RESEARCHING MATHEMATICS IN POLICY MAKING

A case study of peat meadow farming in the central Netherlands

Marion Snijders – 940622783100

March 2020

Chair group KTI

Supervisor: Harro Maat

Second reader: Sietze Vellema

Abstract

The steady process of land subsidence in peat meadow areas in The Netherlands starts to press for societal and technological change. The use and understanding of mathematics are playing an important role in the search for new water management and is the research focus of this thesis. The mutual dynamics of mathematics and social processes influencing each other is studied through a technographical lens, viewing mathematics as a practice and a tool for innovation. A case study is done at a Dutch water board, focusing on two innovative projects with underwater drainage systems (UWD), where actors in the spectrum of researchers, hydrologists, ecologists, intermediates, technicians, field staff and farmers are incorporated. The COIN framework (Crane et al, 2016) is used to show the social dynamics that lies in the use of mathematics, through the different understanding and operationalization that actor groups form of concepts, ultimately leading to certain institutionalizations in society. In analyzing communication between different actors, the concept of 'different ways of knowing' and the UWD projects as a 'border zone' are taken up (Maus and Granjou, 2013).

The use of numbers, graphs and models turns out to have a major social component. An important factor mentioned by those involved in the UWD projects, was the possibility of building trust and understanding on mathematical issues. Therefore, the intention for grounding that actors have, the possibilities for personal communication and the presence of skilled intermediates (social and technical) were playing a key role in the success of the projects. Mathematical literacy is high for the majority of the actor groups and, even though actors do not realize it, mathematics is often used in everyday life by the large majority of the actor groups. A challenge can be found in the assessment of and communication concerning modeling, as uncertainties in these computations are often not quantified (statistically or otherwise), and nuances of specialists get lost while communication is moving further through the network.

Acknowledgement

This thesis could not have been written without the open and welcoming attitude of professionals within HDSR (Hoogheemraadschap De Stichtse Rijnlanden), farmers and others involved in the UWD projects, for which I am grateful. The positive and critical guidance of my supervisor, Harro Maat, stimulated me to take up the challenge of writing a thesis about a subject that was seen as something very far from the social sciences by many others. Writing a thesis was, as it perhaps should be, a challenging process, but the interesting topic and the possibilities that it created to gather insights in the social dynamics surrounding mathematics turned it into a pleasure as well. Furthermore I would like to thank my fellow thesis writers, as with their support, the dark corners of 'De Lebo Library' became the place to be inspired to keep going in phases of struggle and despair.

(Image front page: Polder Lange Weide, source: HDSR.)

Table of Contents

Chapter 1: Introduction

In the Netherlands, approximately 8% of the surface is covered with peat soil, of which around 82% is used for dairy farming (Deru et al., 2018). In order to make peat meadows accessible for heavy machinery and suitable for dairy farming, groundwater levels are lowered via mechanical solutions. Because of the lowered water level in the fields, organic material oxidizes. This leads to a contribution to the emission of greenhouse gasses and the subsidence of the peat lands. As the peat lands lower, the water levels have to be lowered further to keep the land suitable for the current farming practices, thereby continuing this downward spiral. The lowered water levels will also affect the foundation of infrastructure, cause nature reserves to dry out and result in rising costs for water boards to be able to keep the current water management strategy working with ever lowering water levels (van den Born et al., 2016). In the context of the Paris agreement to reduce emission of greenhouse gasses, the issue becomes even more pressing. The Dutch government has assigned €276 million to peat meadow areas within the agricultural sector and expects to gain 1.0 megaton CO2-equivalent emission reduction in return (Klimaatakkoord, 2019).

The scope of the problems that arise and the amount of societal groups that are involved lead to water management in the Dutch peatlands becoming a complex issue. Debates on political and societal level and technological innovation therefore both contribute to the development of new water management strategies. One of the various techniques that is being developed to keep the peat lands watered as much as possible, although at the same time keeping the land still suitable for farming, is a pipe drainage/infiltration system lower than the usual ones. Another vision on the problem is that these technical solutions only postpone or slow down the problematic situation. Instead, the peat meadows should be fully watered, implying that farming practices should change or stop in these areas. The various social and technical challenges are being discussed at different levels such as the Ministry of Agriculture, the LTO (Dutch agri- and horticulture organization), waterboards and researchers.

This thesis will focus on the pathway of developing a drainage/infiltration technique called an 'underwater drainage system'. Studies have already been conducted on the scope of the problem and the possible solutions concerning Dutch peat lands by Wageningen University and Research (WUR) (Hoving et al. 2008, 2011, 2013a, 2013b, 2015), a contra-research initiated by the province Noord-Holland (Couwenberg, 2018) and a reaction on the critique that was given on the first study (van den Akker et al., 2018). In these studies, debate is mainly focused on the interpretation of data, the conclusions that should or should not be drawn from it and what kind of policies should follow from this. The little attention payed by specialists and professionals in these debates to the social aspect of the gathering and analysis of data, led to the problem definition and research aim explained below.

Problem definition and research aim

The results of research are often presented as facts that are not debatable, although they are created from a specific point of view and with a possible disciplinary bias. Furthermore, data is deployed as an argument in discussions that have a political component, therefore blurring the line between facts and opinions. However, consciousness about the social and political aspect of research surrounding the peatlands is low. As data and conclusions are the result of choices for specific models and measurements, the impact of social dynamics in the constant cycle of improving knowledge should therefore not be overlooked by the various actor groups involved.

In the debate surrounding water management, many tools can be used by the involved actor groups to gather knowledge, to argue, defend and ultimately decide upon policies. Mathematics is one of those tools in this context, seen in a very wide interpretation consisting of models and statistics, but also the more general mathematical output of graphics, word choices and use of numbers that are employed by different actor groups in the development of a new water management strategy. Mathematics as a technical matter is therefore used in a very social context in which the livelihoods and interests of the actor groups, but also the long-term future of land and environment, are key. More knowledge on the how, what and who of mathematics fosters increased mutual understanding between actor groups and could thereby contribute to the process of policy making. This leads to the following research question:

"What role does mathematics play through and for different actor groups in the process of creating new water management for the farmed peat meadows in the Netherlands?"

This research aims to contribute to the process of policy making by supporting mutual understanding of the way different actor groups handle mathematical information. In the following chapter this research will be placed in the wider conceptual framework to which it aims to contribute as well.

Study area

The fieldwork of this research is taken up from a case study perspective centered around the waterboard "Hoogheemraadschap De Stichtse Rijnlanden", where two projects concerning underwater drainage (UWD) systems took place. This paragraph briefly explains the context of these projects and the principle of UWD systems. The projects are a well suited case for studying the influence of mathematics in the search for solving societal problems, as they involve a large scope of actors from both a theoretical and practical perspective, the current practical application of a newly developed technique and the pressing question of the effect of UWD on land subsidence on the long term. In both the short and long time frame, a large amount of data and an important social component through the various interests of the actor groups is involved in the monitoring of these projects.

Underwater drainage systems

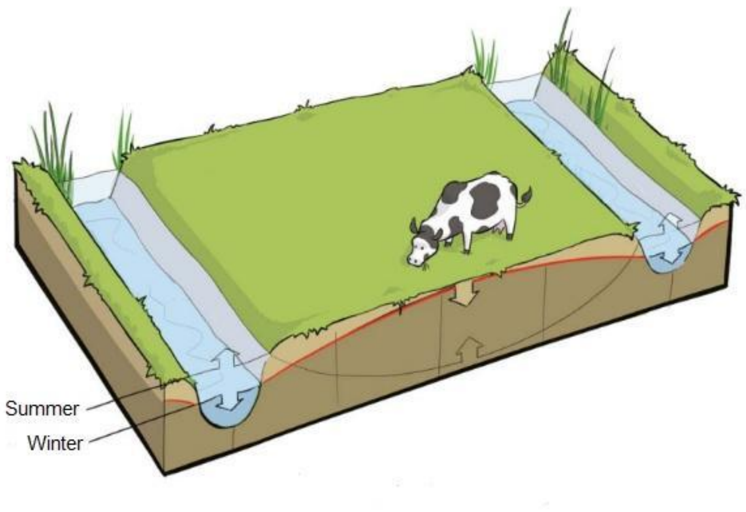


Fig. 1: Situation without UWD. (Source: Bos et al. 2017)

UWD is a pipe system that starts from the ditches at the edges of the farming plots and runs through the fields at 30-80 cm under the field surface. In wet periods they help to drain the fields quicker, in dry periods they help to retain high ground water levels in the fields (Bos et al. 2017). In the image above, the situation without drains is drawn schematically. The red line represents the situation in wetter periods: even though the water level in the ditches is lowered by the water board, the middle of the plots are very wet. This is caused by the physical properties of water and the sponge effect of peat lands. The grey line represents the situation in dry periods. Even though the water level in the ditches is set higher by the waterboard, the groundwater level in the middle of the plot lowers, mainly because of evaporation.

In the situation where the underwater drains are applied, a shortcut is created from the ditch to the rest of the plot. In wet periods, the water can flow out of the plot more quickly through the drains, levelling down the high groundwater level in the plot. In a dry period the water level in the ditch is set above the drains, which will make water flow through the drains to the middle of the plot. In this situation it will help overcome the dip in the groundwater level by infiltrating. In this way, the groundwater level can be kept more constant throughout the year, which is assumed to be better for the profitability of the farmer, slow down the land subsidence and reduce the emission of CO_2.

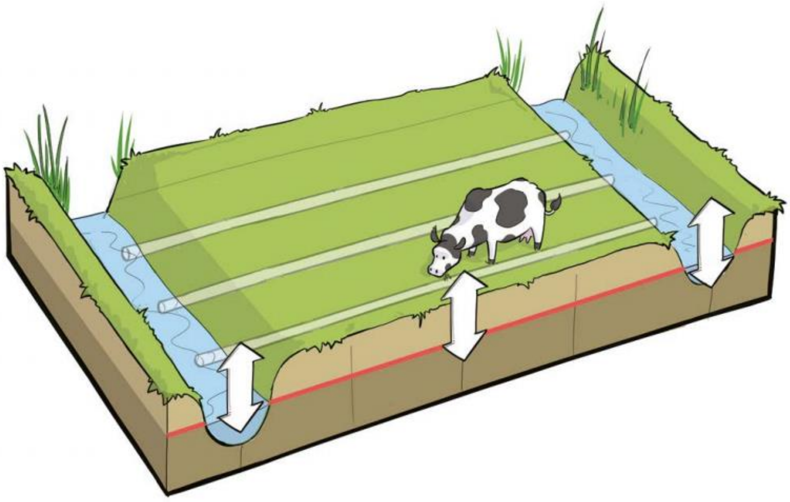


Fig. 2: Situation with UWD.. (Source: Bos et al. 2017)

Starting from the basic pipe concept illustrated in figure 2, additional experiments are run with more dynamic water levels in the ditches and pumps to put extra water pressure on the drains when desired.

Studied projects

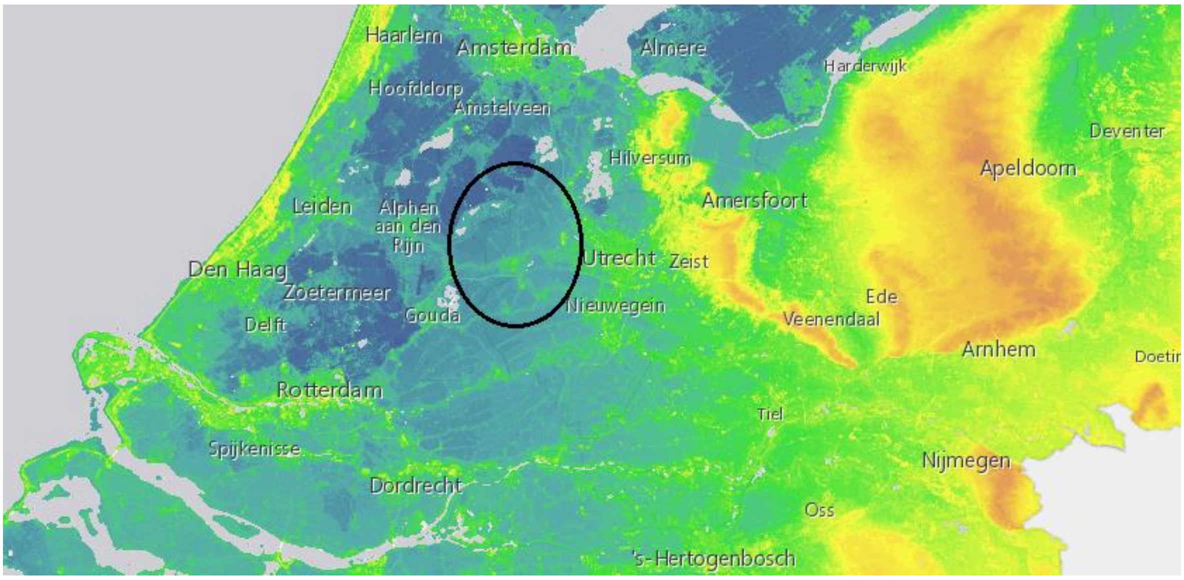


Fig. 3. Height map central Netherlands with area of studied projects. (Source: AHN, 2020.)

At multiple locations in the Netherlands projects and experiments are carried out with these various forms of UWD systems, by implementing it at plot, farm or polder level. The waterboard was a key player in two projects: polder Spengen and polder Lange Weide. Both locations are situated in the circle shown in figure 3. This area is known as 'Het Groene Hart' (The Green Hart) and is valued as an important natural and rural area, as it is situated in the most urbanized region of The Netherlands. The waterboard helped realize finances (a combination of farmer investment and government funding), made monitoring plans for the UWD effects and was the central point of contact for farmers in the project.

In the context of these UWD projects, the main actors that were studied in this research can be pictured in the network below. Apart from the farmers, scientists and media these actor groups are part of the waterboard that was studied.

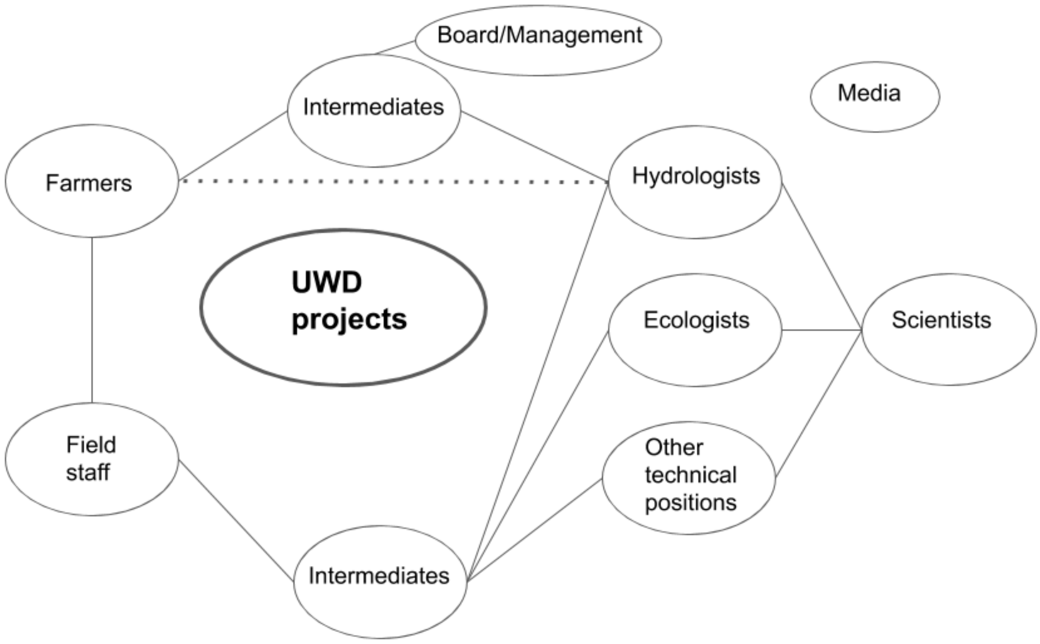


Fig. 4: Schematic representation of network of actors surrounding UWD projects

Thesis outline

The following chapter offers a theoretical perspective by which we can further understand the connections and interactions and how they affect the use of mathematics in the development of new water management. Following these concepts, research questions can be formulated, which are further developed in detail and combined with the description of the methods that were used in the fieldwork. In chapter 3, 4 and 5 the sub research questions of this thesis will be answered by analyzing the fieldwork data of the studied UWD projects, zooming in on daily practices, communication and broader rules and routines in the use of mathematics respectively. Chapter 6 will discuss the fit of the theoretical framework and limitations in relation to the findings and concludes with an answer to the main research question: *"What role does mathematics play through and for different actor groups in the process of creating new water management for the farmed peat meadows in the Netherlands?".*

.

Chapter 2: Theory, methodology and data collection

Conceptual framework

Societal and technological development

This research will be taken up considering technological development and societal development as mutually dependent. One direction of this statement is widely accepted: technology is part of the everyday life of individuals in many aspects and technological developments influence our society on daily basis. The other part of the two-way dependency, that the way science develops itself is dependent on how society forms it as well, is less acknowledged. In the introduction of the book 'Social shaping of technology', Mackenzie and Wajcman (1999) argue that the development of technology should not be seen as a deterministic process with one best outcome, but that the course of development of technology is very much dependent on the context of the society in which these technological developments take place.

An example of important social factors in selection of technologies in the agricultural sector is given by Vanloqueren and Baret (2009), where the development of pathways such as genetic modification or agro-ecological technologies are shown to be largely determined by societal factors. Examples of these can be found in the current capitalistic system of selecting surviving businesses, institutions that give funds, make regulations concerning perceived risks and make rules on what should be incorporated in the cost price of a product. Here it is society that sets the boundaries of the space in which the technology could develop. As mathematics has the reputation of being very theoretical it might already be hard to see links between mathematics and technology, but even more challenging to imagine the dual influence between mathematics and society. Nevertheless, Vanloqueren and Baret show that the analysis of institutional factors should be incorporated in the study of the use of mathematical models in a social context such as the search for solutions in the Dutch peatlands.

The process of this dual influence is exemplified in detail in a historical context by Porter (1995). A striking example he describes herein is the need for statistical information about the French society in the years around the revolution. The newly established government wanted to gain more insight in the French population, but struggled which categories they should take. The pre-revolution 'elite-based' categories were found not to be appropriate anymore, showing a clear influence of society that the statisticians tried to take into account. As they wanted to gain uniform information from every part of the country, they insisted on making new categories themselves, hereby forcing the local officials that were gathering the information to commit to this system as well. Slowly, the newspapers and locals started taking up this system of categorization as well, showing how the statistical science also influenced society. The question Porter hereby raises that is still relevant nowadays, is how the creation of and debate on measurements influences the development of solutions for societal problems such as peat meadow water management.

Objectivity of models and measurements

The mutual influence of technological development and societal change imply the importance of political factors, as argued by Winner (1980). He stresses the fact that developed technologies have political qualities in embodying power and authority. Mathematical modeling is often seen as 'creating a neutral truth', which is not as unambiguous as it may seem. Next to the fact that many choices have to be made in the development of a model, a good example of social influence in modeling is the politics that could evolve around measuring input that is used in models. Porter (1995) argues that defining measurements for concepts is a social process influenced by the power of societal groups, as shown by his example of measuring volume of grain in old-regime societies. As this was of economic importance, the size of a 'unit of grain' was negotiated (e.g. how to make sure that the basket was indeed the right unit). Following the same line of thinking, mathematical models in modern society lose some of their neutrality on similar issues as well. Modeling results are influencing important political decision making. This creates a relevant case for a social study of the context in which models are made and used, to gain more understanding of the process of policy making.

Knowledge creation in a social context

Different types of knowledge are created and shared through (and between) all layers of society, as shown in a case study by Wynne (1992) on scientists interacting with farmers in the aftermath of a nuclear accident. He argues that scientific knowledge is value-laden and based on customs and habits, just as the local knowledge of farmers is. The process of knowledge construction is therefore one that is very socially contextualized. Latour et al. (1979) similarly argue that the construction of a scientific fact is a social process of which the outcome is based on the rules and routines set by, in his case study, the culture of researchers in a laboratory. An illustration of the point made by Wynne (1992) and Latour et al. (1979) specifically related to the use of mathematics in science is made by Lahsen (2005), concerning the modeling of global climate changes. Lahsen brings up the concept of the certainty trough (Mackenzie, 1990), in general described by the pattern that those directly involved in knowledge production (often scientists) and those alienated from institutions or committed to different technology (often critics) are highly aware of uncertainty, but those in between (often users such as policy makers) are not. Lahsen questions the certainty trough by showing that researchers in general try to be objective and 'keep a distance' from their models, but that reality is messier than that in terms of personal hopes, aspirations and relations between scientists. Porter (1995) takes this argument further by showing that in history there has been a dichotomy between the need for objectivity and professional expertise judgement. In Western culture objectivity is often seen as something obtained by making quantified observations that are independent of the researcher, drawing conclusions in such a systematic and prescribed way that there is no room for personal interpretation or politics. Porter (1995) shows that in reality the expert judgements of professionals in the field is often highly valued, by the professional itself and the person receiving the advice, leading again to a partially subjective and a socially contextualized way of constructing knowledge. When it comes to knowledge on the more practical applications of technology it is important to take into account that what is lost on scientific objectivity could surely be compensated by knowledge on the local situation and practices, leading to the non-applicability of scientific knowledge if local knowledge is not taken into account, as illustrated by Wynne (1992). The movement of these different types of knowledge and collaboration between actor groups thus form an important part of the technological and societal developments that take place. Therefore, the theory above is advocating for a focus in this thesis on how the different actor groups work together in creating knowledge and how the thin line between objectivity and expert judgement is playing a role here within the context of a project of applying a technology that is developed in a scientific environment, but is now implemented in a practical an local context of two UWD projects.

Mathematics placed in a process of situated action

Following from the argument above that different types of knowledge exist, the question of 'how to use mathematics' is not uniformly established. Mathematical practice is still under the influence of a social context and not leading to one certain truth. Therefore, it actually is something else than just knowledge, it becomes a technique or tool that is used to achieve practical ends. As Jansen and Vellema (2011) argue, a technique, in this case the use of mathematics, is only meaningful if we put it in the context of the user that is being researched. They bring up the term situated action in this context: "every course of action depends in essential ways on its material and social circumstances" (originally Suchman, 1987, p.50), thereby deviating from the assumption that human beings choose their course of action in a mainly rational way. As much as we tend to believe that mathematics is about rational and neutral choice making, this research aims to stay open for the fact that this might not be the case for mathematics in policy making. Therefore, this notion of mathematics as a tool or technique should be incorporated in the analytic lens of this thesis, thereby creating room for the subjects raised in the theoretical framework: institutional factors influencing mathematical practice, the constant creation of and debate on measurements, the influence of models on political decisions and vice versa, the dichotomy between neutrality and expert judgement and the social dynamics in which knowledge is created and shared. In the following paragraph a methodology is introduced that will help by giving direction in the search for answering the main question of this thesis, on the role that mathematics plays in the process of creating new water management for the Dutch farmed peat meadows.

Methodology

As explained in the conceptual framework, the social context in which mathematics is used is important to see the dual way of mathematics and policymaking influencing each other. Together with viewing mathematics as the use of a technique instead of straightforward knowledge, this is the reason for taking up the approach of technography described by Jansen and Vellema (2011) for researching this case. This methodology helps by making a bridge between the theory and methods through creating a structure and lens that facilitates the analysis of the questions raised in the theory. They present it as an 'interdisciplinary methodology for detailed study of the use of skills, tools, knowledge and techniques in everyday life', consisting of three dimensions: 'the making', 'distributed cognition' and 'rules and routines'. These dimensions are further explained below and give direction to the fieldwork that is done for this research.

The making

'The making' starts by looking at mathematics as a technique used in a practice. It therefore becomes less black boxed and less of a 'magical minds' issue. As it was stressed that it is important to keep in mind that not every action might be a rational one, the focus here will be on what is done, not always probing for a why. Attention will be paid to for example the following: use of numbers in general, the mentioning or critiquing of research results, statements about uncertainties, the visual use of graphics in spoken and written language and the use of models and statistics. To help make this dimension researchable the COIN framework (an abbreviation for conceptualization, operationalization, institutionalization) will be used (Crane et al. 2016). They describe conceptualization as a social act that relates to the worldviews and power relations of those involved in this process. This leads to a certain way of operationalization (making the concept measurable, giving indicators) and institutionalization (incorporating in cultural habits and rules) that is therefore value laden. The use of this concept intuitively most easily fits actor groups close to researchers, as they are used to framing questions in a way of concepts and operationalization. Nevertheless, the COIN framework also helps to make visible how farmers and other 'non-researcher' actor groups frame the issues. These groups will also choose their words and arguments in a way that shows how they conceptualize problems around the peat meadows. An example could be that an actor group contests a certain model, or puts a specific solution forward, with arguments that show a specific understanding and use of mathematical concepts.

Distributed cognition

In 'distributed cognition' the focus is on the notion that knowledge is something shared in a group, thereby viewing cognition as a group achievement. Not one single person has all knowledge required to perform a task and the value of the combined knowledge is "more than only the sum" of the individual knowledge. (In the mathematical theme; the notion that 1+1 can be 3.) The consequence this has for the research direction lies in the fact that instead of looking at individual training and learning, attention is drawn to the configuration of actors in networks of unsupervised learning as well. In this case study, attention will be paid to the way in which parts of the process where mathematics is incorporated are socially differentiated between actor groups such as users (e.g. farmers), specialists (e.g. researchers in different positions), critics (e.g. ecologists) and policy makers (e.g. water board officials). To attain a better picture of the organizational knowing, relations between these groups and the culture of information sharing should be investigated. For this aim, the concepts of 'data friction' and 'grounding' raised by Paul Edwards in a context of researchers and models will be used. In his article (Edwards et al, 2011) he shows that sharing data is a process of constant relationship building, explanation sharing (metadata) and grounding. This can be broadened to all actor groups and shows the relevance of looking at the sharing of information related to mathematics as an ongoing conversation in which constant grounding is needed. Issues of interest could be the agreements and disagreements between groups on how to use models and numbers and the relevance of these two. What communication takes place, for example between hydrological experts and farmers? And what kind of frictions concerning modeling arise between ecological and hydrological professionals? To further investigate these types of questions, Mauz and Granjou bring together the concepts 'ways of knowing' and 'border zone' (Mauz and Granjou, 2013) in relation to research. By being sensitive to the fact that different types of knowledge will be brought together, dialogue and friction can be made visible and understood for this study.

Rules and routines

The dimension of 'rules and routines' focusses on specialized, non-localized organizational forms that might be united by a skill-based specialism. Taken from the mathematics perspective, researchers or hydrologists could be seen as the non-localized specialists, farmers as having local knowledge about the physical situation and farming practices, policy makers standing in between. To take the concept of the non-localized specialist even further, the scientific researcher can be seen as the specialist concerning modeling and statistics in relation to the hydrologist working at the waterboard. Mathematics is a subject with many unwritten and written conventions and associations in every layer of society. These conventions may be very different for scientists than for lay-people and they may contribute to different perspectives and miscommunications in the policy making process. As much as the timespan of the fieldwork allowed, the aim was to make visible what kind of implications this has for these more external factors on the practice of using mathematics, just as the broader implications of the mathematical conventions on the wider practice of policy making. This last dimension of the COIN framework assists this aim, as the conceptualization and operationalization lead to a certain way of institutionalization of practices concerning the use of mathematics.

Focus of case study

As argued in the conceptual framework above, the social context is key in understanding the use of mathematics in the search for solutions concerning land subsidence. This research will therefore be taken up from a case study perspective. As to make this research question a realistic one for a two months field work, the focus is narrowed down to two projects on UWD-systems that are related to current WUR research and the waterboard Hoogheemraadschap De Stichtse Rijnlanden. These projects form interesting cases as a broad variety of actor groups is involved, a technique that was developed in a scientific setting is now applied in practice, the debates surrounding the effectivity of the technique contain lots of data and the subject is often discussed in a societal debates. The projects thereby become a case of the use of mathematics in the search for solutions to a complex social problem such as land subsidence. The aim was to find a balance between good understanding of particular actors and to include the diversity of actors involved in the network. The attention is divided between different positions in the waterboard (intermediates, technicians, hydrologists, ecologists, political directors), farmers, media and researchers. This study will focus on the micro perspective of the practices and processes involved, rather than the wider (e.g. national) societal patterns surrounding the subject of peat meadow farming.

Research questions

Main research question

The main research question that this research aims to answer is:

"What role does mathematics play through and for different actor groups in the process of creating new water management for the farmed peat meadows in the Netherlands?"

Sub research questions

The main research question will be answered using the following sub questions, following the technography framework described as the methodology:

- In what ways is mathematics used in daily discourse and practice surrounding the process of creating new water management?
- How is the use of mathematics distributed between the different actor groups involved in the process of creating new water management?
- How do the written and unwritten rules of institutions and mathematics mutually influence each other in the broader context of searching for solutions to problems in society?

Methods

Focus in collection of data

Following from the technographical methodology, attention is paid to the subjects below. This list is not meant as mandatory checking points and will not be complete, but serves as a good 'manual' of focus points. Within all subjects, the intention was to stay away from valuing a 'right' and 'wrong' way of using numbers, but to just observe the practices, opinions and knowledge as it is.

1. The making:
   a. The use of mathematics in daily discourse and documentation, in both cases consisting of:
      i. numbers in general
      ii. the mentioning or critiquing of research results
      iii. statements about uncertainties
      iv. visual use of graphics
      v. use of models
      vi. use of statistics
   b. The value that is assigned to specific mathematical practices and statements
   c. When applicable and considered to have additional value: reasoning of actors to use certain mathematical practices
2. Distributed cognition
   a. Distribution of tasks to different actors and actor groups
   b. Way of communicating with or talking about other actor groups on mathematical topics (e.g. visual, graphs, …, demo's, word choice)
   c. Friction that actors experience and ways of grounding
   d. Forming of a (virtual of physical) platform (border zone) where different types of knowledge (ways of knowing) come together
3. Rules and routines
   a. Organizational practices, restrictions and rules that are forming the use of mathematics
   b. Ways in which mathematics influences the practice of other actor groups and the broader practice of policy making

Applied methods

The methods that were applied during the fieldwork are:

1. Observation of mathematical practices and social interactions: The main interest of the first and second technography dimension are on the actual practices that are carried out and the sharing and communication about it between groups. Therefore, as much as possible, observations of for example meetings and field experiments were carried out. Observation was carried out both participatory and non-participatory depending on the context.

2. Semi-structured interviews: To be able to get additional insights into the underlying patterns, assumptions and possible underlying frictions, semi-structured interviews were done, trying to find suitable contacts in every actor group and applying snowball sampling as well.

3. Analyzing documents, videoclips and reports related to the peat meadow discussion: Part of the communication on policy development is done via documentation. The observation of visual and written forms of communication is part of the fieldwork data.

4. Whenever possible informal observation and interviewing before and after meetings or interviews, during lunch breaks, etc.. Important and often more sensitive topics were brought up here.

In the fieldwork 39 semi-structured interviews were conducted, of which 31 inside and 8 outside of the waterboard. The total of these groups consisted of 2 scientists (statistics and life stock specialties), 6 peat meadow farmers, 12 intermediates related to policy-making and directors, a board director, 5 hydrologists, 5 staff members in other technical disciplines, 3 intermediates related to more technical matters, 3 ecologists and 3 field service staff members. In the semi-structured interviews the subject list described above ('focus of data collection') was used as a guideline, with the purpose of letting respondents talk freely about examples in order to see more of their natural views, word choice and emphasis on certain mathematical subjects or issues. The interviews would start out by asking very general questions on the role of numbers and mathematics in the work of the respondent, as the first associations and links already form interesting information that is otherwise overlooked. After exploring these associations more in dept, more specific questions on the topics on the list that were not raised yet would be brought up, linked to the daily work and network of the respondent. Whenever a specific example incorporating mathematics was mentioned by an actor group, this topic would be mentioned in a neutral way in interviews with other involved actors afterwards, to gain more insight in the different perspectives on a situation.

The 20 specific situations that were observed consisted of meetings and presentations in and outside of the waterboard, preparations of a director meeting and discussions of a more formal and informal nature. A balance was sought between a mixture of 'homogeneous' meetings within a certain discipline of people and 'heterogeneous' meetings where various disciplines interacted. Notes were taken on parts of the conversations that related to the topics listed above. It was mostly possible to take notes on a laptop, therefore making it easy to cite. Whenever notes were taken on paper, they were written out shortly afterwards.

Documents that were part of my data collections consist of "Informed Science and policy interaction" (proefschrift Henk van Hardeveld at the waterboard, 2019), the website www.slappebodem.nl, the documentary *Het zinkende land* (2017) and various internal waterboard documents such as summaries and proposals that are communicated to the management team, email correspondence, fact sheets and the data monitoring policy. De total number of those documents that were not used as literature research in the common sense, but rather as data collection method, is estimated around 20 documents. Comparable to the data collection via meetings, parts of the documents that related to the topic list were highlighted for later analysis.

The informal interviews could not be directly noted, although the highlights were noted down afterwards, as soon as possible. Even though not all information of these informal talks was formally collected, it is an important contribution to the fieldwork in terms of understanding the social relationships and underlying opinions within the organization, therefore playing a role in the right interpretation of other parts of the collected data.

Method of data analysis

All data was brought together using word and coded by comments in a first round in terms of relevance per sub research question. This was then reflected on and further categorized, following a logical grouping per sub question. For the first sub question this consisted of the sorting of data per actor group. For the second sub question the data was labeled by the occurrence or mentioning of friction and grounding, the interference of intermediates, communication choices of specialists and the role of science in the communication processes. The data of the third question required no further categorization before analysis, as the amount of data was small enough to keep an overview. After these categorizations, the data was reflected upon again and lead to the writing of the results in chapter 3, 4 and 5.

Confidentiality and data storage

As anonymity of respondents in this research is important, the collected data will not be made public. Even when the data would be anonymized, the content of conversations, functions and situations would make it easy to trace back certain quotes to specific persons. For similar reasons respondents are referred to only in terms of general actor groups and the detailed context of a quote is not always explained. The internal waterboard documents that were used for data collection will not be published or cited, as they have to be treated confidentially as well. In case of any questions about the collected data, feel free to contact me via marion.snijders@wur.nl with your question, after which I will try to help you while guarding for the privacy of respondents.

Researcher's identity

As the researcher's identity cannot be forgotten in qualitative research it is important to note that I have a background in mathematics myself, as a mathematics bachelor graduate and high school teacher in mathematics. There is a certain, almost cultural, notion that mathematics must be very complicated. Although I tried to avoid this in my fieldwork, people could be intimidated by this notion. On the other hand the factor of me as a relatively young female researcher, not a stereotype for either mathematicians, technicians or farmers, might also influence attitudes in interviews and meetings. Without being able to pinpoint the exact effect on my data (collection), a note has to be made that my female gender and the fact that I had a bachelor in mathematics was a clearly present factor influencing the daily discourse in situations that are traditionally more of a man's environment or a non-beta situation. In both cases the effect would fade a great deal when visiting a second or third meeting, or after building more rapport and understanding in interviews. Although I tried to first make observations and only afterwards interview people, therefore also limiting their consciousness about my identity and interests in the first phase, my presence and interest for numbers made people conscious about this subject in a way that they might not be in my absence.

Chapter 3: Mathematics used in daily discourse and practice

Introduction

During fieldwork, depending on the audience I would introduce myself as a master student interested in 'mathematics, models and statistics', 'graphs and data' or 'numbers'. I would explain that I was interested in how people would use them and talk about them. One of the puzzling things was the fact that apart from the real 'beta-nerds' (a word this group used to describe themselves), almost everyone answered straight away with almost the same sentence: "I don't do anything with numbers.". Maybe they were busy, already heard about me and tried to politely avoid me interviewing them, who knows. But most of the time, once I found the right subjects to ask them about, we discovered that they actually did a lot with numbers in their jobs. They became enthusiastic and had many examples and most of the time a clear opinion on subjects related to the handling of data. Note the deliberate word choice of '*we* discovered', as they often concluded the interview with a remark of the nature: 'interesting subject, this does actually play a big role in our work, I did not realize that before'. The findings of all of these daily, sometimes unconscious, ways of using numbers in various forms will be described in this chapter. It thereby aims to answer the sub research question *'In what ways is mathematics used in daily discourse and practice?'*.

The findings are categorized by the actor groups hydrologists, ecologists, other technical specialists, intermediates, farmers, field staff, board/management, scientists and media, following the description of the network in the chapter 1 (fig. 4). In the present chapter the focus will be on practices and communication within the actor groups, the next chapter will dive into the details of the patterns found when those actor groups communicate in the larger network. The results of this chapter will be analyzed using the COIN framework explained in chapter 2. Attention will be paid to the various concepts that actor groups value and how they give those concepts a meaning or value via a certain operationalization. These concepts are not meant as an exhaustive list for every actor group, but as a concise representation of the most relevant or outstanding results. This will show how the daily use and understanding of mathematics differs largely between the various actor groups involved in the UWD projects.

Findings

Hydrologists

Hydrologists are part of the 'knowledge team' within the waterboard and are consulted by other departments for questions that are related to the flow of water through the area. Their role is often advisory on issues that other departments raise, but they also take the initiative to put things forward that they think to be urgent. They were, not surprisingly, one of the actor groups far into the technical and theoretical corner. They did identify themselves as the group that uses mathematics most from all the professionals within the waterboard. On the other hand, within their discipline of hydrologists they felt they were not that theoretical, rather relatively practical ('*huis tuin en keuken hydroloogje')* compared to hydrologists working for other companies and institutes. A practical aspect of the work of the hydrologists consists of going to the fields of the farmers to help install measurement instruments, explain procedures and gather the data. This dynamic will be explained in more detail in chapter 4.

The waterboard hydrologists work with models and analysis of data, making measurement designs and writing reports. In communication between hydrologists, jargon related to the general water system and modeling is used, such as delay time, drainage resistance, vegetation constant and software names. In the modeling practice of the hydrologists, there is a high degree of familiarity with settings and inputs of the model. They have practical knowledge on the actual water system that they model in terms of names, pictures and typical values of important parameters. They separate different types of models, for example machine learning, physical models and probability models. The mathematical theory behind the model and the way it works behind the scenes is not that well known by most hydrologists, this is not seen by them as their core task.

> *We have learnt all the relevant formulas and background, but we don't specifically use that anymore. We are modelers, we should know how to use settings, know how to interpret the outcomes and know which results are realistic for the real life situation. If you have knowledge on how the model specifically works or how it actually solves the equation, you are more of a programmer or a mathematician.*

Hydrologists value models that represent the dynamics of reality (goodness of fit) and are reliable in their results (not too much uncertainty). When they talk about data patterns in general they value neutrality and try to look for causal relationships. In the next paragraphs these concepts and their operationalization by hydrologists are made visible.

Goodness of fit

Hydrologists are conscious of the fact that the model they use is a matter of choice, but they also explain this choice is not always a very deliberate one. It is a practical question of money (what license do we have, how much time does it cost to use a model compared to another) and of habits ("we now know this one, so you just keep doing that in order to save time"). Once every few years this question is raised though, and in these situations a much more deliberate choice is made with pros and cons for various models and their implications for the results.

Whether a model has a good fit, is mostly checked via the realistic outcomes that the model should give compared to the real life situation or the expected value of the calculation. Hydrologists of the waterboard do value calibration with data that is gathered over time, but do not do this as much as they wish at the present moment due to time constraints. A goodness of fit is therefore not that much quantified by statistics or systematic comparison, but mostly determined via expert judgement of the hydrologist and other involved professionals.

Uncertainties

Hydrologists see uncertainty in the model as something that is part of the modeling reality:

> *Hydrologist 1: "A model is in its definition not the truth."*

Hydrologist 2: "The question is which one is 'the least wrong'." Hydrologist 3: "Yes, or which one is 'not-wrong' enough" [to use].

Hydrologist 4: "We say we make sure that no one gets wet feet, but if the situation is extreeeeme, we call it force majeure. So it is always 'almost always'. But [as hydrologists] we find this normal. An extreme event, once in every 100 years, could happen three years in a row."

Hydrologist 3: "A model gives a chance for a certain outcome, and that's difficult because 95% chance means that you could be wrong five times in a row. A model is not reality."

For physical models (meant here as: a model resulting in an actual 'number' for a specific real life parameter), they do not quantify specifically how uncertain their model is, or what the confidence intervals are for found parameter values. When talking about this theme, they explain that it is hard to determine these uncertainties or confidence intervals. In case of a physical model they say:

"The model just gives us a number, with so many decimals. It is up to us to determine the value of this result, but there are so many things influencing this model, like the data that goes in, the formulas in the model, the choices for parameters, that it is hard to say what the reliability is in numbers. Of course we do try to use our knowledge for a judgement whether we should further improve a model before presenting a result, or not use a model for that situation at all."

The hydrologists try to do sensitivity analysis with parameters and/or inputs to see whether it is important that certain parts of the model are accurate. In the case that a slight difference in a parameter value has a large influence on the output of the model, more effort is put in determining the parameter value precisely. This can be done by diving into the data, discussing with colleagues or consulting practical professionals.

Hydrologists are conscious of the fact that in some cases it could be hard to actually measure some of the variables of their models and data sets. There is, for example, discussion about whether it is possible to measure groundwater height/level in a reliable way at all. The hydrologists take care in searching a measurement method with high credibility and keep in mind that also after this choice they should keep in mind that the results are debatable. They do however, mainly because of practical reasons, work with the debatable data with the argument that the alternative of 'not modeling or analyzing such a parameter' is not a better alternative.

Neutrality of analysis

The hydrologists see themselves as a party that should be neutral in their advice, staying as close to 'the truth' or 'reality' as possible. They also do identify their position as 'close to science', although they see themselves within the waterboard as 'not in a scientific institute'. In practice they indeed cannot act following what they see as 'scientific practice of experiments' because of time constraints for analysis of data and financial constraints in the amount and quality of measurements. However, the hydrologists still try to stay close to these practices. An example of these conflicting concepts and interests is the choice of reference plots in the UWD projects. Farmers would like to apply the new UWD approach at places where it is expected to be effective. In order to have a reference that is comparable, some of these places have to be kept empty. This lowers effectivity for farmers who invest their money in applying UWD in their fields. Another factor that raises costs is the measurement of various variables.

Due to money limitations the choice is made to have one reference representing a relatively large group of 'treated' plots instead of a one-to-one correspondence of UWD plots and treatment plots.

> *"Sometimes you get your data results in a way which makes you think 'this is horrible'. But it is what it is. If you know certain [side] effects are there, you try to keep that in mind. And you know what you should expect, so this helps you to estimate or value the influences of other factors."*

Cause and effect

Hydrologists try to make the concept of 'cause and effect' visible via numbers. This is done by looking at gathered data and searching for patterns, mostly done by visualization through graphs. They are trying to be careful not to draw conclusions too fast or lightly, but often do not turn to statistics for this purpose. Statistics is seen as something that is also based on choices (e.g. which test and bandwidths) and therefore not necessarily more neutral. It is also seen as something that could make things unnecessarily complicated. Statistics is linked mostly to longer time series of data, to make these data series understandable and make trends visible there. For smaller amounts of data it is seen as something that cannot be usefully applied. However, the hydrologists of the waterboard do think using statistics would sometimes raise the recognition or status of their experiments and projects in the wider publicity and scientific network. As a waterboard they think being scientific is not their core business, as they are more of an 'applied science' institution. In determining the cause effect relationship hydrologist value laboratory work as scientific and valuable, but also see practical constraints here. The reality is often more complex than an experiment in the lab, and some mechanisms such as soil life are not working as usual in a laboratory situation.

There is a high consciousness under the hydrologists of variability and the uncertainness of conclusions this brings in general, an example of this is the land subsidence. This variable has a high variability because of the sponge dynamics of the peat meadow soil. Every year the land could go up and down 10 cm due to seasonal changes, but the trend over multiple years is estimated around 1 cm subsidence per year. The hydrologists are reluctant to draw conclusions based on this variable and advocate some patience of other professional groups as well.

Ecologists

Ecologists concerned with the peat meadows mostly work from an advisory or research position. They plan and assess data collection plans and analyze them afterwards. They easily talk about numbers, graphs and ratios and their jargon is mostly centered around plant types and chemical water parameters. Important concepts for ecologists are 'a good status of nature' and 'cause and effect' of interventions or policies.

Actors of all groups have experienced a change in the use of numbers over the last decades. Numbers became more prominent and the profession has changed, which was exemplified by an ecologist. He described the two different roles that now exist within ecology: 'the people that want to be in the field and value the field most' and 'the ones who specialize in modeling', with a tendency of the profession to move more towards the latter group.

'Good' nature

The aim is often to give advice on how to get the ecological situation 'better', but ecologists do acknowledge that it is hard to define what is 'good' or 'wished for'. When talking about 'improving the ecological value' or 'improving nature around the peat meadows', ecologist often nuance this by bringing up the fact that it is hard to link clear goals to this concept. The struggle to define 'good nature' has two components. First, there is an ideological question of what type of nature is desired. 'Restoring the type of nature that was inherently there before human interference' and 'fostering biodiversity in the sense of having many plant species' were the ideas that were mentioned most often. Second, there is the issue of quantifying, as it is hard to quantify when exactly, for example, a good biodiversity balance is achieved. Ecologists do have quantified rating systems for assessing the ecological status of an area, working with for example indicator species that are labeled as 'not desired' and 'desired'. The presence and quantity of these species are measured, leading to a total score of the area under investigation. Because of the huge debatability of these scores, the ecologists talk about the rating systems without much enthusiasm, but they do use them a lot in daily practice for advisory purposes.

Cause and effect

In analyzing data with the intention of looking at causal relations, such as a new maintenance plan for ditches next to farmland, the situation is similar to that of the hydrologists. Ecologists do value statistics, but due to time and money constraints this is not applied a lot in daily work. Several respondents mention that for larger research questions external companies are hired and that they do use statistics, when a question on this topic was asked. In their own work, observations and practical findings of different patterns are valued a lot and are sometimes taken as results as well. As an ecologist would put it in a presentation of a project about the effect of farming practices on the ecological status of ditches:

> *"We tend to see a lot in these numbers, we might see too much. But when I look quickly at this overview, I do see that [location x] does have better results. And when you walk there, sometimes just outside the plots that were selected for taking measurements, the situation was even better than the measurements I had to take."*

The ecologists within the waterboard do not see scientific research as their core business, because they are working within an executive organization. A large focus is put on being open about the measurement techniques that were used in reports. Communication about the measurement techniques is felt to be important for interpreting the results of the research and for remaining a reliable and neutral party. The issue of the numerous parameters influencing each other is clearly acknowledged, which is a reason for often not drawing straight conclusions. Therefore the work of ecologists has a more 'monitoring' focus, in showing the status instead of searching for clear cause-effect relations.

Other technical disciplines

In the total network surrounding water management in the peat meadows, various other technical professionals are involved. Many processes around the directing of 'water works' (artificially built, meant for managing the water in the system) are automated, with a monitoring team for troubleshooting and daily management. Another team is coordinating the data gathering, validation and storage of data. These teams are closer to the practical situation because they are directly involved with how, why and what kind of data arrives at the systems. The boundary of this group of being a technician or an intermediate between the far practical and theoretical end is getting blurry. In this paragraph the focus will be on the more technical part of their work, the other function of some of the professionals will be discussed in the part on ' intermediates'.

Uncertainties

Technicians in general are concerned about the quality of data, but do not analyze the larger data patterns for drawing conclusions. They are very aware of the measurement issues that could come up when measurement is carried out wrongly, but most technical professionals take results a little more as a fact than the group of advising ecologists and hydrologists above. An exception to this is the group that is specifically making measurement plans and organizing data storage. The main focus of this groups is the uncertainty in the preciseness of the measurement (for example: to how many decimals is a measurement relevant?).

Cause and effect

Most technicians see cause and effect relations in very short term situations. They do analyze measurement values, associate those with short term changes in management and draw conclusions. This fits their job as most of their monitoring and automating tasks are related to short-term problems. The longer term time frame with causal relation questions is seen as the job of the advisory/knowledge departments of the waterboard. The use of statistics is therefore seen by the technical professionals as something not appropriate for, or fitting with, their type of work.

Farmers

Farmers interviewed and observed for this research were involved within the UWD-projects of the waterboard. They are all dairy farmers and feel the political and physical urgency to find solutions for the land subsidence in their polders. In daily practice farmers have to do a lot with numbers in registration and legislation, but identify themselves less with using numbers within the UWD projects.

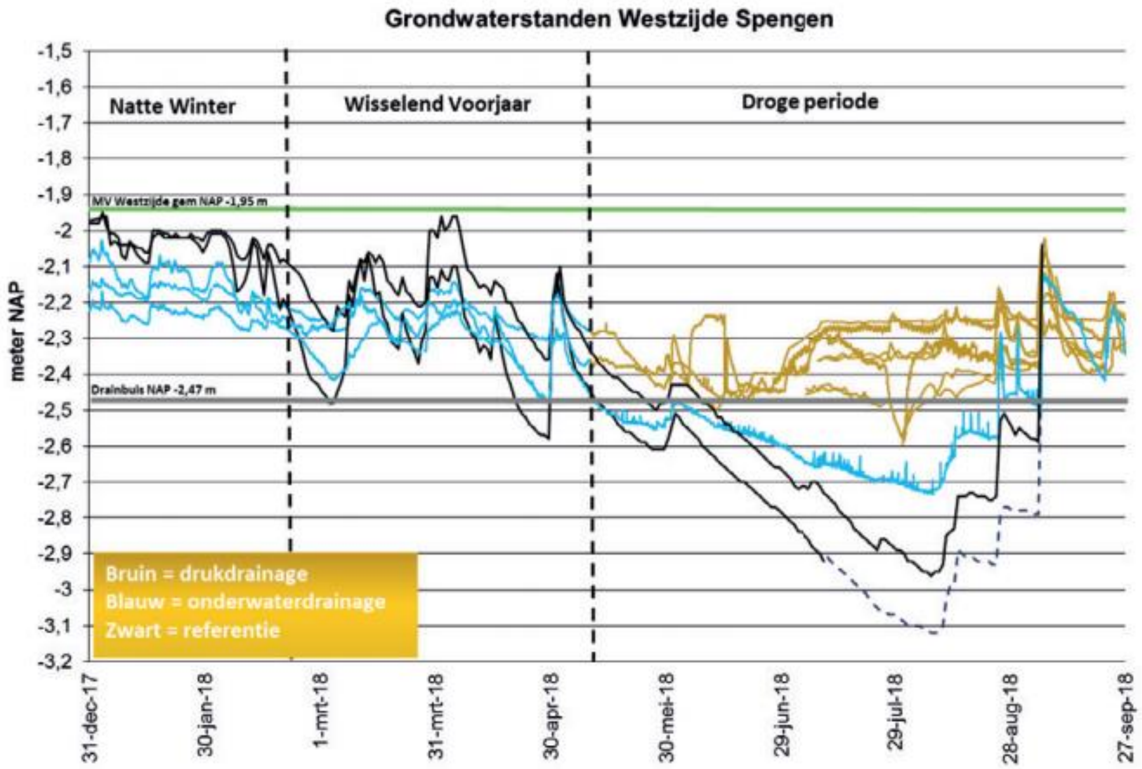
Once a year the farmers have a meeting with the project leader and hydrologist together. In this meeting, graphics are shared by the project coordinator and hydrologist of the waterboard. Farmers say they appreciate these meetings because it is an opportunity to share experiences and see what the situation is at other farms. One could also see this in the fact that the meeting continued a lot longer than it was planned for, mainly because the farmers wanted to ask questions to the waterboard and fellow farmers a lot. An important part of the meeting is presenting the groundwater level graphics and land subsidence measurements. An example of the groundwater level graphic is shown in figure 5.

Most farmers appreciate the fact that this information is presented by the hydrologists because it is quite complicated to read on their own. At the same time, they are very assertive in asking questions and take a critical standpoint. The presenting of the graphs during the meeting was an interactive process, with for example the following remarks from the farmers.

> *"Could you go back a slide again? This yellow and green one, should be equal right? Is there an explanation for that?"*

"Hey, is this graph increased/raised? (Pointing at the y-axis, which is indeed differently scaled because the plot is 2 times larger.)"

"I would prefer the graphs to be presented not with measurements per day, but per week (or so), so the lines will flow a little more quietly."



Figuur 3 Verloop van alle bemeten grondwaterpeilbuizen aan de westzijde van de polder voor het jaar 2018. Het gaat om vijf drukdrainages, één reguliere onderwaterdrainage en twee referentie percelen. De groene horizontale lijn geeft de gemiddelde maaiveldhoogte weer, de blauwe horizontale lijn de hoogte van de onderwaterdrain.

Fig. 5. Example of a graphic of groundwater measurements. (Source: summary Bedrijvenproef Spengen 2017-2018)

Cause and effect

In the UWD project the groundwater level is measured on a daily basis, other variables such as ground level and soil moisture are measured one up to a few times a year. However, to assess what decisions they want to take in handling their grass land plots, farmers mostly use their feelings, experience and knowledge on events in the past.

"When I went looking at the sheep, one would expect [the plot] to be soaking wet. It is a plot of the neighboring farmer, he wanted to do it well and put drains every 4 meter [6 is regular]. And the field was a lot dryer, so you start thinking, what does make this possible?"

When talking about the UWD-systems with each other, farmers mostly share practical issues and solutions such as frost protection, algae growth, and a general feeling on the added value by the system. When talking about the usability of their land they say things as 'they plot was clearly dry enough quicker' without an exact quantification. They see the measurements in the experiment mainly as a business of the waterboard, but are interested in the results. They do take initiative in for example placing an electricity measurement instrument at their UWD pump.

> *"For us, the UWD-system is a minor subject in the whole of running our business. We will not be looking at the measurements on daily basis. The numbers are mostly for the waterboard, they have to show results [to other parties]. But we do like to see the results once in a while. How am I doing compared to a neighbor? And what will it do on the long term with groundwater and land subsidence?"*

In the conclusions about results of 'does it work' or 'does it help' farmers are careful. They are very aware of the fact that lots of factors in their farming practice and the weather influence what is measured. They are less focused on the measurement errors that take place in the measurement itself and are trusting the waterboard on being neutral and not political. They question the conclusions of the links between the variables, not the measurement numbers itself.

> *"In my opinion, the weather has a larger influence on the result of the measurement, than the actual change because of the UWD system. So I told them to consider the weather of the past week when planning the gathering of the data."*

> *"They [the waterboard] said that this was the best method for groundwater level measurement, so I trust them on it. They also explained that it is very hard to measure the land subsidence, but as they let a specific company do that, I hope this method is accurate as well."*

Farmers understand the fact that patience is needed for a few years before conclusions about land subsidence could be made. They are mainly positive about the UWD system, but also advise to wait with other UWD projects because they are not sure if this technique will be a valuable investment for farmers on the long term.

Neutrality of analysis

Farmers do ask for scientific results of researches related to the livestock branch. They value the input in for example the question what the ideal groundwater level or drainage height would be for farming, but also take a critical standpoint in how valuable this will be for their specific situation:

> *Farmer 1: "But don't the deeper layers play an important role in the subsidence as well?" Farmer 2: "Yes, that's what the professors say as well. And they all want the best result, multiple universities, so I'm curious what the outcome will be." Farmer 3: "Yes, but they will compute 'a' number, that does not make any sense, it should be customized advice, all situations are different."*

Farmers do see numbers as something which has a political power in it and as something that is not always 'neutral'. When their social distance to a research project is large, farmers often feel that it gets more political.

> *"You have the 'believers' and the 'non-believers'.."*

> *Farmer 1: "On the short term they cannot say anything about land subsidence. But they did precise CO_2 measurements and out of them they can calculate the subsidence." Farmer 2: "Well, they did that before, and you see that there's a lot of wishful thinking in those, so that might not be the solution."*

In the results close by, for example in the UWD project, farmers don't feel this effect plays a significant role and bring up the good relationship and trust they have with the intermediate waterboard employee as a reason for this.

Uncertainties

When asking farmers about uncertainties, they do see risks mostly in financial aspects. The choice whether to invest is not directly related to the uncertain causal relationship between the UWD system and its profitability. It is rather directed at the current possibilities for co-financing in this project, further opportunities for future farming generations and strategic political motivation. The waterboard had plans to raise the ditch water level in the coming period of time as a way of slowing land subsidence. The political motivation can be seen in the fact that by starting this UWD project, the farmers know that the waterboard will not start the implementation of these plans in the near future.

Field service staff

The field staff of the waterboard is concerned with the actual implementation of policies in the field, guaranteeing stable water levels and doing all sorts of maintenance on water works. Their role in data gathering is checking measurement equipment for errors, sound placement and reading out the measurement values (some regularly, some only once a month as a check of the automatic one next to it). They are the contact person for citizens and farmers in the area whenever there are questions or complaints.

Field staff professionals tend to mainly talk without numbers, more in terms of 'a lot', ' small' or pointing out a height with their hands. However, whenever a quantification is needed or asked they easily translate these words into numbers. Their spatial awareness contributes to easy map reading and clear communication of what specific place or situation is meant when they communicate. The field staff does see a value in the measurement that is done for 'higher purpose', but value 'seeing something work themselves' rather than measurements and conclusions drawn at the office. They do work with the automated system every week, by checking the graphs with water heights and operating status of waterworks that are relevant for their area. Some of the older field staff are not that comfortable with this part of the job, but new staff members are being selected on being open to gain these graph reading skills. Related to the office staff they say that they do understand the basics of the graphics, but that ' the office people 'dig in deeper' and take into account more parameters than they do.

Cause and effect

In general, the field staff has some resistance or cautiousness to believe in models, but do see the value of accurate measurement for the improvement of models and are motivated to contribute to this. In their own work, they are mainly concerned with very short term cause and effect relations of changing the settings of a water work and thereby adjusting the water levels.

Scientists

The scientist that are directly or indirectly related to WUR and the UWD projects are particularly having knowledge on both a topic related to farming (e.g. soil or cattle) and knowledge on statistics or modeling.

Cause and effect

One of the things that clearly differentiates scientists related to WUR from ecologists and hydrologists at the waterboard (the latter two groups generally educated at a university as well), is that the scientists put a much larger focus on proving cause and effect relation by investing in reference plots and more emphasis on statistics. A larger amount of money is spent on making the use of these reference plots possible, as for example plots are split in two where drainage is implemented only on half of the plots. This raises the costs of implementation, which is a reason why this is not done at the fields of the farmers (there an entire plot is chosen as a reference, and entire plots have UWD implemented). When publishing a report, mainly linear regressions are reported with the equation and explained variation (R^2). Whenever applied, data transformation is shortly mentioned, often accompanied with a scatterplot of the data before the transformation. Scientists tend to see a scientific publication as 'better' than a report of results without the accompanying statistics, but due to practicalities and time constraints also the scientists do regularly choose for only writing a report.

Uncertainties

In general, scientists put a large focus on measurement choice and calibration. They show carefulness in relation to the uncertainties and the implications for conclusions in an experiment. Most of the time and energy that is spent on the theme of uncertainty of measurements, is on improving the techniques and describing what technique is used. Comparable to the hydrologists, they do not quantify the measurement uncertainties in most of their results.

Intermediates

Intermediary professionals that are in between different technical professionals are mostly having a technical background themselves as well. They have a position in which they communicate and coordinate between different technical teams and are focused on creating mutual understanding and making things 'move' or 'happen'. They do understand the terminology, but they are less acquainted with the tools such as a hydraulic model or GIS and more focused on results rather than a nuanced story. Towards actors that are not familiar with technical subjects, they try to translate words and numbers into pictures and see this as part of the skill set they should have.

> *Intermediate 1: "Farmers have a reasonable feeling for numbers, citizens don't. We try to use examples, but if I say 13 swimming pools, they still don't know the impact. So you try different examples, FC Utrecht maybe. Farmers know the size of their land. Citizens that have bought a house in a rural area have no idea about these things." Intermediate 2: "And for example 1000 liter water, a citizen does not have an idea, they did not learn mathematics. You could say 1000 bottles of milk, but still, how much is that, could you point that out on the ground?*

The intermediates who are close to political directors and management often take the lead in organizing projects and finding financial resources. Just as the more technical group of intermediary people, those close to policy making often have a technical background in terms of study or farming as well. In their communication with the management team they tend to translate larger, nuanced stories into shorter information and tend to want to draw a conclusion faster than the more specialized and technical professionals.

Neutrality of analysis

Intermediates do think it is their job to make things visible and clear without losing neutrality or nuance and see this as a balance with being able to take action.

> *Intermediate: "It is often frustrating that we get insecure input from hydrologists with stochastic info that could change every day. I need a truth, give me a value and don't change it tomorrow." Researcher: "And what do you do when these inputs stay vague?" Intermediate: "Well, in the end, I do my own thing. Rather in a responsible way than not of course, but decisions have to be taken."*

The intermediary people see themselves more as part of the technical professionals than as part of the management and they do look for tactical ways to present info to the board in such a way that this leads to effective decisions. They see the way they present numbers and the timing as part of their expertise in creating movement in the bigger decision making process.

> *"We always have to find our way to the board and their policies. How shall we do that this time? How do we present the numbers in such a way that the board can do something with it? And when in the process do we present the numbers? We learnt that one should not give the numbers [results] that immediately, because the board first wants to feel more 'involved'."*

Cause and effect, uncertainties

The understanding and operationalization of the concepts 'cause and effect' and 'uncertainties' is highly varying within the group of intermediates. This seems to be related to the background they have and how close the working relation is with specific other actor groups.

Media

Media messages in general contain short messages of the plans for or start of a UWD project. Numbers are typically used to inform on the size of the project, in terms of hectares, length of implemented UWD pipes or money. In journals specifically focused on farming, the focus is usually directed to whether an intervention works. In these journals, links to research are also made. Articles are mostly written as essays, but graphs and research results are presented for argumentation.

Board and management

The political directors and higher management are broadly seen as alpha's, both by themselves and from the perspective of other actor groups. It is not considered to be their job to understand the specifics of a technical problem, or the details of the meaning of a result. The board and management do take decisions about targets and quantify these with numbers, but the implications of these numbers are often not that familiar for them. This is partly due to the fact that the board does not necessarily have expert knowledge of the subjects they take decisions on, with time constraints on the effort they can make to improve this.

Cause and effect

Management is not expected (nor by themselves, nor by others) to have in depth knowledge about the wrongly drawn conclusions on cause and effect and modeling choices. They are often informed with short 'headlines'. As a board member put it:

> *"It is not my job to dig deep into the details of a question. I should be able to trust the specialists. They will present me with the outcome of nuances and good research that they have weighed themselves. If I would always be asking all the details of a computation, I would be spending too much time on it, and for [the professional] it would feel as if I wouldn't trust them on the topic."*

Uncertainties

The concept of uncertainties that do matter to board members and that they come up with when asked about this concept, are 'strategic uncertainties' (who takes responsibility) instead of 'knowledge uncertainties' (what is the effect of the UWD). As examples they name risks of financial and political nature. For the UWD projects, the question which financing party would take up the role of treasurer was a political and financial risk. The large investment of implementing UWD pipes had to be done at the start of the project, and finances were spread over the government, province, waterboard and farmers. As the projects attracted lots of media attention, the course of action that is taken could also strongly influence the future political position of board members.

Conclusion

In conclusion, lots of numbers, graphs, research and models are used in the processes around searching for solutions for the peat meadows in every actor group apart from the board, management and the larger media. From the perspective of a mathematics teacher, it surprised me in a positive way how 'literate' actor groups were with numbers. These skills are surely not something that should be taken for granted. The interesting fact that people do not have the impression that they use numbers before I bring it up, might be explained by the idea that numbers are 'just' a tool to tell a story. As one of the respondents puts it:

> *"I thought I did not use [numbers] a lot, but actually I do. Maybe we don't notice because you translate it automatically, by yourself. It is not about the number, but about the theme or the story, so you forget about the numbers that it started out with."*

In the results of this chapter, focus is put on the different understanding and operationalization of concepts that underly this often unconscious use of numbers. The COIN framework argues that through the operationalization (and the following institutionalization) chosen by actor groups, a power dynamic is reflected. The answer to the sub question of this chapter on the daily use of mathematics by the various actor groups surrounding the UWD projects is therefore answered through this lens of concepts and their operationalization. The focus of the discussion in this section will be on the four (groups of) concepts that were found to play a major role in the interpretation and use of numbers: the value of delivering work seen as 'successful' within the context of the actor group, the assessment of causal relationships, the valuation of neutrality of analysis and the role of uncertainties.

In the focus on concepts such as 'goodness of fit' for hydrologists, 'good nature' for ecologists and 'effectivity' for farmers, a valuation of what is 'successful' in their work is defined by the different actor groups. The power dynamic of the waterboard in the lead becomes visible in the choice of measurements. For the waterboard, land subsidence is the most important issue, for farmers profitability is a very important factor as well, therefore leading to a different concept of 'a successful project'. This is reflected in the operationalization, as the focus in the project is more on measuring variables that relate to land subsidence than to profit investigation. Farmers do influence this operationalization with the example of adding an electricity measurement instrument, asking for these data on practical and financial subjects to be incorporated in the reports as well. Herein lies a power dynamic in which the waterboard has the main financial power to steer the project.

Between the different actor groups a general difference in the assessment of 'causal relations' can be seen in that the practically oriented professionals tend to use their personal experience and feeling for assessing, whereas the theoretically oriented professions highly value measurements. When the question 'Does the intervention of UWD influence groundwater levels?' is taken as an example, one can see that the farmer operationalize by looking at experience and short-term visible variables. For a long term question such as the land subsidence measurement, the value of long term data is seen more by farmers. The hydrologist is likely to be focused on numbers, also for the short-term variables that the farmers tend to look at in the field. One could say that the concept of cause and effect is comparably important to farmers as to hydrologists, but farmers are more focused on practical intuition for an assessment of this relation.

The patterns seen in the assessment of causal relations is carried on in the concept of 'neutrality of analysis'. Scientists are at one end of the spectrum, using little 'feeling', leaving a lot of expert judgement behind, really focusing on objectivity through the use of statistics and 'clean experiment designs'. The regular use of statistics in the analysis of causal relations is almost solely used by scientific researchers. Interestingly, not only for the farmers, but also for ecologists and hydrologists, their knowledge on the situation and their interpretation of the numbers play a big role. The hydrologists and ecologists do not have strict rules in handling data and acknowledge the factor of expert judgement as an important part of their job. Here the pattern of expert judgement versus objectivity is clearly seen, as described by Porter (1995). By using their knowledge on both the outside situation and the expected patterns in research situations, the interpretation of data becomes contextualized and therefore less of a neutral judgement in the scientific understanding of this concept.

Over all actor groups, the concept of 'uncertainty' is considered to be important to take into account in the decisions around UWD systems. One sees that everyone is conscious about the fact that it is hard to draw conclusions about the effect of an intervention, because many parameters could play a role in influencing the data. The question whether a measurement device or a model is precise in itself is less prominent in the conversations. This is only raised at the 'theoretical side' by actors such as hydrologists and scientists, while other actor groups tend to treat measurements more as 'the truth'.

The COIN framework emphasizes that different conceptualizations and operationalizations ultimately lead to specific ways of institutionalization. Whereas we now have a better picture of the daily interpretation and use of concepts surrounding the use of numbers, the consequences of the different conceptualizations that were described in this chapter for broader patterns in society will be discussed in chapter 5. A factor that is highly influencing the institutionalization of mathematical practices is the communication within the network of the actor groups with their different use of concepts. The next chapter will therefore start with zooming in on the way actor groups communicate with and about the daily mathematical practices described in this chapter.

Chapter 4: Communication with numbers in a network

Introduction

As introduced in the first chapter, the network around the under water drainage projects could be pictured in the following scheme:

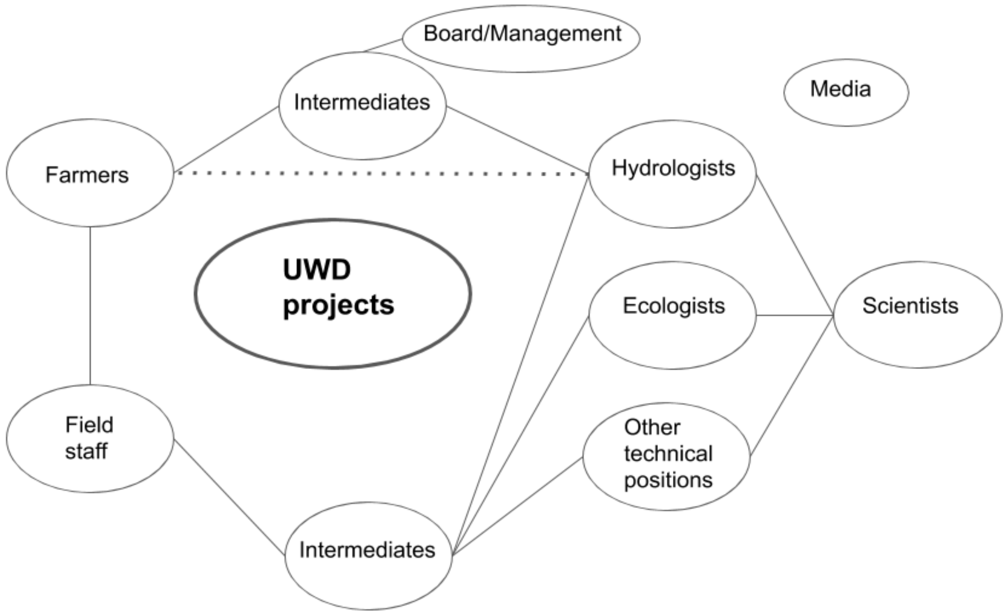


Fig. 6: schematic representation of network of actors surrounding UWD projects

Apart from farmers, scientists and media, the actor groups are all part of the waterboard. The upper part of the scheme is mainly concerned with the practical implementation of the UWD experiments through political choices (board/management), financial and logistic coordination and network building (intermediates), technical/experimental specialist (hydrologists) and the local landowners that choose to participate (farmers). The other actor groups (ecologists, other technical positions, technical intermediates, field staff, scientists) are less directly involved, but do play important roles in the larger institutions that enable the UWD projects. This chapter will show how the use of mathematics is distributed between the different actor groups involved in the process of creating new water management. The findings will not be an exhaustive list of describing all relations in detail, but will bring the attention to relations that shed light on the relevant dynamics within this thesis.

Findings

The office and the field

All actor groups share the feeling that there is some distance between professionals in the field (farmers, field staff) and professionals in the office (the other actor groups), although both sides do experience appreciation and consider the other group as being supportive and often essential. An example of this dynamic is the communication of data specialists with the field staff. Once in a while, unusual data patterns are discovered at the office, for example related to water height in ditches. This results in contact between the office and the field staff. Both parties mentioned this contact in an interview as valuable because of the knowledge of the outside situation on one side and the support of the office people on the other side. The office professional does put effort in the explanation of these problems via phone calls in such a way that the other person is able to understand the point without deep understanding of the graphs, but also acknowledges that this is sometimes hard. In those cases they choose for face to face contact at the office to be able to look at the graphics together. From the office viewpoint there is a belief that the field staff is not always understanding the full scope of theory behind a problem. From the viewpoint of field staff and farmers there is a feeling that theory is sometimes overvalued and that practical knowledge should be consulted more often in decision and policy making. Office staff try to make an effort in closing the gap, for example by joining on a checking round of the field staff every now and then to get a better picture of the situation.

Grounding takes place in many conversations where the links between practical knowledge and theoretical presentation of the situation are linked. An example where common ground needs to be found by field staff, practical technicians, intermediates and hydrologists was in a meeting where the dynamic use of water height in ditches related to the UWD system was discussed. Examples of grounding specifically related to mathematics are:

> *Hydrologist: "The grey one is the precipitation." [pictured as a line in a diagram] Technician 1: "Could you show the precipitation as a bar chart next time? And what about the axes?" Technician 2: "But there is a secondary axis on the right." Technician 1: "Ah okay thanks." Field staff: "It's hard to see the details, could the graph be enlarged next time?" Technician 1: "How should we read this graph now, is this per day? Because it will make a difference whether 6 mm is per hour or per day of course." Hydrologist: " Yes it is per day, I agree on the confusion. I didn't get the scaling tool to work properly today." Intermediate: "Well I do admire the fact that you produce them at all!".*
>
> *Technician 1: "This was the wettest month measured by The Bilt [...], so above the margins." Intermediate: "But does it matter? Because we don't see it in the [extreme] margins. Technician 2: "Could you [the hydrologist] give us the relevant high peaks next time? That will help us judge the situation." Field staff member: "I did not see any irregularities, so I cannot conclude it from the graph, but if your conclusion is that the margins were good as we set them, I agree." Hydrologist: "So, if the whole group agrees that this situation was not causing problems, I'll communicate to other water boards that the UWD system doesn't cause extra problems in managing the water levels." Intermediate to field staff member: "Haha, funny all these people with all these [complicated plans]. But in the end, it all comes down to you, the field staff!"*

Intermediary actors

The intermediate actors play a key role in the network of professionals. Other actors do name these actors as important. An example of this is that farmers bring up these intermediates and their dedication and personal contact as one of the success factors of the project.

Actors at 'both ends' do not have the idea that there are big differences or communication problems, but the intermediates do experience these are present. They are constantly fostering grounding and mutual understanding. An example of this is the friction that took place surrounding gathering of water levels through a phone application. This application was developed to secure more precise and valuable data and make the procedure of finding mistakes or errors easier. The field staff was frustrated with the fact that the application often took the wrong number and that they had to correct this without being able to comment on what was wrong. Here the intermediate person explained the reasoning behind this and resolved most of the friction:

> *Intermediate: "[The technical professional] explained to me that the app works with an algorithm, and that it will take some time for the app to learn to get the right numbers. They are glad if you keep correcting, because over time the algorithm will improve." Field staff member: "But why don't they let us make comments on what's going wrong?" (frustrated) Intermediate: "I got told that there are two problems in that case. The app will still have to learn via machine learning, this works with an algorithm with its own logic, so we cannot use the comments for that purpose. And secondly, if you write comments, there is a lot of data, and this all takes time again to be analyzed and read. Although, they do their best and they are thinking about a multiple choice option, as this is quicker and easier to analyze." [Field staff reacts non-verbally that they are understanding.]*

Several intermediate actors did express that they often had to remind office people of the reality situation of field staff or farmers. The intermediates were translating between the groups or giving communication suggestions as in the following example between farmers and hydrologists:

> *Intermediary: "It's nice to see that the farmers really value the hydrologist, they see that she knows what she is talking about. Sometimes I have to guide a little, as for example with the measurement instruments that we would use. I suggest that [the hydrologist] takes one to the meeting to show. I remind [the hydrologist] of the fact that these instruments are very normal for him/her, but not for the farmers."*

In case of friction in a meeting, the intermediary would often take up a role more close to a facilitator by not choosing sides, making a comment that acknowledges both standpoints and by trying to move beyond this.

The intermediates generally do not communicate about uncertainties and statistics for various reasons, varying from not feeling acquainted with topics such as the details of models and statistics themselves, to thinking that this is not relevant or thinking that this will be too complicated to communicate to the involved actor group.

Hydrologists, ecologists and other technical specialists

Whenever hydrologists, ecologists or other technical specialists talk to other actor groups, they try to be very considerate with their communication. Comparable to the intermediates, they highly value to be a trustworthy party and feel that part of this trust is gained by open and clear communication. An aspect of this lies in the fact that they first discuss with colleagues not only whether the outcomes of their modeling or data analysis is right, but also what part of it should be communicated and how. An example is the modeling outcome of the land levels that had to be communicated at an open meeting for farmers and citizens. Here the specialists tried to improve clarity of the communication by choosing the colors of the legend thoughtfully.

Specialist: "If we would choose blue as the color for the lowest parts of the land levels, which is a habit in these maps, people would immediately conclude that their house or field would get a little lake, while this is actually related to the water level we choose to maintain, instead of the land level itself. But as the numbers don't mean anything to the people, we take those out, choose sensible colors and afterwards explain the actual outcome of a scenario. These presentation are something we think about a lot [together with the intermediate], on how we can improve them."

The specialists value the contribution of intermediates in the sense that they bring together actors and help in fostering understanding. They do however sometimes see friction in the fact that the nuances in their findings are generalized and carried on as 'truths', losing the uncertainty nuances that came with their model or computation. This dynamic was visible in the process of writing a report with the representation of findings on one of the UWD projects. The report was written by a team of a hydrologist and an intermediate.

Hydrologist: "We did need a quick graph of the land subsidence principle for a political person that would visit a farm. I'm always very careful with making such a non-scientific estimated-line graph. She had to promise me to introduce it properly and not to use it ever again afterwards, because it makes me nervous about our scientific credibility. So when [the intermediate] wants such a graph in the report, I'm very clear that we really cannot do that, and this is accepted."

Researcher: "How did the '2 to 4 days' quantification arise in the report?" Hydrologist: "Well, that is a good example of the interaction [between me and the intermediate], I would only write 'quicker' or 'in a few days', because we don't actually know, it was a feeling of the farmers. But [the intermediate] would ask for something more specific, and therefore we put it as '2 to 4 days quicker' in the report in the end."

Although the theoretical specialists sometimes feel that the nuance of uncertainties is lost, they often choose to communicate only part their total picture of uncertainties as well. By other actor groups it is seen as the job of the specialists to make a consideration of the relevant uncertainty and after that communicate a final result. These other actors therefore do not have a desire to know all these nuances. However, there is friction on the fact that they do sometimes think that a wrong conclusion is drawn and that uncertainties were down-played. In these cases these actors have the impression that models or results were put forward that carried more uncertainty than acceptable.

Interaction with science

Overall, scientific research is highly valued by the actor groups. However, everyone (but mostly pointed out by the farmers) shares a feeling that there is a political aspect to scientific research as well.

Farmer: "What surprised me, I had science associated with a high reputation. [hoog imago] These last years I discovered that there actually is lots of discussion, and that the point of view of the university is linked to their general position. It is some kind of a school struggle [(scholenstrijd)]. For example, the university of Nijmegen is a lot more critical on the drains than the university of Wageningen, the latter puts in more effort to find solutions close to the agricultural sector. And then you see that certain political parties choose to use these results of Nijmegen, like Groenlinks, and CDA chooses to use the results of Wageningen."

Even though this opinion is brought up by various farmers, scientific research in general and the research that is done at their own projects is valued as a means to resolve friction and find answers as well. This is interesting, as not only the theoretical people advocate doing more research, but the more practical actor group of farmers do so as well.

> *Farmer: We should not jump to conclusions about the effect of UWD and other solutions. We should first do further research, publications that already advocate strong opinions don't stimulate the open investigation of the possibilities.*

Hydrologists regard scientific research as the standard or goal and the value the insights that result from it. They do feel that their UWD-projects are valued less by other institutes than similar scientific research. A hydrologist wondered if it would have been better to link the projects to a university research because of the higher societal status of the experiment this would lead to. The specialists at the waterboard do express some critique on the fact that as well as their own projects, the scientific research projects have their limitations in terms of randomization and extraneous parameter influence. At the beginning of some of the WUR research studies, it was not clear for the hydrologists at the waterboard how certain measurements would be carried out. The unclearness of methods in the first phase of the research is seen as something that could be improved to keep credibility and open communication high. Farmers largely trust on the waterboard specialists to translate and assess research on their value and applicability onto the local situation of the farms in the UWD project.

Conclusion

The aim of this chapter is to answer the question on how the use of mathematics is distributed between the different actor groups involved in the UWD projects. To answer this question in accordance to the methodology described in chapter 2, first the distribution of tasks and the way of communicating numbers will be summarized. Herein the UWD can be seen as a 'border zone' for actor groups. Using this lens, the findings on grounding and friction, together with the concepts 'different ways of knowing' and 'data sharing' will be summarized, therefore giving the second part of the answer to the question on communication with and of mathematics in the network of the UWD projects.

The differences in daily practices in mathematics found in chapter 3 can be related to the way the actor groups communicate as well. Communication by specialists is mostly done using graphics and maps. The intermediates more often use examples in words that create 'mind' pictures that they think people can relate to. The farmers and field staff tend to explain via a linkage to a real life situation, where the field staff would try to make people understand the exact location of the problem, assuming that their colleagues know the situation, and farmers would mostly want to show something on their field or farm. Uncertainties and statistics are playing a relatively large role in the analysis that is done within scientific research, but the general pattern is that these subjects soon fade away as one proceeds to move to more practical actor groups.

In this network, the concept of distributed cognition is clearly visible, as it is the combination of practical knowledge of the field, together with the theoretical knowledge at the office, with the social grounding skills and knowledge of the intermediates. These three together make the water management effective on the short and long term. The UWD project is therefore a beautiful example of a border zone in which different actor groups come together which their different ways of knowing. The concept of 'different ways of knowing' that is described by Mauz and Granjou (2013), is seen in this network through the different approaches to gather knowledge (e.g. through practice or via measurement, as described in chapter 3). These different ways of knowing all come together via the communication that has to take place for the successful implementation of the UWD projects. Grounding takes place via all the different communication strategies mentioned above, where the actors switch between the more theoretical, practical and picturing approach. Intermediates play an important role in supporting the translation whenever needed and bring the actors together based on trust and personal contact. Friction mostly arises when actor groups have the idea that the other actor group does not have enough knowledge on the subject to express their opinions, or are too unknown to be trusted. Nevertheless, in most personal contact, the drive to find common ground prevails. When Edwards (2011) brings up the concept of data sharing, this is mostly used in the context of the sharing of 'raw' data that afterwards will be used for modeling. This was certainly a relevant issue that came up from time to time in the data gathering process that takes place in water board activities. However, as this was a large new subject that was not directly related to the UWD projects and time was limited, the choice was made to not investigate this new pathway of information. Nevertheless, when taking up the concept of data sharing in a wider understanding of explanation of data in general, this certainly was observed in practice. An example could be found in communication that took place between a hydrologist and farmer, during the process of the sharing of graphics. Edwards argues that data sharing is a constant process of relationship building, explanation sharing and grounding, which is what this case study confirms with the findings described above.

In conclusion to the question on how the use of mathematics is distributed in the network, it is found that numbers and mathematics are highly used in communication. Actors in the network are generally conscious of the fact that there is an issue of 'different ways of knowing' and aim to overcome these differences by employing various visual communication strategies and building robust relations. These aspects are seen in this case study through the importance of trust, personal contact and the high focus on communication. These were factors that were often mentioned as success factors by actor groups involved in the UWD projects. Most friction arises whenever there is a feeling that the reality of an actor is not understood by the other professional because of a lack of personal relation or expertise, a pattern fueling for example the 'office-field' contrast. The intermediate professionals therefore play a key role in the network by fostering mutual understanding.

The consequences of the daily practices in mathematics described in chapter 3 and the distribution of knowledge described in the current chapter influence institutionalization in society. These patterns will be exemplified in the following chapter.

Chapter 5: The written and unwritten rules of mathematics in society

Introduction

Following the technographical approach, the focus of this chapter will be on the broader patterns that influence mathematical practices and vice versa. The related research question is: *How do the written and unwritten rules of institutions and mathematics mutually influence each other in the broader context of searching for solutions to problems in society?*

As the scope of this thesis did not allow for a full and broad investigation of this question, a few examples that came up in the fieldwork will be given, afterwards analyzing the patterns behind these dynamics. Discovering these patterns sometimes requires to zoom out, therefore not all examples will be directly related to the UWD projects. Nevertheless, they are exemplifying the dynamics that take place in situations that influence the UWD projects as well.

Findings

Norms and goals

Throughout the work of hydrologists and ecologists, norms play an important role. Hydrologists have norms of safety that have to be met by law, ecologists have rating systems for the improvement of ecological quality imposed by the EU. Hydrologists explain that these norms contribute to the focus they have on their work:

> *Hydrologist: "It is often the case that the communication we have with other people of the water board about our results is limited to the question: Do we meet the standard? Are we above or under the safety norm? This is what the management or other department is interested in. And this is what is easiest to communicate as well, as it is a clear message."*

Here one can notice that these guidelines, quantifying certain aspects of the assessment of a situation, become leading in the work of the hydrologist who is analyzing the situation. This creates a 'most easy way' of addressing these issues. By the use of these norms, hydrologists have very clear tasks, where the answers to requests for information otherwise could get highly vague and debatable.

During the interviews, several times actors would also bring up examples showing that norms are sometimes arbitrarily chosen by the management or board actors, but do dictate the way of the daily work. An example of this is the policy aim to slow down land subsidence with 50% in 2030. This was entered into the policy agreement of the leading political parties quite suddenly and last-minute.

> *Intermediate: "So this goal was put into the agreement with such a quantification, but they needed a facilitated meeting afterwards to actually define what the meaning of such a statement is."*

[looking amused] "Did they mean 50% less height difference at all places, 50% less subsidence in volume, 50% of the expected increase in costs, they had no idea themselves."

Valuation of models

Within actor groups that are less acquainted with modeling (e.g. intermediates, field staff), there is a shared feeling that models are an added value in extreme situations. The safety norms in case of big precipitation quantities is an example of this. However, for the regular, normal or practical situations, the valuation of models is a lot less.

Intermediate: "A model gives you what you put in. Sometimes I compute loosely [op zijn janboerenfluitjes] what the result of the hydrologists should approximately be [by the use of an excel sheet]. In history they also had to guess, they were no idiots and made things work. Now we still have this experience. But a T100 [extreme rainfall], you cannot design for that. If it is extreme, we need a model. And then we need a good model.

This has a strong link with the former subject, as norms are very clear for extreme situations, but not present for 'normal' situations. Hydrologists who do see value in the modeling of the current situation have to probe for two things. First, a department that recognizes the relevance of asking this question of modeling a 'normal situation', as the water board is organized in such a way. Second, they have to probe for some sort of a norm for this situation, as the hydrologists feel like the choice for a specific norm or valuation of what results are 'good' is not something they should decide on. They consider choosing a norm as a subject where practical knowledge should be incorporated and which has political implications that should be evaluated by those parties.

Interestingly, models were seldomly contested by parties outside of the waterboard. The waterboard did put in effort to have sound communication of the models that were used and the choices that were made herein. In situations where there was a conflict, with for example citizens disagreeing with a certain policy, intermediates could not remember situations in which the actual model itself was contested in court. People would focus on the procedure, older agreements that should be met or the political choices. Within the waterboard, discussion about the models would take place in the first phase of finding a good answer to a question. Once a realistic outcome was achieved and communicated, other professionals within the water board would almost never question the type of model or the choices that were made anymore.

Political positioning

The costs of measurement systems easily get high when the waterboard wants to have a good assessment of for example the ecological status and water quality. Limited money is available for this purpose from the waterboard itself, so intermediates and management actors are often considering the possibility of combining goals and projects to gain more funding. This has happened within the UWD project via CO_2 emissions. The waterboard was mainly concerned with land subsidence, but as CO_2 emission (which is thought to have a link with land subsidence) became a prominent subject for the government, funds became available by combining these goals. This dynamic is present on the level of the EU as well. Actors express the opinion that with everything that is subsidized through EU funds a lot of quantification is asked. This leads to the possibility for political positioning as well.

Intermediate: "Every project you do [for the EU], you have to show a difference [before and after]. So you have to make your intervention measurable. If we make sure that our measurement network is also needed in other projects of other organizations or other goals, we make ourselves an important party at the discussion table.

The high social value of scientific experiments also contributes to the desire to have a good measurement network, as this could be used to attract more scientific research and therefore, again, financial funds for subjects that are relevant for the waterboard.

Conclusion

Following the COIN framework, the larger impact of the conceptualization and operationalization described in chapter 3 is shown in the findings of this chapter, thereby describing how the written and unwritten rules of institutions and mathematics mutually influence each other in the broader context of searching for solutions to problems in society.

Various power relations could be seen, from the waterboard in relation to farmers, the board in relation to other waterboard professionals, or the EU in relation to the waterboard. In all of these examples we see the influence of actors that are eager to choose quantifiable concepts that are operationalized with norms and goals expressed in numbers, to be able to report the effects of policy interventions. This leads to professionals getting questions in those themes and reports focused on these subjects. Within the mathematical practice this is enlarged, as for those actor groups that value computation, measurement and quantification serve to give them clear questions that can be answered by their models.

Hydrologists do probe for quantifiable norms for subjects they think should be modeled, ecologists are in general less eager to quantify, but often do so to be able to show upgoing or down going trends related to policy interventions. The hydrologists state that it is not their task to set the norms, therefore emphasizing the social component in the creation of norms for modeling. Some actors express the idea that norms are sometimes chosen arbitrary by the board or management, but that those norms do have a large influence on the professional daily practices. These patterns are clear examples of the dynamic that the COIN-framework advocates to look at, as the choice of concepts and its operationalization in norms results in certain questions most often answered via modeling and other questions left to the side unanswered, reflecting the power dynamics at hand.

On a longer time scale institutionalization could be seen in that this leads to the investment in technological pathways that are more in in the line of thinking of for example the waterboard than farmers. The social belief of models being useful mostly for extreme situations (and not for normal situations) together with the organizational structure of the water board (hydrologist taking up questions of other departments) lead to the hydrologists mostly modeling those situations, even though they also see the value in more usual situations. The social influence on mathematics at large is seen in the approach in social conflicts of issues related to the waterboard as well, such as court, as models are only sporadically contested there.

In conclusion to the patterns described above, the way of mathematics influencing society is directly observed in the use of results of data analysis and models in the decision making process of the waterboard. The less obvious relation of social factors influencing mathematics, is reflected in the institutionalized use of mathematics through the wish to quantify the effects of policy interventions. An organizational and social influence specifically related to the waterboard is seen in the way mathematics is used in models for the majority of questions surrounding 'extreme' situations rather than 'normal' situations.

Chapter 6: Discussion and Conclusion

The aim of this research was to contribute to knowledge about how mathematics plays a role through and for different actor groups in the process of creating new water management for the Dutch peat meadows. The following three sub research questions served as guidance in this aim:

- In what ways is mathematics used in daily discourse and practice surrounding the process of creating new water management?
- How is the use of mathematics distributed between the different actor groups involved in the process of creating new water management?
- How do the written and unwritten rules of institutions and mathematics mutually influence each other in the broader context of searching for solutions to problems in society?

In terms of relevance for the involved actors, a separate document will be written with the aim of creating more understanding between the actor groups involved in this research, this chapter will focus on summarizing the results for scientific purpose. By discussing the results in the wider context of the conceptual framework, this case study hereby contributes to the concept of 'the certainty trough' (Mackenzie, 1990). The observations of Lahsen (2005) are confirmed by this case study, nevertheless a complementary explanation of the patterns for this specific case study is suggested. Next to the relevance of this study as a case of the use of mathematics in water management, the complementary relevance of the case study in the wider frame of societal friction surrounding agricultural policies is explained. The chapter ends with an aim at answering the main research question and a reflection on the emerging questions concerning the social status of mathematics as a suggestion for further research.

Discussion

The case study of underwater drainage (UWD) system projects in the Dutch peat lands exemplifies the mutual shaping of society and technology. The researching of this mutual shaping followed a technographical approach by starting with the aim to find out in what ways mathematics is used in daily discourse and practice. The COIN framework served well in giving direction to the data collection in the fieldwork. It suggests breaking down these social processes in observable steps of concepts that are operationalized. Hereby the argument of Porter (1995), that the definition of measurements and models greatly influences the societal way of thinking, is reflected in the upcoming custom of defining norms in models that function as goals in political policies. Within the UWD projects the following four (groups of) concepts were found to play a major role in the interpretation and use of numbers: the valuation of delivering work seen as 'successful' within the context of the actor group, the valuation of neutrality of analysis, the assessment of causal relationships and the role of uncertainties. The definition of 'successful' work is clearly linked to the role and interests of a certain actor group, reflecting the power of the water board in the choice for measurement subjects within the UWD projects. The operationalization of causal relationships and the link to uncertainties varies greatly between actor groups, with on one hand scientists and hydrologists trying to assess by mainly measurements, on the other hand farmers preferring to assess causal relations mostly based on practical experience. Uncertainties in conclusions due to the variation of extraneous parameters are seen by all actor groups, whereas the uncertainties on measurement errors itself are in general only visible in daily discourse and practice of ecologists, hydrologists and scientists. Concerning neutrality of analysis, scientists are at one end staying close to a practice of setting up neutral experiments. Moving further through the network the emphasis soon changes to the focus on expert judgement, which is already demonstrated in the relatively theoretical work of the hydrologists.

This thesis contributes to the theoretical debate on the certainty trough by analyzing the case study of UWD projects in relation to this theoretical model. The point of view of MacKenzie (1990), that those close and far away from a technology (often scientists and critics) are more aware of uncertainties and risks than those in between (often citizens, policy makers), is questioned by Lahsen (2005). Accompanied by the argument of Porter(1995) that expert judgement and objectivity form a dichotomy, this case study underlines the view of Lahsen that specialists such as hydrologists do indeed try to be neutral, but that in fact professionals will use a lot of contextualized personal assessment. Even though the intention of specialists is still to be a neutral party conscious of uncertainties and risks, a fully neutral and analytical approach is in reality not possible. However, where Lahsen contributes this subjectivity to scientists mostly not being able to be critical on their own work because of mixed interests, this case study suggests a different explanation. Within the UWD projects, the loss in objectivity is primarily due to constraints in time and money, due to the political pressure to create clear results for policy goals and due to the wish of specialists to create knowledge that has a close link to and high credibility for practically oriented actors.

Second, the communication within the network was studied. This resulted in the conclusion that communication is generally done through visual communication such as graphics and visualization of numbers via examples whenever actor groups thought that their communication partner had a different type of knowledge. The UWD project, where different actor groups came closer together in their mathematical communication, functions as a border zone where constant relationship building and grounding took place. Farmers learnt about the interpretation of graphs and measurement methods and hydrological theories, whereas the hydrologists learnt about the daily reality as it takes place on the farm. Intermediates play an important role in building bridges between other actor groups by forming relationships, stimulating effective communication and fostering understanding on the different realities of actor groups. In the findings on the importance and functioning of the network and mathematical practices, it has to be kept in mind that the actors involved in this research are a group of precursors and that this might not be representative for social groups when UWD is applied on a larger scale.

The concepts 'different ways of knowing' and 'border zone' (Mauz and Granjou, 2013) were supportive in analyzing the distributed cognition network around the UWD projects, thereby following the theoretical position of Latour (1979) and Wynne (1992) that the construction of knowledge is a social process that can take various forms. Edwards et al (2011) links the social processes of relationship building, metadata friction and grounding to the sharing of data, which was indeed a relevant theme within the waterboard on a broader scale of modeling. Throughout the fieldwork this would come up as a topic under development, which required the forming of new relations between actors and the building of mutual understanding. Nevertheless the limited time for fieldwork made it necessary to make choices and therefore this was a topic that is not further investigated, as it was not the most directly related topic. As one of the respondents put it: *'the data, yes, that's a whole story in itself'*. To further broaden the knowledge about the process of innovation and change of water management driven by numbers, this could be an interesting topic for investigation in further research.

The last dimension that was researched in order to be able to answer the main research question was the interaction between mathematical institutionalization and societal change. The mathematical practices and choices of specialists in modeling do largely influence the decision making process of the waterboard through the incorporation of results, as expected. The other way of the dual dynamics is less acknowledged, but of major influence in this case study as well. Important factors in the use of mathematics are the political urge to quantify political interventions, the high or low valuation of models in 'extreme' and 'normal' situations respectively, the use of norms to assess whether a situation is 'good' or 'safe' and the organizational structure of other departments being the commissioner of the advisory department.

Interestingly, the contestation of models and computations is increasingly recognized in other related topics such as the nitrogen discussion (NOS, 2019) that caused big societal movements, but this dynamic is not seen in the case studied here. A possible explanation could be the difference in scale (national and local), the high level of personal contact and involvement of actors in specifically in the UWD projects and in the practical and personal approach of the waterboard in general. The social image of mathematics is seen in the approach in social conflicts of issues related to the waterboard as well, such as court cases. In cases where the water board is sued, models and research results are often used in the decisions that are contested. Nevertheless, the models and computations itself are only sporadically contested in those processes. The absence of contesting models in court could be contributed to the complicated reputation of mathematics, but this explanation is not further researched in the fieldwork. The scope of this thesis does not stretch far enough to scientifically explain the difference in trust in models in this case study and the broader societal trust in science. This thesis does however contribute to the understanding of science-policy-society interaction by researching the case of two UWD projects. Therefore this thesis is resulting in both a specific case of the use of mathematics in solving problems concerning water management in land subsidence areas, as well as a complementary case for studying the recent high frictions arising from the interaction between the government and the agricultural sector.

Conclusion

Concluding this thesis, the main research question on the role of mathematics in the development of new water management can be answered using the input of the findings on daily practices, communication and institutionalization of mathematics.

Mathematics is interwoven with many facets of the process of creating new water management for the peat meadows in the central Netherlands. Even though not all actor groups would identify themselves as using numbers and mathematics, all actor groups actually did. The numbers function as a representation of an idea and become part of the daily discourse and shared meaning that actor groups have and in some ways take for granted. In general, mathematical literacy of actor groups is high. The more practical mathematics, such as graphics and numbers to quantify situations, is widely used amongst all actor groups. Nevertheless, these actor groups differ considerably in their assessment of the success of the UWD project through the consequence of operationalizing concepts such as 'causal relations' differently. Farmers and field staff professionals would mostly rely on practical assessment, with large consciousness of extraneous parameter variation and lower attention to measurement uncertainties. Specialists within the waterboard would focus more on quantifying causal relations, nevertheless still relying largely on expert judgement in the analysis of data. Scientists form the far end of this spectrum, largely valuing and focusing on neutrality in analysis. The group of management and board directors has most distance to both the models and the practical numbers, often not having a clear picture of the meaning of the presented numbers.

When following the stream of communication about mathematics through the network (fig 6, chapter 4), the background of statistics and notion of confidence intervals is clearly present in the work of scientists and sometimes in that of ecologists and hydrologists. In most cases, this is soon left behind and not mentioned in further communication in the network. Within the network of different actor groups, intermediates played a key role in translating between the actor groups that stood further apart in terms of conceptualization. These intermediates fostered lots of grounding, therefore strengthening the notion and understanding that other groups might have a different approach to the same issue. The UWD-project could thereby function as a border zone in which professionals shared knowledge of different types.

The dual dynamics of society and mathematics influencing each other plays an important role in the process of finding new water management strategies. Throughout the choices for projects, investments and political directions, the results of mathematical analysis influences automated monitoring and data driven decision making. The influence of society on mathematical practices is seen in the organizational structure of the waterboard and in the political choice to comply to norms on EU and water board level. The daily working practice of specialists is directly or indirectly influenced by the urge to quantify the effect of policy interventions and the pattern of models widely recognized as useful for 'extreme' situations rather than 'regular' situations by more practical professionals.

In conclusion, the role of mathematics in finding new water management strategies for the farmed peat meadows is large and very socially contextualized. It is influenced by the varying understanding and operationalization of concepts by actor groups, the social valuation of quantified knowledge, the organizational structure of the water board and government regulations. The effectivity of the sharing and use of mathematics is largely influenced by the willingness and capacity of the actor groups in the network to overcome and relate to the perspective and 'way of knowing' of the other actor groups involved. This case study thereby affirms the importance of being conscious of the role and social component of mathematics in policy making processes.

Recommendation for further research

This case study is taken up from a rather practical approach. To complement this, an in-depth study of, for example, the mutual dynamics of social and mathematical conventions (e.g. for specifically hydrological models) could be done. This would contribute to the more detailed insights in how the choice for specific hydrological models (e.g. physical or probability) influences the communication patterns of hydrologists to other actor groups. Furthermore, a more social topic that would be worth investigating is the fact that mathematics in general (and models and computations of specialists more specifically) are still rather black-boxed by other actor groups. The standard reaction, that people do not think that they use mathematics and the implicit way of suggesting that this was complicated, was a pattern throughout the fieldwork. What is the social or cultural process behind this status of mathematical practice that creates this discourse? Whether this question will be investigated or not by further research, with my background as a mathematics teacher, this will surely keep me puzzled and pondering in the future.

References

AHN, 2020. Actueel hoogtebestand Nederland. Retrieved: 30th of January 2020. https://www.ahn.nl/ahn-viewer?origin=/common-nlm/viewer.html

van den Akker J.J.H., Hoving I., Hendriks R., Knotters M., 2018. *Onderwaterdrains zijn effectief.* Wageningen Environmental Research, rapport 2922. https://edepot.wur.nl/466227

Bedrijvenproef Spengen 2017-2018, Summary. https://www.hdsr.nl/@65338/kopie-documentaire/

van den Born, G.J., Kragt, F., Henkens, D., Rijken, B.C., van Bemmel, B., van der Sluis, S.M., Polman, N., Bos, E.J., Kuhlman, T., Kwakernaat, C., 2016. *Dalende bodems, stijgende kosten: mogelijke maatregelen tegen veenbodemdaling in het landelijk en stedelijk gebied: beleidsstudie.* Den Haag: Planbureau voor de Leefomgeving, PBL-publicatie 1064.

Bos, A.P., Gies, T.J.A., van Male, B., 2017. V*ormgeven aan sturen met water. Bodemdaling vertragen in het veenweidegebied met boeren en natuur.* Wageningen Livestock Research, rapport 1040. https://doi.org/10.18174/419822

Crane, T.A., Pronk, M., Lakerveld, R., Weiler, V., Maat, H., Springate-Baginski, O., Udo, H., 2016. *Research Design and the Politics of Abstraction: Unpacking the Environmentality of Scientific Practice in Socio ecological Assessments.* Human Ecology; New York Vol. 44, Iss. 6.

Couwenberg, J., 2018. *Some facts on submerged drains in Dutch peat pastures.* Bulletin of the International Mire conservation group (IMCG), June-July. Greifswald Mire Centre.

Deru, J.G.C et al., 2018. *Soil ecology and ecosystem services of dairy and semi-natural grasslands on peat,* Applied Soil Ecology 125, 26-34.

Edwards, P.N., Mayernik, M.S. Batcheller, A.L. Bowker, G.C., and Borgman, C.L., 2011. *Science friction: Data, metadata, and collaboration,* Social Studies of Science, Vol. 41, No. 5 (October 2011), pp. 667-690.

Hardeveld, 2019. *Informed science–policy interactions: Advancing the support of collaborative management of social–ecological systems.* Proefschrift Universiteit Utrecht, Nederland. https://www.publicatie-online.nl/publicaties/henk-van-hardeveld

HDSR (image frontpage retrieved 27-02-2020) https://www.hdsr.nl/beleid-plannen/veenweide/

Hoving I.E., André G, van den Akker J.J.H., Pleijter M., 2008. *Hydrologische en landbouwkundige effecten van gebruik 'onderwaterdrains' op veengrond*. Rapport 102 Wageningen UR. http://edepot.wur.nl/165

Hoving I.E., van den Akker J.J.H., Pleijter M., van Houwelingen K., 2011. *Hydrologische en landbouwkundige effecten toepassing onderwaterdrains in polder Zeevang.* Rapport 188 Wageningen UR. http://edepot.wur.nl/50630

Hoving I.E., Vereijken P.F.G., van Houwelingen K.M., Pleijter M., 2013a. *Hydrologische en landbouwkundige effecten toepassing onderwaterdrains bij dynamisch slootpeilbeheer op veengrond.* Rapport 719 WageninenUR. http://edepot.wur.nl/265293

Hoving I.E., van Schooten H., Pleijter M., 2013b. *Snijmaïsteelt op veengrond bij dynamisch slootpeilbeheer.* Rapport 719 Wageningen UR. http://edepot.wur.nl/265291

Hoving I.E., Massop H.T.L., van Houwelingen K.M., van den Akker J.J.H., Kollen J., 2015. *Hydrologische en landbouwkundige effecten toepassing onderwaterdrains in polder Zeevang : vervolgonderzoek gericht op de toepassing van een zomer- en winterpeil.* http://edepot.wur.nl/346762

Jansen, K., Vellema, S., 2011. *What is technography?* NJAS -Wageningen Journal of Life Sciences 57 (2011) 169–177.

Klimaatakkoord, 28 juni 2019, Den Haag. https://www.rijksoverheid.nl/onderwerpen/klimaatakkoord/documenten/rapporten/2019/06/28/klimaatakkoord

Lahsen, M., 2005. *Seductive Simulations? Uncertainty Distribution around Climate Models.* Social Studies of Science, Vol. 35, No. 6, pp. 895-922.

Latour, B., Woolgar, S., & Salk, J. (1979). *Laboratory life : The social construction of the scientific facts* (Sage library of social research, 80). Beverly Hills, CA: Sage Publications.

MacKenzie, D., 1990. *Inventing Accuracy: A Historical Sociology of Nuclear Missle Guidance*. (Cambridge, MA: MIT Press).

MacKenzie, Donald, & Judy Wajcman, 1999. *Introductory essay: the social shaping of technology* In: D. MacKenzie & J. Wajcman, The social shaping of technology, Open University Press, Buckingham, p 3-27.

Mauz, I., & Granjou, C., (2013) *A New Border Zone in Science. Collaboration and Tensions between Modelling Ecologists and Field Naturalists*, Science as Culture, 22:3, 314-343, DOI: 10.1080/09505431.2012.753047

NOS, 2019. Retrieved 28-02-2020. https://nos.nl/artikel/2304768-de-stikstofcrisis-hoe-heeft-de-politiek-het-zo-ver-laten-komen.html

Porter T., 1995. *Trust in numbers : The pursuit of objectivity in science and public life.* Princeton, NJ: Princeton University Press.

Suchman, L.A., 1987. *Plans and Situated Actions. The Problem of Human-Machine Communication.* Cambridge, Cambridge University Press.

Vanloqueren, Gaëtan and Philippe V. Baret, 2009. *How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations.* Research Policy 38: 971–983.

Winner, L., 1980. *Do artifacts have politics?* Daedalus, 109 (1): 121-136.

Wynne, B. 1992. *Misunderstood misunderstanding: Social identities and public uptake of science.* Public understanding of science, 1(3), 281-304.

Het Zinkende Land, 2017. Documentary Manfred van Eijk. https://www.hdsr.nl/@65338/kopie-documentaire/