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RESEARCH ARTICLE

Why won't water managers use new scientific computer models?: The co-production of a perceived science-practice gap

Catharina Landström*, [1]

Abstract • The uptake of scientific computer models in water management is challenging. Scientists often face calls to improve stakeholder engagement procedures. However, the involvement of representatives of water management agencies has been common practice in scientific projects for at least a decade. It is therefore questionable whether more stakeholder involvement would lead to greater use of scientific models in water management. This study suggests that computer modeling has historically developed differently in water science and water management. Scientific research has focused on continuous improvement of model process representation, while water management has emphasised usability. Today, the reliance on modeling software packages in water management, exacerbated by the dynamics in the field, mitigates against the adoption of new scientific modeling tools.

Warum nutzen Wassermanager keine neuen wissenschaftlichen Computermodelle?: Die Koproduktion einer vermeintlichen Lücke zwischen Wissenschaft und Praxis

Zusammenfassung • *Die Einführung wissenschaftlicher Computermodelle in der Wasserwirtschaft ist eine Herausforderung. Wissenschaftler sehen sich dabei oft mit der Forderung konfrontiert, die Verfahren zur Einbindung von Interessengruppen zu verbessern. Die Einbeziehung von Vertretern der Wasserwirtschaftsbehörden ist jedoch seit mindestens einem Jahrzehnt bei wissenschaftlichen Projekten gängige Praxis. Es ist daher fraglich, ob eine stärkere Beteiligung von Akteuren zu einer breiteren Nutzung wissenschaftlicher Modelle in der Wasserwirtschaft führen würde. Diese Studie legt nahe, dass sich die Computermodellierung in der Wasserwissenschaft und der Wasserwirtschaft historisch unterschiedlich entwickelt hat. In der wissenschaftlichen Forschung wurde der Schwerpunkt auf eine kontinuierliche Verbesserung der Modelle zur Prozessdarstellung gelegt, während in der Wasserwirtschaft die Benutzerfreundlichkeit im Vordergrund stand. Heute steht die Abhängigkeit von Modellierungssoftware in der Wasserwirtschaft, verstärkt durch die Dynamik in diesem Bereich, der Einführung neuer wissenschaftlicher Modellierungswerkzeuge entgegen.*

Keywords • *computer modeling, water management, stakeholder, science, co-production*

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Introduction

Scientists studying water with the use of computer models are today often expected to not only generate new knowledge but also to create new computational tools for use in water management. Research funding agencies ask for scientific projects to achieve societal impact by providing new model-based digital tools for use by water management professionals (Williams 2020). To effectively deliver such tools university scientists have been advised to involve stakeholder representatives from water management organizations directly in research projects (Colosimo and Kim 2016). Despite devising research projects with extensive stakeholder involvement and creating tools that participating professionals find both useful and usable, getting these computer modeling programs adopted in water management has remained a challenge. Recent discussions in scientific journals in water research address this issue and while there is continuing underlining of the importance of improved stakeholder engagement there is also a growing recognition of the importance

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of the institutional context (Wardropper and Brookfield 2022). The present paper contributes to this emerging theme with an exploratory overview of the historical development of distinct computer modeling practices in water science and water management from the 1970s to the present. It is argued that the configuration of actors and their relationships in the relevant governance contexts are key determinants for the adoption of computer modeling tools in water management. In the following the societal co-production of two distinct computer modeling traditions in water science and water management is outlined and the inefficacy of stakeholder participation as a means to transfer computer programs from science to management is clarified.

Aiming to capture processes evolving through time qualitative document analysis (Bowen 2009) is the primary method used to develop the argument of this paper. Relevant texts have been traced and accessed in online publication databases. Such an effort can only ever be partial, and the findings presented here are not intended to be exhaustive, the ambition is to suggest a critical social studies of science perspective that may inform further investigation of this complex issue.

The paper begins with an outline of the key concepts which are subsequently used to organise the argument in three sections. The first substantive section details the historical evolution of computer modeling in water science and water management drawing on the notion 'matters of concern' (Latour 2004) to emphasise practice. The second empirical section examines the way water modeling is shaped in a water governance space (Lange and Cook 2015), with the United Kingdom (UK) as an example. Finally, the divergence of scientific computer modeling and computer modeling in water management is discussed as the outcome of a wider process of co-production (Jasanoff 2004).

A brief note on key concepts

The objects that this paper pivots on are computer programs that make it possible for users to analyze the aspects of water systems that are of interest to them by simulations. Such programs are referred to with many different terms, depending on who is talking. For example, scientists often talk about them as models and about modeling as a process beginning with theory, concepts and mathematical formulas, that they express in computer code. In contrast water management professionals may speak of models with reference to off-the-shelf software packages, that can include several computer programs, which they apply to a water problem in a particular location. This paper does not prescribe a particular use of the terms but follows the actors and tries to clarify what is meant in each reported conversation.

'Matters of concern' is a social studies of science concept that was introduced by Latour (2004) to distinguish between scientific propositions accepted as matters of fact and contested scientific knowledge claims. Making the distinction in this way opened for new lines of inquiry and of particular interest for the present study is the practical and temporal dimensions. Matters of concern directs attention to the socio-material processes through which some elements are stabilised and taken for granted over time. The emphasis is on actions, on the practices in which some perspectives become self-evident to the people involved. Applying this concept to the evolution of computer modeling of water focuses attention to the actors' discussions about what they want their models to do. In the next section of the paper this concept informs a historical outline of the development of computer models in water science and water management.

In the present paper the reference point is water related decision-making more broadly.

Computer modeling of water plays a role in a wide range of societal practices, here the focus is on the scientific study of water as resource and environmental feature and on the management of it, including flooding, drought, and water quality. Scientific research on water is distributed among many scientific disciplines of which hydrology is a major field but other fields, such as geology and chemistry, also model water scientifically. Water management is also distributed across many actors in society, ranging from national government departments to local authorities and private businesses, which operate on varying geographical scales and with distinctive legal responsibilities. To capture this complex multitude, we adapt the notion of drought governance space used by Lange and Cook (2015). Lange and Cook aimed to capture the complex relationships between the actors involved with drought decision-making in the UK but in the present paper the reference point is water related decision-making more broadly.

The modified notion of 'water governance space' indicates networks of heterogenous actors who are linked together by issues involving water, such as flooding. The water governance space encompasses both science and management and the relationship between them and with other institutions and organizations.

'Co-production' is a well-known and widely used concept in science studies and beyond. Sheila Jasanoff's (2004) elaboration of the notion emphasises historical process and institutional dynamics. This paper embraces Jasanoff's idea that science and society co-produce knowledge and expertise that decide the ways in which environmental challenges, such as drought and flooding, are addressed at a particular time in a specific place. The final section of this paper deploys the notion of co-production in a critical discussion of the discursive emphasis on direct involvement of individual stakeholder representatives in scientific research as the most important measure to increase the uptake of scientific models and modeling tools in water management.

Distinct matters of concern

Computer modeling was adopted as a technique for investigating water in the early days of computing. In a retrospective article Keith Beven, a still active professor emeritus in hydrology, recalls that his first model was "programmed in Algol and physically existed as a pack of punched cards that needed to be fed into a card reader every time a run was made" (Beven 2019, p. 1481). Drawing on his long experience he insists that the reason for water scientists to model has always been, and remains, to "test the understanding of how a hydrological system might function" (Beven 2019, p. 1486). The main purpose of Beven's article is to discuss the priorities for hydrological modeling, the retrospective demonstrates the continuity of the concern with model improvement through the decades. Beven's construction of a genealogy underpins his identification of important issues in hydrological modeling – deciding if a model is fit for purpose, improving process representation and to create "models of everywhere" – as perpetual preoccupations in water science. For the present purpose it does not matter whether other water scientists in academia agree that these are the most important issues, what is of interest is that we can discern distinctly different matters of concern in water management.

The historical evolution of computer modeling in water management can be traced via instruction manuals for water engineers and other texts with a practical purpose, which were written as it became possible to run computer programs on office desk top computers. Potential model users needed information about how to deploy the computer programs. In a 1982 guidance text the US Office of Technology Assessment (OTA) explained that:

> "While many of the economic and social factors in water resource decisions cannot be fully enumerated, models can be used to integrate the available data, and provide estimates of future effects and activities. Such estimates are highly useful in evaluating the consequences of different resource policy options, and are often less expensive than conducting comprehensive surveys and using other traditional approaches" (OTA 1982, p. 6).

This quote explains the purpose of computer modeling in water management in a concise way – to bring the available quantitative information together and enable estimation of potential consequences of actions. It also brings practical considerations to the forefront by noting that computer modeling is often cheaper than other ways of generating the knowledge needed. Further, the OTA also identified challenges to the successful use of computer models in water management:

> "Presently, model development has outstripped corresponding support for models. In the past, model developers have put a premium on developing models, while support for models – documentation, validation, dissemination, user assistance, and maintenance – has been neglected. Often, resources are focused on development, but are unavailable for support activities" (OTA 1982, p. 9).

This shows that maintenance of computer programs and user support emerged as matters of concern in the early days of water management modeling. This was not an issue for university scientists who wrote their own computer programs to address research question they had formulated in relation to scientific discourses. In contrast water management required computer programs that could be used by professionals with different disciplinary backgrounds, whose work included ensuring that good quality water was delivered to households and businesses, that properties were protected from flooding and that there would be sufficient supply of water in times of drought.

Both science and water management in the 1970s and 80s called for improvement of computer models, but with different matters of concern. Scientists sought to achieve more accurate representations of natural processes which emphasized the theoretical and mathematical models encoded in computer programs. In contrast, the concern of water management was to address real-world problems, thus prioritising reliability and usability of computer programs for different users. While reliability requires comparison of different aspects of computer programs, including the scientific quality, usability points in the direction of standardisation of computer programs in software. In the 1990s, a guide for engineers remarked that:

> "The model user community has grown dramatically, particularly in regard to local public agencies, private consulting firms and other non-federal users. Most of the water management models cited throughout this report include user-friendly executable (ready-to-run) versions for desktop computers. Essentially everyone in the water management community now has convenient access to the computer hardware needed to run the available software" (Wurbs 1994, p. 4).

The quote is from a US publication, but computer modeling had become a key tool in European water management too by the 1990s (Seibert and Bergström 2022). Worldwide the issue of user-friendly software featured prominently in discussions of water management, and this appears to have impacted the development of computer modeling programs. The same US guide for water engineers notes that:

> "Model development in recent years has been characterized by an emphasis on interactive user interfaces oriented toward using advances in computer technology to make models more convenient to use. […] Enhanced user interfaces

> have been a key consideration incorporated in the development of newer water management models and have been recently added to a number of older models" (Wurbs 1994, p. 13).

The emphasis on the need to improve user interfaces and user support in guidance texts from both 1982 and 1994 shows that usability is a long-running matter of concern in computer modeling for water management. Scientific computer modeling did not evolve in a way that could satisfy this need, instead there has been a proliferation of models implemented in computer codes which continues in the present. Some scientists view this as a problem.

> "Today the plethora of available models has grown beyond any possible limit and the need for accommodating under a unifying view and reconciling the different approaches has become of great priority" (Todini 2011, p. 73).

Others see good reasons for creating new models:

> "One of the key drivers for the pronounced model diversity in hydrology is undoubtedly the wide range of model applications […] that all require appropriate modeling […]. Two well-accepted characteristics that models should exhibit are parsimony and adequacy to the problem at hand, that is, a model should not be more complex than necessary and should be fit-for-purpose […]" (Horton et al. 2021).

Parsimony requires that a computer model does not include redundant algorithms that may slow down its running and affect stability, adequacy is about the faithful representation of the specific local process. These are scientific criteria that drive ongoing development of new models, other considerations are:

> "Researchers […] are, in fact, very keen on using local models, either developed in Switzerland […] or even at their own research institute. […] This model-institute link is likely to be one of the main causes of the existence of so many hydrological models, since each research group develops its own tools" (Horton et al. 2021).

Water scientists test their explanations of water system behaviour by creating computer programs and running models. That scientists want to use their own computer program codes, or codes that their research team use speaks to the way in which they develop trust in a model. Familiarity confers transparency, scientists see through trusted computer programs to the physical processes they investigate.

When water scientists have completed research projects they often move on to a new project, addressing different questions. In the new project they may create a new computer model or radically rewrite a computer program they have used previously, already in the late 1990s it was noticed that:

> "The majority of the thousands of water-related computer models reported in the literature […] were developed to support a particular study, which was eventually completed and the model shelved" (Wurbs 1998, p. 192).

Computer programs written to address the questions driving particular research projects are rarely used again in the original format, hence the code is not tested for reliability across contexts or made usable for non-scientists. Scientific practice does not push the development of computer programs towards resolving matters of concern in water management, even when they achieve better process representation.

Computer modeling in the water governance space

Water management involves more than knowledge about the physical behaviour of water, a 1990 guide for engineers and other practitioners explains that "the planner must effectively consider the political aspects of the project, and he [sic!] must be clear about needs, goals, objectives and expectations resulting from the socio-economic and cultural system and being influenced by the infrastructure" (Dyck 1990, p. 4). That many elements influencing water decision-making cannot be captured in computer models has been recognised for decades.

> "[… M]athematical programming techniques cannot provide a unique optimal solution for a water resources system. For long-term planning and management, methods are required which reflect the complex, interactive, and subjective character of the decision-making process, taking into account the experiences of the decision-makers […]" (Dyck 1990, p. 5).

In real-life water-related decision-making other people than modelers set the agenda and computer modeling is only one element of many. This raises the question of how to incorporate modeling in decision-making. One approach is to consider computer models as a type of decision-support tools.

> "The application of decision methods and the integration of such methods with hydrological modelling systems for use in water resources control and management will have also to be advanced. At this stage the hydrological model becomes integrated in the new kinds of architectures and paradigms (of object orientation and agent orientation) that are now becoming established in other fields" (Refsgaard and Abbot 1996, p. 14).

The notion of decision-support spreading through the water science literature in the 1990s remains central today as the demand on scientific projects to show impact through uptake of scientific modeling in water management is often met by commitments to contribute model-based decision-support tools. A 2022 special issue of the Journal of Hydrology focuses on the challenges of creating decision-support tools that are adopted in water management. Interestingly, most papers in the special issue discuss improvements of process representation in new decision-support tools (Wardropper and Brookfield 2022).

In the decade around the turn of century 2000 software for water management modeling had multiplied and continued to do so. Creating modeling software for use in water management has become a specialized technical field, done by multidisciplinary expert teams in businesses operating on global markets. These expert businesses provided modeling software packages as off-the-shelf products for purchase, offering user support and regular upgrades. Written advice was needed for what to consider when investing in a software package:

> "Generalized models should be convenient to obtain, understand, and use. They should also work correctly, completely, and efficiently. Documentation, user support, and user-friendliness of the software are key factors in selecting a model for application. The extent to which a model has been tested and previously applied in actual studies is also an important consideration" (Wurbs 1998, pp. 190–191).

In the time that has passed since advice was directed to individual professionals selecting a software package to use when modeling for water management the number of such packages and the cost of using them has multiplied. It is no longer a decision that can be taken by an individual in an organisation that has financial and legal obligations. Today the complexity of water governance requires standardization of modeling software use, UK flood risk management provides an example of how this can be done.

All UK key actors in the water governance space use computer models – the water utility companies have modeling experts who use software packages to generate actionable knowledge to manage water resources, a task including modeling water supply, sewage, run-off, drought, flooding, water quality and more. The UK Environment Agency (EA) – the regulatory authority for water as a natural resource that needs to be used in a sustainable manner – models all processes affecting rivers and lakes, including biodiversity. The EA operates under the auspices of Defra (Department for Food, Environment and Rural Affairs) the government agency responsible for water management nationally, which draws on modeling to develop policies for achieving national objectives such as a certain level of flood protection for all properties. Also important in relation to modeling are the expert consultancies who carry out many modeling projects for private businesses, government agencies and local authorities. For UK water management to work – delivering water to households and businesses, removing foul water (including sewage and road runoff), mitigating flood risk, ensuring sufficient river flows for aquatic and riverine ecology to survive and flourish, and so on – everybody must act in concert. In this context computer programs must be stable and transparent.

The need for stability and transparency of computer models in water management is, in the UK, satisfied through benchmarking of available software packages. Since the 1990s the EA, under the auspices of Defra, has undertaken benchmarking projects in collaboration with major consultancy firms and university scientists, to compare the market leading water modeling software packages. The importance of the benchmarking is visible in the EA guidelines for modeling in flood risk management (often carried out by consultancies commissioned by local authorities).

> "You must be able to demonstrate that the software you choose is suitable for the intended use. […] If the tests are done independently, the EA will need to review the results before you use the software for a project" (EA 2021).

While everybody is free to use any model that they would like, comparing a new computer modeling program with the benchmarked software would require extensive effort. The water management modeler who wanted to use a non-standard modeling program would have to prove that it performs at least as well as the approved packages on the list provided by the EA:

Modelers in science and in water management talk about water in much the same way.

- "To produce a 1D model, you can use: Flood Modeller, ESTRY, HEC-RAS, InfoWorks ICM, MIKE FLOOD
- To produce a 2D model, you can use: Flood Modeller, TUFLOW, HEC-RES, InfoWorks ICM, MIKE FLOOD, JFlow®
- To produce a 1D2D model, you can use: Flood Modeller, TUFLOW Classic, HEC-RES, InfoWorks, MIKE FLOOD, JFlow®" (EA 2021)

All but two of the approved software packages are proprietary. Developed by the US Corps of Engineers HEC-RAS and HEC-RES are free to download and use since they were developed with federal funding. The other approved packages were developed by expert consultants, often starting with a computer program written by university scientists as a PhD or post doc project.

The UK example shows how models can be stabilized and controlled as software packages in the water governance space. In other countries the required stabilization of modeling software may be achieved in other ways. One example is through close long-term collaborations between creators and users of modeling software in Sweden where SMHI (the Swedish Meteorological and Hydrological Institute) has provided modeling services and software for water management to municipal and regional authorities since the 1970s. In the Netherlands the research institute Deltares develops and supplies an array of software tools for use in water management. Regardless of how modeling software is stabilized in a particular water governance space, it is a process that runs counter to the continuous creation of new computer models in academic science.

Concluding discussion: a co-produced gap

Recently science funding agencies have voiced concerns about the creation of computer models in water science that are only used in the funded project. This is considered a problem and scientists have responded to this by promising to deliver decision-support tools for use in water management through increased stakeholder engagement. However, the historical outline of modeling in water science and water management in the previous suggests that increasing, the already common stakeholder involvement, will not lead to more uptake of new scientific computer models in water management.

The document study showed that although computer models are central in both water science and water management the matters of concern arising in these practices that drive model development differed from the outset. Scientists work in contexts where they are free to develop new scientific computer modeling programs that enable them to answer their research questions. A successful scientific computer model points the scientists to the aspects of the studied process in nature that are still poorly understood. In contrast, water management practices require computer programs that can be used to address the same questions in different physical contexts by professionals with diverse expertise. A successful water management model is easy to use, reliable across contexts of use and it produces information that is appropriate for the decision-making situation. The differences between what is a useful computer model in science and in water management explains why water scientists cannot deliver models or modeling tools directly to users in water management. The requirements on water management models have prompted development of modeling software packages. A successful scientific model needs further development to become usable software.

The differences between what computer programs need to do in the two domains can be understood as resulting from historical and institutional co-production (Jasanoff 2004). Water science and water management have evolved as distinct practices conducted in different societal institutions. Science provides a framework for experimentation and invention within the water governance space while water management is responsible for controlling water as a common good.

Interestingly, modelers in science and in water management talk about water in much the same way which could contribute to the positive valuations of stakeholder involvement in research projects by both scientists and stakeholder representatives. This positive interaction does not often lead to the desired transfer of new models into water management practice. An individual stakeholder representative's interest in a new computer modeling program does not make it possible for her or him to start using it in their everyday work that is defined by the requirements of institutional decision-making. Water management computer modeling software must be transparent and trusted by the institutions and organizations in the water governance space, who are affected in by the decisions. The UK example shows how the selection of software packages for modeling in flood risk management can be controlled by institutional actors. Although the constraints of model choice for decision-making may be less explicit in other places and in relation to other issues the time-consuming comparison of modeling software packages and the need to provide user support, technical upgrades and so on mitigate against the adoption of novel scientific computer models in water management.

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