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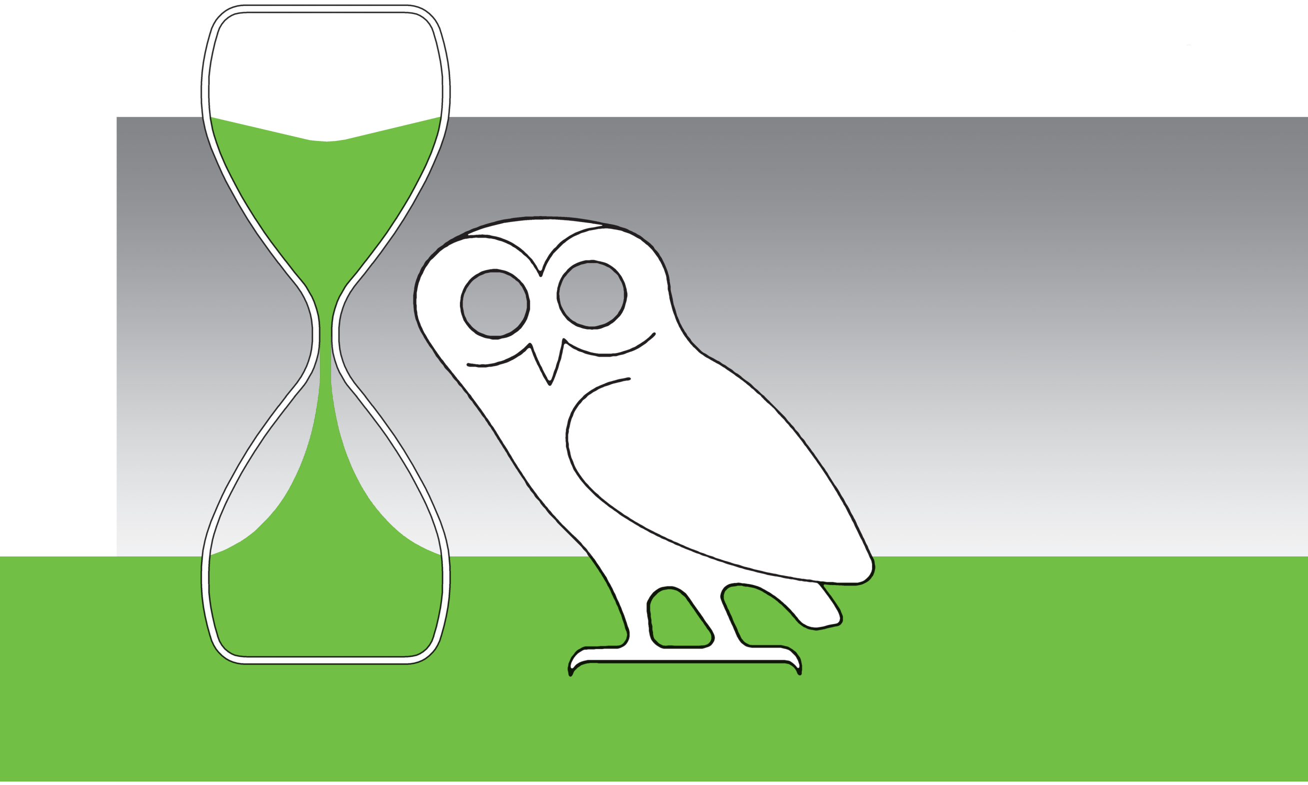

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Risks in the Making: The Mediating Role of Models in Water Management and Civil Engineering in the Netherlands

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Zusammenfassung: Wie Risiken entstehen: Zum medialen Charakter von Modellen am Beispiel von Wasserwirtschaft und Ingenieurbau der Niederlande. Der Umgang mit Vorannahmen, Unsicherheiten und blinden Flecken gehört zur Praxis der Modellierung. Dabei wird das den Modellen inhärente Wissen um Risiken in unterschiedlichem Maße sichtbar, was für technologische Kulturen, die auf Modelle rekurrieren, folgenreich sein kann. Um Kollaborationen zwischen unterschiedlichen sozialen Gruppen wie Ingenieuren und politischen Entscheidern zu ermöglichen, werden in „trading zones“ (Peter Galison) gemeinsame Sprachregelungen gestiftet. Während solche Sprachregelungen tatsächlich soziale Gruppen verbinden und deren Zusammenarbeit befördern können, geht die Rolle von Modellen als Medium häufig nicht in diese Sprachregelungen mit ein. Die Sprachregelungen der trading zones können somit dazu beitragen, den Einfluss der Modellierungspraxis auf Risikoeinschätzungen zu verdecken. Aufbauend auf Einsichten aus den Science and Technology Studies (STS) und empirischer Forschung in hydrologischer, hydrodynamischer und geotechnischer Ingenieursarbeit sowie der Ökologie unterstreicht dieser Beitrag die Nützlichkeit des medialen Charakters von Modellen für den Nachvollzug unterschiedlicher Risikoeinschätzungen von Akteuren im Wasserschutz. Die Fähigkeit, Vorannahmen, Unsicherheiten und blinde Flecken von Computersimulationen und Modellierungspraxen zu erkennen und einzuschätzen, erweist sich bei mangelnder Würdigung des medialen Charakters von Modellen als eingeschränkt.

Summary: Risks in the Making: The Mediating Role of Models in Water Management and Civil Engineering in the Netherlands. Reliance on models can make technological cultures susceptible to risks through the assumptions, uncertainties, and blind spots that may accompany modeling practices. Historian of science Peter Galison has described computer modeling practices as “trading zones”, conceptual spaces in which a shared language is hammered out in an attempt to facilitate collaboration between different social groups, such as engineers and policymakers. Although such a shared language may enable collaboration between diverse groups, it may also make the relation between modeling practices and knowledge of risks less visible, since the shared language does not necessarily acknowledge how models produce knowledge about their world. In that respect, models have a ‘mediating’ role, since they are not straightforward representations of the world, but involve a process of translating phenomena into formalized representations that enable experimentation. Drawing on insights from Science and Technology Studies (STS) and empirical work in the domains of hydrology, hydrodynamics, geotechnical engineering, and ecology, this paper emphasizes the importance of understanding the mediating role of models in shaping the understanding that various actors hold with regard to water-related risks. Failing to appreciate the mediating role of models

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hampers the ability of actors to understand the assumptions, uncertainties, and blind spots that accompany simulation practices, and may put technological cultures at risk.

Keywords: trading zone, risk, hydrology, hydrodynamics, geotechnical engineering, ecology, immersion, uncertainty, exclusion

Schlüsselwörter: Aushandlungszone, Risiko, Hydrologie, Hydrodynamik, Geotechnik, Ökologie, Immersion, Unsicherheit, Exklusion

1 Introduction: increasing reliance on models

Although the history of the Netherlands is marked by catastrophe due to the nation's propensity to flooding, the Dutch have become renowned for their ability to deal with the various challenges presented by the water which surrounds them. Climate change poses further risks in the form of rapid rises in sea level and peak river discharges, as well as surface water quality and biodiversity decreases due to ongoing water temperature increases.[1] The history of the Netherlands features many examples of successful interventions against flood risk, the apex of which is a series of flood barriers known as the Delta Works, situated in the southeast of the Netherlands. In 1953, after a dramatic flood in the Zeeland province, which led to both significant loss of life and capital, a set of flood risk management measures materialized in the form of a 'Deltaplan', a strategy to shorten the Dutch coastline, thereby reducing the number of dykes that needed to be raised, and economically improving the safety of the Zeeland province. This ambitious construction commenced in 1954, and was only completed in 1997. The American Society of Civil Engineers declared the Delta Works, along with the 'Zuiderzee Works', a set of dams, dykes, and land reclamation works in the north of the Netherlands, as one of the 'Seven Wonders of the Modern World'. The success of such large-scale engineering projects in the Netherlands has granted the Dutch the reputation of being able to master Earth's elements.

The ideal of manipulability and control over the elements is problematized by persistent uncertainties posed by water and soil, which may not bode well for the idea flood risks can be nullified by constructing new dykes, improving their construction, or implementing some other technical measure, such as using sensor technology to monitor the structural integrity of dykes. Policymakers working for the Dutch government acknowledge that floods may occur despite their world-renowned system of flood protection, and that the country must continue to prepare for dealing with floods and their aftermath. A position that grates with engineers dedicated to the idea that safety can be engineered by either implementing or improving flood barriers.[2] As a result of climate change, sea levels may rise up to four metres by the year 2200 and river discharges will increase.[3] However, the Dutch appear to be confident in their ability to deal with these challenges. Although, alongside these direct impacts, the secondary impacts of climate change on biodiversity and ecological resilience must be acknowledged as an important risk as well. More widely, climate change will impact geopolitical stability and may have a significant impact on the Dutch economy, which is heavily reliant on international trade. As such, the challenges concomitant with climate change cannot be confined to a 'can-do' mentality, based solely on implementing ever-greater technological solutions.

Activities aimed at ensuring the safety, habitability, economic welfare, and environmental sustainability of the Netherlands make extensive use of models, ranging from scale models of rivers and coastal structures to computer simulations of water flow and ecological aspects of bodies of water. Such models are used to define, monitor, predict, counter, and communicate water-related risks. This has established a 'social reliance'[4] on modeling, which makes it necessary to understand the Netherlands as a 'technological culture'.[5] A technological culture is one which "highlights that the modes of inhabitation and signification (culture) that make up our world are technologically mediated."[6] In this paper, I approach the vulnerability of the Netherlands to water-related challenges by focusing on the 'mediating' role of models, by which I refer to the ways in which models produce knowledge about the world. Models are not mute instruments that represent the world as it is. Rather, models provide a formal representation of the world that can contain assumptions, uncertainties, and blind spots. As a result, risks can be rendered more and less visible. Failing to understand this mediating role of models may be an unaccounted source of risk if left unacknowledged.

The extent to which the mediating aspect of models is acknowledged depends on the actors involved, who can attribute different meanings to models and model output. Sociologist of technology Wiebe Bijker[7] has suggested differences between the meaning attributed to technological artefacts by different "relevant social groups," groups of actors that have a particular interest in a particular technological artefact, can be analysed in terms of "inclusion" and "technological frames." The latter are composed of "concepts and techniques deployed by a community in its problem solving" and consist of "a combination of current theories, tacit knowledge, engineering practice (such as design methods and criteria), specialized testing procedures, goals, and handling and using practice."[8] The notion of technological frame applies to the interactions between different actors, who may hold divergent opinions about the meaning of a particular technological artefact. Technological frames "can be used to explain how the social environment structures an artefact's design" and "how existing technology structures the social environment."[9] Thus, actors' 'inclusion' in a particular technological frame can shape how they view technological artefacts.

This paper first interrogates the extent by which different social groups, modelers and civil engineers, involved in water management in the Netherlands assess the mediating role of models. Secondly, it asks to what extent these various technological frames, regarding the mediating role of models, do put the Netherlands at risk. In answering these questions, I draw on an extended period of participant observation between 2009 and 2011, as well as interviews conducted in the same timeframe at Deltares in Delft, an institute for applied research in the field of water, subsurface and infrastructure. In addition, interviews were held at relevant software development companies working on model development and maintenance, governmental organisations, research institutes, and universities.[10]

My research questions are addressed at three water-related modeling practices, all of which involve a trading zone in which different groups of actors interact. First, I look at the impact of the rise of computer simulations in hydrology, the science of the properties, distribution and effects of water on Earth's surface, and hydrodynamics, the science of the dynamics of fluids. The models used in these sciences are noted for their complexity, which makes it more difficult for modeling actors to understand the knowledge instruments they use on a daily basis. Second, I address how models are used in geotechnical engineering to study the onset of seepage erosion, a form of erosion whereby water flowing through a dyke or its foundations causes structural damage, which can lead to the failure of dykes. I address how such models function in a more general context of flood risk management, and are increasingly brought to bear on possibilities attributed to the analysis of large amounts of measurement data. Third, I examine the use of models in ecology, where they are used to enable participatory processes of water governance, with the aim of improving and maintaining water quality in accordance with guidelines for water quality governance established by the European Commission.

In discussing these cases, I indicate who is involved with modeling in water management and civil engineering, and the extent to which modeling practices can become hidden from view by the actors involved in each modeling trading zone. The title of this paper, 'Risks in the making', refers not only to the constructive role of models in producing knowledge about risks, it also hints towards the possible detrimental effects of failing to understand how models establish an understanding of risks, yielding risks 'in the making', which may loom behind seemingly innocuous modeling practices.

2 Modeling and trading zones

As argued in the introduction, models are not merely mute instruments. They play an inscriptive role in the process of defining, monitoring, predicting, countering, and communicating water-related risks. Although models will bear varying degrees of semblance to their objects of study, their 'target systems', they are not straightforward representations of a presupposed world 'out there'. Sociological and philosophical studies of modeling practices have demonstrated that the translation of target systems into models, upon which simulations can be run, as experiments, is not straightforwardly 'representational'.[11] In other words, the world is 'staged' in a model in order to facilitate experimentation. The ability of models to stage the world through simplification should not immediately be lamented, since it is also what makes them of great value. Models give some idea of what may happen in a probable future, or in extreme circumstances, such as at un-
likely or unfeasibly high or low water levels. Moreover, models enable experimentation in a way that does not interfere with target systems, and can be more economic and efficient than experimentation in such systems. Models allow the temporality of risks to be reimagined in various ways, potentially opening up new opportunities for fruitful intervention in real-world systems. However, this pragmatic 'staging' also suggests the use of models can be accompanied by assumptions, uncertainties, and blind spots, meaning modeling practices risk shaping the understanding of target systems. As a result, once our understanding of target systems is understood as something that is shaped by modeling, it can be appreciated that these shortfalls may have an effect on the practices that draw on model output.

Work on "trading zones"[12] looks at how various actors engage in practices around a particular object or technology, and can thereby aid analysts in affirming the role of models as mediators between social groups, such as engineers and physicists. In trading zones, rules of exchange between different social groups are established despite differences between these social groups. It should be noted that these differences are not overcome by means of some uniform translation of various interests. Rather, trading zones involve partial communication, and can be identified as "locations in which communities with a deep problem of communication manage to communicate. If there is no problem of communication, there is simply 'trade', 'not a trading zone'."[13] Galison discusses how simulations act as intermediaries between different actors: They are objects that are pivotal in activities related to a number of different groups.[14] Echoing the ideas about models as far from innocent instruments of knowledge, Galison describes how modeling practices can form a site where differences are not so much overcome, but rather bridged in a way deemed satisfactory to all involved.

Trading zones involve a practical solution to the existence of multiple perspectives on modeling by establishing a shared language that 'works'. However, as I argue in more detail below, those involved in modeling may be able to exchange ideas and insights without addressing the mediating effects of models themselves. In this paper, I see models as a socio-material substrate of water governance that consists of technological, organisational, institutional, and social elements, and shapes the understanding actors may have of various water-related risks, some of which were mentioned in the introduction. However, since the actors involved have varying degrees of inclusion and occupy different technological frames, potential assumptions, uncertainties, and blind spots may go unnoticed or un-interrogated. This may introduce or exacerbate water-related risks, since potentially harmful mediating effects of models are not addressed, leading to risks that are glossed over until disaster potentially appears. Failing to understand how models can obscure as well as make risks apparent can render technological cultures vulnerable. Accordingly, it is argued that models, as part of a particular trading zone, should be understood as mediating instruments contributing to both the elucidation and production of risks.

3 The rise of computer simulation in hydrology and hydrodynamics

During the 20th century, research in hydrology and hydrodynamics in the Netherlands gradually abandoned scale modeling, such as small-scale physical models of bridges, dams, sluices, and harbours in water bodies or entire river deltas. In their place, researchers began using computational models, consisting of equations that describe the behaviour of water that is described formally as interactions between points on a grid. This led to the establishment of computer simulation as the dominant knowledge instrument in modeling hydrological and hydrodynamic phenomena.[15] The predominance of computer simulation has led to a greater dependence on increasingly complex computer code, making it more and more difficult for hydraulic engineers to fully grasp the design and impact of the simulations and models they use. The increasing complexity of code is due to a variety of factors: Models are developed by greater numbers of people, leading to a more complex underlying computer code. In addition, old, or 'legacy' code may no longer be understood because the human expert enabling its use is no longer available. Finally, modelers may have the tendency to leave parts of the model unquestioned due to successful applications in the past. In this way, computer simulations may become 'black boxed', in so far as their successful outcome leaves the structure, data, and computation of the model unexamined.[16]

In computer simulations, the expertise of modelers is inscribed in the form of computer code, allowing modeling expertise to travel beyond its development site. As a result, simulation practice is distributed over a larger and more varied group of actors that is no longer limited to the engineers who actively worked on the development of the specific code. For example, models' code may travel to consultancies, software developers, decision makers working for city governments, scientists, amongst many others. Contemporary developments have enabled the distribution of simulation practice across a multitude of actors. First, what are termed 'modeling interfaces' are becoming more and more popular. These interfaces are standards that allow model components from different developers to exchange data. Thus, modeling interfaces enable a modular approach to modeling, in which code written by a variety of parties is coupled together to create a working model, provided these model components meet the constraints of the interface. On such platforms, model components can be combined to create a complete model the user deems reliable, even though extensive knowledge of the underlying components is not required. Second, the increasing popularity of simulations in water governance has created a demand for simulations that can be used by non-experts. Such simulations need to be interactive, which can mean underlying calculation rules, the set of mathematical operations performed by a model, are simplified to enable immersive interaction with the model. Users end up using a computer simulation that meets the criteria of a governance context, but such simulations may not have the scientific rigor needed to convey a more complete understanding of hydrological and hydrodynamic phenomena.

The increasing complexity of models, together with their computational codification in the form of software, which enables a larger and more varied audience, amplify issues related to 'epistemic opacity',[17] a term which describes how those involved in modeling practices may be unable to understand the computational principles underlying computer simulations, or may not have the desire to understand these underlying computational principles. A reflexive or critical approach to computer simulations, which is something engineers often emphasize as being of crucial importance, would involve a persistent questioning of the components underlying the model. This could be achieved by examining its design, underlying equations, and the time-consuming process of getting to know a model by working with it for extended periods of time in different projects. When such a questioning attitude is absent, those working with computer simulations straddle discovery and manipulation: Simulations may inform the understanding of hydrological and hydrodynamic phenomena, but the way in which they inform such an understanding may not be subject to reflection. In other words, the mediating role of the computer simulation is left unquestioned. According to sociologist of science Sherry Turkle, simulation increasingly involves manipulation rather than discovery, since simulations are becoming increasingly opaque and more convincing thanks to interactive elements and captivating graphics.[18]

Although epistemic opacity is prevalent when computer simulations are used, it is not given that reflexivity regarding models is decreasing amongst all social groups involved in modeling work. As a result of epistemic opacity, these social groups can fall prey to 'immersion', which can be defined more generally in terms of engrossing, enticing, or captivating influence of technologically mediated practices and experiences.[19] Hydraulic engineers do not object to codification of knowledge in the form of code per se, but do stress it should not lead to uncritical adoption of model output. A reflexive approach to modeling fosters engagement with the epistemic opacity characteristic of computer simulations. Hydraulic engineers attempt to 'tease out' knowledge from simulations and models, either by using them as 'sparring partners', or by 'tinkering'. In the latter case, hydraulic engineers thoroughly examine a model's code and try to familiarize themselves with the model by feeding it different sets of data. The answer to epistemic opacity and the danger of immersion is then not necessarily the mastery of simulations and models, but rather reflexive practices. 'Tinkering' is a promising form of reflexivity that leads to critical engagement with epistemically opaque computer simulations. This way of dealing with such simulations is promising because it is unlikely that the trends that have established opacity can be reversed. The dangers of opacity were signalled in the early days of software development by mathematician and computer scientist Edsger Dijkstra. However, contemporary challenges of hydraulic engineering do not bode well for Dijkstra's suggestion that we "confine ourselves to the design and implementation of intellectually manageable programs."[20] As code grows in complexity, as discussed above, epistemic opacity cannot be ignored, as it may lead to immersion in the absence of reflexivity. Studies of computer simulations in hydrology and hydrodynamics should not focus on epistemic opacity exclusively, they should also inquire into the reflexivity of those involved in simulation work. After all, when model output is considered to be reliable, those involved in simulation may be less inclined to question the authority of simulations and models.

Questioning the extent by which those engaged in a particular modeling practice address epistemic opacity can help to make explicit the technological frames of those involved. In this way, points of insufficient reflexivity can be pointed out and the crucial instrumental role of computer simulations can become subject to further scrutiny. Perhaps it is a characteristic of a particular trading zone that the actors involved fail to address the instrumental role of computer simulations? A language that works may very well be established, but may also limit reflexive engagement with the problem of epistemic opacity. This issue is of importance since models play a crucial instrumental role in imagining possible solutions to climate-related issues in hydrology and hydrodynamics. Without suitable reflexive engagement, the use of computer simulations risks steering the imaginary of possible solutions toward the problems of climate change without the scepticism with which engineers should be required to apply to a model's output.

There are strong indications that a reflexive attitude to computer simulations is prevalent among engineers responsible for model development. Actors outside the realm of model development, such as consultants, decision makers, and policymakers, appear to have a more substantial confidence in computer simulations, and have less of a tendency to take a model's output with a degree of skepticism, which is something lamented by engineers involved in model development. Inclusion therefore has a relationship with reflexivity, since those directly involved in model development appear more likely to adopt a critical stance towards computer simulations.

4 Wrestling with uncertainties in geotechnical engineering

'Piping' is a form of seepage erosion involving the movement of water under or through a dyke that provokes instability, in some cases leading to breaches. The flow of water under or through a dyke may build channels that can eventually form a shortcut between the structure's water and land facing sides, a so-called 'pipe', that runs through its foundations. Pipes dramatically increase the speed of erosion, which may damage the dyke or its foundations to such an extent that it either collapses or breaches. In the Netherlands many dykes can consist of either clay or peat, or a combination of the two, which sit on foundations of sand. Whereas clay and peat are cohesive and relatively impermeable, sand is relatively permeable, which means the foundations of many dykes are prone to seepage erosion of their foundations. As sea levels rise and river discharges increase as a result of climate change, 'piping' is becoming a more pressing issue in the Netherlands.

Sociologist Matthias Gross defines uncertainty as "a situation in which, given current knowledge, there are multiple possible future outcomes."[21] This idea of uncertainty can be aligned with multiple possible outcomes of soil behaviour: will a dyke hold or will it become unstable? The composition of dykes and their foundations, as well as the interactions between different types of soil in dykes and their foundations, are a source of persistent uncertainties in geotechnical engineering. The composition of soil may be known at the locations where measurements have been taken, but soil can be rather heterogeneous, implying large differences between measuring points, even those relatively close to each other. Since the behaviour of soil is dependent on its composition, this leads to difficulties in predicting the likelihood and possible impact of seepage erosion. In addition, geotechnical engineers stress the difficulties imposed by the complexity of interactions between different kinds of soil. Such interactions are not understood very well yet, and remain a source of uncertainty. The lack of data about soil can be solved in principle, but certainly not in practice given the limited amount of resources available for measuring and the fact that some locations may not be accessible, as a result of the position of roads or buildings. Uncertainty about soil behaviour precludes certainty of prediction.

Geotechnical engineers deal with the uncertainties posed by soil morphologies in various ways. Firstly, the geotechnical engineers at Deltares are committed to an elaborate process of research which is intended to reduce uncertainties, and to develop state of the art quantitative methods that can be used in safety assessments. To do so, a variety of scale models and computational techniques are used to understand 'piping.' This involves modeling cross-sections of dykes at various scales, so the occurrence and development of 'piping' can be studied. In some cases, engineers have built 1 : 1 scale models and simulated dyke breaches caused by 'piping' with these full-scale models. In addition, computational models of soil composition have been created that attempt to describe the interactions between different soil types within a dyke. However, since experiments with physical scale models are expensive and 'piping' takes place largely out of sight, within a dyke, seepage erosion remains a phenomenon that engineers struggle to understand, since empirical observations that help to validate computational models are difficult to acquire. In the laboratory, physical models and computational models are assessed in terms of their ability to produce relevant knowledge about 'piping', such as details about the development of pipes and the circumstances that influence pipe formation. Outside of the laboratory, models need to fulfil a different demand, since policymakers wish to use state of the art model-based assessments of seepage erosion to assess the safety of dykes and determine where expensive dyke reinforcements need to be constructed. Such assessments ultimately lead to a binary choice: either a dyke needs to be reinforced or it does not.

More recently, flood risk management in the Netherlands has adopted data-intensive methods which require large amounts of measurement data to monitor the safety of the dyke, documenting everything from registrations of water levels inside a dyke, to measurements of vibrations that may indicate 'piping'. This assessment also involves the development of software aimed at a 'non-expert' audience, such as local decision makers and organisations in charge of water safety, who need to be able to monitor dyke safety and act on reliable information in times of possible flooding. Thus, geotechnical engineering is not only about doing rigorous science, such as understanding the dynamics of seepage erosion, but increasingly also involves the development of technologies that enable audiences outside of the scientific community to act in times of need, for example by developing evacuation plans. In other words, knowledge about 'piping' needs to be not only epistemically robust, produced by ever more accurate calculation rules, it also needs to meet requirements related to 'social robustness'. That is, this knowledge needs to be perceived as innovative and reliable in the eyes of policymakers, or aligned with political commitments to flood preparedness.[22] According to geotechnical engineers, models can only present the 'piping' in a more or less satisfactory manner that provides insights into how complex soil morphologies may behave. As such, geotechnical models only represent geotechnical phenomena in an exploratory manner. However, geotechnical models tend to function in a representational manner outside of the laboratory, for example in policy-making contexts.

Uncertainty can put technological cultures at risk. Attempts to develop definitive calculation rules, implement 'innovative' technologies for geotechnical modeling and flood risk management, and develop policies related to dyke safety can be 'unsettled' by uncertainty. Dyke safety assessments attempt to accommodate uncertainty in the form of multiple possible future outcomes. For example, a calculation rule may turn out to be in need of improvement, an application developed for flood risk management may yield unexpected outcomes or be used in an unforeseen manner, and policymakers may not adopt the insights produced by research into dyke failure mechanisms. This corresponds with Gross' aforementioned definition of uncertainty as "a situation in which, given current knowledge, there are multiple possible future outcomes."[23] As a result, uncertainty can put technological cultures at risk: The methods chosen to cope with various risks may be out of step with the multiple possible future outcomes that various uncertainties may imply.

Uncertainty can be used to describe 'knowledge gaps' or blind spots in dyke safety assessments. However, uncertainty does not simply entail a lack of knowledge, it is a by-product of simulation practices that cannot be wholly excised from the endeavour. From the perspective of geotechnical engineers, claims to certain knowledge need to be approached with apprehension: The reliability of geotechnical models does not imply an objective truth, and calculation rules are always provisional. These rules have acquired credibility through worthwhile insights in the laboratory, but that does not mean geotechnical models are complete or 'finished'. Uncertainties point to aspects of seepage erosion that deserve further examination, and thereby act as indicators of potentially worthwhile research.

However, uncertainties may not be appreciated as such. As sociologist Donald Mackenzie argues, uncertainties are approached and valued differently by various social groups.[24] In that sense it is important to acknowledge that the outcome of modeling practice may be disruptive and cause difficulties in the realm of policy making: Model output can lead to the insight that calculation rules to assess dyke safety are no longer relevant, and updated calculation rules may yield assessments of dyke safety that call for costly investments in order to enhance dyke resilience. Although uncertainties can put technological cultures at risk, they also form a potential source of knowledge about risks. The settling of knowledge in the form of calculation rules, software, or policies that are considered to be both epistemically and socially robust may gloss over uncertainties. As a result, technological cultures may be put at risk, since settled knowledge can imply a diminished ability to evaluate the pros and cons of various approaches to uncertainty, and preclude the adoption of uncertainty as a source of knowledge about risks.

The preceding discussion on 'piping', and geotechnical engineering more generally, has described a trading zone in which the appreciation of uncertainty is shaped by the technological frame of the actors involved: whereas engineers emphasize the provisional and exploratory nature of their research on 'piping', decision makers and policymakers are primarily concerned with developing robust policies for dyke safety. Models are required to fulfil different roles, depending on the technological frames of those involved and their degree of inclusion in contexts that aim for a more scientific approach to seepage erosion. Models are seen as instruments of exploration or as representations of dyke safety. Needless to say, maintaining flood defences is of crucial importance in a country that earns about a third of its gross national product in areas prone to flooding.[25] However, seeing models as representations glosses over uncertainties, which can then no longer be fostered as a source of valuable knowledge. Although much more can be said about different kinds of uncertainties involved with modeling in a policy context,[26] my claim here is oriented towards the tensions between exploration and representation in modeling dyke failure mechanisms, and the potentially dangerous side effects of a preoccupation with models as representations in terms of the extent to which dyke failure mechanisms are understood. The way in which flood risk is imagined changes when the focus on fundamental research in the laboratory is abandoned in favour of the development of techniques for monitoring dyke safety and dealing with the aftermath of floods.

5 Participation and exclusion in water quality governance

In present-day water governance in the Netherlands, public participation is applauded since it "would improve the quality of decision making by opening up the decision-making process and making better use of the information and creativity that is available in society."[27] Extended public participation is said to have the ability to establish more democratic forms of water governance by allowing various social groups, ranging from organisations engaged in environmental protection to those affected by particular policies, such as inhabitants of a particular area, to voice their opinion, which may unsettle traditional hierarchies in science and politics. However, such technologies of participation are not celebrated unanimously, since they still determine how participation takes place by excluding other forms of knowledge and actors.[28]

An example of an instrument that was supposed to enable extended public participation is the 'WFD Explorer': a communication instrument developed to facilitate discussions concerning the European Union's Water Framework Directive (WFD), which aims to prevent the deterioration of aquatic ecosystems, protect or enhance the status of aquatic ecosystems, promote sustainable water use, and enhance protection and improvement of the aquatic environment. These objectives, it was suggested, can be achieved "through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances."[29] Article 14 of the WFD[30] stresses that interested parties can and should be provided with information amenable to shared decision making. Active involvement of such parties meets the legal requirements of the WFD, improves decision making by attuning governance to the concerns of those involved, and increases the willingness of these parties to accept and implement policies so far developed.[31]

In this vein, the WFD Explorer was intended as an instrument of governance that could provide stakeholders, decision- and policymakers with the means to collaboratively explore and understand relationships between the objectives prescribed by the WFD, the range of possible measures, and their potential impact. The WFD Explorer consists of a calculation core and knowledge database containing calculation rules related to water quality. These two components are largely standardized and authored by the WFD Explorer's developers, although users familiar with the design of the model were initially invited to change parameter values, which is something the developers later tended to avoid due to the lack of consensus on the values that needed to be entered. In a further attempt at gaining applied relevancy, a structured database was made an additional component of the WFD Explorer, enabling users to enter area-specific information.

In practice, the WFD Explorer did not reach its intended audience due to disagreements among the developers of the WFD Explorer, ecologists and biologists, and its intended users. The developers' intention to include a multitude of perspectives in the WFD Explorer eventually led to a situation in which conflicting ideas needed to be resolved in the models underlying the software. This resulted in a situation where the developers took matters into their own hands, and made design choices on behalf of the users they aspired to give a voice to. As a result, many users questioned the value of this ecological modeling altogether, lamented the WFD Explorer's lack of adaptability and transparency, and these critics did not adopt the WFD Explorer in their work on water quality governance.

The WFD Explorer can be interpreted as a trading zone that involved contestation between different parties, some of whom had diverging interests. The aim of establishing a consensual understanding between the parties involved was not met, and the developers tried to 'hammer out' a shared language in response to these difficulties. The developers were driven to their ill-fated attempts to stabilize the development process due to two challenges they faced. First, the attempts of the developers to meet the requirements of their user base created a confusing and chaotic process of implementation, in which the WFD Explorer suddenly had to function as an instrument for detailed research rather than producing estimations with the aim of inspiring dialogues between those involved with water quality governance, which had been its original objective. This reveals a discrepancy between projected and actual use, which only became apparent after initial attempts to implement the WFD Explorer. Past experiences and projected benefits of participatory governance were a cause for optimism at the time, particularly on the part of policymakers at the national level. Secondly, the WFD Explorer failed to gain the trust of its user base. Users dismissed its output, lamented the lack of transparency of the model's inner workings, and in some cases even opposed the idea that ecological phenomena could be modeled at all. Since users had conflicting ideas concerning the role the Explorer should fulfil, it became rather difficulth for developers to meet the aforementioned objections.

Although the WFD Explorer was expected to act as an instrument for an inclusive form of participatory governance, requiring it to include a multitude of knowledge and social actors, which included not only model developers, but also ecologists, biologists, stakeholders, and policymakers, development became restricted to a group of 'experts'. That said, the development of the WFD Explorer required some uniformity, which could not accommodate the interests of all prospective users. In addition, the viability of the WFD Explorer in the political arena depended on a degree of standardization, which does not necessarily correspond with the ideals of inclusive politics. Although standardization may imply exclusion, it is also needed in a political context, to enable policy making on a national or European level for example. Instruments of governance therefore imply a degree of standardization, and as a result do not correspond neatly with the varieties of knowledge and social actors that are expected to be included in truly inclusive forms of politics.

In sum, the 'communication landscape' opened up by the WFD Explorer is not devoid of power, but fraught with power relations that shape the communication that takes place. It is crucial to study the effects and sources of these dimensions of power, since they shape the knowledge that is included in instruments of governance and influence the types of participant. Whether the WFD Explorer effectively allows for inclusive forms of politics evokes a tension between standardization and participation. If water quality governance leans more heavily towards standardization, it may reinforce existing hegemonic approaches to water quality and thereby exclude knowledge and social actors. The exclusion of knowledge and actors can put technological cultures at risk, since knowledge and actors that are potentially worthwhile are not included. However, if water quality governance leans more towards participation, its legitimacy in the political arena may be compromised since it cannot meet the requirements posed by policy making on a national and European level. Instruments of governance will involve a trade-off between standardization and participation, and should therefore be studied in terms of exclusion of both knowledge and actors to find out to what extent they put technological cultures at risk.

As became clear in the preceding discussion, the WFD Explorer can be seen as an attempt to furnish an inclusive platform for water quality governance. In establishing a 'trading zone' around water quality governance, the Explorer hammered out a language that only met particular interests. This led to the exclusion of actors whose technological frames were incompatible with the frames of those responsible for the stabilization of the WFD Explorer as an instrument of governance. Thus, water quality governance became imagined in a particular manner due to a shared language, which allowed difficult choices between inclusion and stability to be made, decisions that eventually materialized in the form of the WFD Explorer.

6 Conclusion: the socio-material substrate of trading zones

The three modeling practices discussed above reveal tensions between different technological frames that cannot be easily cancelled out. First, the tension between epistemic opacity and reflexivity continues to imply those modeling are immersed: although reflexivity and tinkering are indicators of critical engagement with computer simulations in practice, epistemic opacity remains a characteristic of simulation practice. Second, uncertainty can put technological cultures at risk, but it must not be ignored as a potential source of knowledge. The appreciation of uncertainty as a potential source of knowledge is presently not yet established firmly in decision making about risks, which is partly due to differences between the commitments of engineers and policymakers that cannot be easily resolved. Third and finally, even in those cases where inclusive platforms are designed to engage water-related risks, as my discussion of the WFD Explorer showed, the standardization needed to make such platforms successful in practice may be accompanied by exclusion. Thus, immersion, uncertainty, and exclusion emerge as three issues pertinent to modeling practice.

These three issues can be seen as side effects of the different technological frames present in the trading zones described above, and cannot be eradicated due to the fact that modeling practices are not confined to one particular social group, such as engineers. Failing to understand the mediating role of models leads to immersion, uncertainty, and exclusion as potential sources of risk. Due to immersion, the inner workings of models can be left unquestioned, which makes it more likely model output will be taken at face value, even if it contains assumptions, uncertainties, and blind spots that have problematic effects. Although the epistemic opacity of computer simulations, and models more generally, is unlikely to ever go away, reflexivity can lead to more responsible forms of modeling practice. Uncertainty, when unaddressed, may cause discrepancies between flood risk management and flood-related risks, ultimately leading to unexpected damages to flood defences or a failure to act properly in times of need due to incomplete flood risk measures. A technological culture that is able to appreciate uncertainty as a source of knowledge can adapt to risks that are only provisionally understood. Exclusion may cause crises in political representation, since stakeholders and other relevant actors are not taken up in water governance. As became clear in the previous section, exclusion may be detrimental to the uptake of knowledge instruments needed using in water governance. Successfully developing such instruments is crucial for water governance, which only maintains political legitimacy if those affected by policies are included in the process of policy making. This task requires walking a fine line between participation and standardization.

It is clear that the mediating role of models, as knowledge instruments, have profound importance in all three cases. Concerning the mediating role of technologies more generally, organisation theorist Wanda Orlikowski questions any rigid divide between social and technical elements. In her analysis of technologies aimed at workplace collaboration, she wishes to advance a 'sociomaterial perspective', which "would highlight how synthetic worlds are not neutral or determinate platforms through which distributed collaboration is facilitated or constrained, but integrally and materially part of constituting that phenomenon."[32] For example, users of the WFD Explorer cannot be considered as free-floating and fully autonomous individuals since they are situated in a 'technical milieu' that influences their actions and perspective.

A stronger focus on the construction and effect of this technical milieu is needed to avoid depoliticizing the effects of instruments of governance. Various authors point out the need for an explicit focus on the technologies of governance.[33] In addition, recent work on what can broadly be categorized as 'software studies'[34] forms an emerging area that is particularly promising in terms of understanding how software and society are interrelated. However, the broader appreciation and adoption of this approach will partly depend on the willingness of social scientists to become familiar with the principles of software development. A stronger focus on the mediating role of technologies can also deal with the epistemic opacity and perceived success of simulations and models, which establish thresholds for participation and negotiation: Users may be incapable or simply not interested in opening the black boxes they confront in simulation practice, or simulations and models may have acquired so much currency in practice that they cannot be easily contested.

In order to understand the relationship between simulation practice and the vulnerability of technological cultures, models need to be analysed as pragmatic constructions, developed with particular purposes in mind, and as knowledge instruments that cannot function as all-encompassing and exhaustive representations of target systems. In this paper, I have shown how the exploratory and pragmatic use of simulation practice is located on a slippery slope towards immersion in increasingly opaque technological practices, seemingly socially and epistemically robust explanations of uncertain phenomena that may prevent the uptake of uncertainty as a source of knowledge, and forms of governance that could exclude knowledge and actors. Immersion, uncertainty, and exclusion need to be subjected to careful scrutiny if technological cultures want to prevent themselves from developing risks that loom behind an ignorant attitude towards the mediating role of knowledge instruments.

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