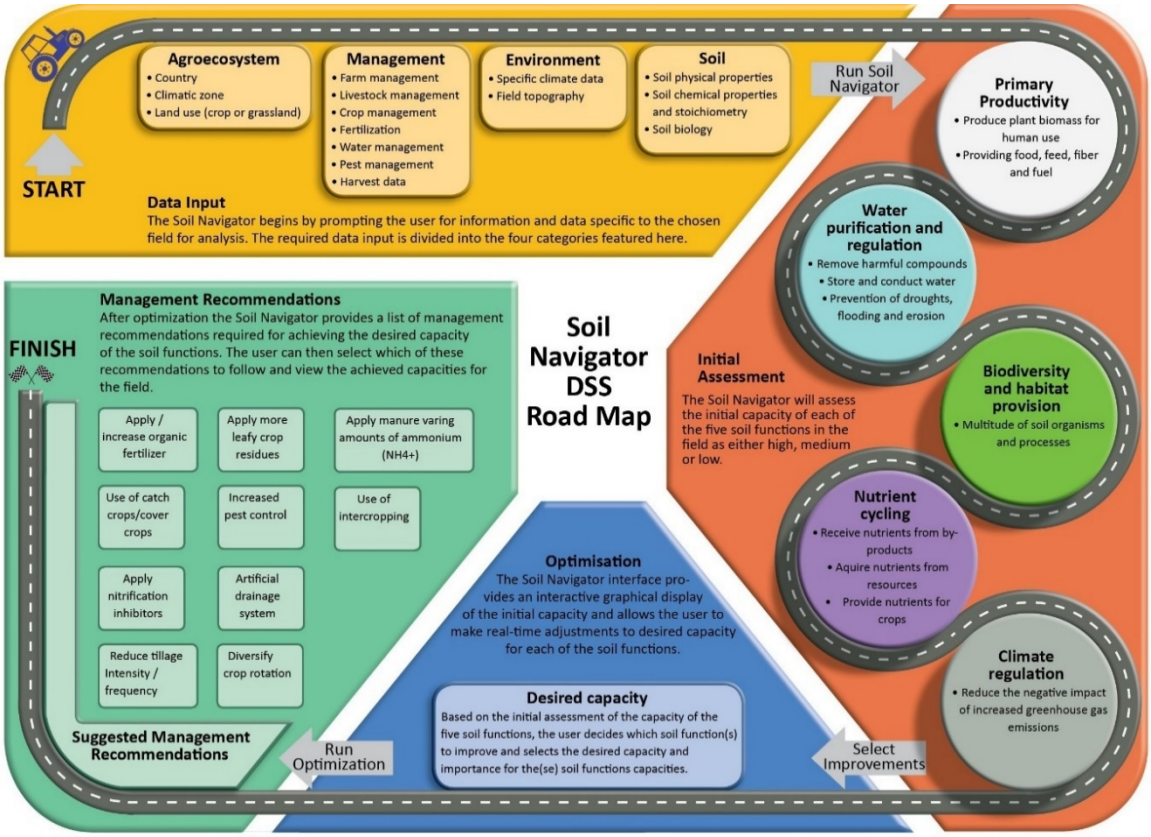


Figure 2: Overview of the Soil Navigator road map developed in the LANDMARK project

[1] https://www.isqaper-is.eu/sqapp-the-soil-quality-app

The first task was to understand the needs and drivers of different stakeholders. The project conducted many workshops involving more than 400 stakeholders spread across different realms (farmers, policy makers, advisory agencies, etc.) to gain insight into their understanding of soil functions (Bampa et al., 2019). The project put particular effort into ensuring that the project outcomes were relevant and well communicated to all stakeholders. A team of experts worked together with stakeholders gathering soil function data from a combination of European field experiments and survey efforts to create models for assessing five essential soil functions: nutrient cycling, water purification and regulation, biodiversity and habitat provision, climate regulation and primary productivity (Schröder et al., 2016; Van de Broek et al., 2019; van Leeuwen et al., 2019). These efforts culminated in the creation of a decision support system tool, the Soil Navigator[2], aimed at helping farmers, soil managers and advisory agencies with their decision making to maximize the multifunctionality of soils (Debeljak et al. 2019). The Soil Navigator also allows the user to input a desired score for a selection of soil functions, and provides suggestions to achieve that scenario (Figure 2).

Scientific and social highlights and impact

The projects produced a variety of scientific publications[3], some of which paved the way for future soil quality assessment schemes and research (Bünemann et al., 2018; Schulte et al., 2014). However, the projects' impact reaches beyond the scientific realm, with publications and policy briefs[4] that also focused on reaching policy makers at national and European level (O'Sullivan et al., 2017). All publications are Open Access to communicate scientific results and implication for policies to a broad audience.

As noted, both iSQAPER and LANDMARK intensively engaged stakeholders in order to bridge science and society. In both projects, various demonstration events were organized with stakeholders to present major findings (Barão et al., 2019). The projects' results were disseminated in a variety of formats and platforms, such as professional publications[5], infographics and videos, and a variety of media, for example, The Irish Times[6] and several policy-related blogs[7]. Recently, the Commission has published a special brief on soil health from a number of Horizon 2020 projects, which includes both articles from LANDMARK and ISQAPER[8]. The iSQAPER project has a Youtube channel[9], Facebook and Twitter[10] accounts, which are used to share news and information about the project to the wider public. The SQAPP has more than 2000 registered users who have applied SQAPP in more than 8000 locations worldwide. LANDMARK has more than 1700 followers on Twitter, 500 connections on LinkedIn, and videos to promote the importance of soils to ecosystem services as well as introduce the Soil Navigator (https://vimeo.com/landmark2020).

The Soil Navigator and SQAPP tools can greatly impact perception of soil functionality, and by taking stakeholders through steps in the evaluation of soil quality and functions, enhance sustainable agricultural management. These tools can also be used for educational purposes. For example, Soil Navigator was used during the Wageningen University Lab Skills course, and during the ISRIC Spring School, and SQAPP assignments have been incorporated in the curriculum of BSc and MSc courses.

[2] http://www.soilnavigator.eu/
[3] https://www.isqaper-is.eu/key-messages/publications and http://landmark2020.eu/publication-trees/
[4] https://ieep.eu/news/isqaper-ieep-s-role-in-exploring-policy-instruments-and-opportunities-for-soil-protection
[5] iSQAPER opinion article in the Dutch professional journal Gewasbescherming 'Lange termijn effecten van bodemmaatregelen op ziektewering' by J. Postma and Giulia Bongiorno; Landmark project published an article on the biodiversity of Dutch soils in the Dutch magazine Bodem
[6] https://www.irishtimes.com/news/environment/soil-is-too-small-a-word-for-it-1.2845602
[7] https://horizon-magazine.eu/article/cultural-cross-fertilisation-rescue-soils.html
https://sciencebusiness.net/international-news/access-information-obstacle-eu-china-joint-research
https://ec.europa.eu/research/infocentre/article_en.cfm?artid=49933
[8] iSQAPER: https://cordis.europa.eu/article/id/429351?WT.mc_id=exp; LANDMARK: https://cordis.europa.eu/article/id/429365?WT.mc_id=exp
[9] https://www.youtube.com/channel/UC7VDo8Z8t6eHjdKnoNe8TEQ/videos
[10] https://twitter.com/iSQAPER

Future perspectives and developments beyond the two projects

The two projects were concluded together with a workshop organised by both projects that took place during the Wageningen Soil Conference 2019. With this event, the projects highlighted their work toward a common goal, and provided a solid basis for further projects and collaboration. For example, the SoilGuard and MINAGRIS[11] projects will continue to advance knowledge about the effect of different agronomic practices on soil biodiversity and functions; new lab methods for soil biological indicators are in development; the BIOSIS platform, a selection tool for biological soil quality indicators is being developed; and collaborations are continuing with the China Agricultural University, WEnR and the Wageningen Student Farm. Further evidence of the quality, and scientific and social relevance and impact of the cluster's research in this area is the new project "Soil health and the potential of remote sensing" (2021 to 2024) which will explore soil quality using remote sensing. The project is funded by the private company Syngenta and will be a collaboration between the Soil Biology Group, the Remote Sensing Group, the Soil Water & Land Use Group of Wageningen Research, ISRIC World Soil Information Wageningen, and Syngenta.

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Case study: Micronutrients for better yields

This case study illustrates collaboration between groups within the Soil Science cluster as well as with research organizations and societal partners outside the cluster. It also demonstrates the use of highly technical research approaches to develop practical products/information that can be used at farm level to improve resource management, food production and livelihoods.

Summary

Crop yields in East and Southern Africa are limited by macronutrient or micronutrient deficiencies – which also leads to reduced food quality and micronutrient malnutrition ("hidden hunger"). Effective fertilisation strategies to overcome these problems are hampered by a lack of reliable information on soil nutrient status and bioavailability, as well as crop responsiveness, at field, regional and national scales. The project "Micronutrients for better yields" uses theoretical and practical approaches to understand the aboveground and belowground processes that control bioavailability of plant nutrients. With a combination of field trials, pot experiments, soil characterisation and geochemical multi-surface modelling, the speciation and mobility of micronutrients in soils and bioavailability to plants is described, both at field scale and regionally by applying developed models to existing soil maps. Outcomes consist of improved understanding of micronutrient bioavailability and grain micronutrient concentrations, simple models that can be used to predict micronutrient bioavailability based on easily obtainable soil parameters, and soil maps that can aid the development of (micro)nutrient fertiliser recommendations. The resulting information can be of direct value to farmers and those who depend on their food production.

Case Description

Background

Global food security (Sustainable Development Goal 2) is threatened by macronutrient and micronutrient deficiencies which limit crop yields and/or nutritional quality. Low micronutrient availability not only affects crop yield and grain quality but also human health: particularly in developing countries where micronutrient malnutrition ("hidden hunger") affects a significant percentage of the population (Sustainable Development Goal 3). Particularly in East and Southern Africa, farmers are facing a decreasing response of crops to regular chemical fertilisers, which is believed to be largely caused by a low availability of micronutrients in the heavily weathered soils. Effective fertilisation strategies to overcome these problems are hampered by a lack of reliable information on soil nutrient status and bioavailability, as well as crop responsiveness, both at the field scale and regional to national scales. A better understanding of the intrinsic capacity of soils in these areas to store and provide nutrients to crops, and of crop response to fertilisation, is sorely needed. This knowledge can then be translated into easily applicable diagnostic tools and spatial data for the relevant soil and agronomic properties, in order to assist stakeholders in providing effective and economically feasible fertiliser recommendations at the field and regional scale.

Research objectives

The project "Micronutrients for better yields" with two PhD students (Soil Chemistry and Soil Biology) is a collaboration between Wageningen University, ISRIC and locally operating partners (International Plant Nutrition Institute, Cascape Ethiopia/WEnR, University of Zimbabwe, AgroCares and IFDC). The project has several objectives. Firstly, to understand the soil chemical processes that control the chemical speciation and availability of micronutrients (i.e. zinc, copper and boron) in soils from various countries in Sub Saharan Africa. This knowledge is used to develop accessible tools and models for predicting soil micronutrient availability. The models will be based on input variables that can be easily obtained through routine soil analysis, and that are available in the form of soil maps. Secondly, we intend to develop a field-scale fertilizer recommendation system that effectively addresses the availability of yield-limiting micronutrients, and digital soil maps of micronutrient availability in Sub-Saharan Africa, including spatially explicit risk assessment of crop micronutrient deficiencies. To develop the field-scale fertilizer recommendation system, the soil

fertility tool QUEFTS (QUantitative Evaluation of the Fertility of Tropical Soils) will be used. QUEFTS is currently calibrated for nitrogen (N), phosphorus (P) and potassium (K) and our aim is to extend it with modules for micronutrients. Digital maps can be developed based on existing soil maps and the use of QUEFTS, as well as other tools developed to predict soil micronutrient availability.

Research approach

In Figure 1, a schematic overview of the research on soil fertility in East and Southern Africa is presented. To better understand plant nutrient uptake, the research began with investigating belowground processes that control nutrient availability (the bottom part of the Figure 1.) This requires extensive characterization of soil samples (Figure 1D), including different nutrient fractions, and quantification of the soil reactivity for nutrient adsorption. In addition, micronutrient adsorption to each of the major reactive surfaces in the tropical soils (particularly Fe/Al-(hydr)oxides and soil organic matter) is studied and parameterized using surface-specific ion adsorption models. These models are then combined into geochemical multi-surface models (Figure 1E) that can subsequently be translated into more accessible prediction tools in the form of empirical partition relations. Existing soil maps can be used as input in these partition relations to develop soil maps that predict the nutrient concentration in solution. Figure 1G shows an example of a map for Rwanda with the predicted Zn in solution. The soils maps are developed in collaboration with ISRIC.

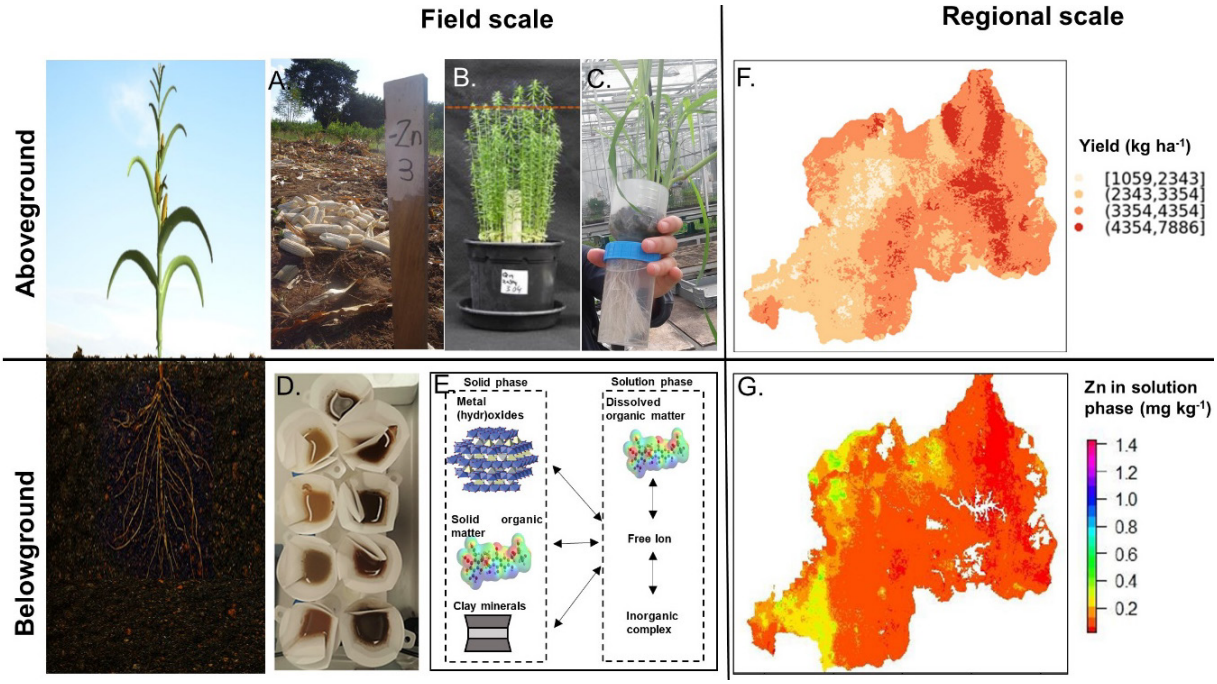

Figure 1: A schematic overview of the research on soil fertility in East and Southern Africa

Moving aboveground, the nutrient uptake by the crop is used as an indicator for bioavailability of nutrients in soils. To this end, nutrient omission field trials are executed in which yields are compared between treatments that receive complete fertilization compared with treatments in which zinc and boron micronutrient fertilisers are left out, in order to assess whether they are growth limiting for maize (Figure 1A). Field experiments were set up in Kenya, Zambia, Zimbabwe and Ethiopia, in collaboration with Wageningen Environmental Research (CASCAPE project), The Plant Production Systems group at Wageningen University, The International Plant Nutrition Institute and local partners such as the University of Zimbabwe. Next to field experiments, pot experiments are conducted to better understand the soil properties that affect zinc availability for plant uptake in a controlled environment (Figure 1B). Next to the regular pot experiments, a double pot experiment has been set-up in collaboration with AgroCares Research, in which a nutrient solution in the lower pot is used next to the soil sample in the upper pot (Figure 1C).

Knowledge derived from the field trials and greenhouse experiments, is used to extend the QUEFTS model by developing micronutrient modules. To move to the regional scale, maps of aboveground parameters can be developed with QUEFTS for fertiliser recommendations. Figure 1F shows a preliminary map of predicted maize yield in Rwanda, developed using QUEFTS (based on N, K and K). This map can be further elaborated and serve as a baseline reference once QUEFTS is extended with micronutrient modules.

Research Highlights

Availability of boron for plant uptake is generally considered to be controlled by adsorption of boron to reactive minerals such as ferrihydrite (i.e., Fe(hydr)oxide with the highest reactive surface area). This adsorption process has not been described previously. We were able to study the interaction of boron with ferrihydrite nanoparticles which are omnipresent in soil systems, and have the data interpreted with state-of-the-art surface complexation modelling.[1] We confirmed that the presence of phosphate reduces the adsorption of boron and changes the surface speciation (Figure 2).

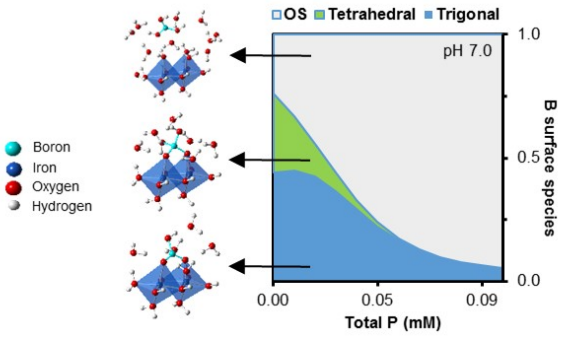

Figure 2: Effect of phosphate on boron adsorption and surface speciation on ferrihydrite

The surface complexation parameters that were derived based on adsorption experiments were applied to soils in a multi-surface geochemical model to understand which surfaces are most important for boron adsorption, and to test the boron speciation in various extraction methods that have been proposed for assessment of boron availability in soils (Figure 3).[2] Our modelling approach has enabled, compared to previous attempts, a strongly improved mechanistic understanding of boron speciation in soils.

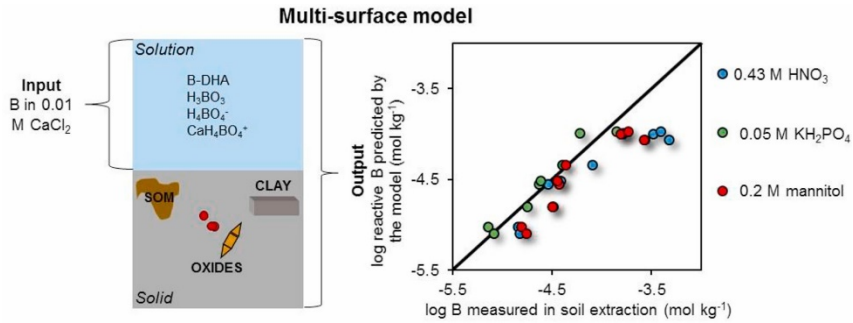

Figure 3: *left*: The multi-surface model with adsorption to solid and dissolved humic acids (SOM, B-DHA), oxides and clay. *Right*: comparison between boron measured in soil extractions and the labile boron calculated by the model

Impact

During the course of this project, transfer functions have been developed for phosphorus and potassium soil tests[3]. QUEFTS requires four input parameters, of which two (pH and organic carbon) are routinely measured. For the other two parameters (phosphorus and potassium availability) several soil tests are employed, giving varying results depending on the method. In order to apply QUEFTS to existing soil maps, transfer functions were needed, so that available phosphorus and potassium data could be translated into the input that QUEFTS requires. These functions greatly increase the applicability of QUEFTS. Besides the potential use by local researchers, ISRIC currently uses the transfer functions to develop soil and yield maps.

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The more accessible tools for predicting soil micronutrient availability developed in this project are expected to have a great impact as well. Currently, assessing micronutrient bioavailability is analytically challenging, especially given the extremely low concentrations in African soils. These tools that are supported and validated by the mechanistic geochemical models developed in this project, can be used to develop maps on a regional and national scale. These maps will enable the identification of regions at risk of micronutrient induced growth-limitations and consequently the development of effective fertilizer recommendations, which are indispensable for increasing yields and resource management in Sub Saharan Africa, as well as for human health and livelihoods.

Case study: Toward Integrated Fire Management

This case study highlights the pro-active connection of Soil Science cluster research to major societal and environmental challenges – in this case wildfire – exhibiting not only the generation of scientifically novel and societally applicable knowledge, but also commitment to engagement of, and ongoing communication with, multiple affected stakeholders in order to effect significant and sustainable impact.

Summary

Wildland fire greatly influences the natural environment, the people living in it and their livelihoods. For both fire prone regions as well as countries that are considered to be less fire prone, the occurrence of wildland fire in combination with climate change and, often, high population densities poses major challenges. These challenges can only be tackled via an integrated management approach that mitigates the impact of fires on the landscape and the people living in it. Here, we present the formation of a knowledge network that grew out of the Soil Science cluster chairgroups, and has resulted in the EU-funded Innovative Training Network PyroLife. The network links the expertise on pyrogeography within the Soil Science cluster groups to other groups. This has the long term objective being to aid society in moving away from the suppression-based approach to dealing with fire to a more integrative approach of living with fire. The central approach of PyroLife is to foster knowledge exchange between disciplines, sectors (academia and practice) and countries. Through the strong connections with multiple stakeholders, a direct influence on policy and awareness is also achieved.

Case Description

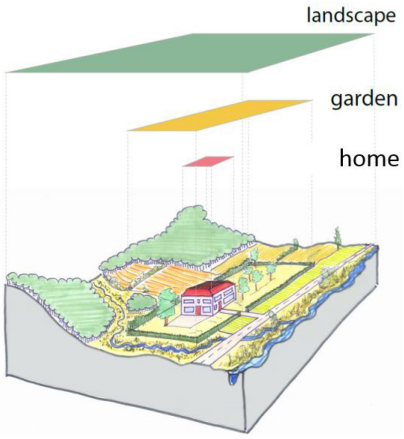
Background

Of the four basic elements earth, water, air and fire, three have been traditionally represented in a range of chair groups at Wageningen University, while fire - the element that connects them all - has long remained missing in our research, education and outreach. Yet wildland fire has the capacity to greatly influence the natural environment, the people living in it and their livelihoods. For both fire prone regions, such as Mediterranean countries, and countries that are considered to be less fire prone, such as northwest Europe and northeast US (Kerr et al., 2018), the occurrence of wildland fire in combination with climate change and, often, high population densities poses major challenges that can only be tackled via an integrated management approach (EC, 2018).

To stimulate such an approach, a knowledge network on fire was created and has resulted in the EU-funded Innovative Training Network PyroLife. PyroLife is built upon four axes of diversity: interdisciplinarity, intersectorality, geography and gender (https://pyrolife.lessonsonfire.eu/). Here, we focus on development of PyroLife, its current embedding within WUR and how it is being used to strengthen both the research on wildland fire within WUR and its impact on society.

Development of fire research in the Soil Science cluster

Research on fire impact on soils at WUR is rooted in expertise on fundamental processes related to soil water repellency (Stoof et al., 2011), potential ash effects (Stoof et al., 2016) and how this affects soil erosion and hydrology (Prats et al., 2019; Pastor et al., 2019; Stoof et al., 2012); built upon the expertise of the SLM group. Prediction of the vulnerability of landscapes to fire requires incorporation of landscape spatial variability (the core focus of SGL), the way fire behaves spatially as affected by this variability, and the impact of this variability on the natural environment and subsequent fires (Stoof et al., 2013). At the same time, there is a major human (socio-ecological) component to fire risk and fire impact (Davies et al., 2016). Therefore, what is needed to mitigate the impact of fires on the landscape and the people living in it is an integrated fire management approach (EC, 2018). That in turn requires the linking of the expertise of the Soil Science cluster groups to other groups.



Research objectives

The overall long-term objective of the fire research at Wageningen UR is to help society move away from the suppression-based way of dealing with fire and toward a more integrative approach of living with fire. This so that i) negative impacts of wildland fires on the human and natural environment can be mitigated; and ii) humans can adapt to the present and future uncontrollable fire types (extreme fires); also in response to climate change.

Specific aims:

a. Develop integrative fire management that combines the Northern European expertise in water management and planning with the long experience and knowledge of fire in Southern European countries
b. Prepare traditionally non-fire prone countries (like the Netherlands and most of Western Europe) for the fires that are already happening and those that are coming.
c. Connect scientific research and stakeholder needs for knowledge on integrated fire management, and to translate this into both applied and fundamental science projects.

Research approach

The central approach of PyroLife is to foster knowledge exchange between disciplines, sectors (academia and practice) and countries. In PyroLife, 22 universities, research institutes, companies, public partners and non-profit organizations work together in research. The network trains 15 early-stage researchers, PhD candidates, in biophysical and social drivers and impacts of fire, science-policy interactions, risk communication and writing policy briefs, culminating in an inter-and transdisciplinary PhD course on integrated fire management within a fire prone community in the Netherlands.

Within WUR, the PyroLife project takes direct advantage of the SGL knowledge on landscape variability and pyrogeography, WSG expertise on integrated water management, and knowledge on landscape design. PyroLife has additionally been a catalyst within WUR: MAQ and SGL now supervise the PhD project of the Catalan fire chief on predicting extreme fires, and other initiatives (with De Vries, Social Sciences, and FAO) include EU proposals on trust, policy briefs on the effects of COVID-19 on fire management (Stoof et al., 2020a), and the granting of INREF seed money to link fire communities in developed and developing countries. Finally, through ongoing MSc projects, the SGL group is working with the GRS group on small fires, and with the Hydrology and Water Management group on fundamental research on fire effects on water flow.

Through strong involvement of stakeholders such as local communities in addition to governmental bodies such as the EU, direct influence on policy and awareness is achieved (see impact below).

Stakeholder involvement

Stakeholders directly involved in WUR's PyroLife research are Águas de Portugal, Technosylva (developing a Dutch fire spread model with a visiting scholar grant from PE&RC), the Pau Costa Foundation, Arup (multinational company), the European Foresty Institute, Landworks (South Africa), the Catalan Fire service, and through its advice and research on extreme fires to the EU and beyond (e.g. California, South America). Stoof was additionally commissioned by the Province of Noord-Brabant to investigate one of the largest wildland fires in the Netherlands (the Peelbrand; Stoof et al., 2020b), establishing a new network of local residents, fire fighters, land managers and several (semi-) governmental organisations (see below).

Research Highlights

Since 2014, the research has resulted in several highly cited papers in important soil science journals like Water Resource Research, Geoderma, the International Journal of Wildland Fire (Stoof et al., 2014; Stoof et al., 2015; Stoof et al., 2016).

Additional highlights:

- SGL expertise shown in book chapters (Stoof, 2019; Stoof, 2020).
- Need for diversity in fire science and integrated fire management highlighted in a Letter to the Editor in Nature (Bowman and Stoof, 2019).
- Together with the Institute for Safety (Edwin Kok), Stoof initiated data collection on the occurrence of wildland fire in the Netherlands in 2017, after the Netherlands stopped collecting these statistics in 1996. The datasets gathered are used by the EU via the Expert Groups of Forest Fires (of which Kok and Stoof are official delegates for the Netherlands) and, with their reports, publicly available at https://effis.jrc.ec.europa.eu/reports-and-publications.
- Marie Curie Innovative Training Network PyroLife, EU-funded, 4 million euros, 2019-2023, 3 WUR groups directly involved.
- Marie Curie Individual Fellowship, 180.000 euro, EU funded, dr. Stoof, 2016-2018.
- Stoof is a board member of the International Association of Wildland Fire and has been invited to give talks on integrated fire management at the Fire across boundaries conference in 2020, at the FAO United Nations in 2020 and the European Geosciences Union, 2019.

Impact

The efforts of the last three years have focused on linking research to the most important actors, to be able to have impact with current and future research. Current research has direct impact on several levels:

- Europe: contributing to the European wildland fire database and the reports of the EU Expert Group of Forest Fires, Stoof has co-written a EU leaflet, and was an invited speaker at the Green Deal conference of EU policy makers. Her co-authored papers on fire management in the UK have been discussed in British parliament (Davies et al., 2016); with Technosylva, SGL is developing a fire spread model for the Northern Ireland government, as well as a Dutch model supported through a PE&RC graduate school visiting scholar grant.
- The Netherlands: SGL research into the Peelbrand (Stoof et al., 2020b) has regenerated much attention, and research findings are cited in the upcoming report of the Netherlands Court of Audit (Algemene Rekenkamer) for the Dutch government. Ongoing discussions with policy makers (provinces, safety regions, ministry of agriculture, nature and fisheries) and locals focus on what is needed to make the Netherlands more prepared for large wildland fires.
- Science communication; Dr. Stoof actively engages with the general public through public media, resulting in a reach of 17.8 million people (57% of those Dutch) in the year 2020 alone (WUR brand monitor, newspapers, radio and tv interviews, and twitter).
- Education: apart from developing new PhD courses for PyroLife, a new interdisciplinary course "Pyrogeography" will train MSc students on Integrated Fire Management.

Future outlook

The Soil Science cluster, in combination with the chair groups both within and outside the graduate schools of PE&RC and WIMEK, is in an excellent position to become the knowledge center on the Integrated Fire Management of North Western Europe by combining its strengths on soils, geography and its expertise in integrated land and water management. Fire, the fourth element that was lacking in research, outreach and education is now in the spotlight nationally and internationally. There are major opportunities for the Soil Science cluster and the broader Wageningen community to build upon the pyrogeography research lines originating from SLM and SGL, using the Wageningen approach linking science and practice. Further development into this internationally leading role requires strategic support for research, policy, outreach and education.

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Case study: SPRINT - risks and impacts of pesticides on the environment and human health

This case study is an example of the Soil Science cluster working beyond the traditional context of soil science, linking directly to human as well as environmental health. It illustrates the kind of wide collaboration the Soil Science cluster can organize - within and beyond WUR - for novel research that is highly relevant and contributes significantly to both science and society.

Summary

The EU-funded SPRINT project (https://sprint-h2020.eu/, 15 M€, 2020-2025) will develop and validate a Global Health Risk Assessment Toolbox to integrate assessments of the impacts of plant protection products (PPP) on ecosystem, plant, animal and human (EPAH) health, using three main attributes for health status: resilience, reproduction/productivity and manifestation of diseases. The goal is integrated risk assessment at the local, regional, national and European level, focusing on different PPP use patterns and detected residue mixtures in contrasting farming systems (conventional, integrated, organic). PPP distribution and impacts on EPAH health will be evaluated at 11 case study sites (CSS). Environmental pathways, and direct (food/feed ingestion) and indirect (air/dust inhalation and dermal uptake) animal and human exposure routes will be assessed to improve current fate, exposure, and toxicokinetic models (e.g. EFSA-FOCUS, BROWSE, BREAM). (Eco)toxicological assays will be performed based on CCS findings, using existing and improved procedures, including alternative testing criteria and new target organisms. The assays will cover direct and indirect exposure to multiple residues, realistic ranges of PPP concentrations, multi-species scenarios, and short- and long-term time horizons. Modelling of sustainability and cost-benefit analysis at the farm and macroeconomic level will be conducted to derive recommendations for sustainable transition pathways, and a research agenda on PPPs. SPRINT is based on a multi-actor approach with CCS platforms to engage stakeholders and identify respective needs, improve farmer and citizen awareness, jointly develop novel management strategies for reduced reliance on PPP use, and create an enabling environment for adoption and change.

Case Description

Background

Most farmers rely on plant protection products (PPPs) to maximise crop yields. However, some PPPs are potentially harmful to environmental, animal and human health. Data on the risks and impacts associated with PPPs' are, at present, fragmented and incomplete. There is, therefore, a need to deliver an integrated approach to fill this data gap. To address this, the WUR Soil Science cluster group, Soil Physics and Land management, conceived and is coordinator of the SPRINT project which will develop and test an integrated global health approach to assessing the risks and impacts of PPPs on environmental, crop, livestock and human health. SPRINT entails a transdisciplinary consortium, including medical and (eco)toxicological research partners, and close involvement of all relevant stakeholders to collaborate in establishing the global one health approach and effectively (co-)developing transition pathways away from reliance on PPP use, and improve farmer and citizen awareness. The project consists of 25 partner organizations in Europe and Argentina with a total project budget of 15 million €.

Research objectives

Main objectives of the SPRINT project are to i) engage with stakeholders to identify their knowledge needs and improve awareness of and trust in integrated risk assessments of pesticides, ii) assess PPP component mixtures & distribution in the environment (soil, water, air), crops, livestock and humans and the related health state of organisms & humans in different farming systems, iii) estimate direct & indirect PPP residue exposure levels for selected organisms, crops, livestock and humans in the case studies, iv) develop laboratory tests for measuring the effects of PPP mixtures on environmental, crop, livestock and human health, v) develop a Global Health Risk Assessment Toolbox for risk and

impact assessment of PPP residue mixtures on the environment, crops, livestock and human health, linking exposure to PPP residue mixtures to health impacts, vi) assess integrated risks, costs and benefits of PPP use in different farming systems at micro and macroeconomic level, including internal and external costs of PPP use, and vii) propose transition pathways towards more sustainable plant protection, provide policy recommendations and develop a research agenda on sustainable plant protection.

Research approach

The main concept of SPRINT (Fig. 1) is as an innovative, integrated global health approach that leverages transdisciplinary expertise, multi-actor involvement and representative case studies. Coverage of the main cropping systems and varied European landscapes, with differentiation of conventional, integrated and organic farming scenarios, significantly contribute to advancing the assessment of the effects of different application patterns on PPP distribution, exposure, and EPAH health. The development of a Global Health Risk Assessment Toolbox within SPRINT is underpinned by holistic attributes/indicators to characterize health status (Figure 1).

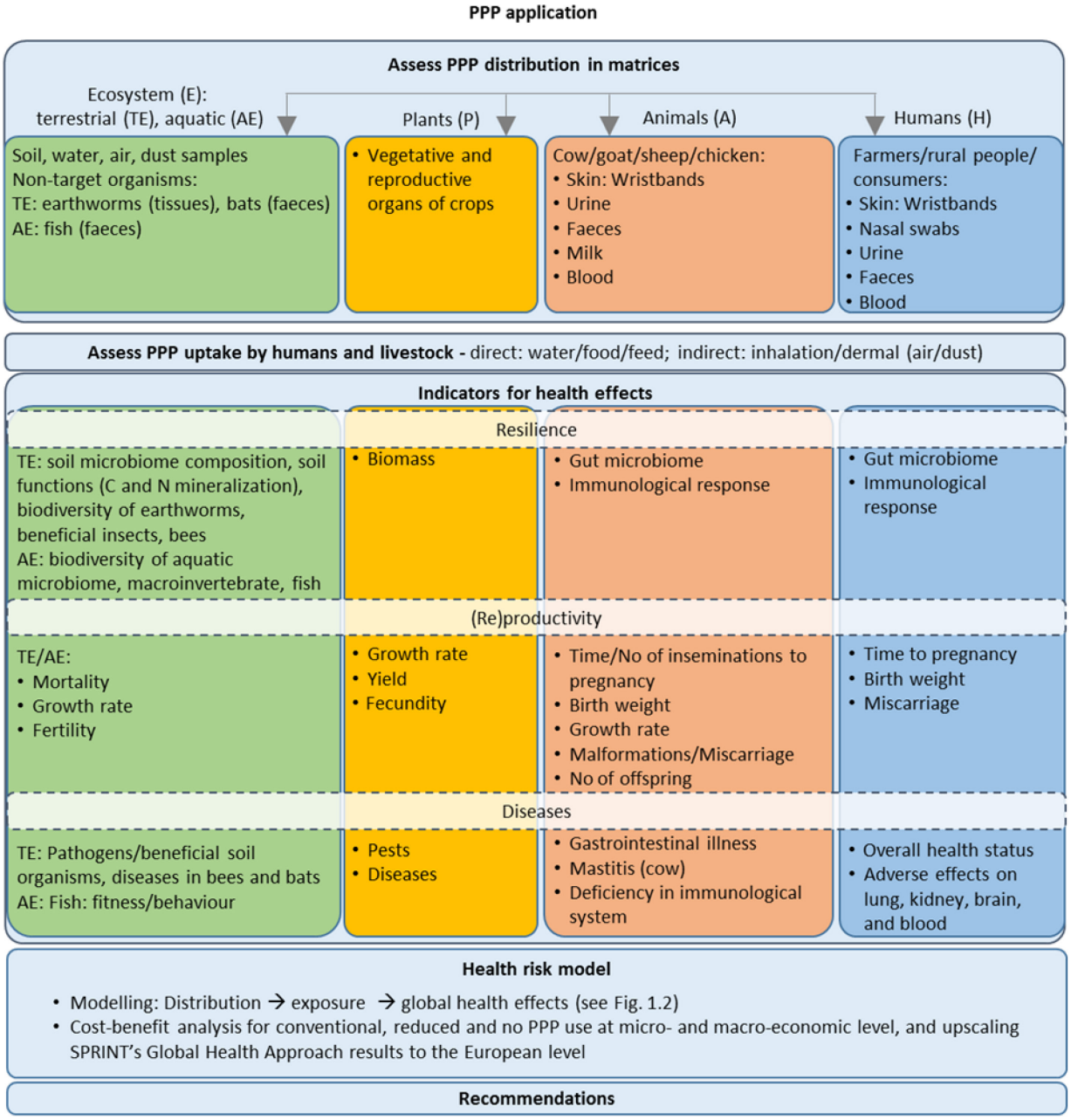

Figure 1: SPRINT's approach with regard to the overall assessment of PPP residue distribution in different matrices, and related EPAH health impacts

The distribution and impacts of mixtures of PPPs on EPAH health will be evaluated across 11 CSS with contrasting farming systems (conventional, integrated, organic), covering the main European crops, and soy production for feed in Argentina destined for the European market (see Figure 2). PPP mixture, environmental fluxes, and both direct (by water/food/feed ingestion) and indirect (by air/dust inhalation and dermal uptake) animal and human exposure routes will be quantified to improve fate (FOCUS), exposure (BROWSE, BREAM), and toxicokinetic/toxicodynamic (TK/TD) models. Relationships between PPP distribution and health indicators for the ecosystem, animals and humans assessed across the CSS will be collated, with a view to providing a clear consensus on cause and effect.

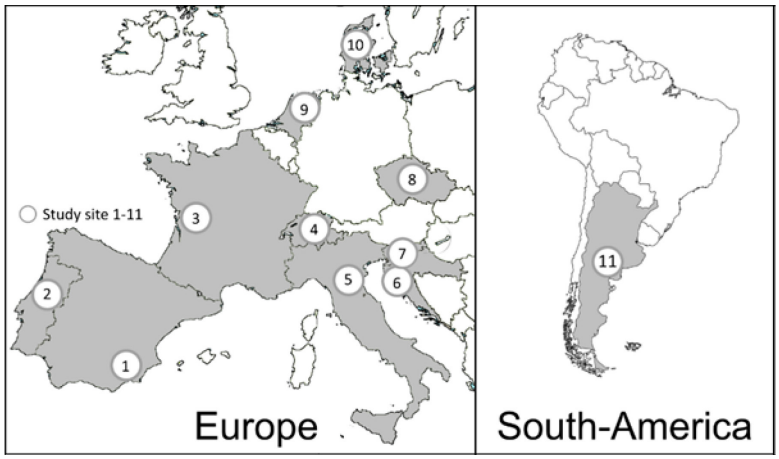

Figure 2: SPRINT Case Study Sites (CSS)

SPRINT will rely on the recently published EFSA guidance for risk assessment of combined exposure to multiple chemicals (EFSA, 2019) and extend the approach to multiple species. Improved (eco)toxicological assays will be performed by WUR and 3 other universities based on findings from the CSS and existing databases such as the LUCAS survey. Data published by Silva et al. (2019) and from 3 of the CSSs (Geissen et al, 2021) show that mixtures of up to 13 PPP residues are present in soils. The assays will cover direct and indirect exposure to multiple PPP residues, realistic ranges of PPP concentrations, multi-species scenarios, and acute and chronic exposures. The risk from exposure to chemical mixtures can be assessed as a whole (whole-mixture approach), or based on the individual components of the mixture (components-based approach). Since we will test known mixtures from the CSS, we will apply the component based approach (EFSA, 2019) with consideration of potential interactions.

SPRINT will be developed for integrated risk assessments at local, regional, national and European levels, focusing on conventional, integrated and organic farming systems, as well as different environmental and socioeconomic conditions. Modelling of sustainability and cost-benefits at micro- and macro-economic scale will be included to derive recommendations for sustainable transition pathways and a research agenda on PPPs. Stakeholders will be involved throughout the project, and overseen by an independently chaired Project Stakeholder Advisory Group (PSAG).

Stakeholder involvement

Stakeholder platforms will use different mechanisms to engage with stakeholders. A detailed stakeholder engagement plan was prepared at the beginning of the project, including mapping of stakeholders to ensure representation of all key actors (e.g. farmers, farm advisory services, EFSA, industry, consumers, NGOs, public authorities, policy makers, and civil society actors). Farmers, rural residents and consumers will be involved using crowd sourced research. Stakeholder networks have been established in all case study sites (Table 1). In addition, training events will be organized for case study partners on the monitoring activities, interviews, workshops and exposure assessment to ensure both quality and consistency in approaches to stakeholder involvement and thus collected evidence. In different work packages of the project, specific training and analysis of activities related to gathering EHAP evidence, and on socio-economics and policy, will be provided. The Project Stakeholder Advisory Group (PSAG) comprises representatives of stakeholder perspectives from a range of EU and non-EU countries, providing objective advice, supporting dissemination, and engaging with the case study sites to assure consistency in evidence gathering.

Link to education

SPRINT is closely aligned with a range of educational activities, providing opportunities for BSc and MSc theses and internships, PhD student involvement, educational oriented field visits to case study sites, and student exchanges between SPRINT partner organizations. In addition, results of the project are used in different courses to provide students with state-of-the-art knowledge, insights and information about the project.

Research Highlights

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Impact

Besides SPRINT's academic impact, the project will support several EU policies, from broad overarching strategies to pesticide regulations and policy evaluations. In particular: i) REFIT (the regulatory fitness and performance programme) - an ongoing evaluation programme which checks that EU legislation is 'fit for purpose'. SPRINT will address some of the key areas REFIT identified as needing improvement, namely cumulative risk assessment, using green diplomacy to promote our green agenda for pesticides, and better enforcement of the Maximum Residue Level Regulation; ii) the European Green Deal – which aims to overcome environmental decline and the threat of climate change by making the EU's economy more sustainable. A significant part of making the EU's economy sustainable will require a transformation of the food system. SPRINT will contribute to this through one of the key strategies of the green deal, 'Farm to Fork'; iii) the Farm to Fork (F2F) strategy - a central part of the European Green Deal. The strategy has several aims which SPRINT can feed into. Most importantly, the project will contribute to the goal of reducing PPP use by 50% by 2030. In addition, SPRINT contributes to the F2F aim of a sustainable food system which has a neutral or positive impact, reverses biodiversity loss, and ensures food is safe for everyone; and iv) the Sustainable Use of Pesticides Directive (2009/128/EC) – which aims to achieve sustainable use of PPPs in the EU by promoting the use of integrated pest management and alternative approaches for controlling pests. SPRINT will contribute to the success of this directive by identifying transition pathways towards reducing reliance on PPPs.