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Assembling, Channelling, and Orienting Watershed Management: The Performative Roles of Computer Models in Environmental Management Institutions

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ABSTRACT: Large-scale watershed management increasingly depends on the use of computational models to inform decision-making and track management goals; however, the roles that models play in environmental management institutions far exceed their informational content. Science studies scholars have approached modelling as also a performative practice that shapes the relational context of watershed management. Drawing on an ethnographic approach, this article examines a single computer model as it is developed and deployed in an environmental management organisation. The study shows that a single model can serve multiple roles within a watershed management institution depending on specific conditions and contexts; further, by serving these multiple roles rather than a single informational one, models are uniquely useful for organising environmental science and management practices and institutions across a heterogeneous set of agents. Examining these multiple roles can help us to understand not only the process of computational modelling, but also the process of management and how different organisations can coordinate with one another through the use of modelling.

KEYWORDS: Computational models, watershed management, performative research, participatory modelling, Chesapeake Bay

INTRODUCTION

Large-scale watershed management increasingly depends on the use of computational models to inform decision-making and track progress towards management goals (NRC, 2007; Canham et al., 2003); however, the roles that models play in environmental management institutions far exceed their informational content. Science studies scholars have approached modelling as also a performative practice that shapes the relational context of environmental management (see Morgan and Morrison, 1999; Landström et al., 2013; Pickering, 1995). In this article, I use an ethnographic approach to examine a single computer model as it is developed and deployed in a watershed management context. I argue that a model can be used in many different ways depending on the specific social context. By taking on these multiple roles, models are uniquely capable of helping organise the relationships that constitute the reality of the watershed and watershed management. Examining the multiple roles of models can help to clarify both the process of modelling itself as a performative practice and the process of environmental management; it can also reveal how heterogeneous actors and organisations can use modelling to coordinate with one another.

I approach this issue through ethnographic research involving computational environmental modellers and environmental management staff in the Chesapeake Bay watershed. For many reasons, the Chesapeake region is an excellent place to examine these questions. First, since 1983, the Chesapeake watershed has been the focus of a large-scale effort to reduce nutrient pollution flowing into the estuary, the sources of which include deforestation, depletion of the oyster population, and agricultural fertilisers (Wennersten, 2000). This effort has been led by the Chesapeake Bay Program (CBP), which is a partnership between the federal government (lead by the U.S. Environmental Protection Agency), the seven jurisdictions that are encompassed by the watershed (Maryland, Virginia, Delaware, Pennsylvania, New York, West Virginia and the District of Columbia), and several academic, private and non-profit organisations (Ernst, 2003). As a result, the process involves heterogeneous interactions at many different scales.

The second reason this region is well suited to these questions is that, in order to coordinate nutrient pollution reductions, the CBP has been developing and implementing a complex ecological model known as the Chesapeake Bay Modelling System (CBMS) (Linker et al., 2002). The CBMS is considered to be a state-of-the-art model that helps to inform decision-making by identifying, tracking and predicting the effects of ecological management practices on nutrient loads (Shenk and Linker, 2013). It plays a role at every level of management and is thus a useful case study for exploring the many roles of computational modelling in an environmental management process.

My research shows that the CBMS plays different roles depending on the specific context in which it is being used. In this article, I outline three of these roles: assembling, channelling and orienting. Though this is not an exhaustive study of the many possible roles that computer models could or do play in environmental management, it provides an initial conceptual and methodological framework for examining these roles and for exploring the limits and opportunities of modelling in the creation of more inclusive forms of environmental management.

THE CHESAPEAKE BAY PROGRAM AND THE CHESAPEAKE BAY MODELLING SYSTEM

Chesapeake Bay is an estuary that cuts into North America at about the middle of the US Atlantic coast (Wennersten, 2000). The Bay itself is about 320 km long, extending from Havre de Grace, Maryland in the north, to Virginia Beach, Virginia in the south. Its north-to-south variation in saline content supports a wide diversity of aquatic species and provides a passage for many types of migratory fish. These features make the Chesapeake a very productive ecosystem that has for over 200 years supported economic activities in the region through its seafood harvest and tourism. Its watershed extends across 166,000 km^2 and encompasses portions of six US states including Maryland, Virginia, Delaware, West Virginia, Pennsylvania and New York, as well as the District of Columbia (Newcombe, 1938; Brush, 2001; Ernst, 2003).

Algonquian-speaking Indigenous peoples have inhabited the region for thousands of years and made extensive use of the Chesapeake Bay's fish, shellfish and migratory fowl. Archaeological evidence suggests that the harvesting of these species was largely sustainable (Young, 2021). Since the arrival of Europeans to the region in the 16th century, however, both Chesapeake Bay and its watershed have undergone a number of transformations that have depleted their ecological condition (Young, 2021). A combination of factors has resulted in the development of hypoxic conditions in the estuary; these factors include overharvesting of shellfish and the introduction of shellfish diseases, deforestation, decimation of the beaver population, and reliance on chemical fertilisers (Wennersten, 2000). Hypoxia is the depletion of oxygen from a water body that results in harmful conditions for aquatic species (Ernst, 2003). First noted in the 1930s in Chesapeake Bay (Newcombe and Horne, 1938), hypoxia is generally caused by an overproduction of algae due to an overabundance of nutrients such as nitrogen and phosphorous in the water. The algae reduces the clarity of the water, which prevents sunlight from reaching the sea floor; this, in turn, reduces the development of aquatic plants that introduce oxygen to the water (Ernst, 2003).

Nutrients are introduced to Chesapeake Bay largely through agricultural runoff from the land. Although hypoxic conditions were identified in the estuary in the 1930s, the problem was not fully understood until the 1970s. As I have described elsewhere (Trombley, 2018), a "watershed moment" took place at that time due to a combination of growing concern about water quality in the estuary, emerging institutional and technological developments, and flooding from a tropical storm that caused a pivotal shift from thinking about the estuary as a standalone entity to considering the entire watershed as a source of the Bay's troubles. The U.S. Environmental Protection Agency (EPA), created at the beginning of the 1970s, began to examine conditions in the Chesapeake. In 1983, after a series of studies, the EPA encouraged the District of Columbia, Maryland, Virginia and Pennsylvania to sign on to an agreement to reduce nutrient pollution in the Bay. This was the first such interstate agreement for the Chesapeake Bay watershed (CBP, 1983), and through it the Chesapeake Bay Program was created. The EPA, simultaneously, released a model of the Chesapeake Bay watershed (Trombley, 2018) consisting only of a simple quantitative model of the flow of water through the basin and the transport of nutrients and other pollutants to the estuary. It was developed using Hydrological Simulation Program – FORTRAN (HSPF) and was technically very advanced for its time (Keiner, 2004).

The CBP, as a watershed-scale environmental management programme, is a unique organisation in the United States (Horton, 2003). Under the Clean Water Act (CWA), the federal government is restricted in its ability to regulate water quality, primarily with regard to pollution from farm run-off (Malone et al., 1993). Due to this restriction, the CBP has been organised as a collaborative federalist partnership between the federal and state governments (Fischman, 2005). The CBP also includes a number of academic institutions, non-profits and private firms that contribute to the management process, primarily through scientific knowledge and advocacy. Organising these various institutional partners is a challenge, but the CBP has been successful over the past few decades at expanding and maintaining these connections despite a sometimes hostile political environment in which legal battles have challenged both the authority of the CBP's management and the use of the CBMS in management (see, for example, CBF, 2016).

Between the early 1980s when it was created, and the 2010s, the CBP evolved from a research organisation to an environmental management organisation. A series of new agreements were signed that included more of the watershed states, expanded the role of the CBP, and outlined strategies for reducing the nutrient pollution of Chesapeake Bay (CBP, 1987; CBP, 2000). At the same time, the watershed model was being continuously updated and upgraded to increase spatial resolution, include new hydraulic processes, and link the watershed model with an estuarine model that could describe and predict how nutrient pollution would affect hypoxic conditions in the Bay. These additions led to what I describe as the Chesapeake Bay Modelling System (CBMS), which is a suite of linked models that help understand and predict nutrient pollution throughout the watershed (Linker et al., 2002; Shenk and Linker, 2013).

By 2010, several agreements had failed to meaningfully address nutrient pollution in Chesapeake Bay. A number of lawsuits had also been raised by environmental advocacy groups such as the Chesapeake Bay Foundation (CBF) which claimed that the EPA was not doing enough to address the problem. At that point, the EPA drew on its powers under the Clean Water Act to impose a Total Maximum Daily Load (TMDL) for nutrient pollution across the entire Chesapeake Bay watershed (CBP, 2010). Commonly referred to as a 'pollution diet', the TMDL sets a maximum quantity of nutrients that can be introduced to a water body and then distributes the load to various users in the system. In the case of the Chesapeake TMDL, the seven watershed jurisdictions were allocated loads and required to find ways of reducing the quantity of nutrients flowing out of their respective states. In 2014, the first Chesapeake Bay Watershed Agreement was signed by all of the watershed states in order to enable the CBP to carry out the TMDL (CBP, 2014).

Throughout the management process, the CBMS has played a pivotal role in developing plans and evaluating progress towards reducing nutrient pollution for the CBP. With the TMDL, the model became even more central to the management process. The TMDL was used to set the overall maximum load for the watershed, and once the load was distributed the jurisdictions were required to submit plans for nutrient reductions to meet their obligations. These plans were then evaluated by the CBMS to assess whether they would result in sufficient nutrient reductions (Hood et al., 2021). The CBMS thus clearly plays more than a simple representational role for watershed management; indeed, it defines much of the way that management will take place across the entire basin. Recent research in Science and

Technology Studies (STS) provides some useful approaches for conceptualising these roles beyond the representational; these can help expand our understanding of why modelling is important to environmental management and how the use of models might be modified to address environmental problems more effectively.

COMPUTATIONAL ENVIRONMENTAL MODELLING AS SOCIAL PRACTICE

Computer models allow researchers and managers to simplify large and complex systems through a reduction in scale or by abstracting key features and processes that shape a particular outcome (NRC, 2007). In the last century, a new form of modelling emerged which uses equations and algorithms to represent complex material dynamics such as the flow of water on a landscape. These models are referred to as 'numerical', 'quantitative', or 'computational' models (Oreskes, 2003; Edwards, 2010). Although such models have been around for a long time, it was not until the last four decades that they have become widely used, thanks to reductions in the cost of computing as well as changes in the perception of their value in decision-making (Edwards, 2010). In that time, the use of computational models became especially prevalent in two well-known fields – finance (Mirowski, 2002), and the environmental sciences (NRC, 2007; Edwards, 2010; Paolisso et al., 2013). In the latter case, they have become an "obligatory point of passage" for environmental management (Callon, 1984), since they allow managers to identify, track and predict changes to the environment that have resulted from human activities (Oreskes, 2003; NRC, 2007). Computational models have been used to understand and address issues such as climate change, ozone depletion, deforestation and water quality (Edwards, 1999; NRC, 2007).

As their use in various fields has proliferated, computational models have generated a great deal of interest among philosophers, sociologists and anthropologists of science. Generally, the interest has focused on the kinds of information that can or cannot be included in models (Munk, 2013), their resemblance (or lack thereof) to other forms of scientific thought (Oreskes, 1998; Lahsen, 2005; Sundberg, 2009), and the politics of knowledge in which models are embedded (Helmreich, 1999; Whatmore, 2009; Tsing, 2011). These concerns reflect what Pickering (1995) calls the "representational idiom", meaning that they revolve around the knowledge that is produced from scientific practices. From this perspective, models are treated primarily as metaphors for physical processes, and questions about the role of models in a given social context should revolve around scientific reasoning, scientific discovery and changes to theory (Knuuttila and Voutilainen, 2003).

While important, these representational concerns do not fully encompass the social causes and effects associated with modelling. Many have thus called for an analysis of modelling based on what STS researchers would call a "performative idiom" (Knuuttila and Voutilainen, 2003; Edwards, 2010; Landström et al., 2013). Pickering describes a performative approach as one in which "science is regarded as a field of powers, capacities, and performances, situated in machinic captures of material agency" (Pickering, 1995: 7). In other words, science is not simply a knowledge production practice; it also involves 'doing things', or acting in a world full of other people, objects, machines and organisms. For Pickering, this process of 'doing things' develops as an iterative interaction between scientists, machines and the material world – a "dance of agency" whose outcome is fundamentally unknowable from the start (Pickering, 1995). In this framework, scientific and technical artifacts are actors within the social dynamic, and through this dance of agency between the artifacts and others actors involved (such as modellers, management staff and members of the public) they take on roles that direct and move others in particular ways. Similarly, for Callon (2007), the concept of performativity develops through linguistic theory; it indicates a discourse or activity that intervenes to alter reality, in contrast to merely constitutive statements that seek only to describe reality. In these senses of the term, a performative approach to computational modelling would ask how models are used in different contexts to produce a particular reality or outcome for the systems they seek to understand (Knuuttila, 2006).

In both Pickering and Callon, the agency of nonhuman actors is an important aspect of the performative approach. This paper, however, focusses on how the broader social context of modelling leads models to be enlisted in particular roles that shape the reality or outcomes of the systems they purport to represent. Acknowledging that models affect the social context in which they are embedded, I focus on the roles that models are ascribed within a given social context rather than the particulars of the nonhuman agency of models themselves (Cusworth and Stanley, 2025).

Within the performative approach, computational models are often described as boundary objects, that is, mediators that help negotiate between conflicting scientific and political perspectives (Morgan and Morrison, 1999; Sundberg, 2007; Leigh Star, 2010; Alberto Franco, 2013; Reilly et al., 2021). Nevertheless, the boundary object concept still focuses on *communication* between social entities rather than on the kinds of relationships that are produced from scientific activity (Leigh Star, 2010). Furthermore, even if this relational component is included in the boundary object concept, it is still necessary to outline the different ways that an object might function as such across multiple social contexts. It is these nuances that performative-based research needs to explore.

Edwards (2010) provides a thorough history of the field of climate science and its development through the 20th century. He describes climate science as "knowledge infrastructures" which "comprise robust networks of people, artifacts, and institutions that generate, share, and maintain specific knowledge about the human and natural worlds" (ibid: 17). Computational modelling plays an essential role in these processes because it allows researchers to overcome 'data frictions' such as differences in collected data that arise from the use of different instruments and methods across space and over time. In that sense, models can be used to bring together the heterogeneous components of the global knowledge infrastructure to form a unified image. Doing so, however, has required not only scientific processes of data collection, but also the negotiation of various institutional relationships that have made it possible to assemble the necessary data and material resources to conceptualise the global climate. This has resulted in the creation of international organisations such as the International Panel on Climate Change (IPCC), which are dedicated to integrating these scientific practices. (Trombley, 2019) describes a similar process in the CBP where institutional data sharing is a process of acknowledging and negotiating institutional constraints such as differing incentive structures, privacy policies, and legal interests. Trombley argues that modellers, in so doing, are actively facilitating relationships across heterogeneous institutional structures.

In a more directly interventional approach, there has been extensive research on 'post-normal' contexts of computational modelling. Post-normal science, according to Landström et al. (2013), describes a process that takes place within a contested social context where a scientific practice is transformed by that contestation. Landström et al. (ibid) examine two case studies; they compare normal and post-normal environmental management contexts in order to examine how the two different contexts shape the performance of computational modelling. In both cases, the modellers were obliged to improvise certain aspects of model construction. In the post-normal context, the learning process involved integrating non-scientific understandings of flooding into the modelling process, which required the scientific researchers to adapt by being more flexible about the tools and modelling techniques that they used. Their research demonstrates that modelling can be a form of collaborative learning across different social sectors.

METHODS

The goal of this research project was to use ethnographic methods to investigate the roles that computational models play in an environmental management process. With that in mind, I focus only minimally on the technical activity of coding, parameterising, validating and running the CBMS, since there is much literature detailing the performative aspects of these activities (Edwards, 2010; Sundberg, 2009). I focus instead on the social work of developing the model, integrating it into the management process, and justifying its place within management. The cases outlined highlight the multiple social contexts of computational modelling and the various roles that models take on in those contexts.

The research covered three years, starting in 2014 and ending in 2016. Most of the data was collected in 2015, which was the 'build year' for the Phase 6 version of the CBMS. The methods that were utilised consisted of participant observation and semi-structured key informant interviews (Bernard, 2006). These methods have enabled me to develop a first-hand understanding of the processes and practices involved in building and implementing a computational model for environmental management. They provide a rich and detailed understanding of the management conditions in which computational modelling takes place (Whitehead, 2005).

Participant observation included spending two weeks working with the CBP's computational modelling staff at the CBP office in Annapolis, Maryland. I spent an additional two weeks at the University of Maryland Center for Environmental Sciences (UMCES) in Solomons, Maryland, with academics who were involved in the CBP's modelling work. I attended 25 meetings that included the CBP's modelling team (the small group of modellers working within the CBP), its modelling workgroup (an extended group of modelling experts with whom the modelling team collaborates to improve the CBMS), and those working on other scientific and modelling projects. In June of 2016, I also participated in the biannual Chesapeake Modelling Symposium (CHEMS) and attended management-focused meetings to understand the application of the CBMS. This array of modelling and management meetings is the primary focus of my research because it highlights the social interactions involved in the management process and enabled me to understand the various ways that the CBMS is used in these different management contexts.

In addition to participant observation, I conducted 25 semi-structured interviews with modellers, natural scientists and management staff working on environmental issues in the region. I selected these informants on the basis of their participation in modelling and management in the watershed. I focused particularly on those who could provide a unique perspective on the modelling and management process and the social relationships involved. My questions were designed to elicit information about how computer models are utilised in the management process; I also wanted to engage my informants in a broader discussion about the social dynamics of modelling and management. The data was transcribed and coded using an inductive coding method in which key themes were identified from the data itself (Bernard, 2006). I selected themes that would highlight the intersection of computational modelling and environmental management.

In the following sections, I use the data collected from my research to examine three ethnographic examples; they show the different roles that the CBMS takes on in the management process, beyond the informational role described above. I describe these roles as assembling, channelling and orienting. I argue that all of these roles contribute to maintaining the watershed-scale organisation of the CBP by coordinating the cross-institutional relationships that constitute it.

RESULTS

Assembling the watershed

In August of 2015, I was at the CBP office in Annapolis, in the room that houses its modelling team. I was sitting in a cubicle that had recently been vacated by a team member who had moved on to another job. It was a claustrophobic space with little in the way of adornment. For the most part, it was quiet except for the sound of tapping on keyboards and the click of computer mice. In such close quarters, even with the cubicles, there is very little privacy and every phone conversation or visit from an outsider is a matter of public knowledge. Allan[1] sometimes calls it "the monastery".

In the cubicles around me there were people from several different institutions: the U.S. Environmental Protection Agency (EPA), the United States Geological Survey (USGS), University of Pennsylvania (UPenn), and Johns Hopkins University (JHU). They were there to work on developing the next generation of the CBMS watershed model, a Phase 6 version that would allow them to carry out the 2017 and 2018 mid-point assessment for the TMDL. They are the core of the modelling team at the CBP, but they were not the only ones working on the model. I knew there was another group of modellers across the complex from this room who were working on the scenario builder – an important piece of the model that translates data from the various jurisdictions into a standardised format that the model could use. I also knew that far away, at the Mississippi office of the U.S. Army Engineer Research and Development Center, Don and his team were working on improving the estuary modelling. I also knew that there were many academics at UMCES, UPenn, JHU, and the Virginia Institute of Marine Sciences (VIMS) who were working on components that could eventually make their way into the finished model. This would be a ground-to-stream model that would represent, among other things, the lag-time between the application of fertiliser and its entry into the water system.

In the context of its construction, the model takes on the role of a heterogeneous and fragmentary entity that must be put together. Much of the work of the CBP modellers (particularly Allan and Stephen) thus involves assembling these components. This includes figuring out what features the model will need, finding people to work on the code, tracking down data sources for calibration and validation, keeping everyone on-task and, ultimately, making sure that everything fits together. Since most of this cannot be done in-house at the CBP, it also requires finding ways to involve people who would otherwise be working on other research. I suggest that it is through the assembling of a model's various components that all of these people are brought together and become cooperatively engaged.

For Allan and Stephen, the process of assembling the model generally means spending a lot of time on the phone and in meetings. I have attended some of the meetings, participated in conference calls, and observed the labour of assembling the model's components. The following is a composite description of several of the meetings that I have attended. It illustrates the sustained collaborative process that produces the finished model.

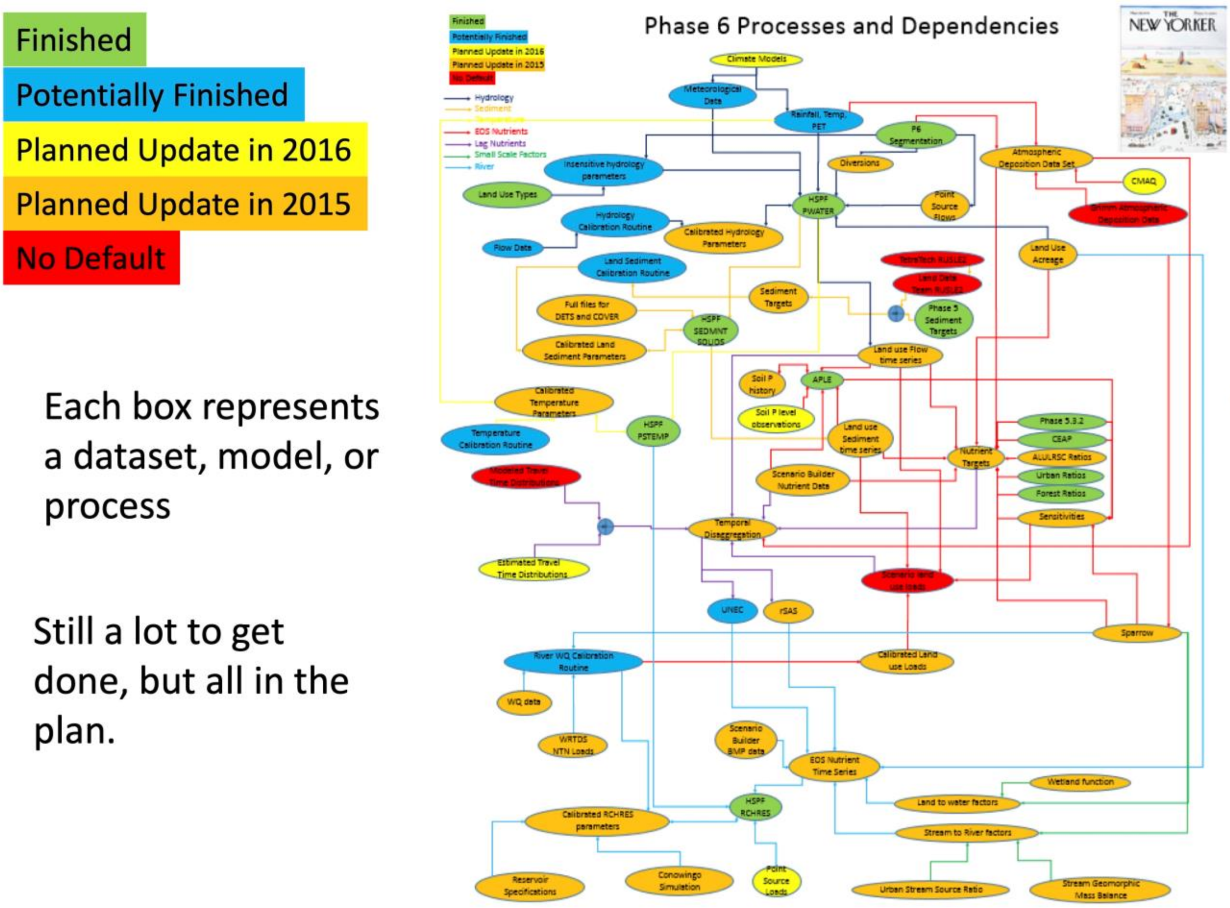
The quarterly meetings of the modelling workgroup take place in a room with a large full-length window overlooking the Severn River, which is a tidal tributary of Chesapeake Bay that runs through the heart of Annapolis. A large table takes up most of the room; a podium and presentation screen occupy one end of the room and several chairs line the opposite wall. The room is in a small building known at the CBP as the Fish Shack, as it sits at the edge of a dock in the parking lot of the office building that houses the CBP. Several boats are tied up to the dock, rocking gently. The meeting is led by representatives Charles and Matt, from two of the watershed states. They introduce the programme and then attempt, often without success, to keep the presentations on schedule. Stephen and Allan are at the meetings, as are most of the members of the CBP modelling team. The composition of the other attendees varies each time, but often there are academic partners, federal and state agency staff, and staff from private firms. All have an interesting the model and many play an active role in the work of building it.

The meetings usually take two days. The first day is generally devoted to the watershed modelling and the second to the estuary model, with other aspects of the model coming up as necessary. Stephen often gives the day's first presentation to update everyone on the status of the watershed model. His presentation generally opens with a slide that illustrates the many different "processes and dependencies" of the watershed model (Figure 1); it is colour coded to show the status of each piece. I

[1] I have changed the names of research participants to protect their privacy.

am struck not only by how many different processes and components go into the model, but also by the fact that each of the ovals represents someone somewhere who is working to produce one of the model's components. This may involve working directly on the model itself, devising new modelling methods, conducting research that will help inform the models, or assembling data that will contribute to the model's calibration or validation. As the image illustrates, it is a remarkable amount of collaboration and effort, and Stephen and the modelling team hold it all together by organising these meetings making all the related phone calls, tracking the process, and talking through the limitations and challenges presented by the model itself.

Figure 1. Processes and dependencies of the Phase 6 watershed model.



After Stephen's presentation, others stand up to present their own contributions to the work of modelling. One agenda from a meeting that I attended included the following: a discussion of model calibration, recommendations on the simulation of climate change and sea level rise, an approach to evaluating ammonia emissions for atmospheric deposition, and concerns about how the model represents best management practices. These meetings help to organise the work of modelling, ensuring that the necessary parts are on track and that everything will eventually fit together.

In this context, the model must be assembled from various constituent parts, including bits of code and data that represents the structure of the landscape and the physical processes occurring in the watershed. Assembling the model in this way organises the various scientists and modellers who are dispersed among the many different institutions involved in the partnership. Together they work to build the model and, in the process, they contribute their research, ideas and efforts to the process of understanding the estuary and its watershed for the purpose of management. In this way, it is not only the model that is being assembled, but also the network of social relationships among the scientists and management staff who take part in the meetings. The model, in this context, serves as an assembling device that is used to bring together these individuals to work on a single project. This network of scientists and management staff provides crucial insights from across the watershed.

Trombley (2019) describes the assembling of many different scientists and interested parties in the process of constructing the model; this gathering together of experts and stakeholders gives credibility to the CBMS as a valuable and accurate management tool. As such, the model is a tool for management and it thus helps inform decisions that may cost people in the watershed money, time or effort, and it has thus been frequently challenged. People claim that the model is inaccurate and therefore that the management practices it informs are not actually beneficial (cf. CBP STAC, 2011). To respond to these claims, the CBP often references the wide-ranging collaboration that contributes to the CBMS; in addition, when such challenges arise the various researchers and organisations that are involved in the modelling process often lend their support to the model. Without the engagement of the many people and institutions in the model's assembling process, such support might not exist.

Channelling the watershed

In June of 2016, I was in a large banquet room in the Doubletree Hotel in Williamsburg, Virginia. Several large circular tables were placed around the room on tiers and set with white tablecloths, pitchers of water, and glasses. At the front of the room was a small stage, a portable projector screen, and a projector on a cart. The room was a little too large for the number of people assembled and there were empty seats at several of the tables. On the stage, Bill was giving an enthusiastic and optimistic talk about the CBP's management process. He was showing the progress that had been achieved over the years and explaining what was needed to achieve ongoing improvements in the Total Maximum Daily Load. The modellers in the audience were listening with interest.

This event took place at the Chesapeake Environmental Modelling Symposium (CHEMS), an annual conference where researchers working on different aspects and methods of Chesapeake modelling gather and present their findings. Bill was one of the three keynote speakers who gave a talk that morning. He works for the CBP, where his job is to oversee the scientific aspects of the management process; his actual work, however, entails much more than that. He is partially responsible for communicating the management progress to diverse audiences and getting their feedback, as well as convincing them to take part in the process. In these meetings, Bill makes use of the model as what I have called a channelling device, that is, as a mechanism for keeping all the different actors who are involved in the watershed management process working towards a set of common goals. In his talk, Bill highlights the observed improvements in water quality in the Chesapeake that are recorded by the CBP's monitoring; he also outlines the different possible management scenarios that the model helps predict.

I have heard Bill give this talk in a few different contexts, including to county- and state-level management staff and to the scientific community. The content always differs depending on the audience; with modellers, for example, he emphasises the modelling, while with county-level managers he emphasises monitoring data. The form of the talk, however, is almost always the same and it is clear that he has given versions of it dozens of times to many different audiences in many different circumstances.

Bill starts his presentation by explaining the progress that has been made towards reducing nutrient pollution in the watershed ("Always start with something positive", he tells me); he then moves on to the work that still needs to be done. At times he talks in circles, directing (or perhaps misdirecting) the audience away from the conflicts inherent in the management process and back to the progress and the benefits that will accrue from taking part in the process. He mixes in anecdotes about walking into large auditoria full of farmers and trying to convince them to trust the models, which generates knowing laughs from the modellers at the conference. He frequently cracks jokes; they are often about the people in the room but just as often are about himself. He pokes fun at his age and his consequent inability to fully understand the fancy new gadgets, theories and modelling methods that everyone else seems to know so well. Again, this earns him laughter from the crowd.

When presenting to management staff across the basin, the audience is often more sceptical. Is the progress real, they ask, or is it just an artefact of the modelling? Does it have more to do with success on point sources or is there also progress on non-point sources? Why are certain management practices not showing up in the model? How much is it all going to cost? How do management staff convince farmers to do something that costs extra money when farmers are dumping loads of milk because the price is too low? Bill's talk becomes a catalyst for these and other concerns. He brings attention back to the progress indicated by the monitoring data and to the future trends described by the model. To break the tension, he tells another anecdote or maybe cracks a joke, and by the end of the talk there is a palpable sense of cautious optimism among the attendees. There is a sense that maybe it is all actually worthwhile, but that it remains to be seen.

Bill's talk is part of the process of holding the watershed management partnership together despite the different interests and goals of the individuals and organisations involved. Each of the partners has their own interests and priorities that often do not coincide with the management goals of the CBP as a whole. States and counties, for example, are concerned with management issues outside of the watershed and with priorities that have no effect on the CBP; environmental non-profits are often driven to endorse more stringent management goals than the CBP is inclined to implement; and academic institutions are interested in furthering scientific understanding but also in finding sources of funding and other resources. To keep all of these institutions involved in, and committed to, the CBP's management process, the CBP staff must continually remind them of the goals of watershed management and of the importance of their particular role in achieving those goals.

Without the model, coordinating these organisations would be far more difficult. In an interview, Bill outlined what he felt were the advantages of the CBMS by comparing the Chesapeake Bay partnership with the experience of those active around the Gulf of Mexico/Mississippi River watershed. The Gulf of Mexico watershed, he explained, is much larger than that of Chesapeake Bay and includes many more jurisdictions. Rather than using a complex watershed model like the CBMS, they have instead worked with a simpler statistical model. Bill claims that the absence of a complex model has prevented the Gulf of Mexico Program from getting participation from the various states in the watershed. As evidence of the value of computational modelling, he points towards the CBP's successes:

> The Gulf of Mexico has gone for a very simplistic [modelling] approach. Almost like a linear regression model (…). I said, yeah, (…) show me where you've convinced the Iowa farmers they need to do it. Yes there's a difference between a 6-state watershed and a 37-state watershed, I agree with that. But (…) they have not gotten the agreement to the levels that we've done. I said, show me where you've got 450 wastewater treatment plants that have gone close to limit technology, or within a reasonable piece of that. I can show you 6, 7 billion dollars worth of investments right here. And I can show you cleaner water!

It is debatable, of course, whether the Gulf of Mexico and Chesapeake Bay watersheds are comparable, but Bill's statement reflects his perception of the importance of modelling in keeping the partnership together. The model per se, is not always front and centre in this process. Bill, for example, likes to downplay the role of the model when talking to stakeholders and county managers; it is always there, however, in the backs of the minds of many of those involved. It provides guidance about what needs to be done and is also a point of frustration for many people who are involved in the process. When it comes up – and it always does – Bill reminds those present that the model is not the "EPA's model", it is a "partnership model". Everyone in the room has had a hand in its construction and/or application, he says, having contributed data, code, feedback and other resources. This does not always allay concerns, but it reminds people in the audience that they also have responsibility for the results and for the management decisions that are linked to it.

When I talk to state- and county-level staff, they do not always speak fondly of the CBMS, as I will discuss in the following section; however, they do use the model and the empirical data from monitoring as a metric for their own advancements and this allows them to feel at least partially responsible for the overall progress that has been achieved in the watershed. The model data helps foster that sense of collaboration and collective effort; it also helps to organise management activities and keep everyone involved in the partnership and working towards the watershed goals. I describe this aspect of the model's role as *channelling.* The term invokes a sense of both 'tuning in' to a particular idea and (in the hydrological sense) coordinating and directing a flow. By channelling the various participants into the CBP's management process, the model helps to hold together all of the cross-organisational relationships that would otherwise diverge due to their own individual interests.

Orienting the watershed

In December 2016, I was sitting in another conference room, this one very different from the Fish Shack at the CBP office. It was located in Owego, New York, in the basement of the Tioga County Sheriff's office. The only two windows were obscured by blinds and the many tables had been arranged into a large square. The people in attendance were also very different from those who were at the meetings in Annapolis. They wore jeans and flannel shirts, rather than the slacks and dress shirts I saw in Annapolis. They had hats that said Caterpillar or John Deere, and in some cases, their hands showed signs of physical labour as if they had spent hours outside working with heavy machinery or digging in the dirt. In fact, many of them had been doing just that.

This was a meeting of the Upper Susquehanna Coalition (USC), a group of county-level management staff from the Southern Tier of New York State and a few of the counties in northern Pennsylvania. They gathered bi-monthly to discuss the work that they were doing to address nutrient pollution, wetland depletion and other pressing watershed concerns. A few of the members gave presentations on specific projects. There were some success stories; these included the initiative that had brought in volunteers to plant trees in depleted areas, and the construction of a wetland on a golf course in the northern watershed. There were also some failures, such as the copse of trees that had been planted on a farmer's land which were then trampled by cows that had knocked over a fence. The stories were of on-the-ground management practices that were being successfully and unsuccessfully implemented in order to improve the watershed and reduce the flow of nutrients into the Chesapeake. Much of their work involves physical labour, such as digging up hard-packed stream banks and replacing them with trees and other buffers that prevent excessive nutrient runoff, removing culverts and unnecessary dams, evaluating environmental conditions such as fish populations, and working with farmers to reduce their dependence on fertilisers.

The majority of the labour discussed at these meetings, however, is not the physical labour of altering the landscape; instead, most of the work they talk about involves obtaining permits for management projects, seeking out and writing grants to fund the projects, and communicating with state and federal agencies about the on-the-ground changes that have been implemented. Most of the discussion is very tedious and bureaucratic, and it pains me to listen to the litany of red tape that must be managed on a day-to-day basis in order to carry out the projects that they want to undertake. Is a permit needed to lay gravel on a road if the gravel comes from the same farm? What is the status of reporting on stream restoration efforts to the state? Can funds from this grant be used for a grazing workshop? … and so on. Although perceived as very cumbersome, The bureaucratic procedures required end up directing the efforts of these management staff in many ways; steering them away from those that are too difficult or cost-prohibitive and towards easier, cheaper and, hopefully, more effective management practices.

When the CBMS comes up, it is usually to voice frustration over the way that certain management practices are represented in the model. In some cases, management staff feel that the model inaccurately represents the landscape; they feel that there are errors, for example, in the number of cows, in the suggestion that there are more beef cows than dairy cows, in the amount of manure that is being applied to certain land uses, in the amount of phosphorous being applied to the land, and in the model's population projections These factors all affect the estimated nutrient loads in the model which, in many cases, means more work for them to reduce those loads. In other cases, these inaccuracies potentially work in their favour and there are discussions about whether to "game the model" to get better results; in the end, however, there is agreement that it is better for them and for their relationship with the CBP to provide accurate data to improve the model.

In individual conversations, members tell me repeatedly that they want simply to focus on the work of implementing the projects but that, to do so, they must first navigate all of the permits, regulations and funding; the computer model, they tell me, simply adds another obstacle that must be navigated. To comply with the TMDL, for example, they have to get credit for the work that they do in the model. One of my informants, for example, described the county's work on stormwater drainage, which is one of the major concerns in the watershed aside from agriculture. Large flows of water that result from storms can cause erosion and accelerate the flow of nutrients and sediment towards the estuary, and the additional water can also overload wastewater treatment systems causing overflows of sewage into the waterways. This problem is exacerbated by large amounts of impervious surfaces in an area, including roads, buildings and parking lots. These prevent the water from being absorbed into the ground, which would slow the flow into the rivers and streams. The Upper Susquehanna Coalition has made significant progress on reducing stormwater in the region by constructing and restoring wetlands, improving road ditches, and other projects; however, it is the responsibility of the state to report these activities to the CBP. The USC argued that their progress in this area was not being accounted for in the model because the New York State Department of Environmental Conservation (DEC) was not submitting the information to the CBP; they had therefore been trying to work with the DEC to get accurate data to send to the CBP. It was the model and the TMDL process, the USC felt, that had required these otherwise unnecessary negotiations.

In this case, the model is used by the CBP as a tool for ensuring that the activities of these on-the-ground workers across numerous states and counties are directed towards the CBP's own goals. Another informant discussed the trouble she and her staff had in keeping up with different best management practice (BMP) definitions as they affected their load reductions. She explained to me that, over the years, the CBP had changed the definitions of several of the BMPs and that, each time this happened, they had to learn the new definitions, determine how they affected their existing loads according to the model, and then change their work on the ground to fit them. All of the work they were doing to keep up with the changes to the model, get credit for their on-the-ground work, and verify existing BMPs took up enough time to require an extra staff person in her office, she claims, but they were already understaffed and underfunded.

One of the county management staffers I spoke to expressed a similar frustration. He explained that he would rather be working on projects that had a direct impact on the economic and environmental sustainability of farms in his county, such as covered barnyards and farmer education about grazing practices. As he put it,

> I think it's always difficult when we try to figure out what work we're going to do and how it's going to impact the model (…), you know the scenario builder, I have not gotten into all of that. I don't have time to learn it, I just want to do work, do my covered barnyards, do my grazing work.

Later I asked him if the model helped his work in any way. He responded that being part of a TMDL helped make them more competitive for grants; but he then turned the question back on me, saying that,

> I don't know it's hard, I think it's a tough question to answer yes or no, I just think it's there, it's something that we look at, and you know, to think about it in the grand scheme, how would it help us? How would the bay model really help us, and (…) could you think of a way that the bay model would actually help us?

I responded that it might help them to identify priority projects, but he responded that they already had those tools in place before the model. He told me that, "all the model has done (…) is given us headaches, but not migraines". Immediately following that, however, he said that the model has made them focus more heavily on establishing stream buffers, which are forested areas between the streams and farmlands that help to reduce nutrient runoff from the farms. This means working on restoring existing buffers that have been depleted, but it also means working with farmers to rebuild buffers that have been destroyed and replaced with cropland. As he explained,

> They were trained for years to cut the trees down, and plant right up to the edge of the stream. And now we're saying "No, no, no we need the woods back, we need fifty feet" or whatever (…), that's definitely been driven by the bay program model.

In this situation, the model is used by the CBP largely as a constraint on the labour of these management staff, an added burden in addition to the permitting processes and the search for funding for projects. It is used to pull their effort in certain directions and pushes back in other directions. It determines what kinds of work are useful and beneficial on the model's terms and which projects are easier or more difficult – and perhaps not worth the effort. I describe this role of the model as *orienting*, or pointing, activities in the direction of what is needed to ensure a clean Chesapeake Bay. Instead of putting time and work into, for example, building farm storage for nutrient wastes, the model orients their efforts towards restoring buffers. At this level, it is a continual point of frustration for the management staff, who would prefer to simply go about their work than have to deal with the model; in identifying priorities and cost-effective management practices, however, it orients their efforts towards the watershed management goals.

CONCLUSIONS

This analysis of the performativity of computational modelling in the Chesapeake Bay watershed management process brings into focus an image of heterogeneous actors working together towards a common goal. Watershed Management is not without contention and antagonism, however, and I have shown how a technical artefact like a computational model can contribute to holding things together despite those antagonisms, contributing to a kind of collective action. I contend, in fact, that it is by performing the multiple roles of assembling, channelling and orienting throughout the process of watershed management that the CBMS becomes an effective organising device. It allows the people involved to quilt together the various stages of the watershed management process, from scientific development, to institutional priorities, to on-the-ground landscape practices. By using the model in these ways, the CBP and its collaborators are able to *produce* the reality of watershed management in Chesapeake Bay. In this sense, reflecting on Bill's comments about the Gulf of Mexico, it is possible that modelling facilitates large-scale and transboundary management in a meaningful way. In other words, building a model may not be a necessary prerequisite for large-scale environmental management, but it certainly helps.

Although the process that I have described appears as a nice collective action that is not without antagonism, there are two key ways that I believe the collective is undermined by the management process. First, as I have outlined in a previous article (Trombley, 2020), the neoliberal style of management organises efforts through a quantitative schema that is facilitated by the model. In this context, the model itself can even be altered to become more simple and less of an exploratory tool. This leads to a management strategy that emphasises a financialised 'biggest bang for our buck' approach to improving the environmental quality of the Chesapeake. In that scenario, the subjective positioning of those involved is not one of collective engagement, but rather is highly individualised and reductive. It manifests as, "what is the least I can do that will maximise my nutrient reduction?" I argue that this is inherent in the TMDL process but not in the modelling itself, which can take on a more qualitative form in certain contexts, despite being numerical.

Second, there are important actors in the watershed who are left out of the collective that is described here. Farmers, Indigenous communities and others whose activities are tied to the landscape are incorporated only as 'those-to-be-managed'. Without their engagement the collective remains incomplete, and collective action then becomes aimed at imposing management policies on them rather than at enlisting them in a collective programme of watershed improvement.

How might an understanding of the performative roles that models take on in various social contexts help to address these limitations? I believe that the roles outlined in this paper can contribute to a "reflexive performativity" (Cusworth and Stanley, 2025). If scientific and technical practices like computer modelling intervene to produce reality even as they describe it, then performative interventions offer the potential to disrupt harmful management practices and bring about "more just and ecologically comprehensive programmes of environmental governance" (ibid: 85).

An understanding of the performative roles of computer models makes it possible to imagine ways of using them strategically in a participatory setting to enhance and extend the collective that is enacted through management. First, by seeking ways to integrate Indigenous and local knowledge into modelling processes, we may be able to assemble a broader coalition that includes – rather than simply manages – those whose activities are closely tied to the landscape. Second, refocusing institutional interests on a more qualitative approach to modelling (see, for example, Trombley, 2020), may help undermine the financialised approach to watershed management. Third, orienting the broader coalition to a new set of qualitative activities, may help generate more comprehensive action and a more holistic management with the land- and waterscape.

These are only speculative conceptions that require further examination, and the roles outlined here may not exhaust the roles that models might take on. The possibilities offered here nevertheless highlight the potential for models to support a reflexive performativity in watershed management. Further research could examine other roles that models might take on and their potential for even greater enhancement of management practices.

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