OF MODELS AND MEN

Unraveling the influence of water models and exploring how to engage

Rozemarijn Hendekien
ter Horst

Propositions

1. A man with a model has more influence than a man without.
   (this thesis)

2. The influence of water models on humans and nature demands accountability of its enablers.
   (this thesis)

3. Creativity and vulnerability are the most important assets of a researcher.

4. Science improves if scientists only publish one paper every four years.

5. The Open Access system is problematic as it privileges Western Scientists.

6. Especially times of polarisation demand our efforts to see others as multifaceted humans.

7. The West has failed to uphold its own values, at the detriment of itself and others.

Propositions belonging to the thesis, entitled

Of models and men. Unravelling the influence of water models and exploring how to engage.

Rozemarijn Hendekien ter Horst
Wageningen, 4 April 2025

Of models and men

Unravelling the influence of water models and exploring how to engage

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Of models and men

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Figures and Tables

“People ask me if I'm hopeful.

Yes I am.

Hope is not the same thing as optimism. Hope isn't the sense that things are going to improve.

Hope is stubbornness.

Hope says "I will never give up, I will never stop trying".
Hope is the sense that some things are worth our life's work.”

Iyad el-Baghdadi via Twitter, 2 November 2023

PREFACE

I embarked on this PhD journey, with this book as one of the outputs, driven by curiosity and frustration. This is great fuel for an individual research project that spans over four years. Namely, in 2017 and 2018, I found myself part of two projects in which modelling water was a core activity. In one Dutch-funded project we used modelling to explore whether we could identify regions with an increased chance of water conflicts. The aim was to support institutions, from the very local to global level, to understand the dynamics surrounding these identified water conflicts, and to identify potential ways to engage with them. Finding suitable data was hard and we had to be very humble about what the model ultimately could say about water conflicts. Nevertheless, it appeared that the modelling exercise, and especially the excellent communication about it, had raised very high expectations. In a conference on an unrelated topic, I was asked by people who worked on water conflict from an international perspective whether I had been part of the team that "could predict water conflict". It scared me. I firmly believe there is no such thing as predicting water conflict by means of a limited model exercise, and also that approaching the world in such a way can have adverse effects. How did this modelling project create such expectations?

The second project that drove me into this PhD is described in the third chapter of this thesis, and relates to Water Accounting Plus. In a very simplified way, this modelling framework is used to assess how much water exists in a certain basin and how it is used. I was invited to join a project that aimed to foster water cooperation interactions related to a federal transboundary water conflict between four states in the South of India. The ingredients for cooperation were the neutral model-based analysis, fostering a data democracy in which data would be transparently collected and shared, and contributing to more effective water management and more crop per drop through the analysis. There were high expectations of the funders and commissioners in the Netherlands and India, but we did not achieve their aims and the modelling exercise was not accepted at the state-level. How could this project be designed and implemented the way it had? Why did the government of the Netherlands fund these two water projects that are so data- and model centred, with such big expectations? Why did certain people believe what models say, without necessarily understanding for what purpose the model ad been developed, and how it was made? Why do we have hopes that such projects will make a difference in other countries, especially in cases of contestations over water where it is obvious that long term investments in trust and relations are needed? And why is it so difficult to steer the focus and money away from these models, and instead sit with the complexity and the trouble?

In the Water Resources Management group at Wageningen University, similar questions were raised. I applied to a position for a PhD researcher, for which the call read: *"Simulation* *models are often-used tools for informing water management decisions. They are likely to involve multiple actors and stakeholders, on the one hand, and performance indicators and scenarios for possible futures, on the other. Such models are often presented as 'objective' knowledge upon which crucial decisions on water management are based. Presented as objective, "truth-making" tools, models can thereby be "black boxed", meaning that the expert knowledge in building them is not adequately examined for the underlying assumptions, suppositions and even politics. While model inputs are often restricted to particular indicators privileging certain perspectives better than others. Additionally, modelling outcomes can be strategically used to legitimize political choices, while models and scenarios themselves are already the result of political processes involving conscious and unconscious choices. In these respects models can be seen as inherently political. From here the call to "open the black box" of modelling processes, performances, and politics on any aspect of the water sector*" (WRM, 2019). This call precisely matched my own curiosity and meant that there was support for such research. I applied, had the luck to get hired, and then had to seek answers to my questions. But how do you open the black box of water models and the many politics surrounding them, when you are not a modeller yourself? In this book, I take you on this journey and share my academic and practical insights.

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Chapter 1

INTRODUCTION

This chapter is written by me, partly based on work I did with others. Namely, I worked on a special issue on "The Role of Data and Models in Transboundary Water Governance" with Veena Srinivasan, Kevin Wheeler, Jos Timmerman, and Pieter van der Zaag. These insights have been instrumental in writing this chapter. Also, The section on 'Defining models and modelling is based on a joint article published in: ter Horst, Rozemarijn, Rossella Alba, Jeroen Vos, Maria Rusca, Jonatan Godinez-Madrigal, Lucie V. Babel, Gert Jan Veldwisch et al. "Making a case for power-sensitive water modelling: a literature review." Hydrology and Earth System Sciences Discussions 2023 (2023): 1-31. https://doi.org/10.5194/hess-28-4157-2024.

Introduction

In water management and governance around the world, engineers play a prominent role in assessing and defining how water could and should be dealt with. Directly related, evidence-based decision making is highly appreciated and promoted in most water management and governance structures. In general models are becoming more central to the work of engineers and designers (Turkle, 2009), a process which is already ongoing since 60 years in the water sector (Rogers & Fiering, 1986). In conjunction, it is acknowledged that for understanding and governing water an integrated approach is required to address the complex challenges (Pahl-Wostl and Brugnach, 2008), including understanding the influence of humans on water systems (Sivapalan & Savenije, 2012). This demands increasingly complex models, including hydrological, socio-hydrological, or hydro-economic models, made possible by more and more natural and social science data and information that is collected, produced and shared, and by technological developments.

Models are not neutral; ideas on how something functions, or should function, as well as who and what is seen and who and what not, are embedded in a model and its development process (Haraway, 1991; Jasanoff, 2004; Litfin, 1997; Melsen et al., 2018; Srinivasan et al., 2018; Swords & Liu, 2015). Even when it comes to data and models that are applied in transboundary conflict settings, the focus is mostly on practical applications even when one would expect people to be extremely critical on why a model is used, how it is constituted, and with what effects (ter Horst et al., 2023). I argue that the non-neutrality of water models requires a deliberate engagement, especially when the knowledge tools are newly introduced in politically sensitive contexts. For instance, it brings up questions on how previously inaccessible and specific information can impact transboundary relations, and how this impacts institutional and legal frameworks that currently govern data and information sharing (Ibrahim, 2020; Leb, 2019). Addressing such issues demands gaining insights in the interplay between water, information and (emerging) technologies, knowledge, and power (Aubriot et al., 2017). Yet, water modelling happens within specific philosophies and cultures, and much of the literature on water modelling seems to be power-averse. Research mainly focuses on how to improve the model instead of understanding its interactions with society from a societal perspective (ter Horst et al., 2024). In return, there are few studies into the influence of water models specifically (see for examples the work of Budds, 2009; Holifield, 2009; Kroepsch, 2018). My question is whether model makers, users, and those impacted are willing and able to recognise how, where and when model as are political, how they function, and what influence they have. This matters, as it may for instance lead to negative effects, such as creating a disadvantage for specific people and places, or leads to missed opportunities to better connect a modelling process to local needs. I specifically engage with water models, as water is a common good that is often managed by a specific group of water experts with a specific way of analysing the world, and as I aim to contribute to a debate in the water sector on how to engage critically consciously with the knowledge tools that are developed and exported to other places.

There are already several proposals on how to engaging with the politics of environmental and water models in practice. These include checking if a model is salient and fits specific needs in particular on whether it works for a certain process, if it is seen as legitimate, and credible (Cash et al., 2003; van Voorn et al., 2016), on sensitivity auditing that is especially meant for models that are used in policy making and in situations where knowledge is contested. It then helps the modeller to identify particular framings and assumptions and to communicate about these (Lo Piano et al., 2023), on modelling ethics that help define what a model should or should not do or contribute to (Amorocho Daza et al., 2024), and situated modelling that states that knowledges are particular and specific, as well as ethics, and that in order to connect modelling with a specific context it is necessary to embrace multiple ways of knowing the world as well as the power relations related to this (Klein et al., 2024). The approaches differ, and when it concerns situated modelling the approach also differs from the other proposals in terms of ontology, understanding that the world works quite differently and that there are multiple ways of understanding and experiencing the world and not one truth that can be captured in a model. Despite these different ontologies and focus, I argue that these approaches are complementary to each other in practice. Yet, they all take the model as a starting point. What I aim to add to this through this research, is to start outside of the model, before even thinking about engaging with it, and to learn what the many influences of water models can be, from problematisation to implementation. If we take the model as the starting point, the model, the commissioner and the funder will determine who and what we see, and how, whose purpose is served, and who defines what is legitimate, salient and credible. In this research I centralise water models and their influence, with the attempt to decentralise them. Models have to be put in their place as tools to think with, not tools that think for us (Godinez Madrigal et al., 2023), and I call for a society and nature-first focus, not the usual model-first approach.

Aim of the research and research questions

The main research question that guides this study is: How do water models gain influence in specific cases, and to explore different ways of how to engage with this influence in practice and science?

To answer this question, the following three sub-research questions have been formulated:

- How are the many ways in which water models and modelling processes can gain in influence analysed and discussed in academic literature?

- If and how do water models, specifically Water Accounting Plus and the Multi Year Water Allocation System, gain influence, potentially beyond their intended reach?
- What practical and scientific lessons can be drawn on how to engage with this political charge of water models, and eventually how to harness the influence of models for progressive transformation?

In the following sections I discuss how I define and approach models, as well as what methodology was chosen to research the questions listed above.

Defining models and modelling

A model is many things. It is in between theory and practice (Morgan and Morrisson, 1999). Seemingly it can act as autonomous agents with power, but more often there are moments they are used by others or just do not do anything at all. Models are often presented as boundary object that allow communication between groups from different social worlds (Star, 2010; Star and Griesemer, 1989). Yet, there is a lot of work that needs to go into making a boundary object, the boundary object may not be accessible for everyone, and it does not mean that this object does not have politics. Woolgar and Cooper (1999, p. 443) summarise the complexity in relation to technology, which encompasses models as well: "technology is good and bad; it is enabling and it is oppressive; it works and it does not; and, as just part of all this, it does and does not have politics". It means we have to find out, or decide, whether it is used for good or bad, designed to be enabling or oppressive, whether it works or not, and if and how politics are embedded in the making and implementation.

In this thesis, I define models as simplified representations of (parts of) the world. They support the processing of input in various ways, to create output that is informative about the input and process. Subsequently, the modelling output is influenced by the process and the input (based on Losee, 1997). A model is therefore not only a computational or numerical model, but could also be a physical or mental model. This definition assumes the model is both an object and a process (Jackson, 2006). Research has shown that the simplifications of the world are based on ideas on how the world functions or should function, enabled or limited by technology, and sustained by particular forms of (expert) knowledges, values and understandings (Krueger and Alba, 2022; Latour and Woolgar, 1986; MacKenzie and Wajcman, 1999; Haas, 1992). For example, the work of Linton and Budds (Linton, 2009; Linton and Budds, 2014) describes the different ways that water is understood, from a purely physical understanding that is often applied in hydrology, taking human influences into account that is common in socio-hydrology, or seeing a deep entanglement of people and water and showcasing that through these deep entanglements water can flow upstream.

Different models, based on these different understandings, will give very different insights in causes and effects.

Models are used for many different purposes, and there are different ways to classify these usages. A simple distinction can be using a model for consolidating ideas about what the world is, or to explore unknown parts thereof, for instance through prediction (Pielke Jr, 2003). This can be complicated a bit more. Prediction may sound like an accurate description of what can be done with a model for some, but for others it is an absolute no go, or something that a model simply cannot do as it may be the task of a fortune teller. In this case, a model is rather used to simulate different future scenarios. What is seen as a model also influences what it can do. For instance, Varenne (2019) distinguishes 21 functions of a models. In his overview of models he also includes model boats and samples, mental imagery, statistical modelling and participatory and action research modelling. These models can facilitate sensory apprehension, intelligible formulation, theorization, the co-construction of knowledge, and decision-making and action. By sharing these different views, I challenge you as reader to keep an open mind for the many different ways there are to use, understand, and engage with models.

Most models used in the water sector are quantitative models, made by hydrologists and engineers, which are also the focus of this research. Although these models are an important part of the toolbox of the water engineer, adoption of the process and outcome by others is not a given. For instance, Rogers and Fiering show, specifically for optimization analyses, how only 7 out of 22 modelling studies assessed were actually used in implementation decisions (Rogers & Fiering, 1986), which even seems to be a high percentage. However, models do not necessarily need to be used in implementation decisions to have influence. Information and knowledge enter and exit models at every stage of the development process, so the relation of models with social processes happens throughout the model development chain. Also models that are purely used in a laboratory setting possibly shapes how a person, or persons, see the world. So whether it is a model that is developed in a laboratory setting, or a model intended to influence implementation decisions, they both have a potential influence that requires a conscious engagement (King and Kraemer, 1993).

This societal influence of models is perhaps clearest and most direct through visual output, such as graphs and maps, that are used in decision making processes. These decisions can be for instance be taken by politicians and civil servants, or by engineers, or by citizens. It is thus not only a policy matter. And, as model processes are not linear, there are different ways that models interact with these societal decision making processes. Some moments may be recognisable, and others more hidden. An example is how indicators – which we can understand as outputs of a modelling process, simplify the world for us and show who or what is performing "better" than others (Merry, 2011). Some elements of the modelling process have more influence than the final product (Lane et al., 2013), for instance by (re-)producing or challenging discourses (Krueger and Alba, 2022). In this process it matters whose information and knowledge is taken into account, who and what is represented in the process, and how. Yet, it is important not to essentialize the influence of models in society, and to recognise that their influence might vary from case to case. My quest is to find out at what moment politics come into play and in what ways, in what many ways water models and modelling processes have influence, how people engage with this influence, and how we can engage in explicit power-sensitive ways.

Conceptual framework

To open the black box of water models, and to analyse their interactions with the world around them, this work builds on reflexivity, deconstructing models as amalgamations of worldviews, expertise and materiality, and the Actor-Network-Theory as methodology. I will explain these elements below and show how they are useful to research water models in conjunction.

Deconstructing models

I open the black box of water models to identify the interactions of the model with the environment it is developed and implemented in, as to derive how it is shaped and in turn shapes others. A crucial step is to unpack the model. Coming back to the definition of Losee (1997), a model has input, a process, and output. Unpacking a model focusses mainly on what defines this process. Mackenzie and Wajcman (1999) have shown that models can be unpacked based on the worldviews, expertise and materiality that shape them and are embedded in them. This approach makes both the makers and the model visible. In my theorization I make a distinction between ideas on how the world works, or ontology, and ideas on how the world should work, or visions of the future. The models are not only representations of the world, but also have embedded aspirations on how it should work. Perhaps this is shown most clearly in projections of the future, or in the subjects that are being modelled and why. Although technology is never neutral, it does not mean it is problematic, or should be discarded as just another opinion. It rather invites us to make the proposed aims of the modelling project explicit and to evaluate it, taken literally as valuing whether this is a goal or a future that we would like to work towards. This also directly opens up the discussion on how this should happen, linking to philosophical work on the influence of knowledge and science (see for instance Knorr-Cetina, 2013; Latour, 1987; Nowotny, 2003; Stengers, 2017).

Worldviews, or ontology, is how (parts of) the world are represented in the model, including the assumed relationships between the different elements within the model, often most directly translated in the mental model that underlies a hydrological model that identifies what is to be included and excluded. Visions of the future is the part of the model that reflects ideas as to how the world should work in the future, including hopes of what can be achieved through the analysis provided (Konrad & Böhle, 2019). Expertise relates to what the developers of the model know, in terms of what they have learned in their studies and through experience, including specific norms and values on how to do their work. The expertise of the makers influences the design choices made in a model and thus what is included and not, as well as how (Addor & Melsen, 2019; Babel et al., 2019). But in practice discipline does much more. It also influences specific relations between the model and the world outside of the model. For instance through knowledge hierarchies and who is seen as having the 'right' expertise to say something about the model, or ideas on what are suitable tools are to address a certain problem.

Expertise and worldviews are thus closely related (Haas, 1992). Materiality relates to the physical properties of the model and its output, which will allow for only specific expertise and worldviews to be conveyed. The codes underlying a model as well as any outputs (such as numbers, graphs, maps) are all part of its materiality and allow for the model and its outputs to be shared independently of the makers (Knuuttila, 2005, pp. 1266–1267). The four elements, as depicted in Figure 1.1, are closely interconnected and mutually influence each other, but also provide clear entry points to understand how a model interacts with, and influences, its environment.

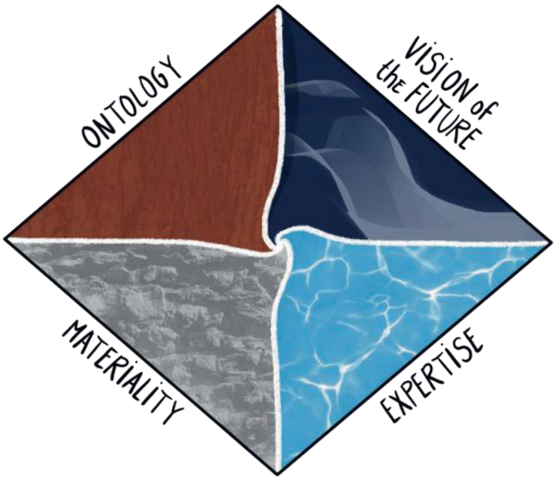

Figure 1.1 Unpacking a model as technology
Source: Based on Mackenzie and Wajcman (1999)

Actor Network Theory as methodology

After unpacking the model itself, I turn to understanding its relations with the place it is developed and implemented in. I build on the Actor-Network Theory (ANT) to identify "establishment and the evolution of power relationships" through, and surrounding the model (Callon, 1984: pp. 201). ANT is not an easy theory to follow and apply (Ingold, 2008). I enjoy thinking through ANT because it invites to think about the world in a completely different way, with an ontology in which everything is connected through networks, where everything moves and flows in a bid to enrol it in their own networks to become stronger. I find it easier to think with ANT by doing the following thinking exercise: I turn everything in particles of which I have to discover the specific properties. Me, as particle, can form alliances with other particles that help me to do certain things. These other particles can be people, or infrastructure, or ideas, based on the material-semiotic nature of ANT (Law, 2007). A human-particle that forms a network with a loaded gun particle, has more potentiality than a human-particle without. Another example is that I am a human-particle with a Dutch passport, that enrols me into the network of the Netherlands, with an anthem, elections, specific norms of how to behave. It helps me to be curious about what is happening in a certain situation, trying as much as possible avoid building an analysis on pre-conceived ideas and biases that explain-away, or that impose (in my case of a Dutch person, working in Dutch knowledge institutes) a Western-centric view on how things are and should be. It has therefore also been helpful to apply ANT to models that travel outside of places that I am familiar with, and places that I have been taught specific things about.

I use ANT as methodology (Kanger, 2017), and especially building on the process of translation, to analyse the many interactions through which water models potentially gain influence. Callon defines four stages in his story on how scientists try to get scallops to behave is they wish, with the scallops having a mind of their own (1984). I greatly enjoyed reading about the this article as it is quite accessible, it gives a framework that theorizes how networks are built, it calls out the assumed dominant position of foreign scientists, it challenges our ideas on what has power or not (in this case scallops) and it shows the many intricate ways through which power flows.

The four stages are:

- *Problematization*: in which initiators define a certain problem and convincing argument for the people, institutions and elements required to start working on solving the problem.
- *Interessement:* Those involved in the problematization attempt to persuade others to buy into the defined problematization in various ways.

- *Enrolment:* specific roles are identified to solve the defined problems, and negotiations happen to get specific actors to play those roles.
- *Mobilization*: the roles are activated and played out, are changed, or are rejected in the context of the specific actors.

These stages do not happen in a linear way, and it can be very likely that no successful mobilization is achieved or that it is not lasting. Akrich et al. (2002b) compare the process of creating support for an innovation to a whirlwind, where the innovation tries to capture as many people or support, and stick to as many places as possible. Success is not guaranteed. In this process, the challenge for the innovation is to find out in what ways it can best connect to particular people, and to find an potentially effective spokespersons. It is thus a process that is inherently about relations between people, places and technology – and specifically for this research it concerns water models. The structure provided by the theory of translation, in combination with information on the constitution of the model based on MacKenzie and Wajcman (1999), is shown in Figure 1.2.

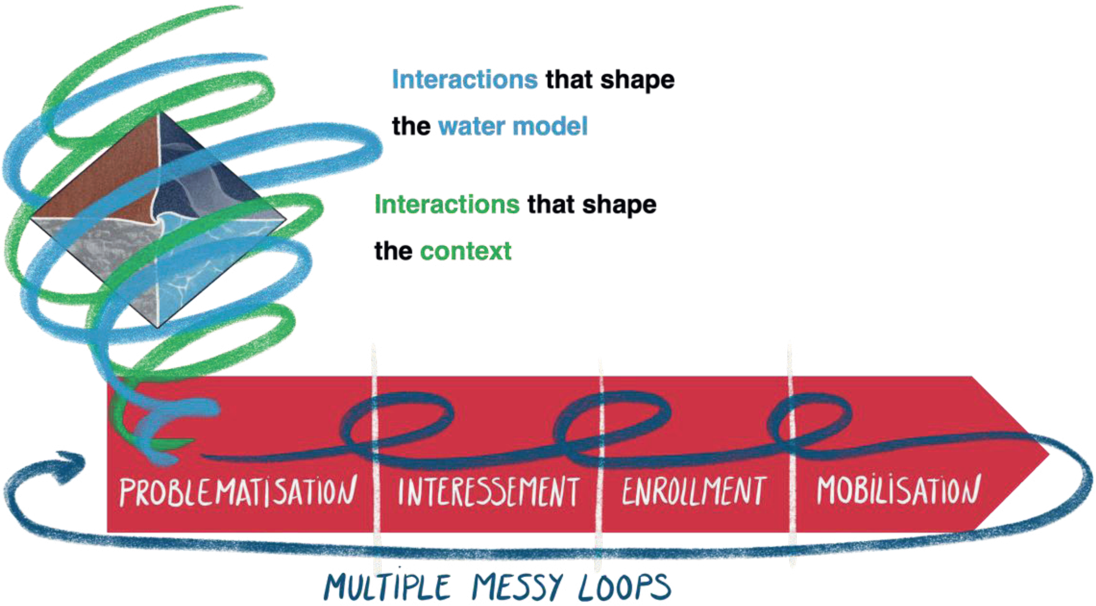

Figure 1.2 Conceptual framework

Specific attention is dedicated to interactions between people and the four elements that constitute water models, based on Latour's reflection on interactions through the theory of translation, as "each of these people may act in many different ways, letting the token [model] drop, or modifying it, or deflecting it, or betraying it, or adding to it, or appropriating it" (Latour, 1986; pp 267). This makes the power relations visible and helps to understand what actual influence the model has, and why. Making especially these dynamics visible can also help to clarify who or what is responsible or able to design the model and modelling process in a different way.

The conceptual framework helps to unpack - in a semi-structured way that takes into account the messiness of the process - how a model, or certain aspects thereof, gain support while others do not, as will be illustrated through the case studies. This approach allows me to engage with models and understand them as a non-modeller, and has invites me to be both open to the positive sides of a model and modelling approach, as well as the potentially negative influence.

Reflexivity as moral guideline, object of study, and research lens

Reflexivity is a key concept in this thesis. Sultana defines reflexivity as "practicing critical consciousness of one's location, actions, and power relations during a research process" (Sultana, 2017: p. 1). It is directly linked to the concept of situated knowledges of Haraway, (1988), that calls for doing away with sciences that feigns neutrality, hiding a specific position and that places itself outside of a certain situation that it is assessing. This disconnect and assessing from afar from a seemingly neutral and superior position is named the 'god trick' by Haraway (ibid, p. 578). Being situated means embracing the idea that there are many ways of knowing and that scientific knowledge is not superior, being mindful of the power-relations that come into play in relation to who knows what, it is about connection and acknowledging histories, and understanding relations between the researcher and those being researched (Klein et al., 2024). Reflexivity then is essential to identify and assess what being situated means or could mean in a specific context. Sultana invites us to specifically engage with one's location, actions and power relations, to identify systems of inequality and difference, and subsequently identify how to engage ethically (Sultana, 2007). It is about the partiality of knowledge, about who is seen as being 'in the know' and who is not, and what effects this has (Zwarteveen, 2008).

I mobilise reflexivity in three different ways, including reflexivity on methodology, as research lens and as object of study, as depicted in Figure 1.3. Sultana's definition of reflexivity invites to be reflexive on oneself, and the first mode in which I apply reflexivity therefore relates to reflexivity as moral guideline for my own research practices. This will be further discussed in the methodology and specifically in relation to research ethics. I find it only ethical to also be critically conscious on myself, especially in relation to the second way I use reflexivity. Namely, I use the concept is an object of study, to analyse the way modellers, commissions, funders and users engage with models and if and how they are critically conscious of the water model and its relations with the world and what this means for the way they engage with the model and modelling process. The third mode is reflexivity as a research lens, to explore how other researchers study and engage with the influence of water models, and how they have followed up on questions on the influence of water models that are similar to mine.

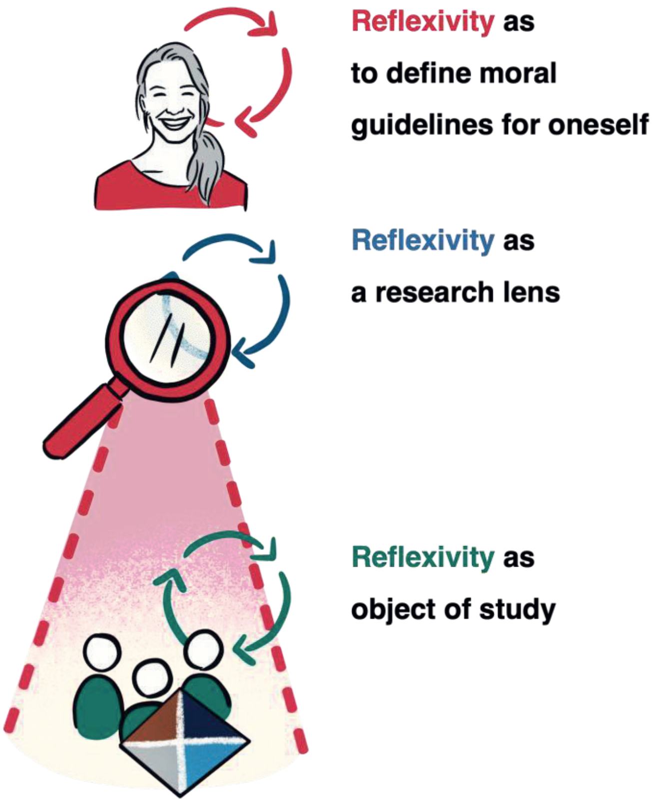

Figure 1.3 Reflexivity as methodology, as research lens and object of study

Methodology

Chapter two concerns a literature review, applied to explore how academic literature discusses critically conscious on why and how water models are developed and implemented and the influence of location and power relations. Reflexivity comes in many different forms, for different reasons, by scientists with very different disciplinary backgrounds, each with their different jargons and focus. Therefore, a mixed method approach is chosen to capture this diversity (Haddaway et al., 2018; Petticrew and Roberts, 2006). This entails to first identify reflexivity in articles that me and my co-authors are aware of. These articles are then used to define a search query, that forms the basis for a systematic literature review. Lastly, the results are shared in the community of Hydrology and Earth System Sciences, to identify if articles were missed. This journal that has an open review policy and hosts an active community. This journal was therefore explicitly chosen to contribute to sparking a debate on the influence of models and how to engage with it.

The question in what many ways water models and modelling processes can gain influence, is also explored through two case studies in which I follow the models throughout their development, to identify how they are shaped and in turn shape the people and environment around them, as well as to practice with how to unpack a water model in context. The case studies include two situations in which water balance models play a role in conflict and cooperation over transboundary water resources. The cases are selected for three reasons. First, I assume that lessons on how to engage with the power and influence of quantitative models can especially be learned from modelling processes that are developed and implemented in environments in which knowledge development is expected to be scrutinized and contested, such as in situations of conflict over water. Second, I chose to engage with a model developed for a context I personally have experience working in, which is OPT and Israel, as well as India. Third, especially in areas in which large imbalances of power exist, I believe it is necessary to understand whether the tools that are introduced have the potential to contributing to improving the situation – for who – and how. This is valid for water models that are locally produced, and potentially more necessary for models that are made in a different place from where they are applied.

The first case study is the development of the WA+ model, intended to inform decisions on water allocation in the Cauvery basin in India. The Cauvery connects Karnataka, Tamil Nadu, Kerala, and the union territory Puducherry. These states have been involved in a century long conflict over their shared waters, created and sustained by colonial legacies, cultural differences and political rivalries (Settar, 2010). It is in this context that the highly complex WA+ model, reliant mostly on satellite data, was applied to calculate the stocks and flows of water in the basin to improve communication between the Cauvery basin states. I will pay additional attention to the role of satellite data and the complex model in creating and shaping sites of politics. This case has been written up together with the modellers and an employee of the Central Water Commission in India who has been part of the modelling exercise. I have explicitly chosen for this approach to ensure a thorough depiction of the model, to engage in conversation and learning together, and to better ground the research.

The second in-depth case study on WAS and MYWAS. Ever since a three-month research visit for my Master thesis in 2011, I have worked on several projects related to transboundary water governance in the area, and have built up a certain familiarity. In one of these projects, MYWAS was employed by a student researcher and I became familiar with the model and the aspirations of the MYWAS project. It is a special case, as the WAS and MYWAS models have been developed over more than 40 years to contribute to water cooperation in Israel, Palestine and Jordan, and therefore there are many publications that allow me to follow the model throughout time, as well as that there are many lessons to be learned from this project. Yet, as opposed to the WA+ project, I have not been part of the modelling process. Being an outsider influences how I relate to the modellers, how deeply I can understand the model and modelling process, and subsequently how I can tell this story. I will reflect on this in the conclusion.

Data is collected through literature review of academic and grey literature, field observations, and interviews. The potential interviewees were identified through following the modelling process, from problematisation to implementation. I identified the commissioners, funders, modellers, as well as those who are affected by this process, as well as observations. The interviews are semi-structured, to allow for additional information to be shared by those I interview. In relation to WA+, I observed meetings and kept notes of how WA+ was introduced to the Cauvery riparian states. The field notes were also important to note my own impressions and thoughts, which I used to develop interview questions.

Studying the two cases provides an opportunity for me to practice with researching reflexivity and the influence of water models. I will use these experiences to more deeply understand the approaches other researchers have chosen to study and practice reflexivity. The question is what practical and scientific lessons can be drawn on how to engage with this political charge of water models, and eventually how to harness the influence of models for progressive transformation? Chapter five asks especially this question to other scientists who wrote about reflexivity on water models, from a focus on the model itself to its impact in the world. Through surveys and interviews I aim to learn what influence their research had in general, and specifically on modelling practices. The conclusion is based on their lessons and on mine, gained throughout this research.

Reflexivity and research ethics

When studying other people's practices and choices, it is all the more important to also critically and constructively examine one's own. To me, this is especially valid in relation to working as a Dutch researcher in places where I have not grown up, with historical unequal geopolitical relations between the Netherlands and places of study (Malcontent, 2022' Ravichandran, 2014), and often in projects that are essentially developed and implanted in a top-down fashion. Being reflexive on my own position is therefore essential to identify how to ethically approach my cases (Gani and Khan, 2024). For me, and based on reflexivity (Sultana, 2007), as well as recognised research ethics for social sciences in the Netherlands, (KNAW et al., 2018; National Ethics Council for Social and Behavioural Sciences, 2018) research ethics is about being aware of locations, actions and power relations in relation to myself, the people I interview, and the people and issues I describe in the documents that I intent to publish. In practice, this means that I am upfront and open to the people I interview about the questions I have and where they stem from, supported by an interview consent form. Being open is especially important in case it concerns people in vulnerable positions who are not in places of power. Especially as I work in places of water conflict, I find it important to ask those interview partners in vulnerable positions about potential sensitivities in relation to the conversation at hand. They know best what contributes to a constructive debate and to learning, and what potentially can contribute to harming them and should be avoided.

As an outsider to the cases, I need to be mindful about my position and make an effort to understand my own biases and to challenge them. In this respect, unlearning is as important as learning. Taking field notes, as well as having critical, open and challenging conversations with colleagues and friends helps in making biases explicit, to inquire where they come from, and to do away with them if possible. Following models from here, applied there, does bring me in a challenging position. In both case studies, the models are developed and implemented with the idea to intervene in another place and to contribute to water cooperation. This always brings up tensions between the needs of the place where the model is developed and the place where the model is implemented in, in terms of flows of money, information, and decision making. It can be an extractive practice. In some cases, I am again extracting information and time from people, which puts the responsibility on me as a researcher to critically think about who to invite for an interview.

Structure of the thesis

This thesis is structured as follows. Chapter two is focused on how other scientists and disciplines research, and engage with, the influence of water modelling through a literature review. Based on this, I conclude with a proposal for a power sensitive approach to water modelling. Chapter three and four are dedicated to the two case studies, on WA+ applied for the Cauvery and WAS/MYWAS for Israel and the OPT, modelled specifically to address water conflicts. The chapters explore how modelling processes influence the world around them, and vice versa based on two case studies on models that are modelled specifically to address water conflicts. These thick descriptions aim to show the complexity of how models and modelling processes gain or lose influence. In a yearning I have myself to approach model-driven work in power-sensitive and situated ways (Klein et al., 2024), in chapter five I turn to learn from other scholars who have aspired the same. I ask them what influence their research has had, and how research, that showcases how positionality matters and how modelling creates particular outcomes and may foster exclusive processes, can make a difference. Chapter five of the thesis is therefore a meta-reflection on if and how reflexive work can be a key to change modelling practices of modellers, funders, commissioners and users. Chapter six, the synthesis, is dedicated to a discussion on the insights of how models have influence, and how to engage. It specifically reflects on both case studies and identify similarities between them, and compares these to the insights gained through the literature review and interviews with authors who have done similar work. I further discuss the theory and methodology, and conclude what main lessons can be drawn from this research. The book ends with a reflection on how the engage with the influence of water models.

2

Chapter 2

MAKING A CASE FOR POWER-SENSITIVE WATER MODELLING: A LITERATURE REVIEW

This chapter is based on the following article: ter Horst, R., Alba, R., Vos, J., Rusca, M., Godinez-Madrigal, J., Babel, L.V., Veldwisch, G.J., Venot, J.P., Bonté, B., Walker, D.W. and Krueger, T., 2024. Making a case for power-sensitive water modelling: a literature review. Hydrology and Earth System Sciences, 28(17), pp.4157-4186. https://doi.org/10.5194/hess-28-4157-2024.

Although it may not be usual in a dissertation in Wageningen University, in this chapter I will use 'we' instead of I, to acknowledge the joint learning that we have gone through together. Lucie Babel worked on making modelling practices visible, and her paper and kindness were inspiring for me. In addition to this paper, I have learned with Bruno Bonté in organising a session on 'Can a model care', as requested by Margreet Zwarteveen. I learned with Rossella Alba and Jonatan Godinez as part of the Constructive Advanced Thinking Project, on 'Models as controversial tools'. Tobias Krueger and Rossella Alba have organised a Summer School on Situated Modelling, which greatly helped the finalisation of this article. Jean-Philippe Venot and Tobias Krueger especially supported me in learning from the comments of reviewers. And Jeroen Vos, David Walker and Gert Jan Veldwisch were just an office away to jointly reflect on tricky modelling questions.

Introduction

Models are not neutral, and those who commission and develop models do have choices in whether modelling should be done and how. The hydrological modelling community is well aware that any one model could have turned out differently with different assumptions, simplifications, or data and if different people had developed it. An iconic example is the study by Holländer et al. (2014), in which 10 research teams were presented with increasing amounts of data from an artificially constructed catchment in order to model runoff from rainfall, leading to results varying initially by 2 orders of magnitude. Reflections on modelling as a social practice and the political consequences of models in the hydrological community have been primarily in terms of how a model could be considered fit for purpose and in terms of model adequacy, uncertainty, and subjectivity (Krueger and Alba, 2022).

Beven (2019) distinguished between two kinds of purpose: accurate representation of hydrological processes and mere forecasting of hydrological variables. The latter does not necessarily require any process understanding to develop output, as recently shown for instance with the resurgence of machine learning in hydrology (Nearing et al., 2021). However, Beven (2019) argued that an accurate process representation is needed if models are to be used for decision-making. Addor and Melsen (2019) and Melsen (2022) showed that institutional factors play a greater role in modellers choosing models than model adequacy in the sense of fitness for purpose. The question of model adequacy began to gain an overtly political connotation when Beven (2019) and Hamilton et al. (2022) considered the possibility of policy-makers or stakeholders being involved in assessing whether a model is fit for purpose. Further developing this point, we would add that the developments (including increasing model complexity, attention for uncertainty, fitness for purpose, and involvement of stakeholders) will bring to the fore ever more clearly the political nature of models as something to utilise and as something to challenge.

One pitfall could be that discussions remain disconnected from the context the models are used in, while this could improve the modelling practice itself. Naturally, the discussions described above take the model as their starting and end points, as the aim is to improve models, but the challenge will be to step out of model land (Thompson and Smith, 2019). Since hydrological science is inherently bound to societal needs (Lane, 2014), being more explicit about the political influence of models is relevant not only from a science studies perspective, but also for hydrology as a discipline and for societies at large. The aim of this chapter, therefore, is twofold. First, we research how the academic literature discusses the many ways in which models and modelling processes can gain in influence, even beyond their intended reach. We start with the hypothesis that there is indeed still limited scholarship attending to the influence of models and modelling practices. Second, we draw lessons on how to engage with this political charge of water models and eventually how to harness the influence of models for progressive transformation.

The chapter builds on the constructivist theoretical approach to, and broad definition of, models and modelling processes that was introduced in chapter one. This theoretical approach helps to make visible that modelling is a process that is susceptible to outside influences in which different choices are made that shape the process and output (Demeritt, 2006; Lane, 2012). Based on the above, we argue that analysing the potential influence of models requires engagement with questions on why modelling is chosen as a method to produce information, which assumptions are included in the problematisation phase and the data and model that are used, how the available technology enables or excludes, and how the process and output are communicated and questioned and by whom. The articles that are included in the analysis do not necessarily apply a constructivist approach, but they do discuss one or all of the aforementioned aspects.

Methodology

This literature review is primarily based on the ROSES (RepOrting standards for Systematic Evidence Syntheses) method (Haddaway et al., 2018), which is specifically developed for the field of environmental management. It uses a similar approach to systematic reviews that is often used in the social sciences (Petticrew and Roberts, 2006). The method provides a three-stage approach that includes searching, screening, and critical appraisal, and it explicitly allows for additional articles to be included during the screening process to accommodate the multi-disciplinary nature of environmental research. In our preliminary attempt to define the query, we collected articles that discussed the influence of models. For this selection, we drew on our diverse set of expertise as an interdisciplinary group. In our final inclusion and exclusion strategy we selected papers that engage explicitly with how models gain and have influence or, put differently, have socially and ecologically differentiating effects. Following Petticrew and Roberts (2006), we included doctoral research in addition to published articles, as these often comprise studies that unpack longitudinal modelling processes in detail. This resulted in 136 articles, of which 60 discuss water models. We finally identified 30 that reflect on the influence the models have. We formed the first query based on the keywords of these 30 articles. However, we were not able to define a comprehensive query that would capture the majority of pre-selected articles in this first selection due to their disciplinary diversity.

To ensure the replicability of the study, we defined a query based on words that related to the influence of water models. The final query is defined as TITLE-ABS-KEY (“water model*” OR “hydr* model*” OR “groundwater model*”) AND TITLE-ABS-KEY (“justice” OR “equit*” OR “politic*” OR “ethic*”). “Politic*” and “equit*” were chosen as keywords because they broadly relate to how models influence issues of distribution in relation to who gets what, when, and how (Lasswell, 1936). “Justice” and “ethic*” were chosen to capture those articles that reflect on why certain actors – including nature – receive or are deprived of water. The query necessarily excludes words such as “influence”, “power”, “values”, “reflexivity”, “accountability”, and “responsibility”; earlier attempts to define a suitable query that included these keywords resulted in large quantities of articles that did not reflect on the influence models have due to the multiple meanings of these words.

Results were taken from SCOPUS and Web of Science, based on the English language literature for the period January 1993–December 2023. The query resulted in 408 unique documents. Following the ROSES protocol, we screened the articles to identify those that explicitly addressed or analysed the (potential) influence of water models. A first screening by title excluded 40 documents that had no author listed, were not in English, or did not discuss water or water models; 368 articles were screened by abstract, of which 98 showed that the article may reflect on the influence of water models. These were subsequently selected for screening of the full text. Of the 98 articles, 27 were finally selected through the query. In addition, we had pre-selected 30 articles and added 4 suggested by the *Hydrology and Earth System Sciences* (*HESS*) community based on the review of this paper, which we included for the critical appraisal stages following the ROSES method after the elimination of one duplicate. This approach is akin to a mix of a systematic literature review and a narrative review (Cronin et al., 2008).

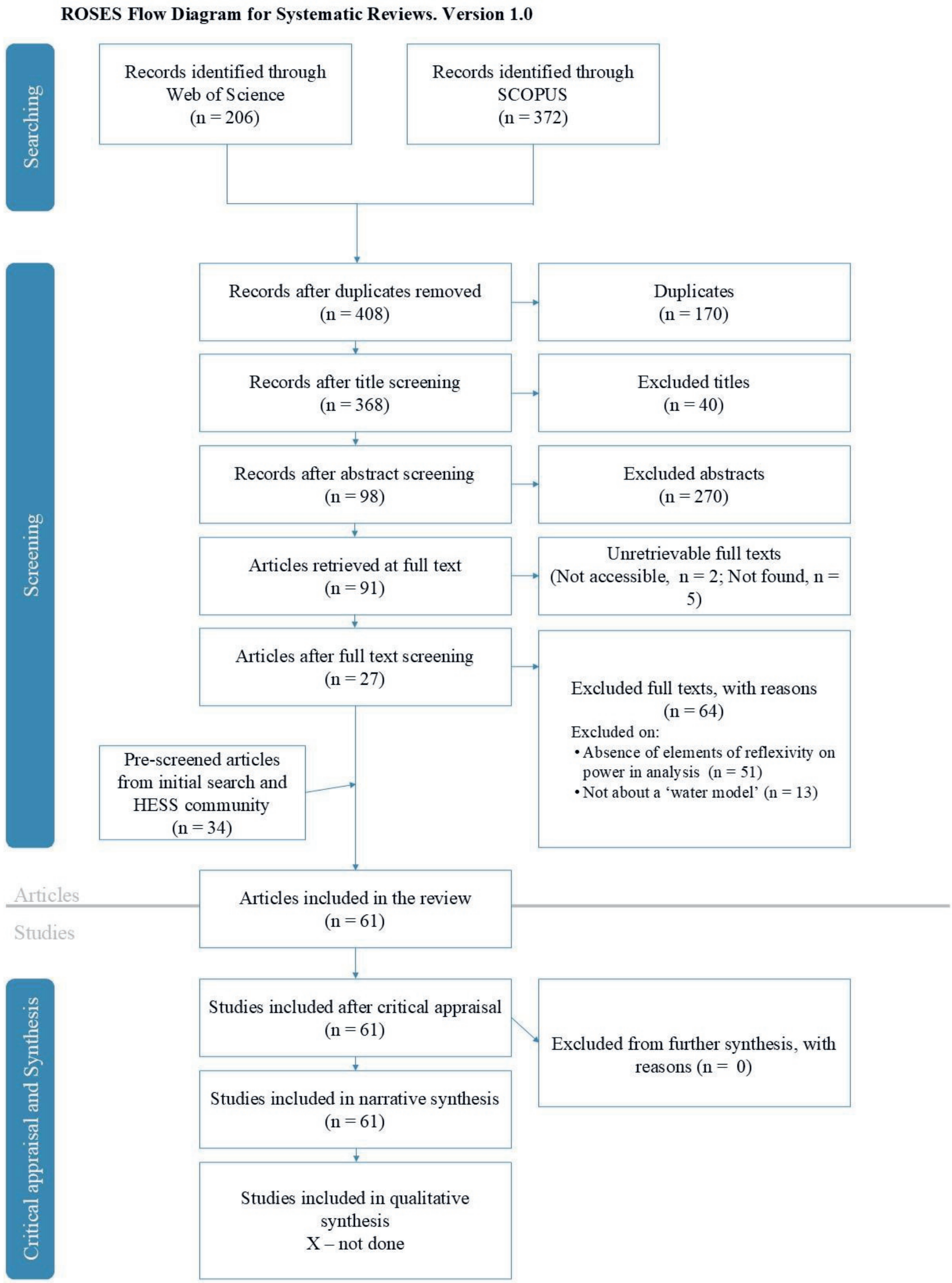

Figure 2.1 provides a graphic overview of the systematic literature review process, and the Appendix provides an overview of the 61 articles included in the literature review. Those marked with "*" were pre-selected through the narrative literature review.

Figure 2.1 The result of the ROSES systematic literature review process

As the first step of the critical appraisal, we identified shared relationships within and between the reviewed studies (Haddaway et al., 2018). We did this by comparing keywords and by listing common patterns in the included literature, based on our own assessment. By comparing the keywords and main issues, we iteratively identified 13 mechanisms through which models have influence. We identified four overarching themes that represent different phases in a modelling process (for other ways to represent and structure, see for instance Refsgaard and Henriksen, 2004; Melsen et al., 2018). The first three themes unpack different activities of model-making and its relation to the world, from mental models and policy projects, the influence of modellers' choices on the model, and the ways in which models relate to the world around us. The last theme includes studies in which people explicitly apply changes in a modelling process to account for the (potential) influence of models. The four overarching themes form the structure of the narrative synthesis, in which we elaborate on how all the themes and topics play out in practice.

The themes and related mechanisms of influence we identified are the following.

- **Mental models and policy projects**
    - Problem framing: exploration versus consolidation
    - Knowing the world in specific ways
    - Working towards different versions of the world
    - Representation: mental models translated into, and shaped by, categories
- **The influence of modellers' choices**
    - How modellers' choices matter
    - Familiarity, habits, and standardisation of practices and technological requirements
    - Modelling developed through interactions and institutional interests
- **The "real-world" impact models have**
    - Naturalising and legitimising world views through models
    - Exclusive and inclusive assessments
    - The influence of presentation: colours, maps, and graphs
- **Engaging with non-modellers through models**
    - Connecting to and disconnecting from people and places
    - Stakeholders confronted with different realities of modelling and measuring
    - Representation and fairness
    - Intent: building reflection on engaging with the real world from a modeller's perspective

Results: narrative synthesis

This review identifies four interrelated dimensions of the modelling process that explain how models gain influence: (a) mental models and policy projects; (b) the influence of modellers' choices; (c) the real-world impact models; and (d) engagement with non-modellers through models (Table 1). We present the main argument of each article reviewed in one of these four dimensions while being aware that several articles present more than one argument. Appendix A provides more details of the articles reviewed, including the different topics discussed, as well as information on the models and case studies discussed in the articles.

Table 2.1 Overview of the articles reviewed and the related themes

Main themes	Publication (only short reference)
Mental models and policy projects	Alam et al. (2022), Bouleau (2014), Budds (2009), Constanza and Ruth (1998), Deitrick et al. (2021), Fernandez (2014), Godinez-Madrigal et al. (2019), Haeffner et al. (2018, 2021), Harvey and Chrisman (1998), Jackson (2006), Kroepsch (2018), Krueger and Alba (2022), Laborde (2015), Landström et al. (2011a), Lane et al. (2011a), Meenar et al. (2018), Munk (2010), Packett et al. (2020), Rainwater et al. (2005), Ramsey (2009), Sanz et al. (2019), Shrader-Frechette (1997), Trombley (2017), Wesselink et al. (2017), Whatmore and Landström (2010), Wheeler et al. (2018a, b)
The influence of modellers' choices	Abbott and Vojinovic (2014), Addor and Melsen (2019), Alam et al. (2022), Babel et al. (2019), Bergström (1991), Budds (2009), Clark (1998), de Oliveira Ferreira Silva (2022), Dobson et al. (2019), Fernandez (2014), Godinez-Madrigal et al. (2019), Haeffner et al. (2021), Haines (2019), Hasala et al. (2020), Holländer et al. (2014), Jackson (2006), Jenkins and McCauley (2006), Junier (2017), Kouw (2016), Krueger and Alba (2022), Landström et al. (2011a), Lane et al. (2011, 2013), Lane (2014), Meenar et al. (2018), Melsen (2022), Melsen et al. (2018, 2019), Mendoza et al. (2016), Munk (2010), Packett et al. (2020), Rainwater et al. (2005), Sanz et al. (2019), Shrader-Frechette (1997), Srinivasan et al. (2018), Trombley (2017), Wesselink et al. (2009, 2017), Whatmore and Landström (2010)
The "real-world" impact of models	Abbott and Vojinovic (2014), Bergström (1991), Bouleau (2014), Budds (2009), Connor et al. (2008), Cornejo and Niewöhner (2021), de Oliveira Ferreira Silva (2022), Fernandez (2014), Garcia-Cuerva et al. (2016), Godinez-Madrigal et al. (2019), Hasala et al. (2020), Holifield (2009), Jackson (2006), Jensen (2020), Kouw (2017), Kroepsch (2018), Krueger and Alba (2022), Lane (2011b), Meenar et al. (2018), Melsen et al. (2018), Rainwater et al. (2005), Sanz et al. (2019), Shrader-Frechette (1997), Wardropper et al. (2017)
Engagement with non-modellers through models	Andersson (2004), Bremer et al. (2020), Budds (2009), Constanza and Ruth (1998), Cornejo and Niewöhner (2021), de Oliveira Ferreira Silva (2022), Falconi and Palmer (2017), Garcia-Cuerva et al. (2016), Godinez-Madrigal et al. (2019), Haeffner et al. (2018), Holifield (2009), Jensen (2020), Kouw (2017), Krueger and Alba (2022), Landström et al. (2011b), Lane et al. (2011b), Lane (2014), Melsen et al. (2018), Opitz-Stapleton and MacClune (2012), Rainwater et al. (2005), Sanz et al. (2019), Shrader-Frechette (1997), Srinivasan et al. (2016, 2018), Wardropper et al. (2017), Wesselink et al. (2009), Wheeler et al. (2018a, b)

Mental models and policy projects

We start by discussing the mental model (also called the 'conceptual' or 'perceptual' model in Beven, 2009, 'mental images' in Beck, 1999, or 'framing' in Odoni and Lane, 2010) that underlies any numerical model. Depending on the process, the mental model is not, or is less, influenced by limitations posed by data and technology and is more of an "ideal type" than an actual model, though Krueger et al. (2016) argue that technological possibilities of what can be modelled may already co-shape what can be imagined. We divide the mental model into two sets of elements, with the first being the ideas of how the world works, including any (causal) relations, and the second being the ideas of what this world should look like. Both elements are based on values, norms, and ideas about what is important and valid to a society in general and a modelling community in particular (Haas, 1992; Haraway, 1988; Jasanoff and Kim, 2009, Morgan and Morrison, 1999). Mental models are developed based on a multitude of factors, including the common interests, backgrounds, knowledge, and skills of those involved. Different communities may have very different ideas of how the world functions (Knorr-Cetina, 1999; Rusca and Di Baldassarre, 2019) or have experience with a particular way of conceptualising that is linked to an already familiar technology (Addor and Melsen, 2019; Babel et al., 2019; Melsen, 2022). In our systematic literature review, 22 articles paid specific attention to mental models. We discuss the main themes, illustrated with examples from the articles reviewed, including (1) problem framing, (2) how different ways of knowing the world influence modelling, (3) how different sociotechnical imaginaries influence why a model is made, and (4) how data and categories embody world views and influence what is included and excluded and in which ways.

Problem framing: exploration versus consolidation

Broadly speaking, there are two very distinct ways to use models. They can be used to explore unknowns or consolidate ideas about reality (Morgan and Morrison, 1999; Pielke,2003). Several articles put forward how stakeholders that are part of the modelling process may have very different ideas about how the modelling process and outcomes should be used. These articles show that consolidation is often used for decision-making processes in which decision-makers seek to reduce uncertainty, while exploration is used in processes in which there is disagreement about the issue at hand. We use the article of Ramsey (2009) to highlight how world views, policy projects, and technology intertwine. This case study details how a geographical information system (GIS) surface water model was created with the hope of "generating shared understandings" among stakeholders as a key strategy in reducing water allocation conflicts in the Thousand Springs area in Idaho (USA) (Ramsey, 2009; pp. 1975–1976). The latter objective led the modellers to try to create a scientifically sound representation of the Thousand Springs area based on objective and measurable evidence. The model excluded some insights from inhabitants concerning the use of spring water as few measurable data were available on this issue, and the surface water model excluded groundwater from the discussions on water allocation. The exclusion of the experience of spring water users and groundwater prevented a deep exploration of the issues at hand, while this was clearly needed in the process of conflict reduction. The conclusion of the author is to call for dedicated time to explore "diverse problem understandings", which entails clearly defining the mental model and modelling vision before engaging with a modelling effort.

To avoid disconnects between the model and user such as described by Ramsey (2009), Trombley (2017) suggested a multi-model approach to avoid a model serving one particular policy project at the expense of others in his PhD research. One of the suggestions they made is to design models for decision-making with the aim of facilitating exploration, models thus becoming mediators that foster a diversity of perspectives. Constanza and Ruth (1998) proposed engaging with the consolidating and exploratory functionality that models can have in the same modelling process by introducing a three-phase modelling approach. The first stage focuses on developing the model structure and "functional connections between variables" in discussions with stakeholders, the second stage focuses on replicating dynamics of interest realistically, and the third stage focuses on scenarios and management options. Alam et al. (2022) proposed a similar approach by calling for inclusion of positive and negative externalities, specifically in relation to agent-based modelling applied to understand the impact of agricultural water management interventions. They proposed such an approach as their review showed that there is limited attention paid to the spatially explicit and inequitable outcomes of interventions.

Knowing the world in specific ways

In the water sector, the way models are developed is often greatly influenced by specific "epistemic communities" that are bound by shared ideas about validity and causality and by ways of working that engender a particular vision of the world (Haas, 1992) or a particular way of doing things through communities of practice (Lane, 2012). Bouleau (2014) theorised about how expertise mixes with political priorities to influence the choice of tools and issues to be addressed and how this in turn influences the world. In the article, Bouleau contrasted the approaches of two different epistemic communities in two different river basins in France. In the Rhône River basin, model development was initially mainly guided by geographers and ecologists who focused on the floodplains. As a result, water was conceptualised as a 'hydrosystem' linking hydrological and ecological processes in the river and floodplains. During the same time period in the Seine River basin, model development was led by engineers who assessed water quality in relation to the economic development of Paris. Water was conceptualised as a condition for economic development that should be closely monitored and modelled. The mental models, developed differently based on different expertise and political priorities on top of the material properties of the two river basins, influenced what was seen and how and consequently what the aquatic environment looked like (p. 253). Another example is provided by Andersson (2004), who confronted a project in which three models (HBV-N, STANK, and SOIL-N) were used to assess options for reducing riverine nitrogen loads in the upper Svartå Valley in Sweden with user opinions. The focus of the project on nitrogen, and not on phosphorus as well, for example, was found to be limiting and to not reflect decisions that had to be taken. Despite this limited focus, the overall modelling process was deemed to create a mutual learning environment for modellers, stakeholders, and decision-makers. A more philosophical reflection is provided by Laborde (2015), who compared their conceptualisation of a lake using MATLAB with a conceptualisation of the same lake by a fisher. By reflecting deeply on the underlying experiences and expertise that shape a (mental) model, they raise rhetorical questions on why the modelling version of the lake is (better) represented in decision-making and why the fisher's is not and whether there is space for complexity that is brought in through lived experiences, as is done by the fisher.

Working towards different versions of the world

Sociotechnical imaginaries are visions of what the future can become, built on a notion that technology can assist in realising this envisioned future and be shaped by values (Haraway, 1988; Jasanoff and Kim, 2009). Working towards a certain envisioned future is also conceptualised as "policy projects" (Haas, 1992). Making values explicit is therefore useful in understanding what a modelling process aims to achieve. Deitrick et al. (2021, p. 12) identified and visualised which ethical and epistemological values inspired watershed modellers in the Chesapeake Bay in the USA by surveying and interviewing the modellers involved. To support modellers and those who use or are impacted by models, the authors made visible in a flowchart what kinds of choices in the modelling process related to ethics and knowledge production. These choices ranged from questions of funding and model selection, over how environmental processes were to be represented, to how users engaged with the model and how the results were interpreted while also scoping out available alternatives. The authors called for more openness and more explicitness by modellers when communicating these choices to contribute to transparency in decision-making. Rainwater et al. (2005) show how different epistemological values and policy projects influence data collection for groundwater modelling as well as how local political borders influence user engagement with modelling results for a shared groundwater body in Texas. Wheeler et al. (2018a, b) also emphasised the importance of making policy projects explicit and proposed a modelling approach for highly political and conflict-related contexts in which intended model users have very different world views and intended uses of the available water. The authors used the case of the Nile to explore possible future designs and operations of the Grand Ethiopian Renaissance Dam and its relation to operation of the High Aswan Dam in Egypt. The method did not focus on optimisation necessarily but started with identifying upstream and downstream state preferences as well as criteria (in this case scenarios based on acceptability and no harm) that guided the modelling exercise.

Representation: mental models translated into, and shaped by, categories

Definitions and categories are important mechanisms for translating world views into models. Building on feminist science and making gender explicit, two articles in our literature review call for more inclusive modelling. Haeffner et al. (2021) showed that available water data often disfavour women and local communities as few disaggregated data based on these categories are available. Disaggregation, which would entail collecting specific data related for instance to gender, class, and caste, can make differences and inequalities visible. When datasets are not aggregated or for instance create biases towards male water users (who are oftentimes more visible), the modelling exercises based on biased datasets inherit the same biases and knowledge gaps unless these are explicitly acknowledged and addressed. The solutions that the authors see to account for the limitations of modelling are to collect data that include specifications including race, class, and gender and to always contextualise results. This means that, in addition to presenting the outputs of the modelling process, the historical and cultural context of what is modelled is described too. Packett et al. (2020) emphasised that not only should the input into a model be of concern but that a balanced gender representation should also be achieved during the whole modelling process, including problem framing and conceptualisation, model construction, documentation and evaluation, and model interpretation and decision support.

Harvey and Chrisman (1998) unpacked the development of GIS technology to show how it can work inclusively and bring different groups together, but it can also work exclusively. Based on a case study on the mapping of wetlands in the USA, the authors argued that an important element that defines who and what are included or excluded is the mental model that underlies the GIS and modelling activities. Their case started with very different ideas about what wetlands are to American institutions. How different these understandings can be was highlighted in a 1995 report that compared four different datasets that represent the same wetland. The datasets disagreed in more than 90 % of the area on different purposes, procedures, sources, definitions, and logic that shaped the different inventory techniques (Shapiro, 1995, p. xiii). To address these discrepancies, one specific system (Cowardin et al., 1979) was chosen as a standard by the US Federal Government in 1997 to define wetlands. The authors warned, however, that even though a mental model is standardised to facilitate exchange, the introduction of different modes to collect data and different approaches to analyse these can again create different interpretations of the same area. In addition, the black-boxed nature of models can obscure these different interpretations, and an effort needs to be made to understand the influence of data collection methods and model choices.

The influence of modellers' choices

The following set of articles focuses on how a model is developed. Thirty-four of the articles in the review explicitly discuss modellers' choices. This includes the influence of modellers' familiarity with the models they use, their habits, and standardisation.

How modellers' choices matter

Modellers' choices matter, as they influence both the development and output of a model. Holländer et al. (2014) showed through a model comparison experiment that, when provided with the same data-scarce fictive watershed, 10 modellers essentially predicted 10 different (some of them very different) discharge time series based on the models of their own choosing. Within the same model, choices also matter greatly. Melsen et al. (2019) systematically demonstrated the impact of modelling decisions for the case of a flood and drought event in the Swiss Thur River basin, specifically for decisions on spatial resolution, spatial representation of forcing, calibration period, and performance metric. Mendoza et al. (2016) showed how hydrological modelling decisions can influence evaluations of climate change impacts. When comparing four different modelling structures and parameter estimation strategies applied to three watersheds of the Colorado River basin, the authors showed that calibration decisions may unexpectedly have more impact than the choice of model structure. Dobson et al. (2019), by comparing eight rival framings of two models of two water resource systems in the UK, showed how these specific representations of the systems influenced which water management decisions were suggested by the models. The choices of system boundaries and the statistical formulation of forcing generators were shown to have the greatest impact. Krueger and Alba (2022) discussed three types of models, a Sociohydrological human–flood model, an export coefficient type model, and a water security model, to showcase the interactions between modelling and policy. These case studies were used to analyse to what extent considerations of uncertainty, subjectivity, and fitness for purpose have led the hydrological community to engage with the political consequences of models and the powers inscribed in those models, be they world views, omissions, or vested interests. The authors especially see an opportunity for both modellers and social scientists to explore and engage with the political consequences of models together in relation to model uncertainty.

Why choices are made: familiarity, habits, standardisation of practices, and technological requirements

The choice of the modelling technology or model type has a great influence on the modelling outcomes. Addor and Melsen (2019) demonstrated, based on a survey of hydrological modellers, how familiarity with a model type is a better indicator of why a model is chosen than whether it is the best fit in terms of representing natural and social dynamics, contrary to what is typically depicted in scientific articles and consultancy reports. Babel et al. (2019) demonstrated that modellers inherit modelling choices from former supervisors and colleagues. This leads to long-lasting and sometimes unquestioned habits in model construction. Jenkins and McCauley (2006) made this visible by unpacking the GIS flow direction algorithm in the ESRI products ARC/INFO, ArcView, and ArcGIS, which can seemingly make wetlands disappear from maps. Without understanding why and how the GIS algorithm functions and without confronting the model world with the modelled world, this could mean that decisions are made that are ignorant of what is left invisible. Fernandez (2014) showed through historic research how the development and embedding of an indicator of minimum flow requirements (MFRs) are influenced by the financial and institutional needs of powerful water users in the Garonne River basin in France. Originally introduced in relation to water quality, the MFR indicator later became a stand-alone indicator in relation to river health and setting the conditions for the construction and management of hydropower dams to define sector-based water savings. This disconnect, as well as changes in decision-making processes for the host institutions of the indicator, led to the indicator becoming unquestioned and black-boxed.

Whatmore and Landström (2010) traced the adoption of a formula for calculating the velocity or surface inclination of water flowing in an open channel of given dimensions, or Manning's *n*, first presented in 1889. Although it is criticised as a simplification, the formula allows for simple tuning of a model that has incorporated it and limits the runtime. As such, attempts to replace this formula have failed so far. These six articles show how important the element of expertise is in modelling and warn of certain blind spots, which, once models become accepted and unquestioned tools, may be accepted as the way things are done. This does not mean that modellers are generally not reflexive. Kouw (2016) showed, for the case of hydraulic engineering in the Netherlands, different ways modellers include reflexivity in their modelling practice, including finding a balance between the detail of a model and the time needed to run it, engaging with models as "sparring partners" instead of "truth makers", and knowing the basic structure of the model.

Modelling developed through interactions and institutional interests

Landström et al. (2011a) drew attention to a wide range of actors that influence modelling by assessing the practices of modelling flood risk of consultants for the Environment Agency of England and Wales. The authors showed how modelling processes are shaped by environmental managers, decision-makers, and developers, which is influenced by standardised modelling processes, including practices to visit the modelled field before and after a modelling exercise as well as long-term contractual agreements, such as the requirement to use a particular software package. The authors argued that the high level of standardisation limits the space for asking new questions, and therefore they recommended that the standard practices be routinely compared with new models developed by academics. In a connected paper, Lane et al. (2011a) discussed how models are used for predicting floods, taking into account climate change. By unpacking the modelling process, the authors showed that a primary assumption in the model was a guideline from the government which estimated that peak river flows for the 2080s will increase by 20 % compared to 2010. Published as part of the same research project, Lane et al. (2013) showed how technology has an influence on the choice of model. The authors discussed developments, from 1D (one-dimensional) modelling to represent water following a specific path to 2D (two-dimensional) modelling in which water can be represented as flowing both down and to the sides to mimic a floodplain. A specific event, such as a flood, provided a moment in which such developments and new sociotechnological constellations become apparent.

Munk (2010) and Junier (2017) also showed in their doctoral thesis how models are developed by a multitude of actors and occurrences. In their longitudinal studies based on interviews and observations, they unpacked the development process of the Hydraulic Engineering Center's River Analysis System used for flood risk analysis in the UK and the WFD (Water Framework Directive) Explorer in the Netherlands. Wesselink et al. (2009) did a similar analysis, in a research article, of how models are developed in conjunction with decision-making processes. They showed that, in the case of the Dutch Meuse River, political considerations have an unexpectedly great influence in relation to technical water expertise, especially in relation to transboundary water management.

Jackson (2006) described in detail the process of how CalSim, a model used by the California Department of Water Resources to estimate and plan water delivery between 2001 and 2021, became a topic of public controversy. Developed in a sphere of trust based on similar professional expertise, it became apparent that the model was scrutinised based on different requirements in the public sphere. This necessitated changes in modelling practice towards more open and transparent processes. Jackson called for a broad take on modelling focusing on not only conceptual, mathematical, and computer-based aspects, but also organisational, political, and broadly sociological aspects, which could lead to decisions to "sacrifice a degree of analytic precision and granularity, but [..] gain in broader stakeholder accessibility and general analytic wieldiness" (Jackson, 2006, p. 8).

Modelling and real-world impact

Models are often discussed within the confinement of the model land they create (Thompson and Smith, 2019) or, in other words, under laboratory conditions insulated from the public and disconnected from the world that is being modelled. Whether developed under laboratory conditions or explicitly to inform (water) governance and management, models can have several unintended impacts. In our systematic literature review, 19 articles have paid specific attention to modelling and its real-world impact. The articles are all based on case studies and have paid particular attention to examining the context in which models are produced and how the model connects with, disconnects from, and influences the surrounding environment. The two main themes highlighted in the literature concern how models are mobilised to naturalise and legitimise certain policies and world views and how modelling processes can work to conceal or exclude some of the affected groups.

Naturalising and legitimising world views through models

Water governance processes are always contested and political, as stakeholders are likely to hold different world views, including contrasting visions of the way water should be managed and allocated and whose expertise and knowledge should be valued in decision-making processes (Zwarteveen et al., 2017). Models, therefore, can have the unintended consequence of legitimising one of these world views whilst concealing others. To illustrate this, coal mining is a contested process in which affected stakeholders might have different perceptions of the threats and potential of this development. To illustrate this, Connor et al. (2008) analysed the discourses related to a local debate on the development of an open-cast coal mine in Murrurundi, a town in the upper Hunter River basin in New South Wales, Australia. Models formed an integral part of the process by supporting the narrative of both the coal mine exploiter and the government. Despite the multiple distinct perspectives ensuing from this project, the models ended up legitimising the world views of the industry and state while concealing those of many affected groups who valued care of and cultural and spiritual connections to the place and water bodies. The paper thereby highlighted two real-world impacts of these models. First, they contribute to policy options grounded on notions of productivity and economic development promoted by the state and industry. Second, building on this first point, they also contributed to grounding the debates in scientific terminology and concepts, thereby forcing groups contesting these world views to draw on the same language and knowledge claims. Cornejo and Niewöhner (2021) showed a similar dynamic in the case of mining water abstraction in Tarapacá, Chile. Based on a groundwater model that depicted an aquifer as two separate water basins, it was decided to grant a mining company water rights as it was scientifically proven that the water resources would not be affected. Here too scientific knowledge generated through modelling was prioritised over local knowledge and everyday experiences. The way the modelling process was designed prevented the affected groups from questioning assumptions about future impacts of water abstraction. In addition, as the problem was framed in the scientific language generated by the model, local communities were forced to adapt to that language and generate data that spoke to the language and arguments of the scientific reports. The authors concluded that, in this contested process, the model became a “real” actor aligned with the interests of private companies and the neoliberal state. While this clearly shows the political nature of models, paradoxically, it is the notion that science is value-neutral that makes these models such powerful actors in water-related decision-making processes.

Kroepsch (2018) and Sanz et al. (2019) also discussed how groundwater models can be used to legitimise policies even if there is limited information available. Sanz et al. (2019) showed that, despite intrinsic uncertainties, and against the advice of the researchers who developed the model, a MODFLOW model was used by a governmental actor to legitimise boundaries drawn that determined which farmers were compensated for refraining from irrigation and which were not. Kroepsch (2018) questioned how it was decided to optimise space for groundwater abstraction instead of limiting it, even when impacts were unknown due to a long feedback time. Based on the analysis of 10 years of groundwater modelling and governance in the northern San Juan Basin in Colorado (USA), they argued that, in this project, in addition to quantitative measures, the "human values in risk-taking or precaution" should have been prominently included.

Exclusive and inclusive assessments

When modelling is presented as a neutral scientific process, a lack of attention to the context and its power relations can have negative effects on marginalised groups in society. An example of such a 'desocialised assessment' was provided by Budds (2009) in a case of the La Ligua River basin in Chile. The author questioned the extent to which a hydrogeological model, used to represent the physical diversity in the La Ligua River basin, was representative. The model was based on data mainly available for the main river and not its tributaries, with limited information on actual water use (including illegal abstractions), and the modelling process included a limited assessment of the model's validity. Despite this, the model was used to define a generic policy for the additional allocation of water rights that could have led to aquifer depletion. Budds pointed out that this was possible partly due to the legitimacy given to the project by external consultants, whose expertise is generally held in high regard. She further argued that the model facilitated the implementation of a policy that reproduced pre-existing water inequalities in the basin. First, the allocation of the additional water rights did not take into consideration that commercial farmers were in a better position to acquire them. To illustrate this, obtaining legal rights for water abstraction required a lawyer and money, thereby favouring large and smaller commercial farmers over peasant farmers. Second, Budds (2009) argued that by excluding knowledge claims from peasant farmers, the model did not account for the fact that the increase in groundwater abstraction by peasant farmers was an adaptive response to the increased water use for agriculture in the valley and the 1996–1997 drought. Not recognising the vulnerability of these farmers by framing their actions as illegal ultimately increased their vulnerability. The author thus concluded that the fact that the water resource agency focused solely on hydrogeological modelling allowed the Chilean state to justify water allocation decisions that reproduced “unequal patterns of resource use” (p. 418).

Holifield (2009) described a similar dynamic in the case of groundwater modelling to understand the extent of pollution in St. Regis, Minnesota, USA. Modelling by the Champion International Corporation was challenged by a ‘counternetwork’ of local inhabitants and scientists, who had to prove that their representation was more scientifically viable. Holifield (2009) showed that this required them to include both disinterested “outsiders” and interested, locally accountable insiders and to make connections with “bigger” centres of power and calculation, which can multiply and amplify the locality’s connections with equipment and resources (p. 371). Inspired by Holifield (2009, 2012), Meenar et al. (2018) applied an environmental justice perspective as a basis for (re-)developing flood mitigation and stormwater management plans in a watershed in south-eastern Pennsylvania, USA. Using the environmental justice dimensions of just distributions, procedure and participation, and recognition as entry points, the authors supported the redrawing of floodplains in a more inclusive way and in interaction with local inhabitants.

Similar dynamics were examined by Godinez-Madrigal et al. (2019), who showed how models supported top-down management of water-scarcity issues and related water allocation policies in the Lerma–Chapala Basin, Mexico. Outcomes of one modelling exercise were not accepted when they conflicted with the interest of an important actor, and a second modelling exercise excluded an important out of basin user which skewed the results. The decision on water allocation was eventually enforced through influence at the highest political level, the President of Mexico. Jensen (2020) also confirmed that the power of high-level decisionmakers plays a key role. In the case of the Mekong River, the author showed that there is a certain saturation in knowledge developed by models, and there is a clear limitation on their impact as governments were unwilling to build on these insights. He argued that, “compared with the inventive energy deployed in modelling, moreover, it can also be observed that the efforts made by modellers to make this knowledge travel are rather less creative” (p. 88). These articles show that a model does not have influence on its own.

The previous examples show how models can work exclusively. The following articles show how pluralising data sources and methods can help to make the excluding nature of models visible, and they show how to mitigate this. Garcia-Cuerva et al. (2016) suggested a participatory modelling method aimed at including marginalised communities in the case of identifying opportunities for stormwater control measures in the Walnut Creek watershed in North Carolina (USA). Although not yet tested, Garcia-Cuerva et al. (2016) opted to first develop a modelled version of Walnut Creek and cooperated with an NGO, Partners for Environmental Justice, to facilitate discussions with stakeholders "to evaluate alternatives and to elicit preferences" (p. 43). Hasala et al. (2020) followed up on the study of Garcia-Cuerva et al. (2016) and compared the approach of collecting information through modelling with a method that relied on interviews. Specifically looking at identifying possible sites for green roofs in majority–minority neighbourhoods in relation to stormwater control measures, they reported significant differences on which roofs should be greened based on interviews of people living in the area and based on the model outputs. When used in conjunction, the authors showed how the model could be used as a tool to bring different stakeholders together to discuss which options fit a neighbourhood best.

The influence of presentation: colours, maps, and graphs

Interestingly, few articles discuss in depth what the influence is of specific ways of presenting the modelling results through illustrations such as graphs or maps. Most refer to this in passing. For instance, Bergström (1991) also concluded that ethics in modelling is becoming more and more important with the rising popularity of models, and he did so based on a review of the development and use of the Hydrologiska Byråns Vattenbalansavdelning (HBV) and PULSE models at the Swedish Meteorological and Hydrological Institute between 1971 and 1990. On illustrations, Bergström (1991) said that "Multi-colour graphical presentations are very useful for illustrative purposes but they should not be used to impress or convince where the scientific foundation is weak" (p. 134). Abbott and Vojinovic (2014) discussed illustrations as a way to connect with stakeholders, claiming that stakeholders are "challenged-out to exercise and develop their own inherent knowledges, imaginations and judgments, and to exercise these both independently and interactively" (p. 528). Abbott and Vojinovic also pointed out the responsibility of the modeller, claiming that the "quality of the character of the modeller, becomes inseparable from the quality of the model within the quality of the total production" (pp. 528–529).

Engaging with non-modellers through models

When it comes to modelling, we want to pay specific attention to the engagement of non-modellers in modelling processes. To counter the exclusionary nature of modelling, a popular approach is to engage those affected by the processes that the models aim to examine. Methods range from taking into account the needs and positions of different stakeholders in the design of and communication about the model (Cash et al., 2003; Harmel et al., 2014; Bremer et al., 2020) to different forms of participatory modelling (Étienne, 2014; Voinov et al., 2016; Venot et al., 2022). However, few of these articles discussed power differences between those involved, accounted for those who disengage or who and what are excluded, or were mindful of the influences the model can have on decision-making processes. In the literature review, 24 of the included articles paid specific attention to including people and values in the modelling process. We discern different themes, including (i) engagements with how models can create connections and disconnections from the people and places that are being modelled, (ii) how non-modellers relate to specific world views and policy projects included in the model, (iii) representations of who and what are modelled in just and fair ways, and lastly (iv) how modellers reflect on engaging with who and what are modelled.

Connecting to and disconnecting from people and places

Lane et al. (2011b) experimented with "doing flood risk science differently" to foster connections between academics and local people for whom flooding is a matter of concern, and they used this as a basis for co-producing knowledge in non-hierarchical ways. The project and approach created a way for local knowledge to be taken into account by the responsible institutions in the case of Pickering, UK. By explicitly confronting modelling results and proposed management options with the experiences and opinions of local residents, it became clear that more inclusive and less invasive flood risk management options were possible. Opitz-Stapleton and MacClune (2012) reflected in a book chapter on elements that create disconnects between affected communities and the hydrological and climatological modelling that is used for community-based climate change adaptation and disaster risk reduction. Based on case studies from the edited volume, they identified a number of issues that can create disconnects between the modelling activity and the community for which it is intended. One issue that plays a significant role in community (dis)engagement is the degree of complexity of the model. The authors warned against thinking too much from a modelling and consultant perspective rather than from a community perspective, and they suggested avoiding the selection of a model that is overly complex and maladapted to conditions of data scarcity, working at scales that are beyond the ones a community is generally thinking at (usually under 10 km), overlooking politics at transboundary and national levels, and not speaking the same language of the communities for whom the model is developed. Opitz-Stapleton and MacClune (2012) concluded that organising modelling activities meets their proposed specification needs: "a rare combination of technical skill, cultural sensitivity, political awareness, and above all, the time to continually engage with and build relationships within the community in order to foster resilient change." (p. 208).

An often-used framework to analyse the uptake of models was provided by Cash et al. (2003). The framework analyses how a model connects with its environment, based on its acceptance by stakeholders in relation to salience (does it fit), legitimacy (is it fair), and credibility (is it believable). We explain it here as the framework is used in 2 of the 48 articles included in this review. Bremer et al. (2020) applied the framework to different case studies on watershed management programmes in the Atlantic Forest of Brazil. Falconi and Palmer (2017) applied it to assess whether participatory computer models for water resource management in the USA, the Solomon Islands, Senegal, and Zimbabwe are indeed effective participatory decision-making tools based on surveys. They also emphasised that a contextual analysis is first required to gain insights into who, when, how, and why questions. Both articles highlight that models cannot meet the expectations of each stakeholder and therefore need to be carefully embedded in decision-making processes. Bremer et al. (2020) also emphasised that it is necessary to take power dynamics into account in this process. They concluded that, as hydrological modelling can influence larger development projects, it is essential to critically reflect on how and by whom these will be used and to what extent they are grounded in local realities.

Stakeholders are confronted with different realities of modelling and measuring

Wardropper et al. (2017) analysed how inherent uncertainty in the application of the Soil and Water Assessment Tool (SWAT) to the Yahara Watershed in Wisconsin (USA) influenced the development and implementation of a water quality management programme. The programme aimed to reduce phosphorus pollution. Modelling was used as a tool to estimate water quality and assign needed pollution reductions to different groups, while monitoring and compliance were based on measurements. An additional challenge in the case study was that results of the policy were not directly visible, as they were most likely to be seen within a 10-year time frame. The authors questioned how the inherent uncertainty in this approach affected people in the watershed. The authors interviewed policy-makers and those who would be subjected to the new policy on how to design such a policy in situations of uncertainty. These deliberations were found to be crucial in designing a policy that was experienced as being both fair and effective, although the risk remained that the resulting actions were not influential enough to reduce the pollution. Kouw (2017) also discussed inherent traits of modelling practices that can create disconnects between models and model users, also emphasising that uncertainty is dealt with differently by engineers, decision-makers, and users. Subsequently, Kouw (2017) called for more integration of social scientists into the practice of developing and using technical tools for decision-making.

Landström et al. (2011b) described in detail a participatory model experiment in which modellers, social scientists, and local residents met on a bi-monthly basis over a period of 1 year to co-produce knowledge about flood risks in Pickering, UK, using a "competency group" approach. This approach asked for all participants to join as individuals, not as representatives of a certain group, and for science to be produced based on questions by the group. What was important for the project was that science was disconnected from institutions that had a role in discussions on flood risks, that scientific questions were not defined in advance, and that scientific questions were open to reframing during the project. Two models were developed as a result of this collaboration: the first was intended to be the final model and ultimately served as a starting point for discussion, and the second was designed based on requests and inputs of the participants and ultimately played a key role in shaping flood management strategy in the area.

Representation and fairness

Haeffner et al. (2018) researched how perceptions and concerns of stakeholders and decision-makers were represented in the management of water systems in urban areas in Utah, USA. First, the authors undertook a review of Sociohydrological frameworks – including models – that sought to unravel the interplay between water and society. Based on this review, they argued that socio-hydrological studies tend to assume that stakeholders have "roughly equal chances of experiencing, perceiving, and responding", while generally this is not the case (p. 666). Drawing on data collected through semi-structured interviews and surveys from city council employees, public utilities, and residents, they concluded that public officials and residents do not share the same concerns about the water supply system. While residents' main concerns relate to shortages and tariffs, public officials are significantly more focused on the deterioration of water supply infrastructures. They also found that citizens who were most involved in decision-making were also more often likely to agree with the perspectives of water system leaders, Based on these results, they concluded that models assuming that residents were well informed and had a shared understanding of the water supply system might lead to an oversimplification of socio-hydrological dynamics in a given location and that more local involvement could mitigate this.

Intent: building reflection on engaging with the real world from a modeller's perspective

There are several authors who reflected on the impact of the work in their field and who subsequently called for modellers to take an explicitly ethical approach (Abbott and Vojinovic, 2014; Bergström, 1991). Clark (1998, p. 833) also pointed to the responsibility of modellers, and specifically when it comes to improved resolutions in GIS applications, as "seemingly omniscient but insensitive systems". Although this is an old article, its reflections are still valid as technology and resolutions keep improving. Besides meeting standards for data use and processing, facilitating access for all, and auditing, Clark (1988) also pointed to the responsibility of the modeller: "Have you personally asked whether what you are doing is beneficial to the business, the customer and society? You cannot transfer this responsibility to someone else" (p. 832). Shrader-Frechette (1997) also called for ethical rationality in hydrogeological modelling, meaning that modelling hypotheses have to be considered in the light of their "ethical goodness" or "ethical badness" for the population on site. de Oliveira Ferreira Silva (2022) called for a similar approach to validate models and their hypotheses, especially when it came to the impact of their use on society. Also, Lane (2014) based his suggestions for principles for Sociohydrological modellers on personal experiences with hydrology. Based on a deconstruction of practices of hydrological science, Lane proposed (i) embracing conflict and controversy in science, (ii) looking for extremes to test knowledge while doing this in a way that is sensitive to political and ethical ramifications, (iii) using real-life events to think with and step out of model land, and (iv) co-producing knowledge with affected groups. Lane concluded that hydrologists cannot do this alone but that it requires both social science and hydrology.

It is here that Srinivasan et al. (2016, 2018) and Melsen et al. (2018b) engaged in a discussion on how modelling should happen. Melsen et al. (2018b) pointed out that models are not value-neutral and that they have significant power, which raises questions about the responsibility and accountability of those making and using models. This, the authors suggested, calls for a reflexive approach to modelling, which should incorporate questions about the model's (potential) impact, who is included and excluded and why, as well as a conscious effort to include less powerful stakeholders. In line with this idea, Srinivasan et al. (2018) proposed a number of practices to improve socio-hydrological modelling, including reflecting critically on model structure and functional form, teaching people to use models as a hypothesis rather than a truth, developing guidelines on how to make modelling choices explicit, soliciting input from stakeholders, and mobilising knowledge brokers or institutions to mediate between modellers and others involved. They warned that educating scientists from both the social and natural sciences would take time and that currently the academic culture does not value interdisciplinarity.

Discussion

The literature review provides an overview of the current state of research on the influence of water models. We closely reviewed a total of 61 articles through our methodology, based on the narrative review and query TITLE-ABS-KEY ("water model*" OR "hydr* model*" OR "groundwater model*") AND TITLE-ABS-KEY ("justice" OR "equit*" OR "politic*" OR "ethic*"). The query embodies a particular way of engaging with the influence of models grounded in the idea that modelling processes are not linear and that they shape and are shaped by society in different ways. The articles that are included in the review represent a broad spectrum of theoretical and practical approaches to the influence of water models as well as a broad range in terms of focus. The four themes used to order the 13 mechanisms models can influence are mental models and policy projects, the influence of modellers' choices, the real-world impact models have, and engagement with non-modellers through models.

We see the list of themes and 13 mechanisms as a starting point for researching the influence of water models as well as an inspiration for the design of modelling processes. Examples from the articles that were reviewed show for instance that modelling with a particular intention in mind, such as environmental justice or gender equality, does impact the way in which a modelling process is carried out (Haeffner et al., 2018; Meenar et al., 2018). This also shows that it is useful to place discussions on the fitness for purpose (Beven, 2019); salience, credibility, and legitimacy (Cash et al., 2003); or post-audits in a broader socio-political context. Attending to the influence of models raises questions such as “whose purpose is served?” and “who decided what a model should do?”.

Our systematic and narrative literature review methodology also posed specific challenges. For example, many of the words commonly used to describe the influence of models (including reflexivity, influence, power, accountability, and responsibility) proved to have multiple meanings that are also used to describe specific – yet different – processes in modelling. This made it necessary to specify the query with the risk of missing relevant articles (low sensitivity). Also, it is known that reflexivity on these political aspects of water modelling comes in many forms and often happens in formal and informal meetings (Babel and Vinck, 2022; Melsen, 2022; Kouw, 2016). This also means that modelling processes may have been informed by reflexive practices, without being mentioned in scientific articles. Increasing the sensitivity (obtaining more relevant publications) by broadening the query for the systematic literature review would decrease the specificity and increase enormously the number of publications to be screened without necessarily providing more papers relevant to the aim of the query.

To complement the systematic literature review, we did an initial literature search with a variety of keywords, and we asked the *HESS* community to suggest relevant literature. These suggestions were very useful and yielded 34 relevant publications that were not retrieved with the systematic literature research. Of course, the selection of these hand-picked publications depended on the set-up of the initial search and who reacted during the public review process.

Interestingly, we saw that in the articles reviewed there is limited attention paid to the influence of vested interests on the choice of technologies used – including private and academic interests – and limited attention paid to the way in which model outputs are presented. Another observation is that several articles that discuss the impact of models do not specify the modelling software used. It is clear that choices have to be made, within the limited framework of scientific articles, on what information can be conveyed, and it is clear that interactions between specific elements in a model (such as a framework) and specific representations of the world are prioritised over how a model is developed (Cornejo and Niewöhner, 2021; Jackson, 2006; Kroepsch, 2018).

Lastly, and interestingly, the power disparities between those involved in and affected by modelling processes, together with the power of models, are addressed by only a few authors in this literature review (Budds, 2009; Godinez Madrigal et al., 2019; Haeffner et al., 2021; Harvey and Chrisman, 1998; Holifield, 2009; Connor et al., 2008; Cornejo and Niewöhner, 2021; Meenar et al., 2018). Few of the articles focus on those who disengage from the modelling process or on who and what are excluded, and few are mindful of the influences the model can have on decision-making processes. It is exactly those articles, and especially the case studies that describe knowledge controversies, that provide opportunities to learn and bring up questions and examples of how accountability can look in practice. Hence, we call for a power-sensitive approach to modelling in the water sector. We argue that this is a crucial endeavour since models are not only influenced by power but also have the power to (re)produce particular long-lasting social, cultural, and technical configurations in the world with more or less desirable social and sustainable outcomes.

Towards power-sensitive modelling

This review confirms that models shape the world around them and that the world around models shapes them in return. This happens in ways we are aware of or in more covert or unconscious ways. There are different mechanisms at play that define how a model and modelling process influence what is seen as a "natural" or legitimate understanding or solution; who and what are concealed, revealed, and in what ways; and possibly also who gets what, when, and how. These mechanisms play out in four phases of model development: the inception and commissioning; the making of the model itself; the use of the model; and, during these processes, the engagement with non-modellers. We have shown that it matters that a model is made in a specific context in which a problem framework is defined, and this problem framework can be altered. The literature also shows that we have to be aware of the ways in which our world view and expertise influence the problem framing, the choice to use modelling for a specific purpose, and how these are embedded by others in modelling frameworks and databases. The modeller is not the sole responsible person in this process, and funders, commissioners, and model users play important roles.

In Section 3 we argued that this is applicable to both models that are developed for practical applications and those that are developed in laboratory settings (King and Kraemer, 1993). Approaching models as neutral tools may conceal opportunities to do modelling in support of more just and equitable water distributions. The review also shows that modelling can be done differently, for instance by exposing black boxing of decisions; explicitly showcasing the development process of modelling and how modelling decisions affect outcomes; openly questioning modelling decisions and the assumptions behind them; foregrounding power relations; calling for particular ethics; and focusing on the process instead of the tool. We therefore call on water modellers, commissioners, funders, and model users to further understand and engage with the power of water models, from ideation to implementation, in an ethical and accountable way. We have identified a few avenues for power-sensitive water modelling, based on this review, and refined these based on other calls related to the politics of modelling (Chilvers and Kearnes, 2015; Doorn, 2012; Krueger et al., 2016; Lane, 2014; Maeda et al., 2021; Rusca et al., 2023; Saltelli et al., 2020; Turnhout et al., 2007; Puy et al., 2022; Venot et al., 2022; Voinov et al., 2014; Zwarteveen et al., 2017). We refer to the literature reviewed in this article, in which practical examples are given of the points made below.

- *Take a holistic approach to modelling.* A model is more than the final product or output. The modelling process stretches beyond programming and coding and includes everything that influences model-making and that is influenced by it. For instance, it includes the processes of problematisation, defining the purpose of the model, commissioning, implementation of decisions based on the modelling, and the co-shaping of discussions (Jackson, 2006; Junier, 2017; Kroepsch, 2018; Munk, 2010; Trombley, 2017). This holistic approach to modelling helps to identify where changes can be made. The development of a water model should be based on a thorough understanding of the interactions with the places a model is developed and applied in (Clark, 1998; Lane et al., 2011b).
- *Foster accountability.* Modellers, commissioners, and model users have an ethical obligation to take possible real-life consequences of a modelling process or use of a model into account and to change a modelling process accordingly (Bergström, 1991; Lane et al., 2011b; Meenar et al., 2018). This also includes reviewing a modelling process after it is concluded.
- *Work towards just and equitable water distributions.* The choice and use of water models happen in a political context and have political consequences in a world where some gain and others are overlooked or lose. A first step is to consciously define ethical and epistemic values that underlie the modelling process (Deitrick et al., 2021; Holifield, 2009; Meenar et al., 2018, Packett et al., 2020). There is a joint responsibility to work towards more just and equitable water distributions for people and nature (Abbot and Vojinovic, 2014, Bergström, 1991; Lane, 2014).
- *Be transparent.* Increasing transparency throughout the modelling process is a way forward to make explicit and ultimately examine and attend to the multitude of interests shaping the development and use of models and their socio-economic and

ecological consequences. Modellers and commissioners can play a pivotal role in fostering such transparency, for instance by explicitly stating the underlying choices, assumptions, normative commitments, and expectations and by tracking the choices throughout the modelling process, which is potentially facilitated through protocols (Addor and Melsen, 2019; Babel et al., 2019; Krueger and Alba, 2022).

- *Democratise modelling.* Give space to multiple bodies of knowledge and multiple stakeholders and incorporate marginalised voices of people and nature at all stages of the modelling. This includes questioning who and what are represented (and how) in the data, problem framing, mental model, and decision-making process (Bremer et al., 2020; Haeffner et al., 2021; Holifield, 2009; Jackson, 2006; Lane et al., 2011; Godinez-Madrigal et al., 2019; Voinov et al., 2016).

We present these five considerations as a starting point for modellers, commissioners, and users to think about the potential power-laden effects of modelling processes and to identify possibilities for altering the design of these processes or identifying alternatives. Our call should not be understood as a suggestion to do away with modelling in the water sector altogether but rather as an exploration of how to improve the practice. Although the proposed approach adds further complexity to the modelling process, it also opens up new possibilities for strengthening modelling processes, models, and their outcomes.

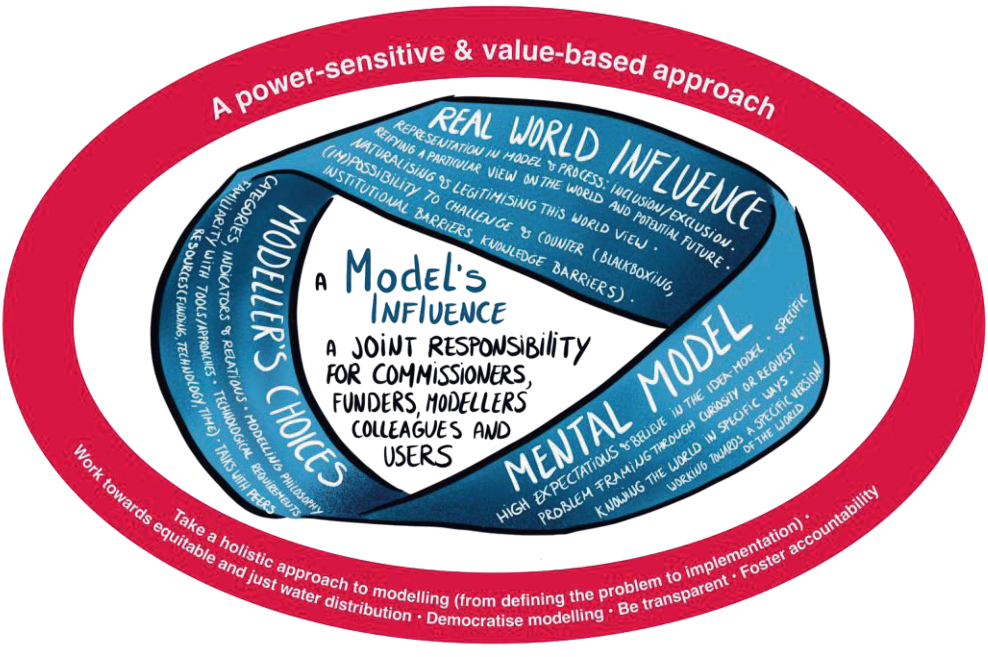

Figure 2.2 Summarising how water models influence the world and introducing a power-sensitive approach

Conclusion

In this article we researched how the academic literature engages with the influence water models have. Driven by a hypothesis that there are few scientific articles that critically unpack or reflexively engage with the socially and ecologically different effects water models and related modelling processes have, we conducted a literature review based on the ROSES method to assess whether our assumption is correct, and secondly we identified which lessons we can draw from the existing literature. To contribute to overcoming disciplinary thinking, we made use of the open peer-review process of *Hydrology and Earth System Sciences* (*HESS*) and invited researchers and practitioners from a broad range of disciplines to think with us, share experiences and thoughts, and contribute the articles that we included in the analysis (Annex 1).

Of the 408 articles included in the systematic literature review, 27 were finally included in the critical appraisal. In addition, 30 articles were added to the critical appraisal during the review process and 4 as suggested by the *HESS* community. The 61 studies reveal how models shape and are shaped by the social and material aspects of the world we live in and how commissioners, modellers, users, and those affected engage with this. Over the years there has indeed been a limited but steady number of studies that have engaged with the influence of water models. The main reason for the exclusion of so many studies from the review is that, while most of them do mention a reflection on the potential impact of the model or an intention or expectation for the model to contribute to a more equitable and just world, these statements are mostly brief, disconnected from a specific context, and do not make explicit how the model did, or could, achieve these goals.

The 61 studies that are included in this review highlight different approaches to unpacking and critically engaging with the influence of water models. The studies show that shaping of models and by models happens in different ways throughout a modelling process, and they show how commissioners, modellers, users, and those affected are involved. The studies highlight the ways in which mental models and policy projects become embedded in a modelling process (including through data and categorisation), how modeller's choices (also impacted by familiarity, habits, standardisation, or institutional interests) have different effects on the models' outputs and the real world, and what impact the models have by legitimising specific understandings of the world and inclusive or exclusive procedures. A large number of studies also showcase how to intentionally and constructively engage with the potential influence of models by mindfully connecting to people and places, understanding the different realities of stakeholders that are modelled and measured, and making explicit how the model and modelling process represent people and places in fair ways.

This has led us to define a call for power-sensitive modelling in which we invite everyone engaged with modelling to work towards just and equitable water distributions, to have a holistic approach to modelling, to contextualise water modelling to engage with impacts, to be transparent, to foster broad accountability, and to democratise modelling. Studying and doing power-sensitive modelling requires a reflexive approach that is grounded and that builds on long-term collaborations and the recognition that modelling is a complex and multi-faceted process. To paraphrase Thompson and Smith (2019), this requires making explicit what happens within model land but also stepping out of it. As such research finds itself at a crossroads, cooperation across disciplinary boundaries is essential for nurturing generative reflexivity and accountability in relation to the power of models (Chilvers and Kearnes, 2015) as well as challenging or enriching modelling results with knowledge from non-modellers and especially those affected by decisions that are related to the modelling exercises (Hasala et al., 2020; Wardropper et al., 2017). Interdisciplinary research, where both certified and non-certified water experts engage with and challenge each other, seems essential (Krueger et al., 2016). This is challenging and is seen as a major obstacle in a professional world that does not value complexity but promotes disciplinary thinking (Melsen et al., 2018b; Rusca and Di Baldassare, 2019; Srinivasan et al., 2018). However, with this interdisciplinary analysis of water models, we hope to inspire others to engage in power-sensitive modelling and to consider how quantitative models may help to foster transformative pathways towards more just and equitable water distributions.

3

Chapter 3

UNRAVELLING THE INFLUENCE OF A WATER MODEL: LESSONS FROM WATER ACCOUNTING PLUS IN THE CAUVERY BASIN, INDIA

This chapter is based on: ter Horst, R., Michailovsky, C. I., Salvadore, E., & KS, C. (2023). Does data lead to cooperation? Lessons from Water Accounting Plus in the Cauvery basin, India. Water International, 48(8), 1025-1045, https://doi.org/10.1080/02508060.2024.2303783.

I want to acknowledge the contributions of my co-authors and use 'we' in this chapter to refer to our joint learning process. The trust among us, and exchanges across disciplines, was what made this chapter possible.
This research was supported by the Water Accounting Phase II Project, funded by the IHE Delft Water and Development Partnership Programme (DUPC2) under programmatic cooperation between the Directorate General for International Cooperation (DGIS) of the Ministry of Foreign Affairs of the Netherlands and IHE Delft (ID DGIS Activity [grant no. DME0121369]).

Introduction

There is an optimism around what remote sensing (RS) and RS-based models can offer to transboundary water management and governance. This relates to a hope that insights from space lead to more transparency and more engagement based on a common under- standing, as well as the belief that technical developments will facilitate better data in the future and thus even more transparency and more engagement (Voss et al., 2013). This applies especially to data-scarce areas, for instance, when the political situation or available resources prevent in-situ data collection (Comair et al., 2014; Habib et al., 2012). However, there are calls for using such data sources with caution. Giordano et al. (2016) show that more precision and different definitions used with RS can counter efforts of practitioners when it comes to defining hydrological and political boundaries.

In a similar vein, Bretreger et al. (2021, pp. 7–8) stress that monitoring and compliance system based on RS need to take local cultures into account and be mindful of unwanted effects on rural communities if they are to contribute to water cooperation using the case of the federal Australian Murray–Darling river. Disconnecting a monitoring or model- ling activity from the local context makes it impossible to understand the influence of the modelling activity, limits democratization in the decision-making process and limits accountability as well as the possibility to mitigate possible unwanted effects. Thus, especially in contexts where water allocation is a sensitive issue, understanding the interaction between the technology used and the (local) context is crucial, for instance, to ensure the tool indeed contributes to a level playing field. Milman and Gerlak (2020) show how river basin organizations consider carefully what science should be produced for facilitating cooperation over transboundary waters, and how it potentially influences different riparians and interactions between their members. However, there is potential gap between the development of science and practitioners, as the vast majority of articles on RS and models for transboundary water management and governance does not detail how the models contribute to water cooperation in practice, nor do they provide successful examples (for examples of the techno-optimistic approach, see Khoshnoodmotlagh et al., 2020; Mobariz & Kaplan, 2021; and Tian et al., 2015). Consequently, researchers have called for being more explicit about how models are developed, and how this development in turn influences water management and governance (Maeda et al., 2021; Melsen et al., 2018). In this article we seek to contribute to this research gap.

We focus the analysis on the application and uptake of the Water Accounting Plus (WA+) framework in an inter-state context, in particular on the Kaveri basin (from here on indicated by its anglicized name, Cauvery).1 WA+ is a water-accounting approach which primarily makes use of RS and open-access datasets. One of the stated expectations of WA+ is that standardization in the presentation of water data and open data policies can contribute to cooperation at 'international basin level, also in conflict areas' (Karimi et al., 2013, p. 2463). We explore this affirmation based on a structured assessment of the WA+ introduction, application and reception in the Cauvery context and contribute to knowledge on WA+ specifically, and to interactions between data-driven tools and water management in general. We are working together as a transdisciplinary team of engineers and a social scientist and have made the effort to write the article in such a way that it is accessible to a wide range of disciplines, avoiding jargon where possible and explaining it where pertinent.

In the following section we introduce the analytical and methodological framework, after which we explain the case study. We then present the analysis of the case study. We conclude the article with a critical discussion on how data and information are expected to contribute to transboundary water cooperation, relating it to the lessons drawn from the analysis of the introduction of WA+ to the Cauvery basin.

Unpacking models and their interactions

Data for this study were collected through interviews in the Netherlands over the course of six months in 2021 and three months of fieldwork in India in 2022, resulting in interviews with 38 people, which included representatives of the states and national institutions, as well as scientists and practitioners working on the Cauvery or WA+. The interviewees were selected through their connection to the development of WA+ and its implementation in the Cauvery. In addition to the interviews, we analysed the grey and scientific literature. Based on the theory of translation, and inspired by the research of Hasan et al. (2020), we have followed the WA+ modelling framework over time, from development in the Netherlands to presentation in the Cauvery.

It was difficult to gain access to government representatives, which is a well-known challenge in researching policy-related issues in India (Mollinga, 2005). This is due in part to highly politicized public debate in which there is little incentive for government representatives to be interviewed by journalists or scientists. The interviews were per- formed following a semi-structured format. We have chosen not to use quotations in this article as they can easily be attributed to certain people in the basin as few people work on the issue. This acknowledges both the sensitivities involved with analysing professional practices (Mosse, 2006), as well as the sensitivities related to water sharing of the Cauvery River. We have indicated which part of the article is based on an analysis of the inter- views. For the sake of finding a balance between researching the WA+ modelling framework and the context in which it is applied, we have made the choice to prioritize relations between Karnataka and Tamil Nadu, instead of all four riparian states which also include Kerala and the Union Territory of Puducherry.

As the WA+ analysis of the Cauvery basin has not been made public, we illustrate the article with figures made specifically with open-source data, and as example of a WA+ study, we use an open- access report on WA+ applied to the three sub-basins of the Indian Krishna River (Salvadore et al., 2020).

Water Accounting Plus (WA+)

We analyse WA+ based on the expertise, worldviews and materiality that constitute the approach. WA+ is an analysis that seeks to understand water availability, depletion and productivity in a basin in relation to land use. The problems WA+ aim to address are manyfold, but boil down to the difficulty to make strategic decisions to secure water resources without information on the resource (Karimi et al., 2013). This position holds the assumption that information is a main obstacle to decision-making, and that data are a key to cooperation. Based on these ideas, WA+ aims to provide an 'unbiased reflection of the water resources and land use conditions' for an entire basin (UNESCO-IHE, 2014), which can also contribute to addressing conflict areas that cross political boundaries (Karimi et al., 2013).

WA+ has a strong focus on agricultural water consumption, facilitated by measure- ments and observations through satellites, specifically to derive evapotranspiration (ET). At the heart of WA+ is a division of the ET flux, the water vapour that ascends from the land surface to the atmosphere, into green and blue ET fluxes. Green ET corresponds to the rainfall stored in the soil and directly consumed through ET. Blue ET results from water that originated in a blue water source (e.g., lake, river or groundwater) before being consumed through ET (irrigation water would be counted in this flux; Bastiaanssen et al., 2012; Karimi et al., 2013). This allows for a distinction to be made between water that is naturally available and consumed in the landscape and water which is actively managed. The assessment of water availability in WA+ is done based on the water-accounting approach of Molden (Karimi et al., 2013; Molden, 1998). Similar to the method of Molden (1998), it adopts the basin as main unit of analysis, and it separates water consumption into beneficial and non-beneficial consumption. Beneficially consumed water can provide benefits for agriculture, energy, leisure, the economy and the environment. Non-beneficial water is defined as 'the consumed water that is lost to the system for no benefits' (Salvadore et al., 2020, p. 38) or water that is unavailable for further use. This includes the water intercepted by wet leaves or impermeable surfaces, and evaporation from soil surface, weeds and degraded water. The WA+ method specifically builds on public domain datasets, and especially those derived through RS, preferably available on a global scale in order for the method to be widely applicable. WA+ also relies on modelling needed for the split of blue and green ET, as well as to compute some important fluxes that cannot be measured through RS (e.g., discharge or water abstractions). While many types of models can be used to produce WA+ outputs, a simple distributed water balance-type model is often preferred as it keeps the spatially explicit nature of RS data and can be set up in data-scarce areas where parameterization of more complex models is subject to high uncertainties as few data points are available to compare the outputs of the model. This is important as WA+ especially targets basins in which in-situ data availability is limited. With support from institutions that aim to improve analysis and communication over water on a global scale, including IHE Delft, the International Water Management Institute (IWMI), the Food and Agriculture Organization of the United Nations (FAO), and the World Water Assessment Programme, WA+ is further developed to 'strive to achieve equitable and transparent water governance for all users and a sustainable water balance' and to improve the hydrological data democracy (IHE Delft, n.d.). The codes used to run WA+ are therefore also publicly shared via the GitHub platform.

The outputs of the WA+ modelling exercises are depicted in 'sheets' that show how much water was thought to be available, and how it is used. The number of sheets produced differs per study, and for the Cauvery six sheets were produced, we add a brief description of these to further explain the WA+ framework.

Sheet 1 is an overview sheet that shows the general water balance in the basin and links consumption to general land-use types to give an overview of the manageable resource. The water balance includes the inflows (e.g., precipitation (P) and eventual inter-basin transfers), outflows (e.g., surface water leaving the basin and ET), and surface and groundwater storage change. Sheet 1 shows the outcomes of the analysis on green and blue water consumption and quantifies the available water for future developments, the water reserved for environmental or legal purposes and can be used to identify any over- exploitation. Sheet 2 details the water consumption through ET for all land-use classes in the basin. ET is divided into evaporation, interception by the canopy and transpiration which is the portion of ET that directly contributes to plant growth. This separation allows for the quantification of beneficial and non-beneficial water depletion by sector. Sheet 3 focuses on the agricultural water consumption and crop production. This information is presented in the form of water productivity (amount of biomass produced per unit of water consumed) and land productivity (crop yield) for major crop groups (e.g., cereals and legumes). Sheet 4 provides information on estimated water withdrawals (blue water) from surface and groundwater sources per sector. The water withdrawn is then partitioned into consumed water (ET) and return flows to either surface or ground- water. Sheet 5 presents surface water flows and storages at the sub-basin and basin levels. Sheet 6 shows groundwater flows and storages in the basin. In addition to the sheets, maps and tables are developed based on the information derived from the model outputs.

Introduction to the case study: the Cauvery

Brief overview of the origin of the conflict

The Cauvery is located in the South of India, connecting four riparian states including Karnataka, Tamil Nadu, Kerala and the Union Territory of Puducherry (Figure 3.1). The century-long conflict over its shared waters is created and sustained by colonial legacies, cultural differences and political rivalries (Settar, 2018). Historically, the Cauvery delta in Tamil Nadu is known for paddy cultivation. Till the end of the 19th century, irrigation in the entire basin was based on run-of-the-river diversion structures without much storage capacity. During British rule, the delta, in the then Madras province, was favoured for irrigated agriculture as it is fertile and easy to irrigate. Upstream Mysore princely state (now Karnataka), which has more hills and highlands, did not use Cauvery River waters much. However, in 1870, downstream Madras complained about the impact of newly developed irrigation systems in Mysore on water availability. The two states negotiated from 1890 to 1892, leading to the Madras–Mysore agreement regarding new irrigation works, requiring the approval of downstream Madras for any upstream developments. After a disagreement over an upstream dam, a new agreement was signed in 1924. This agreement detailed the allocation of water of the Cauvery, favouring use in the delta as agricultural production was easiest there. The agreement solidified the already large power imbalances, and cultural and political differences became more pronounced (Anand, 2004).

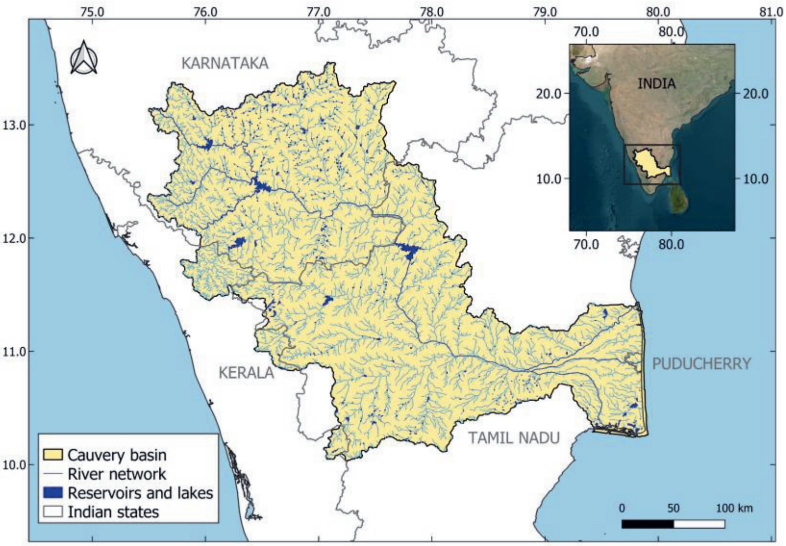

Figure 3.1 The Cauvery basin

Sources: Outline digitized by the authors based on Central Water Commission (2014, map 2(b), p. 4); main rivers and reservoirs obtained from Lehner et al. (2022); and national and state boundaries obtained from https://www.diva-gis.org/gdata

Before the reviewing period of the agreement, 50 years after signing, India had become independent in 1947. The new states of upstream Karnataka and downstream Tamil Nadu interpreted the validity of 1924 agreement differently; Tamil Nadu expected the states to uphold the agreement, whereas Karnataka saw it as a chance to develop its irrigation schemes more independently. The building of four new dams and impounding of reservoirs after 1974 entailed a diminution of the flow towards Tamil Nadu and further sparked the conflict between the two riparian states (Cauvery Water Disputes Tribunal, 2007). Still, the idea that water is more abundant down- stream is strongly embedded in contestations between Karnataka and Tamil Nadu. Our interviews with farmers show that these ideas are persistent. It led initiators of the Cauvery Family, a grassroots initiative to connect people from the two states and foster water cooperation, to dedicate time to having farmers visiting each other's fields across state borders to understand each other's water realities (Iyer, 2007; Janakarajan, 2016).

Water sharing between the states remains highly politicized to this day. For example, after a verdict on water allocation of the Cauvery in 2007, a leader of an influential political party called for a day-long statewide fast to protest the out- come (News 18, 2007). The politicization also affects researchers, with researchers from either party state having difficulties in obtaining data from the other state. In the public debate, anyone who speaks up must take into account that reactions can be harsh and personal. This makes basin-wide research challenging, and as a result there are no agreed-upon numbers beyond the measurements carried out by the Central Water Commission under the Government of India on the amount of water that flows across the border between Karnataka and Tamil Nadu at the village of Biligundulu, and of water levels in the large dams. The fear thus remains that political conflict will flare up. The Cauvery dispute is known to escalate in dry years, when Tamil Nadu requests for water to be released and protests erupt against these requests in Karnataka, pointed towards people from Tamil Nadu who live in Karnataka or business owners who travel between states (Agnihotri, 2016; Joy et al., 2008). The latest violent protests took place in 2016 (Pokharel, 2016).

Division of authority over water

The management of water at the state level, or the role of WA+, cannot be well understood without insights into the constitutional and legal framework related to water in India. Water is still the legal responsibility of the states in India, unless the parliament enacts any legislation regarding regulation and development of inter-state river waters (Cullet & Gupta, 2009). In case of a conflict, states can ask the central government for mediation, and if that fails an independent tribunal can be set up to adjudicate over the issue (Chokkakula, 2014, 2015). This also happened in the Cauvery dispute. In 1972, a report was published with findings of the Cauvery Fact Finding Committee; and in 1976, an understanding between the riparian states was reached over sharing of surplus waters between the states. However, the government that was voted in after in Tamil Nadu did not ratify the same. In 1986, Tamil Nadu made a request to the central government to constitute a tribunal, as mediation was felt to have failed. The tribunal was set up in 1990, and in 2007 a final verdict was reached, dividing the water amongst the four riparian states (Iyer, 2007). None of the parties in the conflict agreed to the verdict. A final allocation was decided upon in February 2018 by the Supreme Court of India and this verdict has not been officially challenged. It stipulates that additional water is allocated for the growing city of Bangalore, at the loss of the volume allocated to Tamil Nadu (Supreme Court of India, 2018). The Supreme Court did not define how to divide resources in drought years and allocated this task to a basin institution that was to be set up.

Basin institutions

To facilitate the implementation of the final allocation, the central government has constituted the Cauvery Water Management Authority (CWMA) and the Cauvery Water Regulatory Committee (CWRC) on 1 June 2018 (Ministry of Water Resources, River Development and Ganga Rejuvenation, 2018, Art. 10§3). The tasks of the authority are, amongst others: to determine the total residual storage in the specified reservoirs; to take stock of the actual yield in the basin; to ensure implementation of the final allocation including the carryover storage during good year and the water releases for environmental purposes; identify situations of distress – caused by diminishing water flows in the river basin; to provide guidance for the integrated operation of important reservoirs; to maintain an account of cropping patterns, cropped area and irrigated area for each party state; to maintain an account of domestic and industrial water usage by each party state; and lastly, to consider proportional and temporary reduction in the allocations. Moreover, the authority is tasked to 'set up a well-designed communication network in the Cauvery basin for transmission of data and a computer-based control room for data processing to determine the hydrological conditions including distress' (Art 10 §3(vi)). The tasks of the CWMA closely relate to what the WA+ can offer in terms of information. It is therefore interesting to analyse how the WA+ connected and disconnected with existing practices when introduced to India and the Cauvery.

The Cauvery and WA+

The following analysis is based on the interviews with 38 people who are either connected to WA+ or the Cauvery. The interviews show that the phase of *problematization* does not start in the Cauvery, but rather in the Netherlands where WA+ is developed since 2012. The lead developer of WA+ at IHE Delft has functioned as its most prominent policy entrepreneur by widely promoting WA+, supported by a representative of the Ministry of Foreign Affairs in the Netherlands. It is not only the current technology, but also especially the future potential of WA+ that was conveyed to potential users. This is based on high expectations of developments in RS (Water Accounting+, 2016). WA+ is first brought to India through the IWMI, which has an office in India, and the National Institute of Hydrology (NIH) in Roorkee in North India. It connects well to a campaign of the World Bank that promotes water accounting for India (2030 Water Resources Group, 2017). Based on good existing contacts, WA+ as specific method for water accounting is subsequently presented to the then-Secretary of the Ministry of Jal Shakti, Department of Water Resources, River Development and Ganga Rejuvenation, by the policy entrepreneurs connected to IHE Delft, the IWMI and the NIH.

The worldviews that WA+ promotes, which includes, first, the idea that with trans- parent data more strategic decisions can be taken, and second, the idea that more transparent data promote cooperation, connects well with the National Water Policy of India. It especially connects with the aim of India's National Water Mission to 'optimize water use by increasing water use efficiency by 20% (Ministry of Water Resources, River Development and Ganga Rejuvenation, n.d.), as well as to long-term efforts to collect homogeneous data from the different states through the National Hydrology Project and the Water Resources Information System (WRIS). The problems are thus understood in a similar way, which enables the translation of WA+ from the Netherlands to India. WA+ is thought to contribute well to the National Water Mission and ongoing programmes, with WA+ being accepted as a framework to provide evidence to help to 'manage excessive and conflicting water demands and negotiate trade-offs especially in a - deficit year' (Central Water Commission, 2019, p. 72). Two basins are selected to function as case studies, which are the Tapi and the Cauvery, the latter seen as the most difficult case and opportunity for WA+ to prove itself in a basin with little data- sharing between riparian states. The idea is to roll out the project all over India in case of success.

In the phase of *interessement*, support is gained from four national institutions including the Central Water Commission, the NIH, the Central Groundwater Board and the National Remote Sensing Centre, who are asked to second personnel to develop WA+ for the Cauvery and Tapi basins. A total of 12 officers are seconded (*enrolment*), and are trained in using the WA+ method for three months in the Netherlands and two months in India in 2017 and 2018 (mobilization). During this training, the WA+ frame- work is applied to the Cauvery. It is in this period that the final verdict on allocation of the Cauvery's water is given by the Supreme Court, and the establishment of the CWMA and CWRC was notified on 1 June 2018, with directions for the CWMA and CWRC that connect directly to the aims of WA+, including taking stock of water flows in the basin, making accounts of cropping patterns, and setting up a communication network (see the section on basin institutions).

Translation, from problematization to mobilization, worked well at the national level. However, the riparian states do not wish to buy into the problematization, or the solution that is presented through WA+. In September 2018, the results are shared with the four riparian states in a workshop (Central Water Commission, 2014). The states all accept the invitation, though this does not necessarily imply an openness to the problematization or to the roles they are asked to play in engaging with the information and in any foreseen cooperation based on the WA+ outputs. In this workshop, time is first taken to show that the developers understand the political challenges, after which the modelling approach of WA+ is explained, and the results of the WA+ study are presented. Ultimately, the state representatives indicate no interest in WA+, and it is not used by the CWMA and CWRC. The process of translation is halted at the problematization phase. The justification for the *problematization* and suggestions made to solve this problem through WA+, that are so well-accepted at the national level are not easily accepted at the state level. In the next section we will focus on possible reasons why the process stopped at the *problematization* phase, how this prevented an adoption of WA+ to happen, and how answers can be found in the relation between the worldviews, expertise and materiality of WA+ and the context of the Cauvery.

WA+ disconnects in the Cauvery

We highlight here four elements that constitute a disconnect between the approach of WA+ and management in the basin, derived based on an analysis of the interviews. It allows us to show how WA+ engages with the context it is applied in and shows how worldviews – including ontologies and visions of the future, expertise and materiality all play a role. Although these four are closely intertwined, we selected examples that speak for each.

Ontology: a basin versus a reservoir approach

WA+ provides an analysis of the water balance at the river basin scale, mainly built on data collected through RS translated into pixels, and inspired by the idea that water should be managed in an integrated way (Karimi et al., 2013, pp. 2461–2462; Molden, 1998). WA+'s strength is that it computes pixel-level water balances throughout a basin and provides spatially distributed information on water availability and consumption. This includes all green water and all blue water, such as reservoirs, but also smaller tributaries. While calculating the amount of water in specific reservoirs, but not all, is possible from RS, it requires additional information on bathymetry in addition to the WA+ method. This information is not always available, and it is not an analysis that is incorporated in WA+ as the focus is on the water balance based on flows of water at the pixel and basin scale, not at stocks in specific water bodies. A result is that WA+ implicitly and explicitly suggests to the riparian states to adopt a basin view while using WA+, which entails taking all water in the basin into account, instead of the current focus the states have on the water in the reservoirs.

This basin approach, facilitated by the worldview of an integrated approach to water management as well the materiality of the RS data, is one factor in creating a disconnect. Historically, the conflict over water allocation in the Cauvery only concerns water in the main reservoirs created by dams on the river. This thus excludes discussions on how surface water in smaller tributaries or lakes, as well as groundwater is used and shared, creating a resistance to engaging with WA+.

Visions of the future: water productivity, beneficial uses and implied objectives

The main causes of contention between farmers in Karnataka and Tamil Nadu are the ideas that farmers in the delta have historically had access to more water and that farmers in the upstream project command areas have started irrigating water-intensive crops that diminish downstream flows. In times of resource scarcity, this results in a limited willingness to share. WA+ provides information about the gross biomass water productivity, calculated in kilograms of biomass produced per m3 of water consumed. This is shown in sheet 3 of the WA+ analysis, but can also be shown in a map (Figure 3.2). Often a conclusion is drawn that high water productivity is good, while low productivity is bad, based on dealing with situations of water scarcity and ideas of what beneficial and non- beneficial water consumption is.

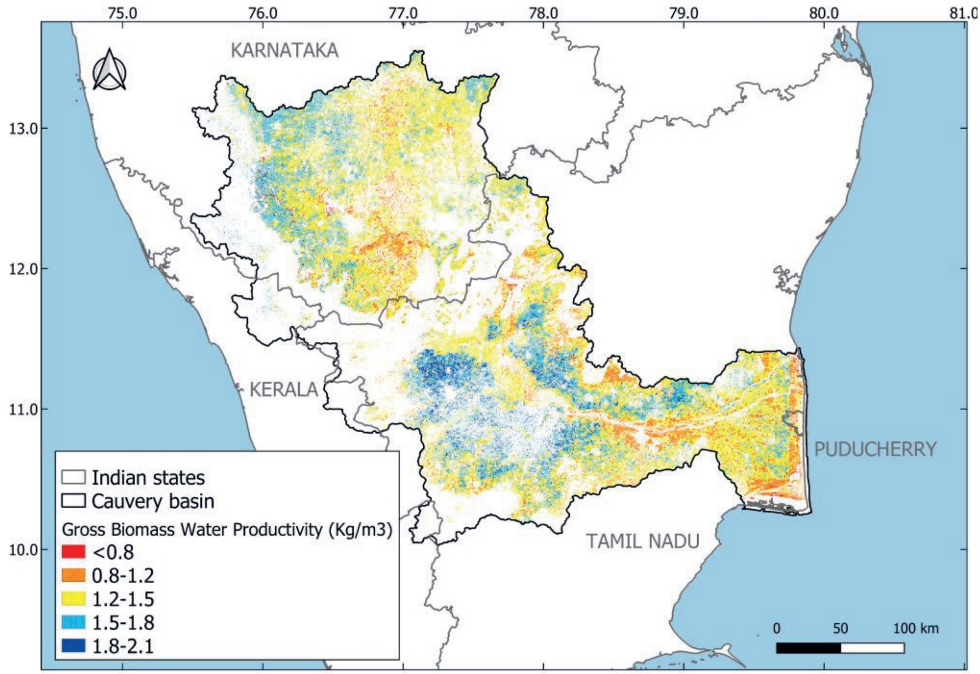

Figure 3.2 Gross biomass water productivity of agricultural areas: June 2006–April 2007
Sources: biomass from MOD17 (Running & Zhao, 2015), ET from Senay et al. (2013) and land use from Zanaga et al. (2022).

Chapter 3

To illustrate this, in the case of the Cauvery we can show with open-access data that a quick conclusion could be that water can be saved in the paddy cultivation regions of the basin (reddish colours in Figure 3.2 indicate low water productivity in the delta region and in the command areas of Krishnarajasagar and Mettur projects). This links to historical causes of contention between farmers in Karnataka and Tamil Nadu described in the brief overview of the origin of the conflict, and can easily be politicized without a further context. The information can be interpreted in bad faith as careless management of a precious resource, and used as leverage to demand the release of water or to ignore claims for more water. Especially judgements based on biomass alone are misleading. Context is needed. For instance, detailed regional and local parametrization is required to be able to determine what amount of the biomass produced can be used for either consumption by humans or animals. Also, the biomass does not provide information about what agricultural alternatives could be available that also work in the specific socio-economic contexts that are analysed through RS. Thus, the WA+ model, presented as neutral, can seemingly provide politically very sensitive results for the actors in Cauvery to engage with.

Materiality: pixels for management versus discrete monitoring

WA+ analyses are largely based on RS data. The resolution of this data directly influences what is observed, why and how. There are great differences between the information provided by WA+, which is intended to manage farming practices, and the data used by the CWRC and CWRA are used for monitoring. Data collected by the CWRC and CWRA are supplied by the states to monitor the water usages in the basin to potentially inform decisions on water allocation in times of shortage. They include the accounts of cropping pattern, area cropped and area irrigated, and domestic and industrial water usage which can be collected at potentially very spatially explicit level and shared at any administrative unit level. If and how such data are verified is not clear, yet the minutes of meetings available in public domain show that there is no discussion about the data itself, although discussions are being held on what data are admissible within the framework of the CWRC and CWRA (Cauvery Water Regulatory Committee (CWRC) Secretariat, 2018a, 2018b). In contrast to these data, the WA+ data can be used to develop outputs that can zoom in to pixel level, which can draw the attention to management at *panchayat* (village) level. However, the pixels do not necessarily tell the whole story. To demonstrate what can be seen and not seen in WA+, we discuss the spatial resolution relating to P, ET and land use land cover (LULC). P and ET are measured and estimated at spatial resolutions of approximately 5 and 1 km2, sometimes at different timescales (Salvadore et al., 2020, p. 72). LULC maps can in theory be done at a very high resolution (currently 10 m), but making a detailed and accurate LULC map requires extensive field data and managing high volumes of data. For the Cauvery, a LULC map with a 270 m resolution was chosen, which was also the resolution at which the modelling was carried out. The mismatch between the resolution of P and ET that are measured at the spatial resolutions of 5 and 1 km2 for the LULC pixels of 270 m requires a generalization of P and ET for every LULC pixel. Very locally, a situation may be different with some of the pixels receiving water, and others not. We also want to draw attention for what cannot be seen within the pixels, but what would be potentially influenced through management decisions based on WA+. The LULC, but to an even larger extent the ET and P, pixels can represent a large variety of farmers and farming practices, as well as different socio-political practices that influence if and what actions may have more or less beneficial effects on water use. Zooming-in to WA+ results at the pixel level should therefore be used as an indication of where to conduct further research, but not as a sole source of information on which to base policies. Figure 3.3 is an illustration of the diversity of areas contained within one ET pixel.

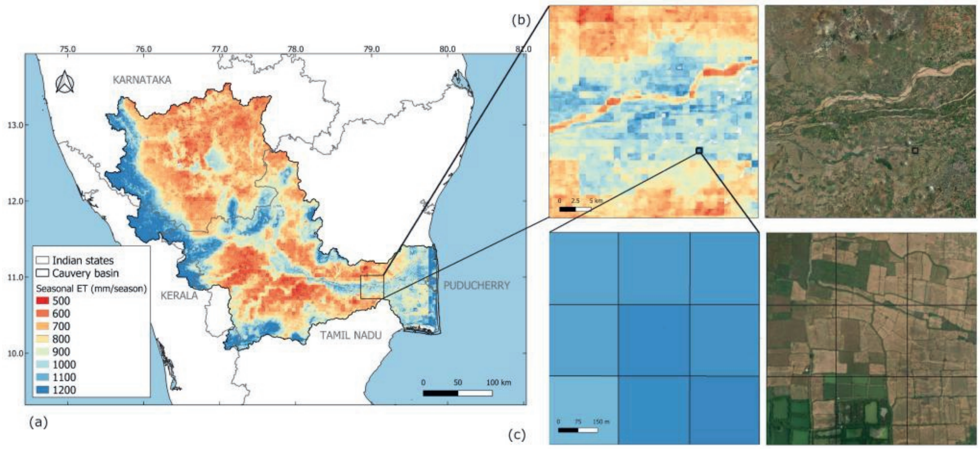

Figure 3.3 Airborne imageries

Sources: Authors, using ET total June 2006–April 2007 from SSEBop (Senay et al., 2013)

Expertise: complexity and specificity

Expertise of the makers influences the design choices made in a model and thus what is included and not, as well as how (Addor & Melsen, 2019; Babel et al., 2019). The development of WA+ has attracted people with a specific expertise that is required to work with RS and hydrological data, requiring people who want to implement WA+ to be able to code in the Python language, or at least have a basic understanding of how the data are produced. In addition to coding, expertise is required to interpret the RS data. For instance, knowledge of the field level is required to interpret an LULC and to identify whether the classes suggested relate to what is happening on the ground. Related to materiality and expertise, the WA+ analysis is based on different data sources with RS data being an important source, as well as calculations based on generalized assumptions, for instance, the percolation rate. It takes considerable time to learn to understand and assess the WA+ analysis and results.

Although efforts are being made to make these steps transparent and explain how and why, and based on what data and theories calculations are made (Salvadore et al., 2020), the high level of complexity still renders the process opaque to many. The 12 engineers seconded to the project had time to learn about the worldviews, expertise and materiality of WA+, although most focused on aspects related to their professional backgrounds. One interviewee remarks how this resulted in discussions that were difficult to follow for outsiders, due to jargon specific to WA+ that became familiar to the engineers. The difficulty to understand all the technicalities of WA+, however, does not necessarily create an immediate disconnect. Three interviewees active at the international and national levels indicated they did not have the expertise to understand WA+ fully, but they had created specific and positive expectations of what the analysis could deliver, which contributed to the way WA+ was accepted at the national level in India. This difference in expectations created different imagined versions of WA+, disconnected from the technology itself, for which people had higher expectations than could be delivered.

Discussion

In this article we aimed to understand how WA+ connected with water management in the Cauvery basin in India, and to draw lessons on if and how models and RS data can be used in the context of transboundary water conflict. The case study shows that the act of collecting and analysing data, even if intended as a neutral contribution, is in essence political. This confirms studies that emphasize the social construction of models (Addor and Melsen, 2019; Krueger et al., 2012; Melsen et al., 2019). At the same time this research adds to studies that remain within 'model-land' (Thompson & Smith, 2019), as well as studies that disregard how a model is made when analysing its impact. The model and the way it gains influence are better understood through the interactions of different elements of the model with the context it is applied.

The model travels and changes in interaction with the people and institutions that use it, and becomes political in different ways for different people (Bijker et al., 1987; Latour & Woolgar, 1986). Seeing a model as an interplay of worldviews, expertise and materiality has proven a useful entry point to analyse interactions between the model and context (MacKenzie & Wajcman, 1999). In combination with the theory of translation it provides insights as to why a model or data-driven tool is accepted or rejected. It provides an indication for both modellers and model-users as to what could be changed in a model and modelling process to improve the interactions between model and the context it is applied in. This is challenging as it requires modellers and model-users to think and work outside of traditional disciplinary boundaries.

What our analysis has not covered in-depth is the (potential) influence the use of WA+ has on water management and governance and thus water users at different levels, such as done by Sanz et al. (2019) for a groundwater model. We have not discussed questions of morality and justice explicitly, which could be useful avenues to explore impact. The WA+ analysis is not intended as being a sole input for decision-making, but makers cannot prevent that it may be used for setting standards and monitoring them. The use of global datasets enables decision- making from afar, disconnected from a local reality (for instance, the work of, e.g., Haraway, 1991; Litfin, 1997; and specifically for WA+, see Zwarteveen et al., 2018). This can also impair democratic decision-making processes. Moreover, in a country in which conflict over water is both highly politicized and localized, and where caste and class play a large role in water allocation and management at the micro-level, bringing in the local context is required to understand water within a pixel and between pixels (e.g., Shah, 2008).

Lastly, the theory of translation draws our attention towards those who support a certain technology, but also those who aim to change or reject it (Latour, 1986, p. 267), to which we emphasize the importance of knowing who disagrees or avoids interaction. The latter group is often forgotten in (participatory) modelling efforts, but crucial when it comes to using data and data-driven tools in conflict settings. These tools are not automatically a useful contribution, nor accepted, based on a seemingly neutral scientific contribution. Often, the conflict is not about data, or data can be politicized, as we have seen in the Cauvery case.

In this discussion we make space to share the following lessons from the WA+ process we, as authors, were part of. We invite others to do the same, whenever possible, to facilitate learning on how data and tools can be used in more conflict-sensitive ways for transboundary water governance and management.

- *Involve actors from the beginning, to define the problem and possible solution together and situate problems and solutions to develop a model (if needed) that is fit for purpose*: WA+ was designed as a one-size-fits-all model – with one goal of standardization being to allow for comparison between basins. Unfortunately, the specific needs of the CWMA and the riparian states were not fully addressed by this approach.
- *Take time for conflict sensitive modelling, with space to adjust a modelling process*: There are high expectations of funders/commissioners of what data and models can achieve. This can influence how a modelling process is designed, with a model presented as a solution instead of an input for debate or decision-making. Be clear about the limitations of the model and the time required for a conflict-sensitive modelling process, be aware that modelling may not be a solution, and create safe spaces for political discussions.
- *Diversify the team:* knowledge diversification is highly recommended, for instance, to limit biases in the modelling process through challenging assumptions, or to be able to design the process based on local as well as modelling expertise.
- *Recognize that the capacity to use the model depends on many factors, including*

technical, institutional and political: An understanding of institutional capacities and expertise is required to ensure the proposed tool can be critically assessed, appraised and applied by those who use it. For WA+, institutional specificities, including a design of local institutions based on disciplines, as well as the position of the CWRC and CWMA as young institutions in a highly political environment, influenced the possibilities to critically assess, appraise and apply WA+.

- *Be aware of the realities of those who are modelled, and potentially affected by modelling*: In the WA+ project, local realities were not taken into account in the problematization phase, but they were partly included in the WA+ modelling activity and the expected action. This brings up critical questions on the data democracy that is aspired by WA+, and how to relate this global aim to local needs.

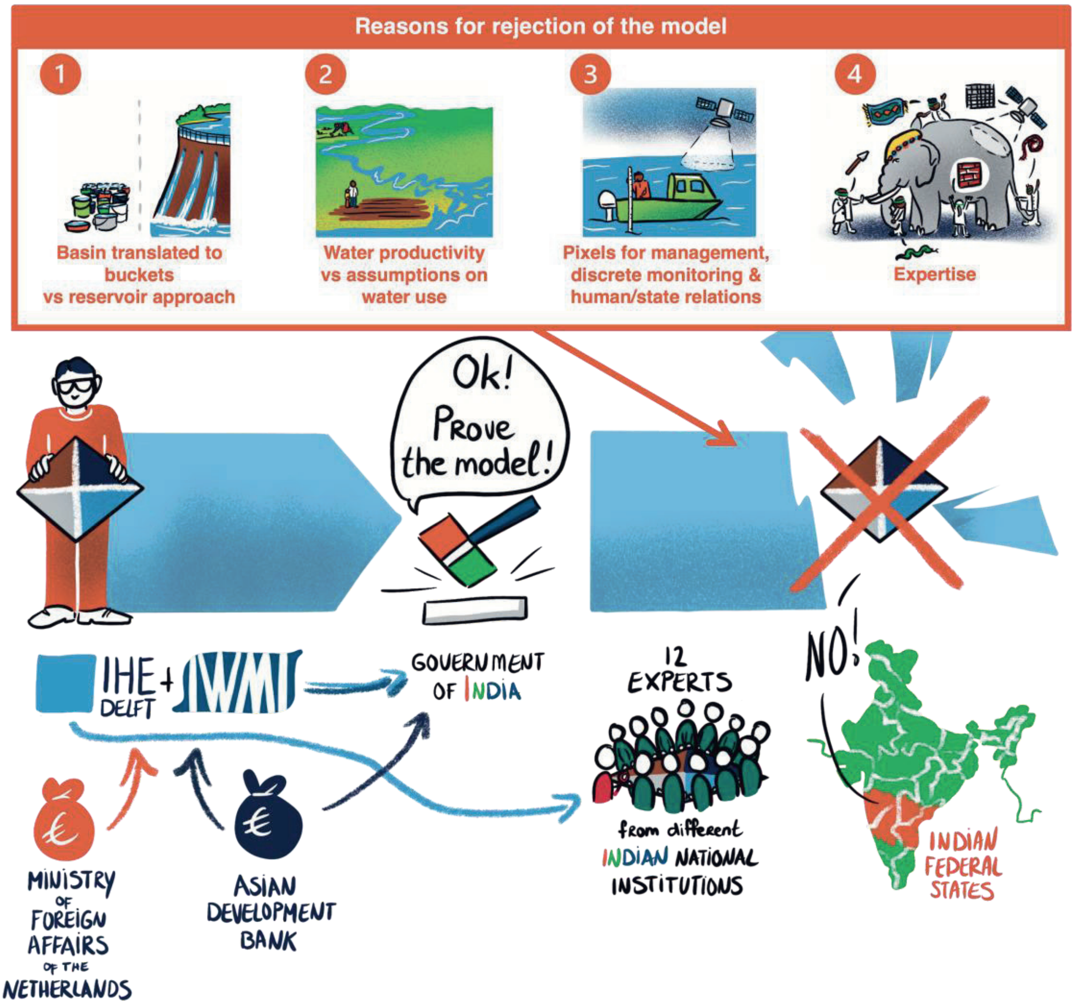

Figure 3.4 Summarising the WA+ case study

Conclusions

This article contributes to a critical and constructive discussion on the application and adoption of RS-based models, specifically by looking at the implementation of WA+ in a setting of water conflict across state borders, with a clear intent to contribute to water cooperation. It calls into question the objectivity of satellite data-driven models and the idea that satellite data could create a level playing field and spark cooperation in a conflict-ridden basin. It shows the influence of ideas on how the world works and should work, strengthened and influenced through expertise and materiality, that are embedded in modelling practices, as well as how models travel and interact with the context they are embedded in, sometimes in different ways than the developers intended. The study clarifies how the worldviews embedded in WA+ which aligned with national-level objectives related to ensuring water-use efficiency were not accepted at the state level where more resistance to management by other parties and the introduction of new potentially contentious data existed.

The study draws our attention to how introducing data and data-driven tools into a conflict needs to be carefully adjusted to the local context. In the case of WA+ and the Cauvery, this was especially challenging due to disconnects and difference in needs between the national and state levels. The approach to create a data-democracy by sharing the same data to all parties involved may sometimes overlook power differences and the political aspects of data and models. By discussing how WA+ was introduced, we therefore raise questions on how data and information, that hold in themselves a clear idea about how water should be managed, can contribute to water cooperation. It shows that working towards transparency and a data democracy should take into account the ideas and ideals that are embedded in data and data- driven tools. Not being aware of these in a situation of conflict over water can inadvertently contribute to more conflict. Bringing these ideas to the fore from the start could ensure that the data and models do not interrupt a potentially very sensitive and long-term process of building trust between parties in a conflict.

Post script

This post script is added after the conclusion, as it was not explicitly included in article that was published (ter Horst et al., 2023), and the chapter that you just read that is based on this work. During my research in Tamil Nadu, I was very kindly supported by George Jeevan, Kalai, and Aadhi who were working with Veena Srinivasan at ATREE at that time. We went on a three day fieldwork in the Kaveri Delta, past Thanjavur, Thiruvarur and Nagapattinam. They helped me to connect with farmers, teachers and government officials, for instance working on extension services for farmers. Kalai and Aadhi had their own land that they managed, and shared their experiences of being a farmer in the Delta and downstream in the Cauvery, and how they knew exactly what the water level was in the Mettur dam and other smaller dams through apps and the frontpage of the newspaper. The dams mattered greatly for them, and how they were managed and how water was shared was not an issue for states and cities, but for people. I joined their interviews with farmers who were turning their land into shrimp farms. In these interviews, power of large scale farmers and their role in local politics became apparent. Shrimp farming is extremely vulnerable to disease, and we spoke to people who had had to sell their land to one of richest farmers in the area. Some of the Water User Associations were connected to political parties.

In Karnataka, close to Bengaluru I was invited to join a field visit organised by Satyukt, who developed apps based on remote sensing data for agriculture. We visited mostly semi- and medium scale farms, from two to ten hectares. The medium scale farmers had access to pumps and were using these to irrigate. Around their fields were small scale or marginal plots with farmers that were not irrigating. One of the ideas of WA+ was to find the most water-productive farmers and find out what the key to their success was, in order to upscale these practices. I was standing in these fields, with marginal and small-scale farmers that were invisible for this eye in the sky, and was wondering what their fate would be when policies that promoted production and water saving, would be implemented.

During my fieldwork, I sometimes yearned for the WA+ maps, as I felt they would provide great information for discussions on sharing water between the states. At other times, I wished for the model to disappear, similarly as I thought it would contribute to the disappearance of the small scale farmers.

4

Chapter 4

UNRAVELLING THE INFLUENCE OF A MODEL: THE MULTI-YEAR WATER ALLOCATION SYSTEM (MYWAS) IN THE OCCUPIED PALESTINIAN TERRITORIES AND ISRAEL

Introduction

In this chapter I aim to unpack the influence of a water model, specifically in the case of the (Multiyear) Water Allocation System (WAS/MYWAS) and Israel and the Occupied Palestinian Territories (OPT)[1], and to reflect what could be learned for applying water models in places with large power imbalances. WAS is originally developed with the aim to inform negotiations over, and management of, water supply in Israel, the OPT and Jordan. The allocation of water within the models is based on economic theory and optimization (Fisher et al., 2005). WAS, a one-year steady state model developed since 1993, and MYWAS, its multi-year version introduced since 2012 are developed to contribute to a fairer division of water and to a two-state solution for the Israeli-Palestinian conflict (Fisher et al., 2005). Several initiatives were developed to operationalise the models for decision making over the course of thirty years, and this research focuses on the application in Israel and the West Bank specifically.

During the lifetime of the models since 1993, and during the period of research until April 2023, water rights have not been renegotiated and the occupation has continued. A deep fear of 'the Other' - the Palestinians -, has continued to grow in Israeli society, based on actual events and propaganda (Konopny Decleve, 2023). The illegal occupation (ICJ, 2024a) is increasingly influencing the lives of Palestinians in the West Bank through the continuous construction and expansion of settlements and outposts, the building of roads only for settlers, the shrinking of liveable space, and continued violence (European Union, 2024). The October 7 attacks in 2023 by Hamas, the extreme violence and taking of hostages, and the extreme violence by the Israeli army that is by many seen as a genocide (Amnesty, 2024; ICJ, 2024b), as well as increasing violence from settlers and the Israeli army in the West Bank, makes that talking about the influence of a model feels futile. I have continued writing this chapter to reflect on the role of people like me, who have worked as external consultants in a situation in which violence and power imbalances are increasing, as well as in solidarity to those who challenge and break down dehumanizing systems.

The chapter starts with a description of the model, after which the analysis in context is described through four phases of development of the WAS and MYWAS models. These sections depict the making process in detail, to detail the influence of the makers, and thus how worldviews, visions of the future, discipline and materiality end up constituting WAS, while being influenced by a specific context. The chapter concludes with a discussion and conclusion on the influence of water models in conflict settings.

[1] Words matter, especially in situations of conflict. In this article, I have chosen to use the term Occupied Palestinian Territories to emphasize the situation of illegal occupation (ICJ, 2024a). I specify between Gaza and the West Bank when needed.

Case study: the basics of WAS and MYWAS

WAS is a one-year steady-state water allocation system, and MYWAS its multiyear extension, that are intended as a "*[..] a tool that the user can employ to explore the consequences of various decisions and alternate circumstances"* (Fisher et al., 2005, p. 25). It does so by allocating available water among users based on a maximization of the net financial and social benefits. WAS and MYWAS aim to show that water sharing is not a zero-sum game in economic terms, and that sharing water will lead to mutual social and economic benefits. The win-wins are identified based on the Coase Theorem (Fisher et al.; 2005: p. 5 and 220), that theorises that it does not matter who has property rights of a certain good, as long as the ownership of the good can be the basis of bargaining to divide the good based on the willingness to pay. A prerequisite is low transaction costs, complete information, equal power relations and bargaining becomes simpler when regulations are clear (Medema, 2020). This specific economic and win-win narrative on water cooperation is brought strongly to the fore in the project as it seeks to counter the narrative that water would be a cause of war. This narrative was particularly popular in the 90s and early 2000s and that still has influence (Starr, 1991).

A first step in modelling is defining districts, often based on political borders. Per district, water supply is introduced by including a number of water resources per district and the annual renewable amount per resource, as well as extraction costs per cubic meter. Treatment costs can be added as additional extraction costs for a particular resource. Limitations in resources can be introduced through constraints. The existing infrastructure and the cost of using this infrastructure per m^3 are included in the model through supply nodes and connectors. Availability of data differs per resource, and estimations may be needed. Specific aggregate groups of users are included per district, which can be households, industry, agriculture and the environment. Per group of users, demand curves are defined, following the same logic for all users, based on the willingness to pay for an additional m^3 of water. The demand curves are downward slopes in which the willingness to pay reduced for additional quantities of water. For a specific run of the model, based on a specific price and quantity of water available, a point on this demand curve is set. The aggregate demand of all users in a district represents the demand in that district, included as demand nodes in the model. All input is either based on data collected or is estimated when data is absent. For instance, in 2005 the demand curve for districts in the OPT in which there were not enough water resources present to meet the demand, was estimated based demand curve for situations where water was abundant (Fisher et al., 2005: p. 127). Specific attention is given to develop the demand curves for agriculture, as these influence water demand most (Ibid: p. 46; Reznik et al., 2017).

The WAS and MYWAS models are economic optimization models, that aim to provide economic information for decisions, as to where to move water from and to (if possible), and where to plan infrastructure such as pipelines, desalination plants or waste water treatment plants. A crucial element of WAS are shadow prices, or shadow values, defined based on the demand curves per user group, and also per district. The shadow values indicate the price a user is willing to pay to receive an additional m^3 of water at a specific location. The model allocates water between districts and users on the basis of optimising the shadow values – earning most in total, within the limits of the restrictions set to allocate water within and between districts. It is argued by the modellers that in a free market situation where the government does not set the price for water, the shadow values would constitute the price of water (Fisher et al., 2005), and that it is rational to allocate water based on the monetary value in addition to quantities only (Fisher and Huber-Lee, 2011). Besides providing insights on how to possibly allocate water between districts, the multi-year model can also be used to identify where additional investments in infrastructure need to be made, such as desalination plants. Research has been done on how to use the model for negotiations, suggesting to use it for instance to calculate the costs of non-cooperation (Kronaveter and Shamir, 2009a, b).

Conceptual framework, methodology and positionality

The model and modelling process is unpacked based on the combination of the theory of translation as methodology with a constructivist approach to models that is introduced in chapter 1. This approach focuses on the direct relations between the model and those that engage with it, either by developing, supporting, using, rejecting, opposing or ignoring it. It does not directly draw our attention to geopolitical developments, unless they directly influence the modelling process. It is therefore that I am inspired to base the contextual analysis on Selby (2003), who shows that the complexity of the Israeli-Palestinian conflict and the role of water in this conflict necessitates an approach that connects the political, economic, and technical dimensions at macro and micro level. In the analysis I will therefore include both the interactions that focus on the models and their immediate context, as well as the events that influence the modelling directly or indirectly.

Data for this research has been collected during fieldwork from January to April 2023, and additionally through online interviews (table 4.1). The interviews were semi-structured and mainly done with people who have been directly working with the WAS and MYWAS models at different stages of their development. I have asked the interviewees about the ways they were involved in developing or using the model, and also explicitly asked whether they thought the model has had influence, and how. As the work is extremely sensitive, I have anonymized the quotes. I also used grey and scientific literature such as the books, reports and scientific articles written on MYWAS. Franklin Fisher, an MIT professor and leader of the projects, has written a book based on notes he took throughout the project, in which he explains his dreams, aims and experiences (Fisher, 2020). This book, close to an autoethnography, is a rich source for this analysis. The names mentioned in the quotes of Fisher are kept, as these are both publicly available and less sensitive due to the historic nature of the text.

Table 4.1 Overview of interviews conducted

Code	Sector	Stationed	Relation to project	Means
Interview 1	Governmental / International	The OPT		Personal interview
Interview 2	NGO	The OPT		Online interview
Interview 3	NGO	Israel		Personal interview
Interview 4	University	The OPT	A student worked on the project	Personal interview
Interview 5	Private sector	The OPT		Personal interview
Interview 6	Governmental	The OPT	Advisory committee	Personal interview
Interview 7	NGO	The OPT		Personal interview
Interview 8	Governmental	The OPT	Part of the project in the past	Personal interview
Interview 9	Governmental	The OPT		Personal interview
Interview 10	University	Dutch	Part of the project in the past	Online interview
Interview 11	Governmental	The OPT	Part of the project in the past	Personal interview
Interview 12	NGO	The OPT	Part of the project in the past	Phone interview
Interview 13	University	USA	Part of the project in the past	Online interview
Interview 14	University	The OPT		Personal interview
Interview 15	University	Israel	Part of the project in the past	Personal interview
Interview 16	Governmental	The OPT		Personal interview
Interview 17	Governmental	The OPT		Personal interview
Interview 18	University	Israel	Part of the project in the past	Personal interview
Interview 19	NGO	The OPT	Part of the project in the past	Personal interview
Interview 20	Governmental	Netherlands	Part of the project in the past	Online interview
Interview 21	University	The OPT	Part of the project in the past	Personal interview
Interview 22	University	The OPT	Part of the project in the past	Personal interview
Interview 23	University	Israel	Part of the project in the past	Personal interview
Interview 24	University	Israel	Part of the project in the past	Personal interview
Interview 25	Governmental	Israel	Potential user	Personal interview
Interview 26	NGO	The OPT	Part of the project	Personal interview
Interview 27	NGO	Israel	Part of the project	Personal interview
Interview 28	NGO	Israel	Part of the project	Online interview
Interview 29	NGO	Israel	Part of the project	Online interview
Interview 30	Public sector	USA	Part of the project	Online interview
Interview 31	Public sector	USA	Part of the project	Online interview
Interview 32	Public sector	Netherlands	Part of the project	Personal interview
Interview 33	Governmental	The OPT		Personal interview
Interview 34	Governmental	Netherlands	Funder of the project in the past	Personal interview

Especially in context of doing research in situations of inequalities and geopolitics, and as fieldwork is contextual, I choose to be open and 'critically conscious' of my own positionality

(Sultana, 2007; 2017). I have found it very difficult to write this article in the past year. Besides the stories and images of violence that have come to me through the news, in interviews, and in non-work related discussions during my fieldwork in the West Bank and Israel, many people living in the West Bank I spoke with indicated to have little hope for a better future for them and their children. Many people in Israel indicated to have a deep existential fear. Processing these emotions took time. Also, during my research I made values and narratives explicit, to identify biases existing in my society and also in me, and to engage with these by unlearning and opening myself up. A strong bias in me is that I was trained to look for win-win solutions, but have grown to believe – also based on this research - that a sustainable win-win is not achievable without making power imbalances visible and seeking ways to address them.

The development of WAS and MYWAS

The following analysis is presented chronologically and structured into four phases: WAS and optimism from 1992 to 1996, the Dutch support from 1996 to 2002, MYWAS and a national focus in the 2010s, and a reintroduction in 2022.

WAS, driven by optimism and dreams of peace: 1992-1996

The early stages of the project focus on the development of the WAS model and on sharing the initial results. WAS is initiated by Franklin (Frank) Fisher, driven by his interest to also contribute professionally to the peace process and a two-state solution as a Jewish American (Fisher, 2020). In the early nineties, there are negotiations and conferences, mainly with the Palestinian Liberation Organisation (PLO) as partner. Summarising a complex history, after the occupation of the West Bank and Gaza by Israel the question is how to allocate water and water rights in a semi-arid and arid area where water resources are limited, and where water is directly connected to state building (Dajani, 2020). Water is highly disputed, and the question of how to allocate it is being connected to topics such as access to land, self-determination, historical use, historical rights, and population size - with Israel approximately 5 million and the OPT approximately 2 million (Berck and Lipow, 1994; Isaac, 1995).

It is in this context that Fisher is invited in 1990 as chair of the water theme at Institute for Social and Economic Policy (ISEPME). After doubting how to give content to this theme, he starts the Water Economics Project in 1992. This project is inspired by the idea that water can be treated *"within the economic theory of resource allocation (and conservation), and with a price attached*" (ibid, pp 5). Fisher is particularly inspired by the following quote of G. Fishelson, an economist at the Tel Aviv University: "*Water is a scarce resource. Scarce resources have value. And the value of the water in dispute is bounded above by the replacement cost given by desalination, with that upper bound not very high." (Fishelson,* *1990, quoted in* Fisher et al., 2005, pp. xvi). Said differently, the economic value of water is not very high, and Fisher concludes that this means that water literally is not worth fighting over. In this phase of *problematisation*, Fisher identifies this as a possible approach to contribute to water cooperation between Israel, the OPT and Jordan, and how to make more efficient use of the scarce resources in the region based on economic approaches.

The project starts out as a series of conferences. The first conference, generally on water and economics and with participants from Jordan, Israel and the OPT, is not a success. The following quote of Fisher is exemplary for the reactions to the conference, as well as the challenge of dealing with water rights in the WAS/MYWAS project: *"The Arab[2] participants were all serious and pleasant enough, but seemed unable to deal with the idea that water could be given a monetary value. They insisted instead on discussing who had the rights to the water. In retrospect, I see that I failed to understand how to deal with that issue – but in any event, the result was depressing."* (Fisher, 2020, p. 6). The way Fisher understands the world, through his particular economic discipline, is a distinctly different one than many of the participants. Interesting is the influence that economic thinking has had in Israel (Feitelson, 2013), making it easier for the Israeli participants to both understand Fisher's worldviews and aims, as well as being more likely to support it. It shows that in this period of *interessement,* specific expertise plays an important role in whether people support or reject the idea.

The Water Economics Project gains a specific focus in the spring of 1993 when Fisher connects with Eckstein, an economist working both at the Tel Aviv University and Boston University who has co-developed a water allocation model, as formulated by the developers, for Israel, the West Bank and Gaza (Eckstein et al., 1994). Due to alignment in ideas, as well as proximity and existing working relations, this modelling approach is adopted by Fisher, and the Eckstein et al. model is chosen as the first prototype model. A second conference is organised in October 1993, and the idea that an economic approach may lead to more water being shared, to increase the total benefit for all parties, gains traction. This is especially facilitated by the signing of the Oslo Agreement a month before, which gives the idea that final status negotiations between Israel and the Palestinian Authority (PA) will happen in the near future and that support for negotiations over water may be needed soon (Fisher, 2020). The project gains support and *interessement* is successful, facilitated by political dynamics outside of the project that make the need for sitting together to negotiate more viable.

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[2] Referring to participants from Palestine and Jordan. A footnote is made here, as Arab is also used to refer to Palestinians, without having to acknowledge Palestinians as a distinct group with a claim to a particular place. It is not used as such in the book on the WAS and MYWAS projects (Fisher et al., 2005), but refers to the Palestinian and Jordanian participants together.

It is decided to form country teams to firstly develop a prototype model for Israel, Jordan and the OPT separately. The team in America plays the role of intermediary and translator between the country-teams, between the teams and the model, and between the model and potential decision-makers. It resembles the idea of the theory of translation that rolls are identified, and that these roles are activated through *mobilisation.* Yet, such translation is also needed outside of the project partners. To identify support for the project, Fisher meets with different policy makers. Water is a sensitive issue, for instance shown in the following quote related to a meeting of Fisher with then Israel's Minister of Foreign affairs Peres early 1994. Peres wants to avoid that the project is seen as a tool that supports Israeli politics in order to avoid a rejection from the Palestinian parties: "*At the conclusion of our meeting, Peres said very deliberately, "Israel will remain officially skeptical of your project, because if we were not to remain officially skeptical, your project would die. However, if your other clients get on board with you, you will not find us behind"." (Fisher, 2020, p. 25).*

Early cooperation on the project is hindered by violence in Israel and the OPT. For instance, the 1994 Hebron massacre leads the PA to stop any official interaction. Despite not being able to meet, the modelling continues. It becomes clear that the model based on Eckstein et al. (1994) cannot process input on recycled water, while it is an important resource for agriculture in Israel and thus an important part of making the positive-sum puzzle (Fisher, 2020). The General Algebraic Modelling System (GAMS) that can be used for optimization is chosen as basis for a new modelling exercise. This (re)modelling takes time, and throughout the project does often take longer than expected. The new model also requires the teams to learn how it works, which takes time as well (Ibid: p. 57).

Due to the relative inaccessibility of the modelling software, an important step in the project is the translation of the analysis at country level into a comprehensive report, developed by the end of 1994 (Fisher, 1994). It is presented to the different teams in 1995, who have not seen each other's results yet. As the report is intended to inform negotiations, the team in America is focused on ensuring traction with policymakers in Israel, the OPT, and Jordan. The report and modelling exercise do raise attention: *"After reading the draft report however, he [Shaul Arloseroff] decided there was something important going on. This mattered not only because Shaul was by far one of the most knowledgeable Israelis about water, but also because he had become the head of an eight-person committee (that included Gideon Fishelson) charged with reporting to the Knesset [Israeli Parliament] and various ministers on Israeli water policy"* (Fisher, 2020, pp 89). A Palestinian participant has very different experiences. He reflects that policy makers he knows do not see the project as more than an academic exercise, and take the different levels of expertise as a way to not engage with the outcomes. It is easy to do this as the Palestinian team is still acquiring the skills to work with the model: "*In the beginning I took it serious, and in the end I regretted it. The decision maker looked at us as students learning something" (Interview 19).*

In the process of collecting the data and developing the model, it appears that undertaking this modelling exercise is much more challenging for the team from the OPT than for the team from Israel: *"The Palestinians had already attempted to run the model. Perhaps in part because of electricity failure, they had failed to get it to converge with one of the standard scenarios"* (Ibid: p. 84). Also, where data for the run of the model in Israel mainly comes from one source, Tahal, an engineering firm that is central to Israel's state building through water (Morag, 2001; Dajani, 2020), the Palestinian team collects data directly from governmental institutions at national and local level, including the Jerusalem Water Undertaking, the Water Supply and Sewerage Authority of Bethlehem, and municipalities (Fisher et al., 2005). This takes much more time. Also, the teams from the OPT and Jordan have less experience with water economics than the Israeli delegation. Water economics is an established field in Israel (Eckstein, 2013), but water management in the OPT is mainly done by hydrologists and engineers (Interview 9). It can be seen as a problem in mobilisation, that due to expertise and technological issues, specific roles cannot be played out as intended. Based on suggestions of the American facilitators the Palestinian and Jordanian teams to appoint an independent expert to review the results and provide advice (Fisher, 2020; Fisher et al., 2005).

The modelling exercise is confronted with the different claims on water and land, and it is chosen to take a pragmatic approach: *"For example, the Palestinians had produced data and estimates that assumed East Jerusalem as their territory. Not surprisingly, the Israelis included East Jerusalem as part of Israeli Jerusalem. Since our project was not going to resolve the Jerusalem issue, it would be necessary to have two versions of the model."* (Fisher, 2020, pp. 26). A similar approach is taken towards how much each party can pump from the Mountain Aquifer, solved within the modelling exercise by using different pumping scenarios for the Palestinian and Israeli case (Fisher et al., 2005).

Where the Water Economics Project aims to contribute to water sharing and a more equal access to water, the signing of a specification to the Oslo Agreement of 1993, the Paris Economic Protocol and Oslo II of 1995, does not provide the stable ground for further cooperation as many had hoped for. A Palestinian negotiator reflects: *"I was member of the negotiation team for Oslo, but after I left because it did become a not- negotiation"* (Interview 19). The agreements reify an economic dependency of the OPT on Israel and increase the imbalance of power, for instance through the agreement that Palestinian import taxes are collected by Israel and then transferred, as well as due to limitations on import and export (Zagha and Zomlot, 2004). A situation is created in which the Israeli government deducts costs for the supply of water and treatment of wastewater that crosses the Green Line[3] before transferring these taxes. Also, a specific division of quantities of water for the shared aquifers, the Central, Western, Eastern and North Eastern aquifer as shown in Figure 4.1.

Figure 4.1 Basin formations and directions of groundwater flows
Source: Zeitoun et al. (2009)

Added up, 18 percent of the water resources are allocated for the Palestinians, and 82 percent for the Israelis (Trottier, 2000), although these numbers differ greatly per water body. For the Mountain aquifer, which is the most reliable natural source of water, this division is 6 per cent for the West Bank and 94 per cent for Israel (Zeitoun et al., 2009). Abstraction beyond what is agreed needs approval of the Joint Water Committee, in which decision making powers are also highly unequal (Selby, 2013). Fisher reflects: *"A strain like that on the*

[3] The green line is the 1949 Armistice Line and de facto border, drawn around Gaza and the West Bank after the war between *Israel*, Egypt, Lebanon, Jordan, and Syria.

quantity of water is destabilizing, and it would not be to Israel's advantage to impose such a solution on the Palestinians because it would lead to considerable and unnecessary tension within the fifteen years. That doesn't make for a stable peace treaty." (Fisher, 2020, p. 137). The Water Economics Project does not engage with water rights and holds on to the original idea of identifying if water can be more equally shared with those who need it most, based on the neo-liberal Coase Theorem, and sets the aspiration to contribute to the expected upcoming final status negotiations. Due to the inequalities reified through the Oslo Agreements, a Palestinian team member decides to leave the project (Interview 12).

When reflecting on how the modelling output has been adopted by others, Fisher writes *"We have been given substantial reason to believe that it has already indirectly facilitated the peace negotiations*." (Fisher, 1995, pp 389). He refers to the remark of Yossi Beilin, then Israel's Minister of Economics and Planning who mentioned that "*The water in dispute isn't worth $150 million dollars per year*" (Fisher, 2020; p. 67). The number may have been based on a WAS analysis and based on the shadow values, shared by one of the participants to the project in a memorandum with the minister. In a way, the output of the model, in terms of the calculations of the shadow values and the report that has come out, has become a tool in another cycle of translation; It provides a convincing argument for a new *problematization* phase that focuses on the output of the model, not the model itself. Through his personal and professional connections, Fisher is able to reach high-placed decision-makers in Israel and Jordan: "*when Julia Neuberger visited Cambridge in early November, she told me she had been told by the Crown Prince [of Jordan] and two of his aides that my project and I had been very influential in permitting Jordan to sign the water part of the [Israel Jordan] treaty*" (Ibid, p. 65). In the OPT it is discussed in the Palestinian Academic Society for the Study of International Affairs in January 1996 (PASSIA, 1996), but otherwise there is no evidence found the WAS has had influence. Meanwhile, the urgency to deliver remains high as the idea after the signing of the Oslo agreements was that *"the negotiations involving Israel would be over [in 1998] (which turned out not to be a particularly astute forecast)"* (Fisher, 2020, pp. 95). Funding is needed to support meetings and developing the model, but intensive lobbying for German and American aid does not materialise into concrete support.

Dutch support from 1996 to 2002

A new opportunity arises when the lobbying of the Ministers of Planning of Israel, the OPT, Jordan and Egypt to the government of the Netherlands results in financial support for regional projects. When presented with a list of projects collected by the four ministers, the 'Harvard Middle East Water Project' is accepted for financial support by the Dutch government in 1996, with funding available until 1999 (Netherlands Parliament, 1998). Dutch funding for a regional project stems from the support by the Dutch government for a two-state solution (Malcontent, 2022). From the Dutch side, "*there was still a bit of optimism about cooperation […] and Fisher was already working on model development*" (Interview 20). Also, such projects are a way to remain in contact (Interview 34).

The project is delayed for another half a year due to a change in government in Israel. Prime minister Peres calls for early elections after the assassination of Rabin by an Israeli fundamentalist, and seeks a confirmation for his policy to drive a two-state solution (Morris, 1996). Netanyahu who wins based on a policy against the Oslo Agreements, and the Dutch Ministry of foreign affairs asks for a renewed approval for the steering committee and modelling team of Israel, to ensure there is political support for the project. The project finally continues by the end of 1996 (Fisher et al., 2005). Changes are made to the supporting team. The person who developed the first WAS model in GAMS leaves the project as his PhD is finished. A new modeller is attracted to join the American team, and also an expert at the Netherlands based Delft Hydraulics (now Deltares) is invited to support in the development of the model and support the country teams (Interview 31, 32). Yet, the chances for a joint model run become smaller due to political reasons. In 1997, the new government of Israel tracks back on agreements of 1992 and decides to build a settlement in the south of East Jerusalem, illegal under international law. The 'Middle East peace process' is officially recognized as being stagnated (United Nations, 1997). The Dutch parliament is informed that the project is not meeting its objectives of running a regional model, but civil servants express the hope that "*This model [WAS] may potentially be of use in the permanent status negotiations on the subject of water*." (Netherlands Parliament, 1998, pp 66.). The model itself is thus not questioned, and the project continues. The idea of a regional model remains alive in thought. An Israeli team member shares: *"I'm a peacenik, and we work with the Jordanians and Palestinians, and really wanted this platform to help us get to a better place in the Middle East."* (Interview 18). Hosting the project at Harvard is expensive due to overhead costs and is increasingly seen as a risk by Harvard as the project works in such a politically sensitive area. In 1998, the project's management transfers from the Harvard Kennedy School to Delft Hydraulics and the project becomes the 'Middle East Water Project' (Fisher, 2020).

Communication on the project to the world outside of the project partners continues, especially driven by Fisher. In March 2000, Fisher presents the project at the World Water Forum in The Hague in the Netherlands. This presentation leads to the following headline in a Dutch newspaper: "Rational thinking can prevent war" (Volkskrant, 2000). It shows that the idea of an economic solution is presented as a neutral one, and that this approach is still fully at the heart of the project despite the political adaptations that are constantly being made.

When it comes to the expertise and ontology embedded within the model, an Israeli team member shares that he had a different view on what modelling approach would fit best, suggesting a multi-objective modelling approach to Fisher. Fisher wants to hold on to the single-objective version of WAS. The interviewee reflects on how this influenced his relation with the model: *"[Frank] tended to believe in the model beyond what the model could actually do. [..] I tried to temper his presentation to the world for the own good of the modelling exercise. If you encounter people in the real world, and they see the deficiencies, then it loses credibility. The whole purpose was credibility. [..] I could go around and explain, it was something that was useful although it is not reality itself*" (Interview 18). As consequence, the modelling process had become more important than the model itself. Another interviewee shares that for him it was not about the model, but mostly that it provided a reason to meet (Interviewee 34). With different model philosophies and disciplinary backgrounds, this also creates tensions. A Palestinian team member reflects: *"One of them [Israeli team member] sometimes told me: we have much more sophisticated models. We don't need these models. We're just doing it to show that we cooperate. He was very, you know, straightforward. I said, well, then you're cheating yourself before cheating the other people. And you are lowering the voice of people like me.*" (Interview 22). It appears that differences in ideas on how to go about the modelling exercise, and thus differences in the *problematization* identified by Fisher, leads to disconnects. It may be that more attention in the phase of *interessement,* the phase in which others are persuaded to buy into the specific problem, could have partially avoided this.

In March 2000, the Dutch newspaper article also shares that the governments of Jordan and Israel have signed for a next phase of the project, and that the Palestinian government is about to sign (Volkskrant, 2000). In the meantime, the Camp David Summit hosted by the US in July 2000 does not lead to an agreement. In September 2000, the second Intifada erupts after a provocative visit of Sharon, then the leader of the opposition in Israel, to the Temple Mount. Said to be a defence against increasing violence including bombings and knife attacks and as a means to control, the Israeli government and parliament decide to build a wall around the West Bank (Weizman, 2024). The construction of the wall[4] starts in 2002, reifying and solidifying the difficulties Palestinians already experienced in travelling across the green line (Alatout, 2009).

The Second Intifada and decision of Palestinians not to meet with Israeli counterparts make it impossible for the project to continue in the way it was intended (Interview 20, 22). Despite

[4] The wall is deemed illegal under international law (ICJ, 2003 - https://www.icj-cij.org/case/131), and is referred to in different political ways, such as West-Bank barrier, security wall, separation wall or apartheids wall.

the difficult situation, the teams work on a book on the project that summarises the work that has been done since the start of the project in 1992 (Fisher et al., 2005). The maps allow the results to be shared with a wider audience, but the technology that is used also creates unexpected obstacles. When a key person who works on water allocation within the Israeli government asks for the model, it appears that the model is not yet ready to be shared and the choice is made to charge users the $800 license fee of GAMS to use the model: "*[He, government employee tasked with water allocation planning] in 2005 wants a license, but licenses are not a free give away, and beyond that, MYWAS was not yet really ready. A lot of work had to be done, especially to provide a user-friendly interface. As it stood, we could show how it worked on some simple, made-up examples, but were not ready for it to be used on real complicated data.*" (Fisher, 2020; 445 & 446). MYWAS is not ready to play its intended role.

MYWAS in the 2010s: a national focus

The intifada and decision for Palestinians not to meet with Israeli counterparts make it impossible for the project to continue in the way it was intended (Interview 20, 22). The activities slow down and communication on the project is based mainly on results of earlier model runs, such as presented in a conference in Amman (Fisher et al., 2007). Scientific articles are being published on how WAS could be used to provide economic information for different scenarios to allocate water in negotiations (Fisher and Huber-Lee, 2008; 2009; Kronaveter and Shamir, 2009a,b), but the model and its output are not used as such. The focus turns towards application of the model for national water management, and funding is found to develop separate modelling processes. This can be seen as new rounds of translation, with a different problem, namely national and local water allocation, which requires new efforts for persuade others, identify roles, and activate these.

Official funding for continuation of the project in the OPT is found in 2008 by Fisher through the Czech Representative Office in Ramallah[5]. The intention is a two-staged project, from 2008-2009 and 2010 to 2013. The American team continues to develop WAS into a multiyear version, first introduced in 2011 (Fisher and Huber-Lee, 2011), and MYWAS is introduced in the second phase of the project to become a 'National Water Management System in the Palestinian Autonomous Territories' (Körner and Shaheen, 2014: pp. 3). The Palestinian team consist of a consultant and people working at the Palestinian Water Authority. Modelling is not central to Palestinian water management. Especially the senior water experts avoid using models as a lot of data is not trusted. Individuals use models that they learned to deeply

[5] In case Palestine is not recognized by a country it is opted to have a representative office instead of an embassy, which often functions in similar ways.

understand and trust during their education, and few models that are used by a larger group (Interview 9). The intention of the Czech project is therefore to train a group of Palestinian Water Authority (PWA) employees to fill this assumed gap.

The collection of input-data, especially on water supply, is challenging. One modeller reflects: *I find the approach a bit difficult for what you get out of it. You also need that water balance. And that is doable in Israel, but not in Palestine [..] Then we checked with the farmers to see which pumps they had. And then they said 'here under this lime tree is this pump' and then they looked up to see if an Israeli drone was coming over, and then I was allowed to take a quick look. Those pumps are everywhere. We came to a farmer, and [the pump] had just been beaten to pieces. Israelis had passed by there. So it is not an option to draw up that water balance"* (Interview 10). This quote shows also how the Oslo agreements determine who can pump water and who not, and how there are situations where the agreements are enforced by the Israeli army instead of Palestinian institutions. The challenge on collecting data for this study in 2013 is partially solved through using remote sensing data, it merely provides an estimation for a water balance, especially in a karstic system.

The project is stopped in April 2014, before its extended end date. The relevance, effectiveness, sustainability and impact are assessed as low or rather low (Körner and Shaheen, 2014). The MYWAS project is not well connected to projects and people that are working on strategic planning for water and wastewater at the PWA. Internal disagreements and payment issues render the local team ineffective, and only three out of the thirteen team members end up understanding the model well. Those who learned to work with the model have little opportunity to apply it in their daily work (Interview 8; Interview 11). An interviewee who had a government function shares that policies based on MYWAS have been made and implemented, to identify where infrastructure could be placed, and if and where water could be transported from places with abundant water to places with less water availability. The policies appeared to have no effect on consumers or water managers. Pricing has little impact on water consumption in a system that experiences such water stress as the OPT, where willingness to pay is low, and where water distribution systems have little coverage and high levels of water loss (Interview 6). Also, the Palestinian water sector is based on shorter-term planning as it has to deal with low levels of control due to the division of jurisdiction in Area's A (Palestinian Authority (PA) controls), B (PA has civil control and Israel military control) and C (full Israeli control), and limitations on import and demolishing of infrastructure. Agreement of the Joint Water Committee must be found for infrastructure planned for Areas B and C, and for area C, approval is needed from the Israeli Civil Administration (Zeitoun, 2008; Selby, 2013). This makes it difficult to plan infrastructure and use MYWAS as intended. Mobilization does not work out due to the realities on the ground.

In Israel, the modelling process has stopped as a main team-member decides that multi-objective criteria modelling is better than the approach of GAMS and MYWAS. To ensure that the model continues to be developed, it is decided that the Hebrew University takes up the development of the model for Israel: "*He [Frank Fisher] wanted to start, and he saw he could not move forward together, so he decided, ok let's start with this. [..] There we started from scratch, but only for Israel. That was our condition. [..] If you work with the Water Authority they don't like you to have Jordanians and Palestinians involved in it, because otherwise it is hard for them to cooperate* [with the project]*"* (Interview 15). It shows the low level of support of the Israeli government for regional cooperation at this time. A big decision is made in terms of funding. The research at Hebrew University gets funded by the Jewish National Fund (JNF) (Reznik et al., 2014). The JNF, a Zionist organisation active since 1901, is working towards a very different version of Israel than Fisher envisions. An example is his work with the New Israel Fund, in which he promotes democracy, equal justice for all who live in Israel and human rights (NIF, 2019). Upon earlier suggestions to apply for the JNF, Fisher writes *"involving the JNF would have been a signal to the Palestinians that the project really was a Jewis*h-*run operation. Shula opposed this [raising funds from the JNF] vigorously*." (Fisher, 2020: pp. 269). However, Fisher decides that funding from the JNF for modelling at the Hebrew University is acceptable after consulting Israeli friends who are in favour of a two-state solution (Ibid).

Where earlier connections in Israel were made on a basis of existing networks, sharing modelling outputs now happens via official channels. An Israeli team-member reflects: *"the communication with the authorities happens at different levels. First there are research grants and proposals, and that is how they can hear from us. And when we need data, we turn to them. [..] Sometimes we are a threat, they have a policy, and we are criticising them." (Interview 15).* Expertise plays a crucial role in whether people are willing to accept the analysis and its results. One interviewee who works on planning water distribution at the Israeli Water Authority (IWA) shares that he feels the model did not have any influence on the way that the IWA works on planning for water supply and allocation for Israel and water that is supplied to Gaza and the West Bank:[..] *"It [MYWAS] didn't have any influence, as we didn't want to incorporate economic considerations in the way they did it. [..] MYWAS is based on taking the consumption function into the model, based on price, based on what the crops can take for water today. We do not agree with this concept, because for planning, if you go backwards to what the agriculture was in 1970, it is totally different than agriculture we have today. [..] We do not think it is the good idea for long-term planning."* (Interview

25). Also in Israel mobilization does not work out, mainly due to different expertise and ideas on how to approach water allocation.

A challenging reintroduction in 2022

MYWAS is re-introduced in 2022 in an attempt to influence regional cooperation, returning to the original objective of Fisher. In 2024, MYWAS is also introduced in a lecture at the Arava institute in Israel, that also promotes regional cooperation (Arava institute, 2024), but this research focuses on the project that is hosted by EcoPeace. EcoPeace is an NGO with offices in Amman, Ramallah, and Tel-Aviv and aims for *"the promotion of cooperative efforts to protect our shared environmental heritage. In so doing, we seek to advance both sustainable regional development and the creation of necessary conditions for lasting peace in our region*" (EcoPeace, n.d). The aims of MYWAS connect with those of EcoPeace, to promote regional cooperations with a strong emphasis on the need for identifying win-wins. The expectations of the commissioners are high, having identified MYWAS a potential game-changer (Interview 28), with the expectation to *"eventually produce policy recommendations to highlight win-win situations that would allow Palestinians to have more access to groundwater resources and that would support the idea of Palestinian water independence, or water independence or even water rights.*" (Interview 26). There is hope that making visible where water is wanted most by calculating the shadow values of additional units of water, and by showing based on scientific methods how unevenly water is divided, that this information can open up conversations, leads to informed negotiations and a fairer division of water.

Another reason MYWAS is adopted by EcoPeace is that a model is functioning and only needs to be updated: *"I was like, why are we not utilising something that is existing? Why don't we try it out*?" (Interview 26). The materiality of the model, and that there are modellers who understand how to use it, make it an attractive project to adopt. When the project starts, it becomes clear that the modelling exercise for the OPT needs to be fully updated or redone (Interview 22). The project teams remain the same, and funding is secured through USAID to run MYWAS for Jordan, Israel and the OPT. Working with USAID as donor comes with specific challenges in the OPT as funding is conditional on people signing an anti-terrorism statement. This practice is criticized as criminalising resistance and normalising the occupation (Awashreh, 2020). A related issue is that the Palestinian Authority, or Palestinian Water Authority, cannot be beneficiaries of USAID funds due to the same anti-terrorism act. This influences who can be supported to understand and use the model: *"Who would be the final owner of this product is still vague, and the Palestinian Authority thinks that if they are not fully recognised as an owner, then why should they be engaged?"* (Interview 26). The project thus needs to find other approaches to transfer the insights of the modelling exercise once they are available (Interview 27).

Although the modelling approach has remained the same, the context in which the model aims to have impact has changed. In 2023 large protests are ongoing in Israel against an attempt of the government to diminish the role of the Israeli Supreme Court in judging whether new legislation is reasonable. There is an increasing number of settlements announced by the Israeli government, and new or growing outposts-connected settler-violence, as well as roads that Palestinians are not allowed to use (European Union, 2024). A Palestinian interviewee shares to see no hope for a better future for her children. An Israeli interviewee shares that he feels so unsafe that he is carrying a gun constantly.

In discussions on merging the national models into a regional model, several issues arise. The teams have to decide how to engage with the progress made on MYWAS at the Hebrew University. Especially the interface, which show the infrastructure and demand and supply nodes, spark questions when shared beyond the Israeli team. A Palestinian team member has an emotional reaction to the visualisation of demand in the West Bank through one demand node: *"You cannot treat West Bank as one demand point. That's very unacceptable."* (Interview 22). This representation, which could be seen as a simplification of a complex situation, becomes extremely political in a situation where Palestinians are increasingly dependent on buying water from Israel, while negotiations over access to the aquifers have stalled. The act of representing is not only political, but also emotional, as it is about being acknowledged and seen, and a call for people who work on the other side of the wall to understand the struggle. Also, there is an extreme lack of trust in each other's data and an actual, as well as perceived, difference in access. A Palestinian team member reflects: *"They can at any, at any time, go to anywhere in the West Bank and do the readings [of measurement devices, or collect samples] and leave."* (Interview 26). The imbalances in – amongst other things - access to land, water and related data still have an influence on the project. Also in this phase it is difficult to plan meetings. An Israeli interviewee shares in May 2023 "*We had two meetings, not only with us, but many guests, and we discussed the issues of water management and cooperation with the Palestinians. In the last 2 months… nothing." (Interview 15).*

This research does not cover activities after April 2023, and the interviews and analysis of WAS and MYWAS are done up to April 2023, long before the 7th of October 2023. The modelling has continued, but the analysis is drawn based up the period up to April 2023.

Discussion

I dedicate this discussion first to how the WAS and MYWAS processes aspired to contribute to allocate water in a highly political and economic unequal situation, as it is this content that matters most. Only secondly I will reflect on the conceptual approach and its applicability.

The WAS and MYWAS models build on a neo-liberal idea that a free market can fairly allocate goods among people. The Coase theorem is the main mechanism in the models, which theorises that a good can be divided based on the willingness to pay, translated into shadow values, when a good is up for bargaining. It is exactly the question whether such bargaining happens fairly. Coase also theorises that such negotiations should happen with complete information and equal power. Yet, it is clear that this is not the case when it comes to negotiations between the representatives of Israel and the OPT (Selby, 2013). This view is also shared by the former economic advisor to the Palestinian and Jordanian teams. In an article, he praises the project and participants for their efforts to contribute to peace, but criticises the central theory and states that optimization of water allocation takes place within "*Israeli dominance and exploitation*" (Kubursi, 2005). His main argument is that participants to a negotiation need to know what units of water are under negotiation, and thus require clarity of quantities and ownership. Fisher reacts in his own book that he thinks this is other way around (Fisher, 2020). Namely, he thinks that negotiations over water can lead to more clarity on water rights. The question is whether a fairer division of water can be established in a situation of occupation, economic inequality and water scarcity, based on neo-liberal thinking such as the Coase Theorem. During the time of the research, this has not happened. The question is also whether the suggestion to pay for water will not drive Palestinians in an even more dependent position as only a buyer of water, not owner with independence.

This links to the question whether a complex modelling exercise is needed, while simpler calculations could suffice to show that a fairer division of freshwater sources is possible. Such calls do exist (see for instance Brooks et al., 2019; Isaac, 2000; Lautze and Kirshen, 2009; Philips et al., 2005; 2007, Zeitoun et al., 2009). It is certainly questionable if the modelling outputs will open up a discussion on Palestinian water rights. Yet, a modelling process and its output is only one input in the discussion. It also matters what story is told, and how systemic and historic issues and inequalities are addressed in these stories. What WAS and MYWAS have done, is visualising that water allocation is highly unequal at the detriment of the Palestinians, to provide a platform to explore different modes of water allocation and sharing, and ways inquire about the possible impact of management decisions. Explore different visions of the future, including those visions of the future provided by MYWAS, are important in identifying ways forward. Yet, I argue, and many with me, that fairer allocations of water require an explicit engagement with power, which the Coase theorem does not do. Enriching the project with additional analyses (model-based or not), and making explicit that this analysis takes place in the context of occupation, is a necessary step. As the occupation continues and increases, the question is what water is – and will be – left over to negotiate about in good faith. Directly related to this funder of the project reflects, while looking back, that he put too much trust in the goodwill of the Israeli government, especially in the light of the war on Gaza (Interviewee 34). History has so far not shown that negotiations on water allocation will lead to water rights eventually.

The second part of this discussion focuses on the methodology. It has been analytically useful to unpack the model based on ontology, vision of the future, expertise and materiality (MacKenzie and Wajcman (1999), as well as ANT as methodology (Kanger, 2017), to identify the "evolution of power relationships" (Callon, 1984: pp. 201) through, and surrounding, WAS and MYWAS. It has led to a fine-grained description of the modelling processes over time, and in context. The value of this analysis is that it makes visible what interactions take place that make a model have small or large effect on people and places, as well as who is supporting or using the model to realise their own visions of the future. The detailed reports of Fisher (2020) have been of key importance for this research, and also confirms the value of keeping track of important moments in a modelling process. The challenge of the methodology is that the focus on fine-grained interactions draws the attention away from the bigger political picture. The introduction of Selby's work, which has shown systemic inequalities in power and decision-making structures (Selby 2003; 2013), has been useful to bring this into the analysis. Yet, it requires matching the interactions around the model actively to geopolitical dynamics, which in effect requires the researcher to apply and combine two very different ways of analysing the world. It is exactly such exercises in applying different ways of seeing the world that may merit model-driven projects in politically sensitive contexts. Namely, the analysis also makes visible that a particular way of seeing and understanding the world embedded in the model is seemingly reified over time and not easy to change, especially as the main developer held onto the approach chosen . The WAS and MYWAS models share the same expertise, worldview and visions of the future. In a context of conflict over water, and in relation to our understanding that rejections of the model mainly are based on expertise, a better approach – for the modellers, commissioners and funders, may be to bring together different knowledges before selecting one, multiple, or no modelling approaches. The data and knowledge collected, and relations forged, could also be used to discuss different types of analysis.

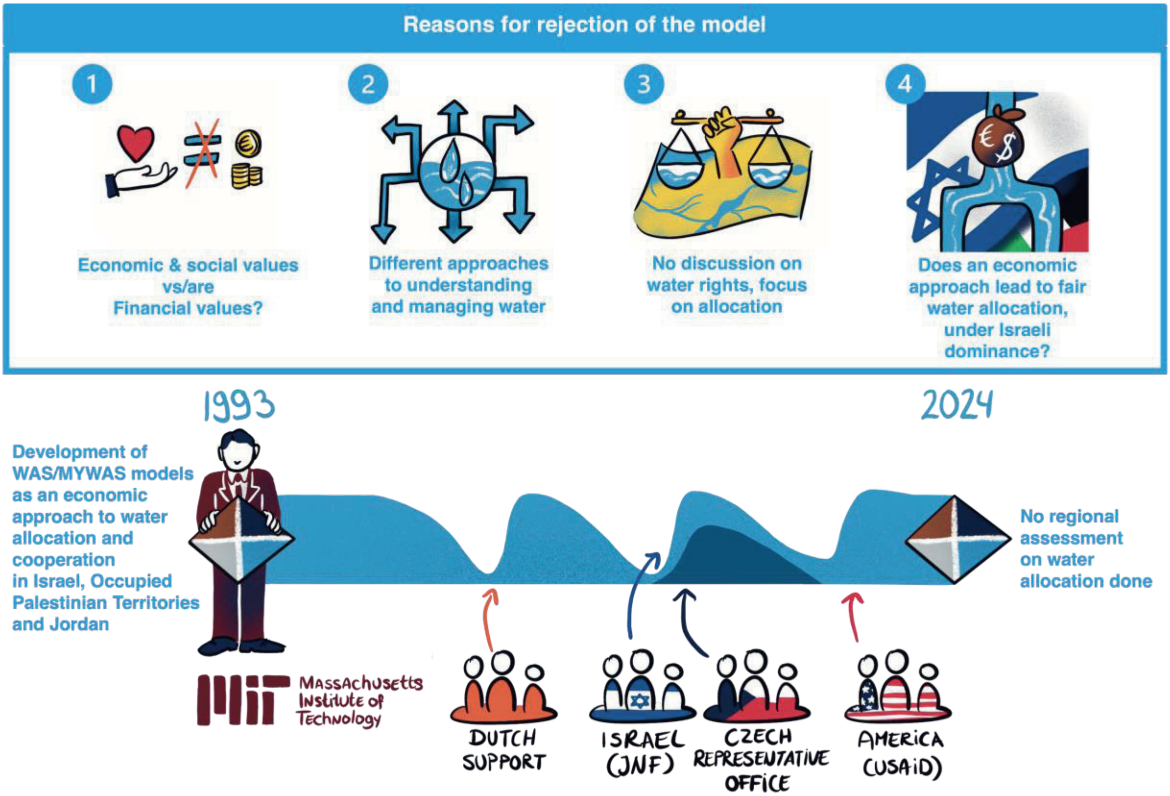

Figure 4.2 Summarising the WAS/MYWAS case study

Conclusion

In this article I followed the development of the hydro-economic optimisation model WAS/MYWAS in the context of water conflict in Israel and the Occupied Palestinian Territory, since its inception in 1992 until its reintroduction in 2022. Using the theory of translation (Callon, 1984) as methodology (Kanger, 2017) has led me to focus on moments where the model becomes part of a bigger network, or when people refuse to be enrolled or leave the network, and why. I have unpacked the model based on MacKenzie and Wajcman (1999), to understand how the policy project, ontology, expertise and materiality of the model create these connects and disconnects. Different cycles of translation can be identified. In the case of WAS and MYWAS, the model had impact especially through the modelling process, and not necessarily the output. The role of Fisher as spokesperson, and his link with strong networks, has been instrumental to make the model travel. Interest was gained by other mainly based on the combination of the vision of the future, combined with the backing of specific expertise and materiality that made that the projects gained support, particularly of Western donors. Simultaneously, the specific expertise, based on neo-liberal economics and related language, led to rejections of the model, or required additional efforts to engage and convince people. Especially in the OPT, the ontology of the model and its simplification did not match the reality on the ground, creating sensitivities and making it very difficult or impossible to implement the recommendations

The analysis shows that disconnects from, or rejections of, the modelling process are mainly caused by the difficulty to implement the ideas and suggestions, and changing views on the feasibility of the policy project. The latter is especially influenced by changes in the context such as increasing violence and occupation. Also, expertise creates disconnects, based on ideas on what the best modelling methodology is, as well as the requirement of funding to use the software. The development and use of the model is also shaped by the difficulty for people to join project meetings due to checkpoints or permits, the availability of electricity, disagreements on how people and places should be represented. This research shows that analysing the model and interactions that directly relate to the modelling process is not sufficient to understand how a model gains influence. For a power-sensitive analysis, it is required to understand politics at different scales.

By following the development of WAS and MYWAS over time, it became clear that the core ideas, being the Coase Theorem and the translation of water into economic values to contribute to negotiations and planning, did not change over time, reified in the modelling structure and guarded by the strong conviction of its developer. Everything was done to ensure the model remained relevant, including separate model development at national scale and accepting limitations set by donors in the hope that at a certain time it could contribute to a fairer water allocation and peace. Yet, while doing so, team members operated within the confinements of the model, while the world outside of the model was changing. Based on the Oslo agreements and expanding occupation, the economic dependence of the OPT on Israel had increased since the signing of the Oslo Accords in 1993 and 1995. The dependence on water from Israel had increased too, certainly with the introduction of desalination, forcing the Palestinians in a role of buying water. The question is whether negotiations in this situation, based on neoliberal considerations, will give the Palestinians a stronger position, or whether these are non-negotiations in a non-level playing field. It is a criticism on foreign aid that does not address the systemic injustices, and may even indirectly support an increasingly violent oppression (Awashreh, 2020; Eid-Sabbagh et al., 2024). For everyone working in this or other (protracted) conflicts, it is a call to actively engage with the potential influence of knowledge tools, and to critically analyse what futures are potentially made possible and impossible through their work.

5

Chapter 5

THE INFLUENCE OF CRITICAL AND REFLEXIVE RESEARCH ON WATER MODELLING: CAN SCIENCE MAKE A DIFFERENCE?

The extended abstract related to this chapter is preliminary accepted for Special Issue on Modelling Water Worlds in Water International, drafted by Rozemarijn ter Horst, Stuart Lane, Jonatan Godinez Madrigal, Jeroen Vos and Lieke Melsen.

This research builds on chapter 2, the literature review, and the work done together with researchers of IRI THESys at the Humboldt University in Berlin, where researchers were looking into the same questions, especially focusing on how models are developed (Klein et al., 2024; Krueger et al., 2012; Krueger and Alba, 2022) as well as the University of Montpellier, where there is a long experience of engaging with the influence of models and modelling with stakeholders (Bonté et al., 2022; Etienne, 2014). Important discussions took place during a Summer Course on situated modelling organised by IRI THESys in Berlin in 2023. I would like to thank all those who responded to the survey and were available for interviews.

Introduction

There have been numerous calls to recognise and engage the potential traits of water models in ways that foster inclusivity and justice (see for instance Abbott and Vojinovic, 2014; Klein et al., 2024; Lane, 2014; Maeda et al., 2021; Saltelli et al., 2020). Yet, there are few examples that critically assess how models shape and are shaped by the places that they are made for and implemented in, or engage with this through action research, as shown in Chapter two. A simple bibliometric search in Scopus offsets publications on water, hydrological and groundwater models, against research on the same type of models in addition to justice, equity, politics or ethics (Figure 5.1). Based on the search queries, Figure 5.1a shows that only a tiny fraction of the total publications in water modelling mentions topics related to reflexive and critical research, such as justice, equity, politics or ethics. This percentage is consistently well-below 1% of the total number of publications in this domain (Figure 5.1b). The average number of citations from papers in this subset seems overall somewhat higher than the average number of citations in the full set (Figure 5.1c), suggesting that such work does get appreciated by the academy. However, bibliometric analyses do not reveal what number of articles actually address justice, equity, politics or ethics in-depth, nor the extent to which this tiny fraction of papers influences water modelling as a practice.

The question we aim to address in this chapter is what influence the relatively small, but consistent stream of critical and constructive research and action research has had on water modelling in research and practice. Given that influence, especially on modelling practices, cannot be well captured in formal scientometrics and bibliometrics, we instead explore this question through surveys and interviews with authors who have published scientific work on this topic, and through the exploration of two longitudinal case studies.

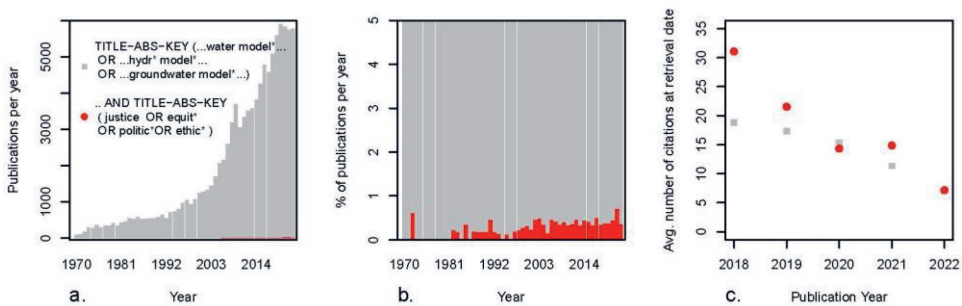

Figure 5.1 Outcomes of the bibliometric search

Source: made by the authors based on a bibliometric search in Scopus in September 2024

Our research set-up is shown in Figure 5.2. We build this research on a broad definition of the influence of science, which we define as the set of social and material effects achieved through doing, communicating, writing and publishing research. It is an interplay of many factors that make that research and science communication do something in the world. That is the reason we have chosen for an inductive research approach to accommodate for the diversity in experiences and interplays. Data is collected through a survey with open questions, as well as interviews. The cases were selected as they concern longitudinal studies conducted by two of the authors. In the first case, modellers and social scientists have worked together to understand flood risk modelling in Pickering, England between 2007 and 2011 (Landström et al., 2011; Lane et al., 2011). The second case study concerns the role of water modelling in a water conflict in Lake Chapala, Mexico, where research took place from 2016 to 2022 (Godinez Madrigal et al., 2019; 2022).

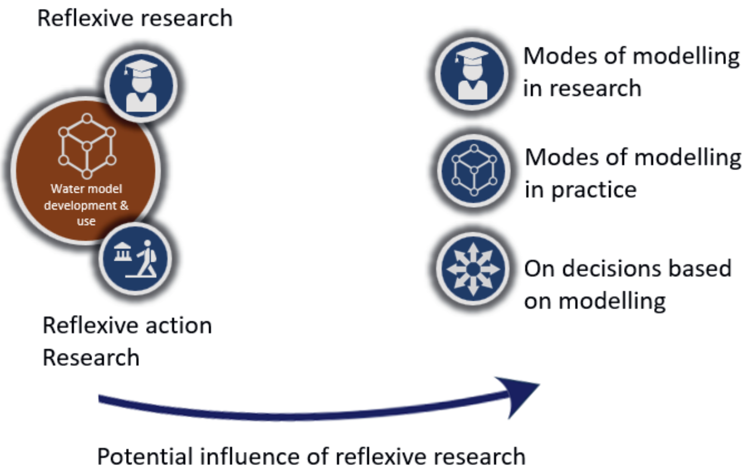

Figure 5.2 Set-up of the research

The chapter is set-up as follows. First, we explore what the influence of publications is. Then we focus on the influence of research in practice, more deeply explored through two case studies. Then we discuss how research influences the researcher oneself, and lastly what the challenges are for research to have influence. We conclude with a discussion on how adopting a more critical approach to modelling is not itself a sufficient condition for a more inclusive and equitable process and outcome, and conclude what is required to achieve this.

Methodology

This research builds on a literature review that explored scientific publications that engaged reflexively with water modelling (ter Horst et al., 2024). This reflexive research is critically conscious of the locations, actions and power relations (Sultana, 2017) related to water models. 61 Scientific publications were identified through a generic document search, and suggestions by co-authors and the HESS community, as well as a systematic search in Scopus and Web of Science based on the following query: TITLE-ABS-KEY ("water model*" OR "hydr* model*" OR "groundwater model*") AND TITLE- ABS-KEY (justice OR equit* OR politic* OR ethic*). The keywords were chosen to broadly capture scientific discussions on the role of water models in issues of water allocation and distribution of benefits and risks, as well as on values and ethics in relation to the development and implementation of water models.

The outcomes showed that there are very different approaches to reflexivity, as well as with different foci in relation to the modelling development and implementation. It can be seen as a continuum. On one end of this continuum, there are studies that remain in the modelling domain or 'model land' and aim to understand how the input and process are shaped and how they have an effect on the modelling output. These can be more technical studies often done by modellers themselves (Addor and Melsen, 2019; Bergström, 1991; Melsen et al. 2019) or focused on the practices of modellers, which is often done by social scientists (Landström et al., 2011a; Laborde, 2015; Babel et al., 2019). On the other end of this continuum is research that considers the impact of models in practice, also considering why models are used in the first place to answer a specific question. These studies emphasise the neglect of the interests and knowledge of marginalized groups in society, and how this results in winners and losers when a model is applied (Budds, 2009; Cornejo and Niewöhner, 2021; Godinez Madrigal et al., 2019, 2022). This type of studies is often based within political ecology or environmental justice studies, sometimes combined with Science and Technology Studies (STS). In the middle of this spectrum we find research that identifies how water models are used in practice, for instance based on approaches that consider the Social Construction of Technology (SCOT) (Sanz et al., 2019), or how models are being used to represent or to connect to specific local social dynamics, for instance based in feminist studies or environmental justice (Haeffner et al., 2021). Similar to general studies, reflexive action research can happen anywhere on this continuum.

We defined six questions in relation to the influence of such scientific work. We based these on our broad definition of influence, which is all social and material effects that were achieved through the process of doing research, and writing and publishing of scientific material. The questions are purposefully formulated as open questions to provide space for the respondents to think broadly about the differing effects of their research. We tested the questions ourselves based on comprehensibility, by filling out the survey and refining the questions based on our own experience with doing such research (Godinez Madrigal et al., 2019; Lane, 2014; Sanz et al., 2019; ter Horst et al., 2023). We defined the following questions which will be addressed in the following sections:

1. What impact did your research have, according to you? Please be as explicit as possible on what and/or who has changed, and how.
2. Besides writing the article, what other activities did you undertake to share your insights? Who were your target groups?
3. In relation to the previous question, what ways of communicating your insights were most effective, according to you, and why?
   This question is more deeply explored in relation to two cases of action research
4. Has the research changed your own modelling practices? If so, what fostered this change, and what do your changed modelling practices look like?
5. If there have not been any changes, or if change has been challenging, why do you think this is? Please be as explicit as possible on what, who, and how.

Based on the 61 scientific works on the influence on water models, identified by ter Horst et al. (2024) we contacted the first authors of these works, 52 in total. In some cases, we have reached out to other authors, mostly upon advice of the first authors, or in case the first authors were not reachable. We provided the option to answer the questions in writing, but as people found this challenging we also provided the option for an interview or for answering through a voice message. Table 1 provides an overview of those people who answered, as well as the way in which they have answered. 21 persons responded, in relation to 24 scientific documents. They answered through 10 written responses, one personal interview, 8 online interviews, and 1 voice message. All interviews and the voice message were transcribed and included in the same format as the surveys. In the interviews, we asked the same open questions as in the surveys.

Table 5.1 Overview of the survey and interview respondents

Date	Means	Person who answered	Title	Authors	Year	Source title
7-6-2024	Survey	Nans Addor	Legacy, Rather Than Adequacy, Drives the Selection of Hydrological Models	Addor, N.; Melsen, L. A.	2019	Water Resources Research
6-6-2024	Personal interview	Faiz Alam	Understanding human-water feedbacks of interventions in agricultural systems with agent based models: a review	Alam M.F. et al.	2022	Environmental Research Letters
14-6-2024	Online interview	Lucie Babel	Decision-making in model construction: Unveiling habits	Babel, L. et al.	2019	Environmental Modelling & Software
27-4-2024	Survey	Sten Bergström	Principles and confidence in hydrological modelling	Bergstrom S.	1991	Nordic Hydrology
11-4-2024	Survey	Jonatan Godinez Madrigal	Production of competing water knowledge in the face of water crises: Revisiting the IWRM success story of the Lerma-Chapala Basin, Mexico	Godinez Madrigal J., et al.	2019	Geoforum
27-6-2024	Online interview	Melissa Haeffner	Representation justice as a research agenda for socio-hydrology and water governance	Haeffner M., et al.	2021	Hydrological Sciences Journal
			Social Position Influencing the Water Perception Gap Between Local Leaders and Constituents in a Socio-Hydrological System	Haeffner, M., et al.	2018	Water Resources Research
18-6-2024	Online interview	Ryan Holifield	How to speak for aquifers and people at the same time: Environmental justice and counter-network formation at a hazardous waste site	Holifield R..	2009	Geoforum
30-4-2024	Survey	Casper Bruun Jensen	A flood of models: Mekong ecologies of comparison	Jensen, C.B.	2020	Social Studies of Science
29-4-2024	Survey	Erik Mostert	Modelling expertise: Experts and expertise in the implementation of the Water Framework Directive in the Netherlands	Junier, S.J.	2017	Delft University of Technology
21-4-2024	Online interview	Matthijs Kouw	Standing on the shoulders of giants—and then looking the other way? Epistemic opacity, immersion, and modeling in hydraulic engineering	Kouw, M.	2016	Perspectives on Science
			Risks in the Making: The Mediating Role of Models in Water Management and Civil Engineering in the Netherlands	Kouw, M.	2017	Berichte zur Wissenschaftsgeschichte
19-06-2024	Survey	Tobias Krueger	Ontological and epistemological commitments in interdisciplinary water research: Uncertainty as an entry point for reflexion	Krueger, T. & Alba, R.	2024	Frontiers in Water
20-3-2024	Survey	Lieke Melsen	What is the role of the model in socio-hydrology? Discussion of “Prediction in a socio-hydrological world”*	Melsen L.A., et al.	2018	Hydrological Sciences Journal
			It Takes a Village to Run a Model—The Social Practices of Hydrological Modeling	Melsen, Lieke A.	2022	Water Resources Research

Date	Means	Person who answered	Title	Authors	Year	Source title
			Subjective modeling decisions can significantly impact the simulation of flood and drought events	Melsen., et al.	2019	Journal of Hydrology
24-6-2024	Online interview	Pablo Mendoza	How do hydrologic modeling decisions affect the portrayal of climate change impacts?	Mendoza., et al.	2016	Hydrological Processes
16-5-2024	Online interview	Karen MacClune & Sara Opitz-Stapleton	*Scientific and social uncertainties in climate change: The Hindu Kush-Himalaya in regional perspective	Opitz-Stapleton S.; MacClune K.	2012	Community, Environment and Disaster Risk Management
11-6-2024	Survey	David Sanz	The social construction and consequences of groundwater modelling: insight from the Mancha Oriental aquifer, Spain	Sanz., et al.	2019	International Journal of Water Resources Development
18-6-2024	Voice message	Veena Srinivasan	Moving socio-hydrologic modelling forward: unpacking hidden assumptions, values and model structure by engaging with stakeholders: reply to "What is the role of the model in socio-hydrology?"	Srinivasan, V., et al.	2018	Hydrological Sciences Journal
17-6-2024	Online interview	Chloe Wardropper	Uncertain monitoring and modeling in a watershed nonpoint pollution program	Wardropper C., et al.	2017	Land Use Policy
21-5-2024	Online interview	Anne Wesselink	*Hydrology and hydraulics expertise in participatory processes for climate change adaptation in the Dutch Meuse	Wesselink A., et al.	2009	Water Science and Technology
26-4-2024	Survey	Kevin Wheeler	*Exploring Cooperative Transboundary River Management Strategies for the Eastern Nile Basin	Wheeler K.G., et al.	2018	Water Resources Research
			Modelling to bridge many boundaries: the Colorado and Murray-Darling River basins	Wheeler, K. ., et al.	2018	Regional Environmental Change
21-7-2024	Survey	Dave Tuthill	GIS, modeling, and politics: On the tensions of collaborative decision support	Ramsey, K.	2009	Journal of Env. Management

The data is analysed based on an inductive content analysis, in which general themes and relations within and between the answers were identified based on the data we collected (Seidman, 2006). In addition to the interviews, we explore the general themes identified through the surveys and interviews in the context of two case studies on water modelling to deepen our understanding of the influence of water modelling in practice. These two case studies have been selected based on the involvement of two authors of this article, and include longitudinal studies of how those authors evolved their own approaches to modelling as a result.

The influence of doing the research and scientific publications

We have asked the authors we reached out to the following question: "What impact did your research have, according to you? Please be as explicit as possible on what and/or who has changed, and how". In the answers, authors made a distinction between the scientific publications and their influence and the influence of the process of doing research. We firstly focus on if and how the scientific publications included in Table 5.1 have had an influence on studying and practicing water modelling.

It may not be surprising that the overwhelming majority of interviewees did not think that their publications directly had influence on science, applied science, or on the management of water. Only two of the 21 authors indicate that their article has resonated outside of their networks. Addor shares experiences in relation to research that demonstrates the role of legacy in model selection, and that suggests Modular Modeling Frameworks (MMFs) as a way forward (Addor and Melsen, 2019). The article details how the selection of models can be traced back to specific people who educate others to use models, rather than models being selected as they fit a specific question. Addor indicates that the article seemed to resonate with people: *"[..] the title helped with the communication. And the result that "in ~74% of the studies, the model selected can be predicted solely based on the affiliation of the first author" is something that people understand easily."* (Addor, survey). Addor frequently heard that the publication is included as reading for courses on universities. Yet, "*Did the paper change behaviours? Did it help with the adoption of MMFs [as we suggested in the paper]? I don't know."* (Addor, survey).

The second publication that resorted broader reactions is from Haeffner, who wrote about how water modelling can better represent society by including social constructs such as gender (Haeffner et al., 2018; 2021). For Haeffner, the article has had impact in the sense that it caught the attention of scientists who were working on socio-hydrology, and who were curious on how to model people and water interactions (Sivapalan et al., 2012). Sivapalan, one of the founders of socio-hydrology, reached out to her based on the publication with the interest to incorporate her ideas. Yet, Haeffner is also not sure on whether this interaction has led to a lasting change. When asked by the interviewer: *"So personally for you it had a lot of impact. And do you think then in this kind of networks, does it do anything?"* Haeffner answers: *"I don't know yet. I don't know the answers to that. I'm not sure."* (Haeffner, interview).

Besides reactions of others, the authors also use the publications to initiate interactions themselves. Respondents mention five times that the publication is an instigator for conversations or brainstorms with colleagues. A crucial element of these interactions is that colleagues are open to engage with interdisciplinary research that is consciously critical on current practices and that there are possibilities to follow-up in practice. Creating places that facilitate such interdisciplinary interaction can take time. For instance, Ramsey did his PhD research connected to the Idaho Department of Water Resources (IDWR). It was part of a longer effort of his PhD supervisor Tuthill to promote the use of GIS for decision making. Tuthill wrote his own PhD dissertation on the topic (Tuthill, 2002), and later became director at this Department. In this role he provided institutional embedding for the research of Ramsey on GIS, modeling, and politics: On the tensions of collaborative decision support' (Ramsey, 2009). Other examples are research institutes that bring together engineers and social scientists. Krueger works in such an institute, IRI THESys in Berlin. He co-authored an article with Alba on how knowing water from certain disciplinary perspectives, while presenting these views as neutral and depoliticized, influences what questions can be asked and decisions taken. Presenting the research to colleagues has led to unexpected connections with colleagues: *"[..] for Rossella [Alba] and me and our group [at IRI THESys], the talk and later the paper was the starting point of a series of collaborations exploring not only epistemological and ontological aspects of models (perhaps less so) but the political and ethical aspects that for us follow from those."* (Krueger, survey). Alam has similar experiences as Krueger, in relation to his work in IWMI in New Delhi. Alam wrote a review of agent-based models to understand human-water feedback, and calls for more grounded research that represents local people better (Alam et al., 2022). He has brought these ideas back to his office where engineers, economists and social scientists work together: *"There is no resistance.[...] And especially in meetings, when you have social researchers and hydrological people sitting, if you show socio-hydrology, somehow people find it like a nice idea [..], because everyone wants to do this integrated research."* (Alam, personal interview). The approach of socio-hydrology provides then an entry point for the social researchers to contribute to technical projects.

Several respondents indicated that the process of doing research had influence, rather than science communication. The methodologies that are chosen therefore matter. For instance, Babel noted that conducting interviews are a significant moment in which change can occur in the form of a new insight. It can create a moment of reflection for the interviewee and the interviewer. Babel shares: *"And then the person is suddenly developing under your eyes, you know, and this is very much what I saw in my interview. So at first the persons were very certain of why they did it like that. And then suddenly you just ask something and then they start to think differently."* (Babel, interview). Also, people are engaged in the studies matter. Two of the respondents have explicitly chosen to model with people who had a political question on water management, in processes in which modelling played an important role in decision making (Godinez Madrigal et al., 2022; Wheeler et al., 2018b, 2018a). The research covered cooperative modelling exercises that sought to level an unequal playing field in which the development and access to information played big roles. Continued engagement, building of trust, as well as a deeper understanding of the issues and people and institutions involved allowed Godinez Madrigal and Wheeler to bring people together, and to use the model to identify a joint view on the water, and discuss existing and proposed infrastructural developments in relation to this water.

Work that is done to bring back the insights to decision makers is also mentioned as important to create influence. Wardropper shares her experience with the project she was connected to: *"We had several follow up conversations, particularly with the sewage district, which is the regulatory entity in this case, and they were receptive and they were also involved with other research."* (Wardropper, interview). How the research had influence beyond these meetings is not clear to us. Godinez Madrigal also managed to speak to those who made the decisions on the management of a dam, but this was not because these decision-makers were intrinsically motivated. He noted *"The model was the vehicle to make this [the idea to retrofit the dam] clear, but it could have not made a difference without the UNESCO-IHE credential, without the Dutch expertise credential [..], and without the contacts and network that people with those credentials had*." (Godinez Madrigal, survey).

To conclude, respondents indicate that scientific publications, in their perception, generally have little influence. Only two respondents reported their articles resorted reactions outside of the direct networks of the respondents which led to exchange and adoption of ideas and inclusion of the paper in education. Yet, further explorations show that the articles are useful for the authors themselves, to showcase their expertise to possible funders or to share and discuss their insights on water modelling with colleagues to identify if and how these can be integrated. The research itself creates changes in different ways, from deeper awareness through interviews, to providing space for people to meet and share their thoughts.

In-depth longitudinal studies

We further explore the process of moving from insights by the researcher to awareness and action, as well as the role of reflexivity in this process, based on two longitudinal studies in which water modelling played a central role and in which this process was closely monitored. We are highly familiar with the cases as Godinez Madrigal and Lane worked as key-researchers in these studies. The following questions were asked and form the basis of the descriptions: How did the reflexive work on the role of water modelling take place/was done in practice? How did insights from this work gain traction, and with whom? What can we learn from this for future work on water modelling?

The Pickering case

In 2001 foot and mouth disease had a big impact on the rural economy in the United Kingdom. This led to the 'Rural Economy and Land Use' programme, that funded research that addressed the challenges related to the rural landscape in innovative ways. In response to a call within this programme, a project entitled 'Understanding Environmental Knowledge Controversies: the case of flood risk management' was supported. This project brought together an interdisciplinary group of scientists - with the three project leads being geographers - to identify if it was possible to use knowledge controversies around flood risk management as entry points to new ways of collaborating between academics undertaking flood risk modelling and those living with flood risk. Based on expertise of the scientists, the project focused on flooding in the U.K. towns of Pickering and Uckfield (see Figure 5.3).

Figure 5.3 Locations of Pickering and Uckfield in the UK
Source: adapted from Nilfanion, 2012

The project was based on ideas coming out of research into alternative food networks in relation to competency groups (see for instance Stassart et al., 2008).The project set up environmental competency groups, with academics and local people who volunteered, to work together to create new competencies in environmental management. Moreover, the project was dedicated to follow what happened professionally to those academic modellers as they participated in this process, based on the assumption that expertise in relation to flood risk is more distributed – beyond science - than one might think. It was assumed that working with this dispersed knowledge actively, such as by modelling together, would enable the development of new expertise (or competencies) capable of making an intervention in a controversial decision-making process. Central to this process was making knowledge together, through modelling together and through working with disagreement and controversies to foster learning.

Activities started with the establishment of a competency group, being people who are motivated and brought together by the status quo, but with awareness that the status quo might be formulated poorly, understood in different ways, perhaps is the source of conflict or simply is in a state of impasse. The group then worked together in a way that makes knowledge on the status quo, and in doing so made a new "public" capable of making an intervention related to the same. Such a group was not designed to be representative of people in Pickering or Uckfield, or of any other group. It was rather judged simply by its capacity to create something new, applied to make an intervention and then move things on. Unexpectedly for the researchers, on the day that the advert for members of the competency group was printed in the newspaper, Pickering experienced a serious flood that created serious interest. In Uckfield, that had not experienced floods in the recent years, interest was less which also affected how the results were embedded in this society.

In both cases, the work of the competency groups, one in each location, sought to begin with a framing of their activities shaped by what individual members each could bring to the group. A critical challenge was to understand and celebrate different expertise in the group, and to question biases on what an expert is. This process was aided by material objects that attached group members to flooding; Stuart Lane, as a flood risk modeller, was able to bring a damaged laptop related to one of the three times he had been flooded himself, for example. Such objects became entry points to other objects such as flood risk maps, buckets to understand runoff generation, field visits, historical photographs, oral testimony, formal published reports and so on. These objects and knowledge collection led to framing the status quo and identification of follow up activities. Both groups chose to engage in joint modelling activities. The two models, that were based on the two different processes, turned out very different, with different purposes and ultimately different flood risk reduction solutions. Both models explored how to "slow the flow" by looking to the upstream catchments where the runoff that caused flood inundation was generated. In Pickering the focus was on a small-scale flood storage scheme to cut the top off the flood peak hydrograph. In Uckfield, solutions were more oriented to large numbers of small woody dams in tributaries to slow the flow. Social scientists researched the work of the competency groups as well as that of the academic modellers separately, to understand how modelling shaped both flood risk management and the work of those involved in doing it (Landström et al., 2011a, 2011b; Lane et al., 2011b). Central to the latter was the clear demonstration that the modeller, and the modelling they do, is shaped by the places and people around them, conditioned by wider requirements, norms and expectations about modelling as a process, both in academia and in application. The models were adapted and evolved as the modeller worked at the place and with the people who experienced the specific flood risk and as he learned with the competency group.

Focusing on Pickering, the outcomes were presented in a public exhibition. There was real excitement from the local population to the solutions proposed, but translating the new knowledge into a practical solution proved challenging. The regulatory agency's fundamental assumption - that any flood protection scheme must prioritise the most frequently flooded properties - would lead to the failure of the proposed solutions in a cost-benefit analysis. Based on these new insights, the competency group suggested to combine property level flood protection for the most frequently flooded properties, with an engineered flood storage for more extreme events. This solution has now been put in place. Whilst a positive outcome, the case shows how modelling is not only shaped by the problem but by the power of regulatory bodies in determining how flood risk management should be defined and done.

Academically, the project had significant impact but more so in terms of a new way of doing science with respect to controversial environmental problems (Lane et al., 2011a) than with respect to the science of flood risk modelling. The models developed through the research were not published within the timeframe of the project. Lane (2017) describes why, in the sense that his repositioning towards the impact of the joint modelling and learning process in Pickering and Uckfield, shifted his attention away from writing up models. This was not just an epistemological shift regarding the nature of the knowledge production process, who it was produced for and who he was reporting to (Landström et al., 2011b) but also a deeper ontological shift in the nature and purpose of scientific enquiry, one that challenges directly what is assumed to be “excellence” in academic research (Lane, 2017). This is further discussed in the section on the influence of the researcher.

The Zapotillo water conflict

This case concerns a conflict related to the ambition of two large cities, Guadalajara and León in Mexico (Figure 5.4), on the development of a large-scale intra-basin water transfer to alleviate their systemic water shortage problems; and the struggle of local communities from the donor region to protect themselves from forceful dispossession of their ancestral land and water (Godinez Madrigal et al., 2020). Although originally erupted in 2007 in Western Mexico, this arguably intractable, water conflict has its causal roots decades prior. The cities' development pathways are based on the reproduction of urban water systems that require large-scale supply augmentation as a solution to structural water shortages (Godinez Madrigal et al., 2022). A solution was to build a dam and transfer water to the cities, which also entailed that local communities in the designated reservoir would be inundated.

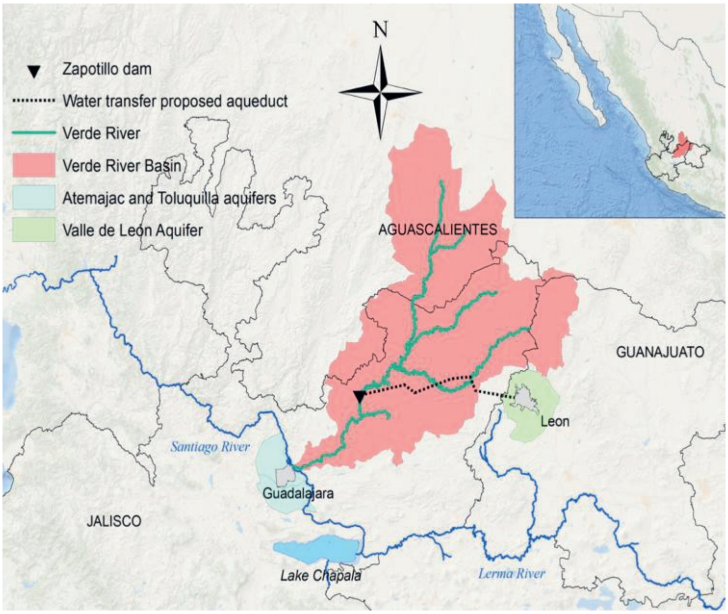

Figure 5.4 Map of the Lerma-Chapala Basin
Based on Godinez-Madrigal et al. (2019)

The building of the dam generated multiple controversies. For instance, how to compare the costs and benefits and efficiency of the different alternative water shortage solutions for the recipient cities (for instance different dam sizes, demand management, decentralized small-scale water supply infrastructure, etc.)? What would be the scale of risks and negative consequences for actors from the donor region (for instance the amount of water transfer vis-a-vis local needs; impact of climate change on water availability directly impacting the filling of the dam and the sustainability of aquifers, socio-environmental impact of the dam, etc.)? How to assess the historical legal and decision-making processes in relation to a human rights approach (for instance the lack of informative and deliberative processes with the affected actors, lack of proper compensation mechanisms, involvement of private interests in the development of infrastructure)? Should a utilitarian or distributional justice perspective be adopted to understand and resolve the conflict (for instance, should the benefit of millions trample on the rights of thousands or should the rights of those few be protected even at the expense of millions)?

In 2014, the regional government of the area that would receive the water from the intra-basin water transfer hired the United Nations Office for Project Services (UNOPS) to try to settle the controversies. The request was to develop a comprehensive water resources model of the donor basin to identify how the intra-basin transfer could be realised. In 2017, UNOPS published and communicated its results and concluded that the solution was to build the Zapotillo dam as originally intended (inundating three villages), with the only caveat to reduce the volume of water transfer by 13 per cent after accounting for previously unknown excess of water use in the donor basin (Godinez Madrigal et al., 2022). Obviously, such a conclusion disparaged the affected communities, but it also disappointed most of the actors involved in the conflict given the complex controversies previously raised. This modelling effort was perceived as a fiasco by the media and water experts of the country (Godinez Madrigal et al., 2020). UNOPS lost the confidence of key actors in the conflict by showing a perceived bias towards the Zapotillo project, as the only solution for the structural water shortage problem in the cities.

The UNOPS model not only failed to provide a solution to the case that was accepted by local stakeholders, but the modelling exercise also functioned as a barrier for local communities to engage with the issue; only engineers who understood the model and the dam and who were considered to be able to talk about the consequences for infrastructure were taken seriously. Godinez Madrigal decided to dedicate his PhD research on understanding the model, and identifying if the modelling process could be adjusted to imagine different solutions that would lead to more acceptable outcomes for local communities. The research tried to open up the conversation beyond the particular solution investigated by UNOPS focused on one particular solution (ibid). Godinez Madrigal led an interdisciplinary team effort in which two supervisors and a technical master student took over a year to analyse the UNOPS model to understand its structures and assumptions.

By early 2018, the team managed to replicate the results and found out that the key scenario UNOPS used to reach its conclusion had not taken climate change nor future water demand in the donor basin into account. After including those variables, the team developed a new scenario that showed that the dam was not feasible using the same indicators employed by UNOPS (including vulnerability, reliability and resilience). Godinez Madrigal and his team refurbished the UNOPS model to also include other proposed alternatives to address the overall water problem in both the donor and recipient regions. This included proposals to fix leaks in urban water distribution systems, rainwater and stormwater harvesting, progressive water prices, tradable water rights with farmers, irrigation efficiency, securing environmental flows and different infrastructural configurations of the Zapotillo project. Doing so was complicated as it needed and adaptation of the model code, as well as to compare hundreds if not thousands of combinatory scenarios - compared to only five developed by UNOPS.

The team found it important not only to arrive at an optimal solution for different stakeholders and especially for the local communities, but also to kickstart a social deliberation process that was absent since the inception of the Zapotillo project. It was decided that participatory modelling was an appropriate tool to explore the decision space and allow conflict actors to deliberate about their preferred scenarios. A user interface was developed to facilitate the interaction with the model and a workshop was organized with government officials and the potentially affected communities. Effort was taken to use language that facilitated thinking in solutions. That strategy was successful in positioning their message in a way that a compromised solution was possible.

A breakthrough came when the President of Mexico decided that this conflict should be solved before his term ended. He appointed a legal representative of the local communities, and gave her the mandate to generate an agreement. In this process, it is unclear if the refurbished model directly caused finding a solution, but it is clear that it helped to imagine to retrofit the dam. It was finally agreed that the city of Guadalajara would still get a considerable amount of water, albeit less than planned, that the city of León would not get water, and that the communities would not be inundated, guaranteed by doors being fitted in the dam to ensure the agreed reservoir level. The final results are shown in Figure 5.5, a photo of the retrofitted dam.

Figure 5.5 The retrofitted dam
Source: photo taken by P. van der Zaag (2024)

From the two case studies we learn that models are potentially useful tools to explore a situation or imagine different futures, but that they can also be used to foreclose thinking or render decision making processes exclusive. In the case of the Zapotillo dam, modelling was used as method to facilitate discussions in a community. In the case of Pickering, the model was used to support already ongoing discussions. In both cases, the duration of the engagement, the models, scientific knowledge, as well respect for scientific expertise, helped to engage decision makers and were instrumental in challenging or countering decisions that were already taken.

The influence on the researcher

The process of doing consciously critical research does not only have influence on those who are interviewed, or those who the researchers work with or talk to. Of the 15 respondents who model themselves, eight explicitly indicate it has changed their own modelling practices and research. Striking is that Wheeler, Srinivasan, Tuthill, Opitz-Stapleton, and MacClune, indicate exactly the same development, which is that they have become more committed to put societal needs for information and specific processes first, and adjust the model to these needs, as opposed to taking the model as a starting point. Srinivasan states *"I would say the research has changed my own modelling quite a bit. I would say that what I do better and a little more explicitly now is firstly being really front and center about the why." (*Srinivasan, voicenotes). Opitz-Stapleton also puts the why first, by focusing on community needs: *"So getting to know either the community or the particular group of policy makers that we're working with and understanding how they think, what their decision criteria are, their constraints in order to digest and translate the information."* (Opitz-Stapleton, interview). Wheeler also focuses more on the process than on the models: *"Over the last two decades, my research has increasingly focused on understanding and exploring the process that models are being used, as well as distinguishing what characteristics of models are useful for reaching agreements vs ineffective or problematic."* (Wheeler, survey). In a similar vein, Alam aims to better represent the people that he meets in the field in models. He describes how he is developing an agent-based model himself that includes the lesson he learned through his PhD research as much as possible: *"These are the limitations or something that you want to take [into account]. The last model that I end up building definitely covers a lot of those limitations"* (Alam, interview).

There is also a group that changed their engagement with models. From the case studies it became clear that for Lane it became less important to write a scientific article based on the modelling exercise as the focus was on the local decision making processes (Lane, 2017). Melsen notes that she engages with models more critically and uses them with a certain humility: *"Yes, it has changed my own approach. Especially in my guidance with students, I* *always keep an eye on not over-interpreting."* (Melsen, survey). Krueger states that it was his experience in modelling that have led him to critically question modelling practices and occasionally refrain from modelling (See for instance Krueger et al., 2012). Yet, reflexive research (see for instance Krueger and Alba, 2022; Klein et al., 2024) has invited him to look at modelling in a way that considers how it could be used progressively as well (Krueger, survey).

Doing research on other people's practices also leads to reflection on oneself, and thus also influences non-modelling practices. Holifield critically reviewed modelling practices and the representation of communities, and states: *"I Know that the doing [of the research] it had an impact on the way I thought about things. [..] I tried to be very attentive to all the different geographic dimensions".* (Holifield, interview). Babel also shares that the reflexive way of analysing modelling practices influenced her way of doing research: *"Of course it changed totally the way I was looking at that things afterwards. [..] There are specific types of questions, and path dependencies and things like that. You can see it in absolutely every field."* (Babel, interview).

From the descriptions on how research has influence, we can identify the following. Research has influence through communication such as scientific articles that form input for education, as well as conversations with colleagues or people in the same field. Openness of colleagues and students to interdisciplinary work is mentioned as an important factor for lessons from a reflexive article to be received. Interviews may provide a moment for people to reflect on their own practices, facilitated by questions that are reflexive on what the model represents, why, and with what consequences. Also having follow-up meetings with institutions and communities is a way for research to gain influence. What accommodates such interactions are networks, having a clear message, and working bottom up or issue-driven. Action research often helps to develop these, jointly with the people and institutions that are involved. These insights are summarised in Figure 5.6.

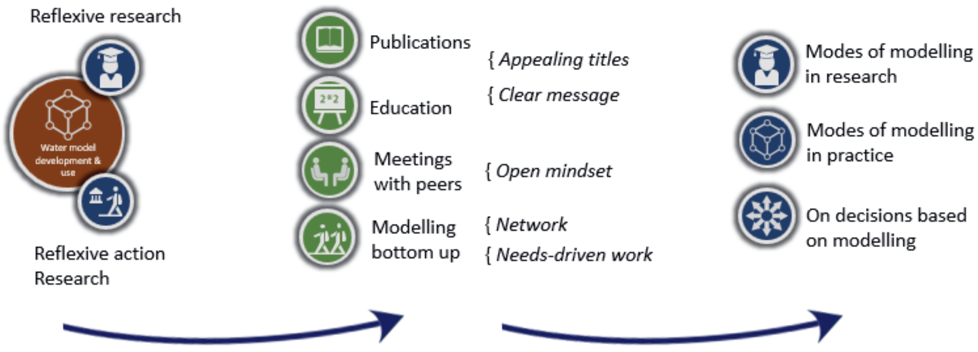

Figure 5.6 Enablers for reflexive research to have influence

When the work does not work out

As is shown in the previous sections, dedicated work is needed to establish influence with reflexive research. This section focuses on answers in which respondents indicated that this work has been difficult, or has not materialised as they had hoped.

There are three articles that explicitly discuss how modelling and decision-making is done, taking a Science and Technology Studies perspective. It draws attention to why things happen in the way they happen. Creating awareness of these processes does not automatically lead to actual change. Kouw confirms this when he shares in a reflection on research he has done on modelling practices. He shares that his focus has been on the modellers, and not those who decide on policies: *"In retrospect, I looked at the makers quite a lot. And I could have done more to really create an impact at a higher level."* (Kouw, interview, translated from Dutch). Holifield also reflects on the challenge of ensuring that work that is reflexive on practices, is also useful for a broader public, in his work on health risks associated with a hazardous waste site: *"I felt disappointed that there wasn't much I was able to offer to the community other than well, here's my dissertation. What they were interested in was getting their groundwater cleaned up and their health protected, not what science studies had to say about groundwater modelling."* (Holifield, interview). It can also be a deliberate choice not to connect to practitioners or communities. Bruun Jensen shares notes in relation to an article on the development of models for the Mekong: *"We had the whole project so there were many publications etc. But it was not intended as an outreach program or a guide to better policy, so the audiences were academic"* (Jensen, survey).

There is significant work needed to make a change, especially in situations where people and systems are used, or designed, to work in a top-down manner, or working within disciplinary boundaries. Babel states *"And you need actually quite a lot of reflection or a distance to actually recognise them as choices [in a modelling process] because they are. [..] And to put this into question, you need of course a very long process to reverse that."* (Babel, interview). Another aspect is vested interests, and how changing current practices or approaching modelling in a way that emphasises power relations can challenge vested interests or long accepted practices. It may make someone stand out in a negative way. Babel notes based on her research on modelling practices: *"With [challenging modelling choices] you have cost, maybe you're risking also your social place in a group or something like that. And at the same time you have the cost of the time aspect and which is also very much linked to economic aspects."* (Babel, interview).

Communication also requires dedicated efforts. MacClune reflects on this, taking example of a colleague from the field: *"And he maintains a steady drum beat in op-ed articles, in scientific pieces, in a constant feed to LinkedIn. He'll make a difference. Over the course of his career he will make a difference. But that's what it takes."* (MacClune, joint interview). Srinivasan discusses this too, and shares how she has moved on from creating knowledge in the scientific realm, to ensuring that this scientific knowledge can be used by local communities and policy makers. From a scientist who creates information, she has recently started her own organisation in which she focuses on the role of knowledge broker. An important driver was the lack of impact. Srinivasan shares: *"Especially after I moved back to India, it felt almost self-indulging to be in a research institution to produce papers and not have those papers actually benefit the urban poor, the rural poor, the people that in this game we were raising these research grants."* (Srinivasan, voice note).

Knowledge brokering is hard work, and Holifield discusses how important it is to find people who are open to learn what you want to share. He reflects on his article on 'How to speak for aquifers and people at the same time: Environmental justice and counter-network formation at a hazardous waste site' of 2009, and shares: *"I mean, now the EPA [Environmental Protection Agency of the USA] hires social scientists, so it's a different world… to some degree*." (Holifield, interview). Several other authors indicate that the absence of a receptive audience is most probably an important factor of why the research has little influence. Jensen puts it as follows in relation to his research on modelling the Mekong river: *"Modellers don't like to be told that their models have no consequences, and policy makers that won't listen to modellers will listen less to social scientists talking about modellers."* (Jensen, survey) Simultaneously, few studies are done by social scientists on the topic: *"Many people from STS or from social sciences don't look at anything that has to do with the informatic* *infrastructure because they don't understand how it works."* (Babel, interview). Yet, a challenge is also that reflexive work on modelling practices finds itself at an intersection of disciplines. Alam states: *"You can have both hydrologists and social science people ridiculing it. You haven't done this right. You haven't done this right. Instead of just hydrological people criticising it, you can have both set of people criticising it now. And that's a risk."* (Alam, interview)

The reasons that were identified through the surveys and case studies for why the work has not worked out, included that it took ample time to learn both how to understand the influence of certain choices in a model, as well as how to model in a way that is sensitive connected to local needs and mindful of political and power relations. Sharing these insights requires dedicated effort, and is often not inherent to doing research. In addition, there is a lack of openness to interdisciplinary cooperation, and a lack of resources such as time and funding to facilitate connecting to people and places. From the case studies we learned in addition that there are strong vested interests related to doing modelling in a certain way, including using specific models or achieving a particular goal. These points are summarised in Figure 5.7.

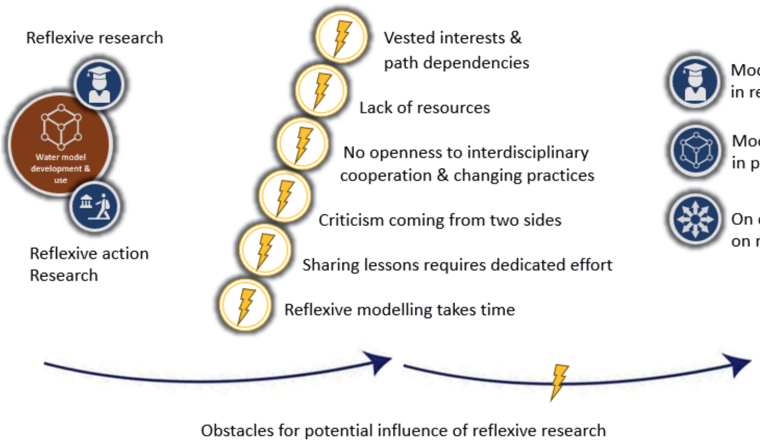

Figure 5.7 Obstacles for reflexive research to have influence

Discussion

In this article we explored what the influence is of doing, communicating, writing and practicing research that is consciously critical on how water models are constructed or have a real world impact. Finding fertile ground for such constructively critical messages is not always easy; neither in scientific circles nor with modelling practitioners. It is therefore useful to learn what influence such research has, and how, as well as what does not work. In this discussion we focus on what may enable this influence and what not, relate this to broader critique on science studies, and discuss how science is valued.

This article is based on interviews and surveys with researchers who have engaged with water models in different ways. It is not explicitly addressed in this research, but it is very clear that the focus of the research and its potential influence closely relate. Using the continuum of modelling research we introduced in the beginning of this article, we see that studies that remain in model land and that focus on modelling practices or on the model itself, mainly aim to influence the modeller. This happens through creating awareness or through practical suggestions for modelling choices. This requires attention and care, especially when it is done by non-modellers, but they can reveal what choices are unconsciously made. In the middle of the continuum, we placed studies that engage with how models represent the world. These often have a broader intended audience, and may require engagement with different scientific disciplines and ways of knowing. Such studies benefit from a personal and institutional openness to interdisciplinary cooperation. On the other end of the spectrum we placed the studies that focus on the influence models have in practice. These studies, both the action research as usual case studies, show that the process of doing research and being engaged in a certain area or with certain people for a long time – very logically - greatly increases the chance that a reflexive modelling process has influence. It requires not putting modelling first, creating alliances, building relationships, and finding entry to those organisations that generate accepted information for policy-making (Lane, 2011). It logically follows that reflexive modelling projects should take time to connect too. It is no surprise that these outcomes strongly relate with the positions taken by thinkers who reflect on the influence of science and who call for connection, representation and justice, differences, love and care, and going slow (Haraway, 1988; Holoka, 2006; Martinez-Alier et al., 2011; Schlosberg, 2013; Stengers, 2018).

There is work to be done to make fundamental changes that connect modelling better to people and places, and change does not come from articles. As MacClune states, it takes beating the drum over and over again. The surveys and interviews teach us that it starts with a general awareness of the political side of modelling, after which it can better be understood how the potential influence of modelling can play out in a specific situation. Based on these insights, a suitable approach to modelling (or not), can be identified. This does not need to be done by one person, and at every moment. An awareness that a model can turn out differently based on different choices taken throughout the modelling process, as well as that these choices are not always made in a conscious way, is an important starting point (Hämäläinen, 2015; Hämäläinen and Lahtinen, 2016; Addor and Melsen, 2019; Melsen et al., 2019).

It is a reminder of the critique of Winner (1993), published at a time where constructivist science was quickly gaining ground. Winner states that such research does not have much to show for, except for how research is made (opening the black box) and subsequently "finding it empty" when no conclusions can be drawn based on these insights. Winner makes an important point. Yes, it is clear that there are consequences of certain ways of developing scientific information and knowledge and the development and use of water models. And yes, there is also a need to identify how this information and knowledge can contribute to more equitable, just, sustainable and inclusive engagement with water. Yet, there is also a value in showing how something is made to make visible where space exist to make changes. Acting upon this is a shared responsibility, not only of the person or persons who show how it is made. It takes time and effort, and would therefore be best be included in formal education or workshops, in which participants can practice with this deeply interdisciplinary way of water modelling.

A question is what incentives there are for those who engage with models, from commissioners to funders to modellers to users, to actually make an effort to do modelling in a more connected and reflexive way. This process is certain to be more complex, may take much longer than the regular three or four years that are reserved for such projects in relation to political cycles, and requires multiple ways of knowing, including different scientific disciplines. Also, outcomes are not guaranteed, as shown through the great efforts put in place to change modelling practices in the Zapotillo dam and Pickering cases. Godinez Madrigal shares that great efforts were taken to open up the model to enable the communities and politicians to engage constructively, and that his research gained traction through the networks that he had. Lane shares also that a specific approach was chosen that put the local process first, that modelling was optional and in support of the local process, and that a flood event created a momentum in one case study that greatly contributed to its success. In these cases, success was both made and dependent on the circumstance. What can be learned from these cases is that through the action research, with the bottom-up modelling approaches, the outcomes of the modelling and decision making process are more likely to be fair and just, with environmental benefits and burdens more equally divided and marginalised groups not disproportionally hit. Furthermore, the activities are also much more likely to be well-connected to local natural and societal structures, and therefore more likely to be sustainable.

A last point we want to address is the role of formal scientometrics, such as impact factors. The two case studies, as well as the interviews and surveys show that research has influence in different ways that are often difficult to track. Creating awareness and changed behaviour cannot be captured in impact factors. Most impact seem to be achieved with the activities that are currently not valued in popular science-impact metrics, such as output instead of process, top-down engagement versus long term relations, and the status quo versus curiosity. We can hypothesise that if doing water modelling conscious critically improves water modelling as a practice, the way we measure success ought to change.

Conclusion

In this article we have considered the influence of reflexive research on modelling practices in science and the public sphere. The reason we have undertaken this research is that throughout the past decades, there has been a small yet constant stream of articles, both focused on deconstructing water models, as well as the influence of water models. As each of the authors has different experiences with such research, we were curious to learn what the influence of such work is. We shared questions with 52 authors of articles that are reflexive on how water models are made and how they act, and received answers from 21 authors, both in the form of writing, voice notes, or via (online) interviews.

We broadly identified four relations between specific ways of doing research and its influences. First, scientific literature is a way to share insights with colleagues and peers, yet the authors we surveyed find in large majority that their articles had little effect. Second, using articles and research in education is an important element of having influence. Third, the interviewees noted an effect of doing the work. For example, asking questions in interviews led to deeper reflexivity on modelling practices, although this influence is mostly limited to the modellers involved in the study. An open mindset of those peers to interdisciplinary work is noted as prerequisite. Fourth, the main way to establish change in modelling practices came through action research that sought to include specific values, local needs, long-term engagement, and combined this with the willingness to adjust the modelling process. What helps such work are needs-driven projects and having networks that include – or can convince – decision makers.

The challenges and barriers identified through the surveys and case studies included that it took ample time to learn both how to deconstruct a model, as well as how to model in ways connected to local needs and mindful of political and power relations; a lack of openness of others to interdisciplinary cooperation; strong vested interests related to doing modelling in a certain way, including using specific models or achieving a particular goal; and a lack of resources such as time and funding to facilitate connecting to people and places. This research shows that there are no simple ways to organize more inclusive and transdisciplinary modelling processes that care about representation, different knowledges and social and environmental justice. It requires time, dedication and connection, and calls for more action research that engages with modellers, those affected, but also funders, commissioners and decision-makers.

6

Chapter 6

DISCUSSION, RECOMMENDATIONS AND CONCLUSION

Introduction

In this research I examined the different overt and covert, very direct and indirect ways in which water models gain influence through a literature review and especially in practice, based on two cases of model-centred projects. I further explored different ways of how to engage with this influence, specifically learning from scientists who engage with models in science and practice. The main reason I started this work was that I had big questions on why models had become so centralised in two projects on water cooperation that I personally worked on, and why these models had gotten support to be exported to other parts of the world. Through the process of doing this research, and by speaking with so many people along the way, I learned about the many interactions between humans and the technological tools they use. Therefore, I aspired to gain an more complete overview of these interactions, from problematisation to implementation, and specifically broadening the scope from science-policy interactions, to personal-technology-water interactions. It is therefore that I have looked at decisions and interactions in the broadest sense of the word. Yet it is not so easy to deal with the influence of water models in their complex totality. It takes committed time to unpack the technology in the environment it is made and implemented in, to define values in relation to the project, and to design the knowledge tool and process in such a way that fits these values. Yet, based on my own experiences and what I have learned these past four years, I am convinced that it is time and energy well-spent.

In this final chapter, I will first discuss the results by explicitly comparing the insights from the literature review and the case studies. I will then reflect on the applicability of the conceptual approach and methodology, and end the discussion by sharing recommendations for engaging with the influence of water models in science and practice that are based on this research process. I conclude by coming back to the research questions that guided this work and by summarising the main insights per question. And, as models do have the tendency to create a disconnect by creating a modelled version of the world, and as the case studies concerned models for water cooperation, I end this research with a reflection on connection and humanity.

Discussion on content

How water models gain influence

In this discussion I compare the results of two case studies and the literature review on how water models gain influence. Based on the case studies on Water Accounting Plus (WA+), intended to contribute to peaceful deliberations on water allocation in the Cauvery river in India based on water productivity and remote sensing, and WAS/MYWAS for fairer water allocation between Israel, the Occupied Palestinian Territories (OPT) and Jordan based on economic principles, the following conclusions can be drawn on the influence of water models:

- A model, or the idea of a model, facilitate worldviews – ideas on how parts of the world work and should work - to travel through networks and to gain support. Therefore, a man with a model is more influential than a man without.
- In turn, a model's influence depends on a person with a strong vision of how the world is and should be, and a capability to convince other people of his or her dream.
- A model reifies assumptions on how parts of the world can be understood, how it works, and should work. This is especially challenging when a model is applied for other purposes than it is intended for, or when it becomes the main or only source of information.
- Expertise, and related to this strong ideas and values developed in a certain discipline, become embedded in the model. It takes time to and dedicated effort to explain such ideas and values for people outside of a certain discipline.
- Modelling cultures, including the expectations, customs, social behaviour and values related to modelling, differ between institutions and places. One should take these cultures into account and avoid transposing one culture of modelling onto another without understanding the implications.
- People who are not able to see the inner workings of the model – for instance due to not having access to the technology used or not having had experience in a specific academic culture - connect or disconnect to the model mainly based on the vision of the future embedded in the model and modelling process.
- The idea of what the model is and can do, is often more able to gain support than the actual model itself. This also leads to high expectations on what the actual model and modelling process can deliver, and a letdown when the model and modelling exercise does not live up to these.
- The same model is likely to have different functions at the same time, from learning to managing, or to achieving a goal that is not related to the model at all. It is difficult to know beforehand how a model will exactly be used.
- The two models were presented as neutral or rational, which suggests that they are the best way to understand and engage with a certain issue. Unpacking the modelling process shows that there are many moments in which choices are made that are highly political, in the sense that they include, exclude, or represent people and nature in a specific way and not another.

To deepen the results I compare the insights gained through the literature review and the case studies. What the literature review and the cases on Pickering and Lerma-Chapala in chapter five show is how models gain influence once adopted in policies or as accepted knowledge by legal institutions, such as very clearly described in the case of decisions on environmental flows (Fernandez, 2014). It is extremely challenging to change models that are embedded in institutions, where it is easy to effectively black box them, making it very challenging for outsiders to understand how decisions are made. This can happen through the elevation of particular expertise above other knowledges, through costs of working with particular models, or by bureaucratising a model and data and hiding these behind complicated or costly procedures.

The case studies on models that were not accepted yet, make additional dynamics visible through which water models gain influence, which were not explicitly found in the literature review. Following a modelling process over time makes visible how models and modelling processes change over time, that these require continuous tinkering (Kemerink-Seyoum et al., 2019). For instance, the case studies show that there are multiple cycles of translation, including *problematization, interessement, enrolment, mobilization*. Not all these cycles are successful. Once people are mobilized to make or employ the model, a new round of translation is started linked to the outputs of the model, to create a bigger network of support. The work that needs to be done to gain support often makes use of existing networks, that subsequently help a model to travel beyond the place it was made in. The case studies also visibilise the charismatic people that drove the modelling processes and created support, which emphasises the need to select good spokespersons for an innovation to succeed, as mentioned by Akrich et al. (2002b). In relation to the cases I studied, the spokespersons were also influential in defining the expertise and approach that is dominant in a particular modelling process. They were able to bring convincing arguments, persuade others, and make suggestions on how others could engage with the model. The studies also show how people get connected to their model and how difficult it can be to let go and adopt another (modelling) approach.

The in-depth case studies show that when people do not have the expertise to unpack a model, they often have high expectations of the same model. The model and modelling process is supported based on an alignment between the worldviews embedded in the model, and the idea that this vision can be supported through a modelling approach. It also appears that not the model itself, but an ideal version of the model gains most support in this case. The model seems to travel through networks as idea. This closely relates to research on imaginaries and technology, and how ideas of what the world is and should be co-produce and are embedded in technology and has specific influence on what the technology looks like (Davoudi and Machen, 2022; Jasanoff and Kim, 2015). Disconnects or rejections happen for many reasons, and more often those who reject the model also have to engage with it in more detail. The reactions of the Indian states for instance, as well as those who rejected MYWAS, went beyond the idea-model in order to reject it. They explicitly engaged with the world views embedded in the model and compared these to their own vision. An example is the reaction of an employee at the Israeli Water Authority, who reacts to the way demand curves are calculated in the MYWAS model, and explaining how – in his view - this is not helpful to plan for the coming decades. This happened mainly in a different round of translation. Based on the whirlwind model of Akrich et al. (2002b), in the first cycle of translation those who support the development of the models are visible. In next cycle(s) of translation, when the model is expected to enact the worldviews that are embedded in it, more opposition is seen.

On exporting models for water cooperation and power-sensitivity

The case studies both concerned models that were applied with the idea to contribute to water cooperation in situations of conflict over water between countries and federal states. Both models were developed in other countries and modelling cultures than they were implemented in. Both were funded by donors with the explicit intent to contribute to water cooperation. Yet, in comparison to the literature review, the dynamics of how models gain influence in the two case studies appear to be highly comparable to cases where models are developed and implemented for other scales, and other purposes. The concerns are similar, in terms of how a model forecloses or enables thinking, how some issues become more important or completely left out, how particular ways of seeing become legitimised, or how the problematisation, process and results can be questioned or adjusted if needed. The space to explore how modelling processes can be done differently may feel or appear limited in cases of conflict over water, but it could be argued that especially in these cases, and in cases where specific groups are carrying an unequal burden of the environmental bads, it is needed to invest in creating this space. In the recommendations below I share ideas on how this could be done in practice by modellers and non-modellers.

Discussion on the methodology, conceptual framework and research

On deconstructing water models

The case studies were analysed based on a connection between a constructivist approach to seeing models as amalgamations of visions of the future, ontology, expertise, and materiality (based on Mackenzie and Wajcman, 1999), and ANT. This approach of deconstructing models has proven a useful entry point to assess the models as a non-modeller. It allowed me to identify why and how a model and modelling process is shaped in a certain way, and also useful to showcase what aspects of a model change, and what remains the same over time. As models and their processes are not only specific representations of the world, but also embody what might or ought to be in the future, it was necessary to include 'visions of the future' as well. I argue that this is the case for models that explicitly simulate future scenarios, or models that are used to explore how parts of the world function. There is always a curiosity that links with how the world can or should work, as is also argued by Kraemer (1993).

Deconstructing models also provided clear entry points for the interactions between the model and the world it is developed and implemented in. The case studies show how important expertise is, in whether a model gains support or not, as was the case for MYWAS, or whether people can understand and engage with the model, as was the case for WA+. Materiality of the model itself, as well as its outputs, through maps, graphs, and reports allows the model itself to travel and being used or changed by people other than the original developers. Yet, it is mostly the idea of the model, or a ghost model, that gains most support, in relation to the world views and vision of the future that is embedded in the model, combined with the promise of calculations that verify this worldview and imagined futures. It is a type of measurementality through which the model gains influence (Merry, 2011; Turnhout et al., 2014). Based on the case studies, it could be argued that the visions of the future and worldviews seem the most important determinators for a model to have influence.

On ANT as methodology

In this research I applied ANT as methodology (Kanger, 2007) to make the power-relations around the model visible over time. In the Introduction I explained my excitement about this radically different way of thinking that challenged me to look at interactions between people, objects and structures. Indeed, ANT was helpful in unveiling a complex and changing network around the model, over time, and was also helpful to unpack interactions between people and models in cultures that were different than my own. In both case studies, my fieldwork took three months, but would not have been useful without the experience I already had. In the case of WA+, I worked on the project, attended crucial meetings and could be an observer, and thus also had prior knowledge that was useful in the interviews and in designing the field work. In terms of working in the OPT and Israel, I had prior experience of researching and working there that helped me greatly. Otherwise, it would have been necessary to at least double the amount of time in the field.

I enjoyed reading the work of Callon (1984), that clearly invites to think about how humans and non-humans influence each other, and to avoid to take a position of knowing it all. Callon describes four stages of translation - *problematization, interessement, enrolment, mobilization* - to get others to act in such a way that supports a specific goal, and thus to influence. In the case of WA+, it was a useful framework to understand who supports the model, and why, and who is driving the activity. It shows that translation itself happens in multiple rounds, where it was successful especially with donors and the central government of India, but not successful in a second round with the representatives of the Indian federal states. The four stages, combined with deconstructing a model, were useful to identify at what point, and why, certain people or institutions let the model "drop, or modifying it, or deflecting it, or betraying it, or adding to it, or appropriating it" (Latour, 1986; pp 267). In the case of WAS and MYWAS, using ANT as methodology showed there were different overlapping processes of translation. One process relates to using the model at regional scale, which is a process that is ongoing for longer than thirty years. The others are using the model at the national level, for planning purposes. The analysis shows that the process of translation is especially successful with donors, as well in places where no strong modelling culture exists that can counter the suggestions that are made. The model – or idea of the model -, is an important actant in this process to define the problem and possible solution. Yet, the analysis also shows that the process of translation is highly impacted by political events, outside of the network of the model. In writing up this analysis, I opted for a thick description to clarify the impacts of this event, and showcase the different rounds of translation, with different aims.

In both cases, the fine-grained analysis facilitated by the theory of translation was very useful to identify individuals that were crucial in driving the process of translation. Yet, it has also posed challenges. Through the application of ANT in two case studies, it became clear to me that ANT reveals many interactions, and power is everywhere in this way of understanding the world. It is then a very difficult task to identify what power relations matters most, and what to highlight as researcher. Also, it makes the interactions around a model clear, but can be distracting from other power dynamics at play. This became especially clear in the analysis of the WAS/MYWAS models for Israel and the OPT, in which such power dynamics by states and actors disconnected from the modelling exercise, did have influence. It was necessary to operationalise research done at macro-scale as well, effectively applying two very distinct ways of analysing the world, in which ANT for example focuses on networks and relations and geopolitical analysis on scales and money and arms. This research also showed how important it is to decentralise the model, as the thick description made it very difficult at times to focus on what matters. In the end, it is about humanity and livelihoods and access to water and land, and thus about what worlds are being realised through a particular modelling exercise. It is not about the model itself.

Thinking further through centralising and decentralising the model, I encountered very practical problems in my research. As I chose to publish the chapters as scientific journal articles, I also chose to limit the word count for specific chapters. However, the conceptual framework, and especially ANT as methodology, invites for a thick description of a model that develops over time. In the journal articles, I have had to choose very specifically what to include and what to exclude, but this took me ample time. This directly links to the question on whether understanding what something is, and why, is a good enough question. Is unpacking the black box of water modelling and showing how it is made enough? Is showcasing how modeller's decisions influence a model's output enough? By focusing on understanding of how models are constructed as object and process, I found myself in a decades-old discussion on technology and power.

Winner called out the work of Science and Technology Studies in his article 'Upon opening the black box and finding it empty' (Winner, 1993), stating that it foregrounds the process and not the consequences, that technology is seen as scientific knowledge while it may be something different, and that it creates a dichotomy between those supporting or using the technology, as well as all the others not involved. I find this criticism certainly holds true, also based on my own experience during my research. By focusing on models and following them as a central element, those who are not using the model do not automatically become visible. Work is needed to draw conclusions on power-relations and how to engage with it. Yet, it is dangerous to take Winner's critique as a call to do away with the aim of opening the black box totally. When the aim is to find tools or processes that better fit a certain question, then it is useful to showcase how a process happens in order to decide to alter it, not do it, or keep it the way it is. It takes specific experience to make such processes visible, and thus calls for cooperation between those who open the black box, and those who want to question it critically. STS research fosters reflexivity and reflexivity is the basis for power-sensitive approaches.

On Reflexivity

In the first chapter I shared how reflexivity plays an important role in this research. Reflexivity is defined as practicing critical consciousness of one's location, actions, and power relations during a research process" (Sultana, 2017: p. 1). It is operationalised in three different ways. First, I have used it to understand my own positionality and to formulate my own values in relation to water modelling. Second, I have invited my interviewees to be reflexive on the model they were working with, by asking questions on how the model is made, how they define their own position and relation towards and with the model, and to reflect on if and how the model has influenced them, or has been useful for them to influence others. Their reflexivity was an object of study for me. I have noticed that this needs to be done with care and kindness, and with an openness and curiosity about the motivations of others, as being critically conscious, and especially in relation to the practices of others, can be experienced as criticism and can foreclose thinking and damage relations, while it is my intention to learn and build relations. Lastly, I use it as research lens, to explore with others how reflexive research practices can have influence themselves. This triple reflexivity perhaps sounds complicated, but the meta-approach (being reflexive on reflexivity), was a useful entry point. I could use my own approach to reflexivity, as well as what I had observed in the case studies, to relate with researchers who worked on the same and had developed their own norms and values, and forms of reflexivity.

However, being reflexive alone does not give clear indications of why to change. Introducing a clear value-based approach can help, as for instance is done in most political ecology work or feminist scholarship, that makes power relations visible not for the sake of power relations, but for the sake of emancipation (Schlosberg, 2004; Martinez Alier, 2013 ; Zwarteveen and Boelens, 2014). That a value-based approaches work is proven through the examples provided by the Zapotillo-dam case and Pickering in chapter five. Godinez Madrigal decided to specifically make a model that would answer questions of the local communities that were threatened to be inundated, and decided to do this by using the same model that was also used to plan the height of the reservoir. Lane, Whatmore, and Landström decided to develop a competency group that was anti-representative, to highlight their position and bring their questions, concerns, and possible ways forward to decision makers. These two approaches entailed stepping away from the idea that models and modelling processes are neutral or purely rational, and to be aware of the limitations and possible positive and negative influences of the models.

Recommendations

Adopting a value-based approach

ANT and STS naturally invite the research to be reflexive about the development process and how and why a technology is shaped in a certain way. It also makes visible what potentially could be altered to come to a different outcome. Yet, we learnt that reflexivity alone does not indicate what can be changed, and that a value-based approach is needed as basis to identify what can be done. The invitation to STS scholars is to enable such value-based approaches, for instance by making clearly understandable what possible influences certain technologies have, and providing insights as to what opportunities exist to adjust the technologies if needed. Here is where my personal challenge comes in. I greatly enjoyed working with ANT, and was excited about how it helped me to understand the world. Yet, it is not an easy field to become or feel part of, due to specific jargon and ontologies that may be difficult to engage with. Ingold wrote a criticism that resonated with people, ending his reflection with *"'You are indeed a master of lofty thoughts', admits SPIDER wearily. 'But I cannot, for the most part, understand a word of what you say'"* (Ingold, 2008, pp. 215). I felt so often like the SPIDER in this quote. Yet, I can also feel the excitement of how new words can deepen an understanding of the world. Jargon serves a purpose, and being 'disciplined' into a specific field helps to understand it, engage, and critically engage. I was not too disciplined, and have tried to weave my own web in between the webs of others. It comes sometimes at the detriment of an in-depth understanding of a specific discussion. On the other side, it has given me the opportunity to be very curious about the work of others, to try to make my own work accessible for other disciplines, and to find ways to exchange ideas with people who are used to work with other scientific methods.

As the dynamics I revealed are useful, yet also not new, there is a clear path forward. What is needed are more modelling activities that most importantly do not centre modelling (Lane, et al., 2013), that foster thinking instead of replacing it (Godinez Madrigal et al., 2024), that are power-sensitive (Lo Piano et al., 2023; ter Horst et al., 2024), situated (Klein et al., 2024). It is action research on how water models can contribute to environmental justice that can make a difference in practice, while building up more expertise on how to model in such a society-mindful way. The research shows that this is not easy, and requires changes in institutions that need to be open to new approaches and unexpected results, people that have to be open to different ways of knowing – outside of their own discipline and expertise, and to have a critically constructive approach to technology.

Deliberations on how to implement a value based approach

After working on the two case studies, I found the following quote of Law (2004, p. i), that resonated greatly with what I aspired to do through this research: *"If methods want to know and to help shape the world, then they need to reinvent their practice and their politics in order to deal with mess. That is the challenge. Nothing else will do."*. Yet, reinventing modelling practices is easier said than done. Shaping a modelling process, and adjusting it along the way takes time and resources, and requires learning and unlearning, as shown in the analysis of the case studies. In my conversations with modellers, funders, commissioners, and also in conversations with myself, I noticed how much time, empathy and care this requires.

This research has shown how a model is shaped and shapes others. By making these interactions visible, it also becomes clear that many people are involved in this process, and that accountability for changing modelling practices is not only on the shoulders of modellers. The commissioners and funders are extremely important actors in this process too. Changing practices is not easy, and calling for an explicit inclusion of ethical approaches that contribute to a fairer and just world requires negotiation and deliberation (Doorn, 2012). It therefore requires speaking up. Coming back to Figure 1.2, the conceptual framework that depicts the interaction between a model and the world it is developed and implemented in, I recommend to take time to introduce a value ring as in Figure 6.1. This ring resembles deliberations within the modelling process, from problematisation to implementation, to understand the interactions between the model and the world, and to define explicit values related to the intended influence of the modelling exercise. What values do you want to introduce into the model and modelling process, and what does this mean for the influence you seek to have on yourself, or on others? Define possible changes you have to make in the model and modelling process based on the value ring. What is working out, and what is not, and what should be adjusted?

Figure 6.1 Introducing the value ring

As basis for such deliberation, or to call for accountability of those involved, I formulate the following questions that can be asked at different stages in the modelling process, and that can support discussions between commissioners, funders, modellers, users and those affected. The questions are valid for situations where models are developed only to explore parts of the world, or in situations where models are explicitly developed for decision making. To support this process, it helps to keep track of decisions or junctures in the modelling process, as suggested by Krueger and Alba (2022), Klein et al. (2024), as well as the relations between the model and the places it is made and implemented in, as for instance done by Fisher (2020) and shown in chapter four.

- **Problem framing**:
  - Who defines the problem, and why? Are there alternative understandings of the problem? Who has been excluded from identifying the problem?
- **Introducing a modelling approach:**
  - What are the expectations with using a model to address the problem/question? Are they based on generally high expectations of what models can do?
  - Who finances the modelling process, and with what expectations? Is it possible to suggest alternative approaches?
- **Defining the modelling approach:**
  - Is modelling needed?
  - What are the values embedded in the model and modelling approach, and related aims? Does the model and modelling process contribute to a more just and fair world, directly or indirectly, and should values be adjusted?
  - How do representation and categorisation embedded in data influence the modelling process, and does this correspond to the defined values?
  - Are influences of familiarity, habits, standardisation and institutional interests recognised, in terms of how they enable or limit the modelling approach? Are actions needed to counter these?
  - Is the modelling grounded, and in what ways? For instance, was field work included in the methods, and , and are those or what is modelled visited?
- **Relations between the model, it's output, users and those affected**
  - What is done to provide opportunities to endorse or counter the information produced through the modelling process? How are alternatives ways of knowing included in the modelling process or decision making to counter limitations in the model or knowledge hierarchies?
  - Is explained how the input and process influenced the output?
  - How do the colours, maps, and graphs used create a specific understanding of the outputs, and does this represent the values embedded in the model and modelling approach?

Conclusions

Water models do have influence, in different ways. Approaching them as neutral tools that do not influence us without outside interference, would be an underestimation of how they shape people and processes. Developing, funding, commissioning and using models and their outputs thus requires a conscious engagement. It is therefore that the main research question this study addressed is how water models gain influence in specific cases, and to explore different ways of how to engage with this influence in practice and science. To answer this question, three sub-research questions were formulated:

- How are the many ways in which water models and modelling processes can gain in influence analysed and discussed in academic literature?
- If and how do models, specifically Water Accounting Plus and WAS/MYWAS, gain influence, potentially beyond their intended reach?
- What practical and scientific lessons can be drawn on how to engage with this political charge of water models, and eventually how to harness the influence of models for progressive transformation?

What are the many ways in which water models gain influence?

The literature review in chapter one showed there is a diversity of approaches to both research and engage with the influence of water models. These diverse approaches make different elements and dynamics visible that shape how the model and modelling process can have influence. The resulting overview gives a quite complete image of the different ways models and modelling processes have influence, and are therefore useful to keep in mind when assessing the influence of a model and its process. I have argued that such an overview provides a suitable starting point to discuss the shared responsibility of modellers, commissioners, funders and users to discuss how to design a modelling process in such a way that it contributes to fairer and more just engagements with water.

The first concerns the problematisation phase and the development of the mental model. In this phase, many different actors are involved, from commissioners, to funders to modellers. What especially merits our attention in this phase is how the problem is framed and by who, what approach is chosen to know the world in a specific way, what vision of the future is embedded in the model and modelling process, the specific categories and indicators that are chosen to represent the world that is modelled. Second, the articles show that models can turn out different, and are therefore not neutral. The choices of modellers matter, influenced by familiarity with certain modelling approaches, habits, as well as standardisation of practices and technological requirements. Yet, these choices are also influenced through interactions with others, or institutional interests that define what a model and modeller should or should not do, and how the model and output shall be used. Combining these elements, models can have real-world impact through naturalising and legitimising particular worldviews, by including or excluding people and nature from the model or modelling process, or by presenting the outcomes in a certain way, for instance through colours, maps and graphs. All these elements requires a conscious engagement and setting a specific intent, being mindful of how the model is shaped and shapes a specific place and people, how the world and future is represented and whether this is a fair representation, and lastly how people and nature that are affected by the modelling process are confronted with the modelling activity and how they can engage.

Additional insights from the case studies

In addition to the literature review, two case-studies helped to further explore how water models and modelling processes have influence, potentially beyond their intended reach. The cases comprised two models that travelled respectively from the US to the Occupied Palestinian Territories and Israel, and from the Netherlands to India, to contribute to water cooperation. Building on the Actor-Network-Theory, I identified how the models develop over time, and how they gain and potentially lose support. In the interaction of people with the model, I used reflexivity as object of study to assess how models shape their environment to identify if and how people act in relation to models, and how power relations develop over time. The case studies show the value of following modelling processes in practice and over time, as indeed there are additional important elements identified that contribute to the influence of a model.

The two case studies show similar dynamics. The projects are developed by one person with a strong idea of how the world can be known and how this can contribute to water cooperation. These persons are able to convince others to support the suggestion on how to realise this vision of the future, importantly because the ideas are translated, changed and shaped into numbers, equations and finally into computer models, and then into maps and graphs. In the case of MYWAS, the first report that came out was an important step to connect to more people outside of the group of modellers. For WA+, the sheets, and later the maps, were means to communicate, although it remained difficult for users to interpret them. The models are presented as either being a rational approach in the case of MYWAS, and as neutral in the case of WA+. Although both models are applied in contexts in which water is highly politicised, the outputs are presented as rational and neutral, seemingly keeping politics out of the door.

It is not only the actual model and modelling process that gains support. Following the model from problematisation to implementation shows multiple rounds of translation in which people and things are mobilised towards a specific goal. It became clear that it is mostly the idea of the model that gains support from donors and commissioners. When a person is not able to engage deeply with the inner technical workings of the model, it is easier to engage with the story inside of it. Related to this, the modelling outputs and process are mainly accepted by donors, commissioners and users when it fit into their vision of the future, or a specific policy project of donors and commissioners. Rejecting the model happens for different reasons, including related to rejecting the specific visions of the future and not seeing them as feasible or good, to not agreeing with the assumptions made about how the world works or how it can be understood best, to not having access to the model. Lastly, following the WAS and MYWAS projects over its lifetime of more than 30 years showed that the worldviews of the model do not change over time, mostly as they are reified in the equations and the modelling structure. Yet, its application did change, from contributing to a fairer allocation of water at a transboundary level to applying the model for optimal water allocation and policies at a national level. WA+ was also applied for a goal it was not originally intended for. It was firstly designed to identify how water can be more optimally used by farmers and how it can be managed at a basin level. It is then later used to promote water cooperation across federal boundaries, supposedly as WA+ can contribute neutral data.

Learning from the work of others

Many of the insights I have collected throughout my research are not new. It is proven over and over that technology has specific influence on us, and that we shape this technology in conscious or less conscious ways, for instance as summarised through the literature review in chapter two. Why then, does the same literature review show that there is so little engagement with the influence of water models? This is addressed in chapter fives. Based on surveys and interviews I explored what practical and scientific lessons can be drawn on how to engage with this political charge of water models, and eventually how to harness the influence of models for progressive transformation. Through an inductive content analysis, three relations were broadly identified between specific ways of doing research and its influence. First, most authors reported minimal influence of their studies on discussion, debate and decision-making processes, yet proofed important for the researchers themselves in terms of education, showcasing knowledge development, and outreach to partners. Second, engaging in critical work prompted the modellers themselves to be more reflexive and so influencing their own modelling practices. Third, those studies that achieved meaningful change had often embraced action research, integrating local values and needs, and so mobilising a new public capable of using models to make an impactful intervention.

The challenges and barriers that identified through the surveys and case studies included that it took ample time to learn both how to deconstruct a model, as well as how to model connected to local needs and mindful of political and power relations; a lack of openness of others to interdisciplinary cooperation; strong vested interests related to doing modelling in a certain way, including using specific models or achieving a particular goal; and a lack of resources such as time and funding to facilitate connecting to people and places. This research shows that there are no simple ways to organize more inclusive and transdisciplinary modelling processes that cares about representation, different knowledges and social and environmental justice. It requires time, dedication and connection, and calls for more action research that engages with modellers, those affected, but also funders, commissioners and decision-makers.

Based on the literature review and the case studies, I conclude that the most important step is to develop modelling processes and its implementation that are not neutral but explicitly based on values, and to work towards just and equitable water distributions and engagements. Taking this as a starting point for power-sensitive modelling, it becomes clearer how to further engage with the political charge of water modelling, as also shared in chapter two: i) take a holistic approach to modelling to include everything that influences model-making and that is influenced by it, ii) foster accountability, as modellers, commissioners, funders and model users by taking possible real-life consequences of a modelling process or use into account and adapt accordingly, iii) be transparent throughout the modelling process is a way forward to make explicit and ultimately examine and attend to the multitude of interests shaping the development and use of models and their socio-economic and ecological consequences, and iv) democratise modelling by giving space to multiple bodies of knowledge and multiple stakeholders and incorporate marginalised voices of people and nature at all stages of the modelling.

Not an afterthought: water modelling and dealing with disconnects

In my analyses I identified how models make connections or disconnects with the world around them. Working on this research has left me yearning for connection personally as well. In the past four years, and during my research on, and working with models, there are several ways that made me feel disconnected. Firstly, the two in-depth case studies described in chapter two and three focused initially on negotiations and policy making at the transboundary level. Water in these discussions is not flowing through the meeting rooms. It is brought in through data, stories, policies and the models. This naturally creates a distance between the water, people and places. In addition, as researcher, I placed myself outside of the modelling process. So I observed the observers and their method. This created a double-distance. Coming in as a foreigner created a triple distance. Lastly, in my research, I have chosen to work on cases of conflict over water. I have seen a lot of empathy and interest, but also misunderstandings and dehumanization. The war on Gaza, fear in Israel, increasingly violent occupation – with so many deaths had a crippling effect on me. This created a quadruple distance, which I found incredibly difficult to bridge and that left me yearning for connection.

Throughout my PhD, I encountered different ways of fostering these connections. Dona Haraway calls for being situated (1988). This was beautifully operationalised by Klein et al. (2024), who propose situated modelling that is grounded in a specific place, embraces multiple knowledge and is aware of power differences. Directly related to this feminist approach is reflexivity (Sultana, 2007), that is about being very aware of the places and thoughts you are constituted in. It is about connection. Haraway further invites us to be kind and to see how we can make ourselves and others thrive, based on everyone's particularities. From this viewpoint, she also calls for creating new kinships, and more-than-human approaches (Haraway, 2016), that helps me to identify who or what a modelling process does not take into account.

In my work, the push to publish articles formed a challenging task to reduce complexity and cutting out stories that I felt had to be told. When writing the first chapter, I felt I was doing violence to the story and the farmers locally, having to reduce the complexity of the real world to fit the needs of the journal. Isabelle Stengers has posited her call for slowing down science, against knowledge production for the sake of knowledge production driving by economic values. She invites us to take time to build 'intelligent relationships' (Stengers, 2018, pp. 4), that reflect the plurality of science – also beyond those with the label of scientists. She calls for evaluating research not based on articles and indexes, but in a pragmatic way that fits a particular science and situation. This call speaks to me, as especially writing the article on MYWAS felt extractive. I have chosen to author this on my own, feeling the need to show the complexity of working in a place of ongoing violence and occupation. It felt extractive, and also is, as it engages with politics that are perhaps intended for people, or for certain people, and not with people. Also, especially in Palestine, a place under occupation, donors have tried to enforce certain ways of seeing and collaborating and obstructing resistance. I also have experience of working with such funding, and although I had lofty aims, the work and research does takes place in a deeply violent and inequal system and is always influenced by this. It also puts responsibility on me as privileged observer, on what to do with the knowledge obtained. It was my aim to show that, even with the best intentions, one has to call out occupation, violence, injustices, and that work that glosses such injustices over and calls for win-win solutions without addressing inequalities actually contributes to a status quo, or worse, a deteriorating situation. Learning about this was an important part of my PhD, and identifying how to approach this, by supporting or becoming part of intelligent relationships that do not shy away from calling out injustice.

In my search for connection, I am also attracted to the work of Simone Weil, a French-Jewish philosopher who lived from 1909 to 1943. I find her work not easy to read, but there are two aspects that resonated greatly. The first are her comments on mathematics, looking translating parts of the world into mathematics risks cutting or destroying the relation between the numbers and the thing or person observed, and in which the signs become important instead of what it signifies (Weil, 2004). It relates strongly to examples given by Yarina (2024), who shows that the model replaces or remakes the river, which was also the reason for Babel to engage in her research (Babel et al., 2019). It relates directly to her idea of 'force', which I could only understand through a re-interpretation of her texts (Weil, 2004; Zaretsky, 2021). Force can be explained as what turns humans into things or objects. This is also done through modelling, and the modeller and model user need to make an effort to re-humanize. In all of this violence, Weil also offers a suggestion on how to connect. She calls for attentivity, making ourselves empty and open for others, and to wait for the other to come to us instead of digging, seeking, asking. It draws a person towards openness towards a situation, instead of imposing solutions. It asks for time to explore and learn, and also for unlearning – or emptying yourself of biases or judgment. For me, this is an essential part of doing research.

The call for attention of Weil has also become important to me in my exchange with modellers. I learned that relationships are formed with specific models and methods. Criticizing them is seen as an easy thing to do, as fence-sitting and pointing out what can be done better without having experienced what the challenges are and without seeing how this is a way to contribute to a better world. I fully agree that being consciously critical, especially in publications, needs to be done with attention and openness and curiosity. In many interviews and exchanges over coffee, modellers have shared how they felt about the conversations, but also what their aims were with the modelling, and also how reflexive they were on their personal influence on the modelling process as well as the different ways a model could have turned out different. The best discussions with modellers came when there was vulnerability and curiosity towards the other. In turn, I learned to be critical on my own methods and positionality. This is similar to what Lucie Babel experienced in her research (Babel and Vinck, 2019; 2022). Yet, reflexivity is not the responsibility of a modeller alone, and should not be left to internal processes. I therefore do not agree that criticism on modelling, coming from non-modellers, is not valid. In this research I have shown, and many others before me (see chapter two) that modelling is not only technical but also a social and political process and that social scientists do have relevant things to see. When it comes to building intelligent relationships, as Stengers calls for, there are many hands needed, also those of non-modellers.

Weil, Stengers and Harraway may come from slightly different approaches to science, yet have similar proposals in moving forward. It is about connection, plurality, taking others seriously, about humanizing, questioning power imbalances, unlearning and learning together. I join their quest.

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Annex 1: Final list of 61 articles included in the review, that explicitly engage and reflect on the power of water models

30 through a general search and personal collection

27 additional articles through the systematic review

4 through the HESS community and reviewers

Based on our assessment, the "X" indicates that an article discusses explicitly i) the mental models and policy projects, ii) the influence of modellers' choices, iii) the impact models have, and/or iv) engaging with non-modellers.

"x" indicates an article discusses one of the abovementioned elements, but not explicitly

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
Number of articles that mention a certain element of modelling explicitly					22	34	19	24	
Narrative review	Towards a hydroinformatics praxis in the service of social justice	Abbott, M. Vojinovic, Z.	2014	Journal of Hydroinformatics		X	x	x	A general review on hydroinformatics, no model or area defined
Narrative review	Legacy, Rather Than Adequacy, Drives the Selection of Hydrological Models	Addor, N.; Melsen, L. A.	2019	Water Resources Research		X			Hydrologiska Byråns Vattenbalansavdelning model (HBV), the Variable Infiltration Capacity model (VIC), the mesoscale Hydrological model (mHM), the TOPography-based hydrologic model (TOPMODEL), the Precipitation Runoff Modelling System (PRMS), the Génie Rural model à 4 paramètres Journaliers (GR4J), and the Sacramento soil moisture accounting model
SCOPUS and Web of Science query	Understanding human-water feedbacks of interventions in agricultural systems with agent based models: a review	Alam et al.	2022	Environmental Research Letters	X	X	x		General review, focused on including externalities in modelling Agricultural Water Management interventions, focus on Agent Based Modelling

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
SCOPUS and Web of Science query	Experiences of the use of riverine nutrient models in stakeholders dialogues	Andersson	2004	International Journal of Water Resources Development				X	HBV-N, STANK, and SOIL-N, applied in theUpper Svarta Valley in Sweden
Narrative review	Decision-making in model construction: Unveiling habits	Babel et al.	2019	Environmental Modelling & Software		X			General review, with input of European and North American modelers in a variety of disciplines within Earth and Universe sciences
SCOPUS and Web of Science query	Principles and confidence in hydrological modelling	Bergstrom	1991	Nordic Hydrology		X		x	HBV and PULSE models at the Swedish Meteorological and Hydrological Institute between 1971 and 1990
Narrative review	The co-production of science and waterscapes: The case of the Seine and the Rhône Rivers, France	Bouleau	2014	Geoforum	X		X		Models (undefined) within the PIREN Seine and PIREN Rhône project, France
Narrative review	Who Are we Measuring and Modeling for? Supporting Multilevel Decision-Making in Watershed Management	Bremer et al.	2020	Water Resources Research				X	A suite of hydrologic models, such as SWAT, InVEST, and ARIES, as well as proprietary models such as HydroBID, three watershed management programs in the Atlantic Forest of Brazil
SCOPUS and Web of Science query	Contested H2O: Science, policy and politics in water resources management in Chile	Budds	2009	Geoforum	X	X	X	X	An undefined hydrogeological model by the National Water Directorate, La Ligua basin, Chile
SCOPUS and Web of Science query	Putting water in its place: a perspective on GIS in hydrology and water management	Clark	1998	Hydrological Processes		X	x		General review, no model defined, with reflection on the US and UK.
SCOPUS and Web of Science query	Watercourses and Discourses: Coalmining in the Upper Hunter Valley, New South Wales	Connor et al.	2008	Oceania	x		X	X	An undefined hydrological model used by the Bickham Coal Company, Upper Hunter Valley, New South Wales

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
Narrative review	Using Dynamic Modeling to Scope Environmental Problems and Build Consensus	Constanza, and Ruth	1998	Environmental Management	x	x		**X**	STELLA II modeling environment, Louisiana coastal wetlands
SCOPUS and Web of Science query	How Central Water Management Impacts Local Livelihoods: An Ethnographic Case Study of Mining Water Extraction in Tarapaca, Chile	Cornejo and Niewöhner,	2021	Water	x		**X**	**X**	Undefined hydrological models, Tarapacá, Chile
SCOPUS and Web of Science query	The Challenge of Model Validation and Its (Hydrogeo)ethical Implications for Water Security	de Oliveira Ferreira	2022	Studies in Computational Intelligence		**X**	x	**X**	General review, related to hydroogeological modelling
SCOPUS and Web of Science query	Investigating the Influence of Ethical and Epistemic Values on Decisions in the Watershed Modeling Process	Deitrick et al.	2021	Water Resources Research	**X**	x		x	a wide array of models, such as the Soil & Water Assessment Tool (SWAT), SPAtially Referenced Regressions on Watershed attributes (SPARROW), and Chesapeake Assessment Scenario Tool (CAST), Chesapeake Bay Watershed
Narrative review	How Important Are Model Structural and Contextual Uncertainties when Estimating the Optimized Performance of Water Resource Systems?	Dobson et al.	2019	Water Resources Research		**X**			Simulated Water Resources System models, South West of the UK (research on effect of framings in models)
Narrative review	An interdisciplinary framework for participatory modeling design and evaluation— What makes models effective participatory decision tools?	Falconi and Palmer	2017	Water Resources Research				**X**	Shared Vision Model (System Dynamic model built on STELLA) for the Tri-State Water Conflict in the ACT-ACF River Basin, USA; System Dynamic Model, Las Vegas, Nevada; Bayesian Network; Solomon Islands
Narrative review	Much Ado About Minimum Flows…Unpacking indicators to reveal water politics	Fernandez	2014	Geoforum	**X**	x	**X**	x	Undefined hydraulic and hydrological models, Garonne system, France

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
SCOPUS and Web of Science query	Exploring Strategies for LID Implementation in Marginalized Communities and Urbanizing Watersheds	Garcia-Cuerva et al.	2016	World Environmental And Water Resources Congress 2016				X	hydrologic/hydraulic stormwater modeling system d using HEC-HMS and SWMM, Walnut Creek Watershed in Raleigh, North Carolina
SCOPUS and Web of Science query	Production of competing water knowledge in the face of water crises: Revisiting the IWRM success story of the Lerma- Chapala Basin, Mexico	Godinez Madrigal et al.	2019	Geoforum	X	X	X	X	System dynamics models, Lerma-Chapala basin, Mexico
SCOPUS and Web of Science query	Representation justice as a research agenda for socio- hydrology and water governance	Haeffner et al.	2021	Hydrological Sciences Journal	X	X			General review, for (socio)hydrological modelling
SCOPUS and Web of Science query	Social Position Influencing the Water Perception Gap Between Local Leaders and Constituents in a Socio-Hydrological System	Haeffner et al.	2018	Water Resources Research	X			X	Socio-hydrological/coupled system models, WasatchRange Metropolitan Area, Northern Utah
Narrative review	Reckoning Resources: Political Lives of Anticipation in Belize's Water Sector	Haines	2019	Technology Studies		X		x	GIS software and the N-SPECT (nonpoint-source pollution and erosion comparison tool), Belize
Narrative review	Boundary Objects and the Social Construction of GIS Technology	Harvey and Chrisman	1998	Environment and Planning A: Economy and Space	X				GIS technology, including ATKIS standard database model and A L K / A T K I S - G I A P software, applied to wetlands in the USA
SCOPUS and Web of Science query	Green infrastructure site selection in the Walnut Creek wetland community: A case study from southeast Raleigh, North Carolina	Hasala et al.	2020	Landscape And Urban Planning	x	X	X		Participatory Geographic Information Systems, Walnut creek, southeast Raleigh, North Carolina

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
SCOPUS and Web of Science query	How to speak for aquifers and people at the same time: Environmental justice and counter- network formation at a hazardous waste site	Holifield R.	2009	Geoforum			X	X	Groundwater models:SLAEM (Single-Layer Analytic Element Model), MLAEM (Multi-Layer Analytic Element Model), MODFLOW, St. Regis, Minnesota, USA
Narrative review	Impact of modellers' decisions on hydrological a priori predictions	Holländer et al.	2014	Hydrology and Earth System Sciences		X			DWRSIM, used by the California Department of Water Resources to manage the State Water Project; and PROSIM, used by the Bureau of Reclamation in its Central Valley operations
SCOPUS and Web of Science query	Water models and water politics: Design, deliberation, and virtual accountability	Jackson	2006	ACM International Conference Proceeding Series	X	X	X	x	CalSim (generalised model for reservoir analysis, FORTRAN), California, USA
SCOPUS and Web of Science query	GIS, sinks, fill, and disappearing wetlands: Unintended consequences in algorithm development and use	Jenkins and McCauley	2006	Proceedings of the ACM Symposium on Applied Computing		X			General review, based on ARC/INFO, ArcView, and ArcGIS, applied to wetlands
Narrative review	A flood of models: Mekong ecologies of comparison	Jensen.	2020	Social Studies of Science			X	X	Different models, including MRC SWAT, MIKE, HEC ResSIM, applied to (parts of) the Mekong river
Narrative review	Modelling expertise: Experts and expertise in the implementation of the Water Framework Directive in the Netherlands	Junier.	2017	PhD dissertation: Delft University of Technology	x	X		x	Water Framework Directive Explorer, the Netherlands
Narrative review	Standing on the shoulders of giants—and then looking the other way? Epistemic opacity, immersion, and modeling in hydraulic engineering	Kouw.	2016	Perspectives on Science		X		x	General review, Hydraulic engineering models, The Netherlands

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
Narrative review	Risks in the Making: The Mediating Role of Models in Water Management and Civil Engineering in the Netherlands	Kouw.	2017	Berichte zur Wissenschaftsgeschichte			X	X	General review, Hydraulic engineering models, The Netherlands
Narrative review	Groundwater Modeling and Governance: Contesting and Building (Sub)Surface Worlds in Colorado's Northern San Juan Basin	Kroepsch	2018	Engaging Science, Technology, and Society	X		X	x	Groundwater models (by 3M project, CBM, AHA, and Questa), Northern San Juan Basin, USA
SCOPUS and Web of Science query	Environmental Research from Here and There: Numerical Modelling Labs as Heterotopias	Laborde	2015	Environment and Planning D: Society and Space	X	x			ELCOM, supported by MATLAB, Lake Como, Italy
HESS review	Ontological and epistemological commitments in interdisciplinary water research: Uncertainty as an entry point for reflexion	Krueger, and Alba	2022	Frontiers in Water	X	X	X	X	socio-hydrological human-flood models, an export coefficient type model, water security model of Dadson et al. (2017)
Narrative review	Virtual engineering: computer simulation modelling for flood risk management in England	Landström et al.	2011a	Science & Technology Studies	X				Discussion of different models, including ISIS, HEC-RAS and MIKE11, HEC-RAS, etc. at the Environment Agency of England and Wales
SCOPUS and Web of Science query	Coproducing flood risk knowledge: redistributing expertise in critical 'participatory modelling'	Landström et al.	2011b	Environment And Planning A-Economy And Space	x	x	x	X	CRUM2D v 3.1, Pickering, UK and Wales

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
HESS review	Doing flood risk science differently: an experiment in radical scientific method.	Lane et al.	2011b	Transactions of the Institute of British Geographers	x	x	X	X	FEH & ISIS's routing methodology, Pickering, UK and Wales
HESS review	Explaining rapid transitions in the practice of flood risk management.	Lane et al.	2013	Annals of the Association of American Geographers		X			Flood mapping science (HEC-RAS, ISIS and MIKE-11, RMA2 TELEMAC-2D model)
SCOPUS and Web of Science query	Acting, predicting and intervening in a socio-hydrological world	Lane	2014	Hydrology And Earth System Sciences		X		x	General overview
Narrative review	Imagining flood futures: risk assessment and management in practice	Lane et al.	2011a	Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences	X	X			Flood Estimation Handbook based models, UK and Wales
SCOPUS and Web of Science query	Planning for watershed-wide flood-mitigation and stormwater management using an environmental justice framework	Meenar et al.	2018	Environmental Practice	X	X	X		ArcGIS, HEC-HMS, HEC-RAS, and HEC-GeoRas software, Pennsylvania, US
SCOPUS and Web of Science query	What is the role of the model in socio-hydrology? Discussion of "Prediction in a socio-hydrological world"*	Melsen et al.	2018	Hydrological Sciences Journal		X	X	X	General review

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
Narrative review	It Takes a Village to Run a Model— The Social Practices of Hydrological Modeling	Melsen	2022	Water Resources Research		**X**			Hydrologic modelling, Western Europe
Narrative review	Subjective modeling decisions can significantly impact the simulation of flood and drought events	Melsen et al.	2019	Journal of Hydrology		**X**			Three Variable Infiltration Capacity (VIC) models (version 4.1.2.i), Thur Basin, Switzerland
Narrative review	How do hydrologic modeling decisions affect the portrayal of climate change impacts?	Mendoza et al.	2016	Hydrological Processes		**X**			Including Weather Research and Forecasting (WRF) regional climate model, Noah-LSM,hompson mixed-phase cloud micro-physics scheme, Colorado River Basin, USA
Narrative review	Risking the flood: Cartographies of things to come	Munk	2010	PhD dissertation: Linacre College, University of Oxford	**X**	x	x	x	HEC-RAS 4.0, UK
SCOPUS and Web of Science query	Scientific and social uncertainties in climate change: The Hindu Kush-Himalaya in regional perspective	Opitz-Stapleton and MacClune	2012	Community, Environment and Disaster Risk Management	x		x	**X**	Different Community Based Modelling inititatives, Hindu Kush-Himalaya
Narrative review	Mainstreaming gender into water management modelling processes	Packett et al. .	2020	Environmental Modelling & Software	**X**	**X**			Biophysical modelling guidelines, general
SCOPUS and Web of Science query	Impact of political, scientific and non-technical issues on regional groundwater modeling: Case study from Texas, USA	Rainwater et al.	2003	Developments in Water Science	x	**X**	**X**	**X**	MODFLOW based groundwater model, Texas, USA

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
Narrative review	GIS, modeling, and politics: On the tensions of collaborative decision support	Ramsey	2009	Journal of Environmental Management	**X**		x	x	GIS Surface water model, Idaho, USA
Narrative review	The social construction and consequences of groundwater modelling: insight from the Mancha Oriental aquifer, Spain	Sanz, et al.	2019	International Journal of Water Resources Development	**X**	**X**	**X**	**X**	A groundwater model, Spain
SCOPUS and Web of Science query	Hydrogeology and framing questions having policy consequences	Shrader-Frechette .	1997	Philosophy of Science	**X**	**X**	x		USA, the Yucca Mountain in Nevada and Maxey flats, Kentucky
Narrative review	Moving socio-hydrologic modelling forward: unpacking hidden assumptions, values and model structure by engaging with stakeholders: reply to "What is the role of the model in socio-hydrology?"	Srinivasan et al.	2018	Hydrological Sciences Journal	x	**X**			Socio-hydrological models, general overview
Narrative review	An Environmental Anthropology of Modeling	Trombley	2017	PhD dissertation: University of Maryland, College Park	**X**	**X**	x	x	Chesapeake Bay Modelling System, Chesapeake Bay, USA
Narrative review	Uncertain monitoring and modeling in a watershed nonpoint pollution program	Wardropper et al.	2017	Land Use Policy			**X**	**X**	SWAT, Wisconsin, USA
SCOPUS and Web of Science query	Hydrology and hydraulics expertise in participatory processes for climate change adaptation in the Dutch Meuse	Wesselink et al.	2009	Water Science and Technology		**X**		**X**	WAQUA, SOBEK, Meuse Basin, The Netherlands

Origin	Title	Authors	Year	Source title	i) the mental models and policy projects	ii) the influence of modellers' choices	iii) the impact models have	iv) engaging with non-modellers	Model type discussed and Area of study
HESS review	Manning's N - Putting roughness to work	Whatmore and Landström	2010	How Well do Facts Travel? The Dissemination of Reliable Knowledge	X	X			1D floodrisk modelling, TUFLOW, general review
SCOPUS and Web of Science query	Exploring Cooperative Transboundary River Management Strategies for the Eastern Nile Basin	Wheeler, et al.	2018	Water Resources Research	X			X	Eastern Nile RiverWare Model, MOEA = multiobjective evolutionary algorithm, Nile Basin
Narrative review	Modelling to bridge many boundaries: the Colorado and Murray-Darling River basins	Wheeler et al.	2018	Regional Environmental Change			x	X	The Colorado River Basin in North America and the Murray- Darling Basin in southeastern Australia

Annex 2: List of PhD related publications and activities

My learning process was richer than I could capture in the previous chapters. In this annex, I therefore share insight in my PhD journey through the illustration below, a list of related scientific and non-scientific publications, presentations and lectures, and an overview of students I had the privilege of working with in relation to my PhD.

Figure X My research Journey

PhD related articles and blogs

Alba, R., ter Horst, R. (2022). Towards a reflexive approach: connecting critical research on water modelling. *Flows, The Water Governance Blog at IHE Delft Institute for Water Education*. https://flows.hypotheses.org/7300

ter Horst, R., Bonté, B., Venot, J. (2022). Can a model care? *Flows, The Water Governance Blog at IHE Delft Institute for Water Education.* https://flows.hypotheses.org/8830

ter Horst, R., Srinivasan, V., Wheeler, K., Timmerman, J., & van der Zaag, P. (2023). Exploring the use of data and models in transboundary water governance. *Water International,* 48(8), 909-914

ter Horst, R. (2024) Reflexivity on modelling for transboundary water governance. *Flows, The Water Governance Blog at IHE Delft Institute for Water Education.* https://flows.hypotheses.org/12272

Godinez Madrigal, J., ter Horst, R., Tran, B., Alba, R. (2024) Models do not think, *The water dissensus: Water Alternatives Forum, Online discussions and debates around water*https://www.water-alternatives.org/index.php/blog/models

Alba, R., ter Horst, R., Tran, B., Klein, A., Unverzagt, K., Godinez Madrigal, J., Verzijl, A., Rusca, M., Vos, J., Venot, J-P., Zwarteveen, M., Krueger, T., (forthcoming) Situating: a proposal for engaging with the power of hydrological models, *WIREs water.*

PhD related presentations and lectures

ter Horst, R. (2022). *Data, Hydrological Models And Diplomacy* [presentation], Interdisciplinary Centre for Water Research (ICWaR), at the Indian Institute of Science in Bangalore

ter Horst, R. (2022). *Data, Hydrological Models And Diplomacy, A Reflection on water allocation practices in the Cauvery and the Rhine* [presentation], at the Roorkee Water Conclave

ter Horst, R. Godinez Madrigal, J., Tran, B., Alba, R. (2023). *Controversial tools, researching modelling practices in water governance* [presentation], Swedish Collegium for Advanced Study, Uppsala.

Godinez Madrigal, J., ter Horst, R., Tran, B. (2024) *Controversial tools, researching modelling practices in water governance* [presentation], Institut d'études avancées de Paris, Paris.

ter Horst, R. (2024). *Lessons from opening the black box of water modelling in conflict settings,* Stockholm World Water Week for InventWater, Stockholm.

Alba, R., Godinez Madrigal, J., ter Horst, R., Tran, B. (2024). *Modelling for just water transformations* [presentation], MAK'IT and GEAU, Montpellier.

Working with students on PhD related topics

I greatly enjoyed teaching and learning with students. I taught on topics related to my PhD at Wageningen University and designed a two-and-a-half day module on this topic for the Summerschool on Water Governance at the Geneva Water Hub. In addition, I worked with the following students and colleagues on topics related to my PhD in the past for years, with great pleasure:

- Marco Laan did research on how remote sensing and model was an important factor in the development of the current governance system in La Mancha Oriental in Spain. He organised a field visit for Jaime Hoogesteeger and me, and I look forward to finalise the joint article based on this research.
- Lisa Camfferman researched on imaginaries, ideas on what the world is and should or could be, become embedded in models and with what effect. She focused on the Maasmodel, applied for the Grensmaas. She showed how ideas on water safety that are embedded in the model, make it more difficult for the environmental groups to challenge these ideas. With Lotte de Jong and Lisa we are working to develop this into a paper.
- Jan Kleijn researched how a model for water cooperation in South Africa, Mozambique and eSwatini, was proposed and if and how it was accepted to be used. He spent three months in the three countries to do interviews.
- Marthe Gunnink researched how a decision support system for water management in Uzbekistan, developed by ICARDA, can adopt in a more human-centred approach. She has worked closely with ICARDA to develop this research and spent three months in Uzbekistan.
- Joost de Jonge is developing his research currently, and will focus on ethics and the development and adoption of Digital Twins for decision making on water in the Netherlands.

Annex 3: WASS Training Certificate

Rozemarijn Hendekien ter Horst

Wageningen School of Social Sciences (WASS)

Completed Training and Supervision Plan

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
A1 Managing a research project			
WIMEK 'Environmental Research in Context'	WIMEK, WUR	2020	2
Writing your research proposal	WRM, WUR	2020/2021	6
Reviewing papers (2 papers)	WRM, WUR	2020-2022	0.3
Scientific Writing 1	Wageningen In'to languages	2021	1.8
Organisation of discussion group on 'models, water and society' for WRM chair group	WRM, WUR	2021	2
A2 Integrating research in the corresponding discipline			
Capita Selecta Political Ecology, WRM50403	WUR	2021	3
Researching Socio-Technical Practices, Innovation and Futures, CPT37806	WUR	2021	6
Do You Trust (Your) Science? – A Perspective of Theory of Science and Sociology of Knowledge	UFZ	2021	0.3
Understanding State Capabilities	Centre for Policy Research	2021	0.7
Analysing Discourse: Theories, Methods and Techniques, CPT56306	WUR	2021	6
B) General research related competences			
B1 Placing research in a broader scientific context			
Ethics for Social Sciences Research	WUR	2021	0.5
NEWAVE e-Lecture Series, Water Governance Theoretical Perspectives	NEWAVE	2021	0.3

Name of the learning activity	Department/Institute	Year	ECTS*
Constructive Advanced Thinking (CAT)	Institute of Advanced Studies of Uppsala (SCAS), Paris (IEA), and Montpelier (MAK'IT)	2023-2024	5
Summer School: Situating Hydrological Modelling	Humboldt university	2023	2
"Lessons from opening the black box of water modelling in conflict settings"	InventWater	2024	1
B2 Placing research in a Societal context			
Organisation of the Water & Peace Seminar on 'Water cooperation, data and policy making'	WUR/IHE	2021-2022	3
C) Career related competences/personal development			
C1 Employing transferable skills in different domains/careers			
Editing Special Issue: Developing a proposal for a special issue, identify group of editors and potential authors, editing articles, guiding peer review process	WUR/IHE	2021-2023	4
Total			**43.9**

*One credit according to ECTS is on average equivalent to 28 hours of study load

Summary
Models both discursively and materially influence the way we engage with water. Although often perceived as neutral, there are many decisions that influence what a model and modelling process looks like, what the model can do, the outputs it creates, and how people can engage. The shaping of models, and by models, happens consciously and openly, or unconsciously and more covert. This calls for critically conscious engagement, while models are often presented as neutral tools or are difficult to challenge. The main research question that guides this research is therefore: 'How do water models gain influence, and what are ways to engage with this influence in practice and in science?'. This question is answered through a literature review, to identify how researchers engage with the influence of water models, through two case studies that examine how models gain influence in practice, and through surveys and interviews with scientists who engage reflexively with water models, to explore how to engage with the political charge of water models and how to harness the influence of models for progressive transformation.

The second chapter of the thesis answers the question how the many ways in which water models and modelling processes can gain influence are analysed and discussed in academic literature. The question is answered based on a literature review of 61 articles that engage reflexively with the influence of water models. Reflexivity entails to be critically conscious on the places, actions and power relations that shape models and in turn shape those who commission, make or use water models. The 61 articles are identified through a combination of familiarity, suggestions by the community of the journal of Hydrology and Earth System Sciences, and a query in Scopus and Web of Science. The review shows that in scientific literature relatively little attention is given to the influence of water models. Only a tiny fraction of the total publications in water modelling mentions topics related to reflexivity, such as justice, equity, politics or ethics. This percentage is consistently well-below 1% of the total number of publications in this domain. Moreover, the review shows that of the literature that mentions such topics, an even smaller subset actually engages in-depth with justice, equity, politics or ethics.

The 61 articles included in the review showcase several ways to research the influence of water models in a reflexive way, and also the dynamics they identify. Broadly summarized, three approaches are identified. First, there are studies that remain in the modelling domain and aim to understand how the input and model are shaped, and how these have an effect on the modelling output. These can be more technical studies often done by modellers themselves or focused on the practices of modellers, which is often done by social scientists. The choices of a modeller can be influenced by familiarity, habits, and standardisation of practices and technological requirements. Also institutional interests define what a model can

look like, how it is used, what costs are involved, and whether it can be challenged or not. Second, there are studies that consider the influence of models in practice, but are less interested in unpacking the model itself. They often explore the question why models are used in the first place and with what effect, or how outputs are communicated through colour, maps, graphs, manuals, and through what procedures. These studies emphasise the neglect of the interests and knowledge of marginalized groups in society or specific representations of these groups, and how this results in winners and losers when a model is applied. Lastly, there are studies on how water models are used in practice, for instance based on the social construction of technology or on action-research. These studies emphasise how models are developed, and with what influence on specific local social dynamics. In conclusion, the way the model and modelling process is designed influences what is seen as facts and how these can be challenged.

The literature review concludes with a call for power-sensitive modelling which includes the following considerations: take a holistic approach to modelling beyond programming and coding; foster accountability; work towards just and equitable water distributions; be transparent about the expectations and choices made; and democratise modelling by giving space to and being mindful of representations of multiple bodies of knowledge and multiple stakeholders and by incorporating marginalised people and nature into the modelling process. This call should not be understood as a suggestion to do away with modelling altogether, but rather as an invitation to interrogate how quantitative models may help to foster transformative pathways towards more just and equitable water distributions.

To have a better understanding of how water models can gain influence, and to learn how to do power-sensitive modelling, modelling processes are further explored through two in-depth case studies. There are only a few studies on modelling processes on water that describe the process from problematisation to the consequences water modelling practices have. Through in-depth case studies this research aimed to explicitly contribute to this small body of literature. The case studies include two situations in which water models are applied to contribute to water cooperation, in situations of conflict over water allocation across political boundaries. The models are developed in in the US and the Netherlands respectively, and applied in India and Israel and the Occupied Palestinian Territories with the support of donor funds. The main assumption is that important lessons can be learned on how to engage with the influence of quantitative models, from modelling processes that are developed and implemented in environments in which knowledge development is expected to be scrutinized and contested, such as in situations of conflict over water. The cases are analysed based on the social shaping of technology, combined with the Actor-Network theory applied as methodology. Models are unpacked as being constructions of worldviews, visions of the future, expertise and materiality. To analyse the evolution of power relationships around the models, the way models travel, gain and lose support, create opposition, or do nothing, is analysed based on the Actor-Network Theory. This approach helps to centralise the model in the analysis, in order to subsequently decentralise it and foreground the people, places and questions that are addressed through the modelling exercise.

The first case study discusses the application of Water Accounting Plus (WA+) in a federal river basin in India. WA+ was applied in the Cauvery basin to contribute to solving transboundary water-sharing issues by providing a source of transparent data obtained through reproducible methods. The WA+ approach is mainly supported by the Netherlands Ministry of Foreign Affairs, the Asian Development Bank, and the central government of India, as a way to monitor neutrally and efficiently. The intended users, the Cauvery riparian states, rejected the modelling approach. Specifically, there are four elements that constitute a disconnect between the approach of WA+ and the way water allocation is currently managed in the basin. WA+ promotes a basin approach, while water in the Cauvery is allocated between states only based on water in the main river, main tributaries and reservoirs. WA+ promotes a management approach while states base their conversations on discrete monitoring. Management is a state issue, not a topic for discussion at the transboundary federal level. WA+ is based on the idea of water productivity that can easily be interpreted in bad faith as careless management of a precious resource, and used as leverage to demand the release of water or to ignore claims for more water. Lastly, specific expertise on remote sensing and integrated water resources management, and preferably ground truthing, is needed to interpret the results. The analysis of shows how data and models are political and challenges the assumption that more data automatically lead to more equitable decision-making.

The second case study follows the Water Allocation System (WAS) and Multiyear Water Allocation System (MYWAS) throughout their development and application from 1993 until 2023. The models aim to identify win-win options for allocating water between Israel, the Occupied Palestinian Territories and Jordan mainly based on the economic Coase Theorem. It theorises that it does not matter who has property rights of a certain good, as long as the ownership of the good can be the basis of bargaining to divide the good based on the willingness to pay. The analysis showed that the worldviews embedded in the model do not change over time, mostly as they are reified in the equations and the modelling structure. Yet, its application did change, from contributing to a fairer allocation of water at a transboundary level to applying the model for optimal water allocation and policies at a national level. Over the course of thirty years, the project is funded by four different donors. Donors mainly support the model in relation to the idea that there can be a win-win solution for water allocation based on economic terms, and the expectation that these proposals can be substantiated with numbers. In the case of WAS and MYWAS, disconnects mainly arose with through disagreements on how to best understand and manage water supply in general, as well as disagreements on whether fair negotiations and the identification of win-win solutions is possible in a situation of occupation.

In addition to the literature review, the case studies make several important interactions visible that contribute to the influence of a water model. For instance, the case studies draw attention to the question why a model is chosen and accepted as a solution, and especially make explicit what work is done to gain support for a modelling exercise. This work often makes use of existing networks that subsequently help a model to travel beyond the place it was made in. The case studies also show the important role of the charismatic people that drove the modelling processes and created support, and who are influential in defining the expertise and approach that is dominant in a particular modelling process. Also, when people do not have the expertise to unpack a model, they often have high expectations of the model and support the model based on its vision of the future and the idea that this vision can be supported through a modelling approach. The cases shows how models and modelling processes change over time, require tinkering and dedication, how people get connected to their model and how difficult it can be to let go or change it. What has not become clear from the in-depth case studies, but has become clear through the literature review is how models gain influence once adopted in policies or as accepted knowledge by legal institutions.

Lastly, the question is how research that is reflexive on water models, in terms being critically conscious of location, actions and power relations, actually changes modelling practices in science and in practice. Through surveys and interviews with 21 authors of modelling-critical studies, along with evaluations of two inclusive modelling projects—a flood risk modelling project in Pickering, UK, and the Zapotillo infrastructure project in Mexico—we identified three main findings. First, most authors reported minimal influence of their studies on discussion, debate and decision-making processes, yet proofed important for the researchers themselves in terms of education, showcasing knowledge development, and outreach to partners. Second, engaging in critical work prompted the modellers themselves to be more reflexive and so influencing their own modelling practices. Third, those studies that achieved meaningful change had often embraced action research, integrating local values and needs, and so mobilised a new public capable of using models or modelling processes to make an impactful intervention. Reasons for lack of impact were often cited as time and resources constraints, resistance to interdisciplinary cooperation, being criticised by both social and natural sciences, vested interests, and how communication requires dedicated efforts. The study emphasizes the complexity of achieving inclusive and equitable modelling processes, highlighting the need for dedicated, long-term engagement and challenging restrictive conditions of the institutions or decision-making processes within which it is situated. A more holistic approach is needed, of which the development is not only the responsibility of modellers, but especially that of commissioners and funders.

Gratitude

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Rozemarijn

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