The Collaborative Policy Modeling Paradox: Perceptions of water quality modeling in the Chesapeake Bay Watershed

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Abstract

The Chesapeake Assessment Scenario Tool (CAST) serves multiple key functions in meeting nutrient reduction targets across the Chesapeake Bay Watershed (CBW) and is embedded in the water quality governance system. To investigate contested perspectives regarding the model, we interviewed 59 stakeholders engaged in model governance across the CBW. We recorded statements regarding the accuracy, legitimacy, and credibility of the model, influences on its use, and on challenges and opportunities. We found skepticism regarding the legitimacy of CAST, including suggestions its role facilitates a "paper process" of policy design and that past experience has greater influence on policy decisions than model predictions. However, despite its perceived shortcomings, CAST has been central in helping stakeholders in prioritizing mitigative activities. With respect to credibility, most respondents believe the model underestimates the effects of nutrient-reduction practices, thereby underestimating progress toward TMDL-related goals. Respondents also identified opportunities for model improvement, emphasizing co-benefits of conservation practices over and above nutrient reduction. Overall, our analysis demonstrates a Collaborative Policy Modeling Paradox: collaborative model development is necessary for effective policy modeling, but the political processes of collaborative model development can negatively impact perceptions of salience, credibility, and legitimacy. Although it is important to recognize this paradox, as it is linked to dissatisfaction with the models, our findings also point to areas where improvement has occurred and to future opportunities for development.

Keywords

collaborative modelling; model governance; water quality

1. Introduction

Computational models have emerged as vital tools for guiding more sustainable and resilient management decisions, and for offering a means to simulate and understand interactions within complex socio-environmental systems (Bitterman & Bennett, 2018; Bitterman & Koliba, 2020; Oreskes et al., 1994; Schlüter et al., 2019). These models integrate a large volume and variety of data with sophisticated algorithms, forecasting potential futures and evaluating the implications of different management strategies. The predictive capabilities of these models have the potential to shape the trajectory of environmental conservation and restoration efforts, particularly when governing complex, large-scale, multi-stakeholder social-ecological systems (e.g., land use impacts on

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hypoxia) (Boesch, 2002; Diaz & Rosenberg, 2008). The utility of computational models in addressing socio-environmental issues is contingent on – and can be enhanced by – their salience, credibility, and legitimacy in the eyes of experts and stakeholders. These three factors are often enhanced by engaging stakeholders during model development, but participatory modeling is not a panacea (Cash et al., 2003; Goelz et al., 2020; Jones et al., 2007; White et al., 2010). Here we examine one particular set of conditions that prevent effective participatory modeling, the Collaborative Policy Modeling Paradox (CPMP).

The CPMP occurs when participants use participatory modeling as an opportunity to engage in political maneuvering to attain distributional gains. This politicization of the process prevents participants from developing the shared perceptions, beliefs, and values that are the hallmark of effective participatory modeling and thereby undermines the salience, credibility, and legitimacy of the process (see Figure 1). It is paradoxical because distributional issues are important to stakeholders and so including them is necessary for the legitimacy of the participatory process but at the same time increases the risk of politicization. We do not argue that the CPMP occurs in all participatory modeling projects, but we show that it has occurred in the Chesapeake Bay watershed and is therefore worthy of additional study. We need to systematically investigate how and why the CPMP affects certain systems so we can improve model development and the entire policy process. Note, we distinguish the emergence of the CPMP in the context of participatory modeling from broader policymaking processes, many of which are participatory or collaborative. Political negotiation, maneuvering, and coalition building, among other processes, are features of (environmental) policymaking (see Dryzek, 2002; Sabatier & Weible, 2007), the complexities of which are outside of the scope of this work. We instead focus on the collaborative development and use of models to improve environmental decision-making.

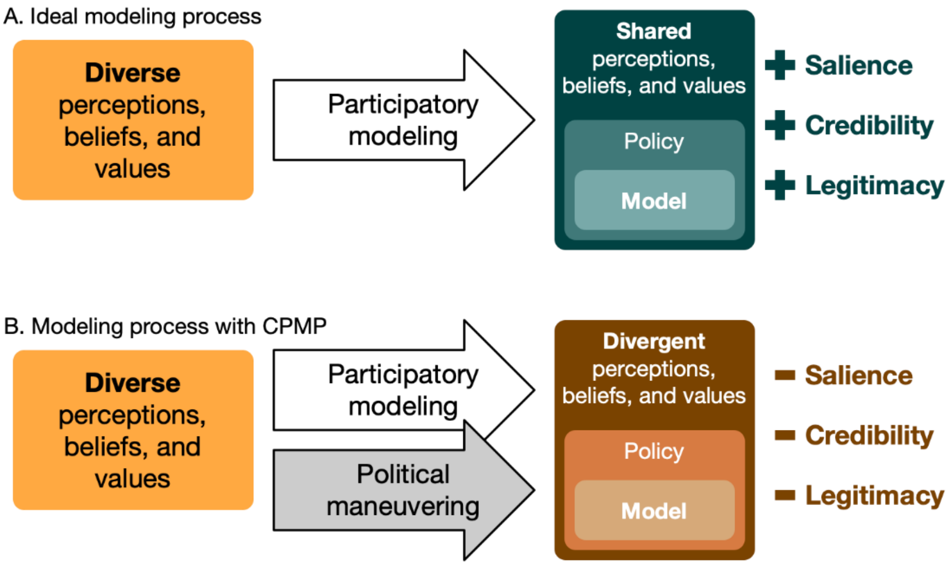

Figure 1: General framework of the CPMP. In the ideal case shown in panel A, participatory modeling activities effectively harmonize diverse stakeholder perceptions, beliefs, and values to shared ones, increasing salience, credibility, and legitimacy. Panel B demonstrates that participatory processes can enable political maneuvering and gaming of the system(s), reinforcing divergent beliefs and reducing salience, credibility, and legitimacy.

The Chesapeake Bay Watershed (CBW) is an exemplary case of this CPMP. The CBW has long been a focal point for extensive restoration efforts, driven by the need to mitigate nutrient pollution and the consequent hypoxic conditions (Batiuk et al., 2009). Efforts to improve water quality in the CBW are both simulated and assessed by a series of computational models, many of which are subject to epistemic and ethical values held by modelers (Deitrick et al., 2021). That is, the models are used to develop policy plans and to assess how much implemented policies contribute to overall water quality goals. However, as we show here, decision-makers have learned to manipulate the modeling process to further distributional goals and this political use of the model has reduced its perceived salience, credibility, and legitimacy. At the core of the modeling suite, and central to the present analysis, is the Chesapeake Assessment Scenario Tool (CAST), which is designed and managed by the Chesapeake Bay Program (CBP) (CBP, 2023). This research explores the use and perceptions of CAST as a representative example of computational models, interrogating its position in the planning and implementation processes of the CBW and the associated stakeholder perceptions. Our findings show that addressing the collaborative policy modeling paradox (CPMP) can be an important component of effective model-based governance.

2. Literature review

Science – and models derived from scientific inquiry – may be politicized when an actor within the socio-environmental system questions or emphasizes uncertainty to raise doubt or challenge consensus (Bolsen & Druckman, 2015). While the adoption of modeling standards (Barton et al., 2022) and measures to simplify models may help to reduce uncertainty and minimize politicization (Ivanović & Freer, 2009), there still exists the potential to exploit the complexity and inherent uncertainties of these models for political objectives. The inclusion of stakeholders in governance processes (e.g., natural resource management) is often viewed as a method for increasing the diversity of perspectives and improving adaptive decision-making (Gray et al., 2012; Walker et al., 2002). However, like all policy processes, participatory modeling can be more or less effective depending on the context in which it is undertaken. Here, we introduce the concept of the CPMP as a barrier to effective participatory modeling and examine its impact on three key components of successful model governance: salience, credibility, and legitimacy (Lim et al., 2023; White et al., 2010).

With respect to environmental modeling, salience generally refers to the relevance and timeliness of the information provided to decision-makers (Cash et al., 2003). For models to influence policy and active management, they should address the problems or questions faced by relevant stakeholders (Sarewitz & Pielke, 2007). However, despite technical and scientific advancements, models may fail to capture the dynamic complexity within complex socio-environmental systems, potentially compromising model salience (Lemos & Morehouse, 2005). Salience can also be compromised by legal restrictions on model uses, temporal divergence between model development and social expectations, and failure to account for human behavior or other sources of feedback and feedforward within the system (Van Voorn et al., 2016).

We expect the CPMP will reduce salience for environmental protection even as it increases salience for distributional purposes. That is, politically motivated participants will push for a modeling process that makes it easier to estimate and then allocate the costs and benefits of environmental protection. Although they may not intend to erode ecological effectiveness, the choice to center models around allocation will affect the design of outputs and inputs. Outputs will likely focus on a few measurable outcomes rather than an array of indicators that are difficult to compare. This will then make it easier for participants to manipulate inputs to achieve allocation goals while appearing to adhere to environmental goals. To be clear, politically motivated participants may not initially recognize this trade-off and believe that a model that facilitates allocation is necessary for achieving environmental goals. However, there is literature that suggests that distributional uncertainty is more likely to result in effective environmental governance (see literature on the "veil of uncertainty", e.g., Kolstad, 2005). Moreover, models that limit outputs to a few simple indicators will restrict opportunities for side payments or issue linkages that foster improved environmental protection (Dinar, 2006; Haas, 1980; Harstad, 2007; Tollison & Willett, 1979). In some cases, these may not be necessary, but with diverse participants and incomplete central authority (i.e., US federal structure), participants may benefit from having more opportunities to find agreement.

At the same time, the CPMP may push model development toward a wider array of input variables than would otherwise be the case. In an ideal participatory modeling system, stakeholders could focus on the policy levers most likely to reduce the environmental problem, regardless of distributional outcomes. However, where the CPMP is in play, a wider variety of policy options in the model would provide users with more opportunities to manipulate outcomes in their favor. A greater variety of inputs also provides more opportunities for negotiation over distributional concerns through issue linkages that reduce rather than increase environmental protection (e.g., if you accept a high load reduction value for the management practice that is important to me, I will accept a high load reduction value for a practice that is important to you). Negotiation over model inputs may also provide substitute opportunities for stakeholders to exert political influence in place of affecting the interpretation or application of model outputs. Of course, other factors could also account for a high number of inputs in a model, including the complexity of the system itself and legal requirements regarding policy options.

Of particular interest for the CBW case, it is also possible that the CPMP would lead to limited participation in model development as powerful actors seek to maintain control over an important distributional tool. It may be difficult to differentiate this effect from the influence of model scope and complexity. Stakeholders that use the model to design management strategies may (rightly) argue that one cannot include all or even a majority of stakeholders from a region as large as the CBW without compromising communication, trust building, and other factors necessary for successful participatory modeling. In addition, the design of institutions like the CBP is constrained by existing legal structures, notably the tension between federal power and states' rights that ensures jurisdictional mediation between local and national level decision-making. Nevertheless, participatory modeling will not provide any of its potential benefits for model salience, credibility, and legitimacy if the people who are expected to act on model results (e.g., local-level stakeholders) are not included in model development.

Model credibility refers to perceptions of the underlying quality of the science, arguments, and technical modeling (Cash et al., 2003). The credibility of models can be improved through rigorous model description, specification, calibration, validation, and empirical representation (Van Voorn et al., 2016). However, credibility may be viewed differently by different stakeholders. A model perceived as credible by scientists may not be viewed the same way by policymakers or local community leaders due to differences in understanding or trust (Jasanoff, 1998). Further, as model complexity increases to accompany increasingly complex and connected socio-environmental systems, the ability of models to capture all components adequately and accurately is likely reduced, potentially harming credibility. Participatory modeling can increase credibility in these settings by helping stakeholders develop a shared understanding of the model. In addition, stakeholders also have information about model components not directly observable by scientists, so their input can improve model credibility (Van Voorn et al., 2016).

The effects of the CPMP on model credibility primarily stem from attempts to manipulate model design to achieve distributional goals rather than realize environmental outcomes. In particular, contestation over the specification of model inputs may reduce credibility as actors with different perceptions and motivations reach consensus by agreeing to disagree, by excluding stakeholders who do not agree, or by engaging in issue linkage rather than achieving a shared acceptance of given model parameters. This problem may be increased when there are many inputs to be negotiated, as would also be expected in a CPMP-dominated system (see above). In fact, many of the CPMP effects on salience would also affect credibility. Restrictions on participation would mean that fewer stakeholders have input or even get to observe the modeling process, which in turn will make it easier for them to question decisions that do not conform to their own knowledge base. Furthermore, if stakeholders join consensus without truly agreeing, they may choose to critique the model's credibility outside of the modeling process itself, including in engagement with stakeholders and through the press. This, in turn, may affect perceptions of legitimacy.

Legitimacy relates to the perception that the creation of information by the model and the model development process is unbiased, fair, and respectful of the values and beliefs of all stakeholders (Cash et al., 2003). While these factors may at times be contradictory, it is important that the modeling process be seen as inclusive and transparent to stakeholders (Hegger et al., 2012). Resistance to participation and policy implementation may occur if the model is perceived as favoring one group over others (Turnhout et al., 2007). Accordingly, policy-relevant models should be designed while incorporating stakeholder perceptions and concerns.

This is the crux of the CPMP, as distributional issues are almost always an important concern for stakeholders, which suggests that costs and benefits must be considered in the modeling process to ensure model legitimacy. We suggest there may be different degrees of CPMP depending on the scale of conflict over the allocation of costs and benefits. Participatory modeling will be less affected by the CPMP when differences between "winners" and "losers" are small, or when "win-win" options are available. In such cases, finding common ground tends to be easier. The CPMP is likely to have greater impacts on participatory modeling when gaps between "winners" and "losers" are large and it is difficult to find solutions that will directly benefit powerful participants. The CBW certainly fits the latter description.

Similarly, the CPMP will be more likely to affect modeling processes in contexts where governance is already highly politicized. Settings where groups already have entrenched positions on distributional issues are most in need of collaborative shifts, but in such cases, groups are also likely to be more resistant to collaboration because of group polarization and in-group or out-group bias (Allison & Messick, 1985; Baumgartner, 1998; Whitney & Smith, 1983). Perceptions of legitimacy may also be skewed by preconceived notions of fairness that do not include giving other groups the same degree of respect or input in the modeling process (Jones, 2000). In other words, simply allowing everyone to participate equally may be perceived as unfair when group-based prejudices are strongly entrenched.

While each of these attributes is important on its own, their specific combination affects the influence a particular model may have on decision-making. A model may be technically robust (credible) but lack relevance (salience) or be perceived as biased (a lack of legitimacy), and therefore fail to inform policy (Guston, 2001). In addition, perceptions of each of these variables may vary across groups, and individuals may hold contradictory opinions about the same model or modeling process. In theory, collaborative modeling helps to ensure that stakeholders develop a shared perception that the model is salient, credible, and legitimate (Cash et al., 2002; Falconi & Palmer, 2017; Ulibarri, 2018), but due to the presence of the CPMP this many not always be the case in practice.

Here, we expand on the logical extrapolation above by exploring how the CPMP affected the salience, credibility, and legitimacy of collaborative policy in the CBW. To do so, we leverage qualitative methods to investigate potential sources of contested perspectives within the collaborative modeling system. First, we establish the political nature of the development and use of CAST in the policy process. Second, we examine how this politicization has affected perceived salience, credibility, and legitimacy in the modeling process and in the use of the model for planning and implementation. Given the high level of politicization surrounding CAST, we expect respondents will frequently question its salience, legitimacy, and credibility, particularly when distributional issues are considered (e.g., when accounting for nutrient reductions). Finally, we expand our analysis from strictly considering the use of CAST to include a broader discussion on the role of the CPMP in implementation of conservation practices.

3. Methods

The primary method of data collection for this study was interviews with decision-makers directly involved in some component of the policy process in the Chesapeake watershed. The instrument we followed to guide each interview was broad in scope, and included many questions not presented here (see Supplemental Materials and Webster, 2022). Although the interviews did not explicitly target CAST, we asked how the respondents used CAST during the WIP design process, and broader perceptions of the CBP modeling process were commonly raised voluntarily by subjects during our discussions. Where useful, we augment these interview results with details on the CBW modeling and decision process drawn from current documentation provided by the Chesapeake Bay Program via its website.

3.1 Study area

The CBW covers approximately 166,000 km^2 across six states and the District of Columbia. The CBW empties into the Chesapeake Bay, which is the most productive and ecologically diverse estuary in the continental US (Boesch et al., 2001; Chesapeake Bay Program, 2023b; Kemp et al., 2005). However, nutrient and sediment pollution have threatened the health and productivity of the estuary for decades (Batiuk et al., 2009). In response to this degradation, the Chesapeake Bay Total Maximum Daily Load (TMDL) regulation was developed in 2010 to set limits on the amount of criteria pollutants legally allowed to enter the Bay (US Environmental Protection Agency, 2021). The TMDL's restrictions on nutrient pollution have slowed water quality degradation in the Bay, but climate change, population growth, land use change, and the high economic and political costs of nutrient management pose significant governance challenges across the watershed. Managing the "pollution diet" for the Bay requires a substantial multi-state and multi-scale governance effort, including the CBP, as well as legal frameworks to ensure cooperation (e.g., the 2010 Chesapeake Bay Agreement) (Chesapeake Bay Program, 2023a).

To help set pollution reduction goals, design plans to reach those goals, and credit the implementation of best management practices (BMPs) against those goals, the CBP has created a highly sophisticated nutrient management and modeling system that couples land use, watershed hydrology, airshed, and hydrodynamic-biogeochemical-sediment transport models (Hood et al., 2021; Shenk & Linker, 2013). CAST serves multiple key functions in helping jurisdictions meet their TMDL responsibilities and is deeply embedded in the water quality governance system (Chesapeake Bay Program, 2020). The model was developed through an ongoing collaborative – and sometimes contested – governance process marked by phases of new development, simplification, and challenges to its legitimacy (see Lim et al. 2023). CAST was designed for use by member jurisdictions as a planning tool to create watershed implementation plans (WIPs), which contain sets of BMPs aimed at meeting pollution reduction goals. However, CAST is also used to assess, credit, and manage the implementation of WIPs across the CBW (CBP, 2023). Thus, the legitimacy, salience, and credibility of CAST (and of the broader processes in which it is rooted) are relevant to achieving the socio-environmental outcomes at the center of the TMDL.

3.2 Sampling

The study's sample frame included individuals who worked at or with CBP, worked on CBP programs for state-level agencies, and worked directly with stakeholders on BMP implementation. We also included some individuals without any official role as decision-makers but who were long-time observers of the process, usually in roles as stakeholder representatives and/or watchdogs. All respondents had some familiarity with CAST, but this varied from some who used or contributed to the model regularly to those who may not have technical knowledge of the model but saw the results of its use in other CBP governance processes. To preserve subject confidentiality, we set a minimum criterion of five interviews each from nine groups: federal-level agencies (e.g., EPA, CBP, etc.), independent observers, and each of the seven state-level jurisdictions. Within these groups we developed a sample that would provide sufficient information on each component of the policy process: 1) setting the TMDL for all the CBW, 2) allocating loading goals among the state-level jurisdictions, and 3) designing and implementing the watershed implementations plans.

Respondents were recruited using stratified snowball sampling. Following standard practices, some recommended individuals were not invited to participate because we had recruited a sufficient number of respondents with similar expertise from their jurisdiction. In a few cases, respondents were not invited because their areas of expertise appeared to be well outside the CBW or because they did not fit our rather broad definition of "decision-makers". We also invited a larger proportion of recommended participants from jurisdictions with lower response rates to ensure our criterion of five responses from each jurisdiction. Through this process, we identified 122 possible contacts, invited 91 individuals to participate, and ultimately recruited 59 participants (64.8% response rate).

While we paid particular attention to representativeness by jurisdiction and area of expertise, we did not over-sample for demographic characteristics, as the focus of the study was the set of decision-makers, rather than the overall diversity of the public. In other words, we expect our sample differs from US Census distributions on factors such as education, income, race, and gender but expect that this primarily reflects attributes of the population studied rather than bias in the sampling method. Background information provided by our respondents suggests that the sample is overwhelmingly college-educated, with a large proportion holding advanced degrees (e.g., MA, PhD, JD). All were professionals working in environmental governance in some capacity. Just over half (n = 33) worked for government agencies at the local, state, or federal level, with the majority of these (n = 20) employed by a state-level environmental agency. The remainder of respondents (n = 26) were employed by consulting firms, universities, or other nongovernmental organizations. Based on apparent rather than self-expressed gender, 34.4% of recommended participants, 39.5% of invited participants, and 42.4% of recruited participants who completed interviews were female. We did not attempt to evaluate other demographic variables, but Washington DC stood out as being more racially and ethnically diverse than any of the other jurisdictions, based on participants recommended, invited, and recruited.

3.3 Data collection and analysis

During the recruitment and interview period, data on participants were collected from the internet, including title, affiliation, e-mail address, and professional biographical information. Similar information was provided by some participants when they recommended other potential contacts. This information was used to track our snowball sample, identify jurisdictional affiliation/expertise, and prepare for interviews. We verified this background information at the start of each interview. The interview instrument was designed to provide a flexible guide given the diverse areas of expertise of our respondents. The interviews balanced the ability to compare across participants (i.e., asking at least some of the same questions of all participants) with the need to collect more detailed data on different aspects of the policy process from participants with the relevant expertise. Accordingly, the instrument contained 5 sections, with the expectation that respondents might have different levels of knowledge across sections 2-4:

1. Background on the Respondent (verified/expanded information collected from the internet)
2. Setting of the TMDL/Watershed-wide loading goals and allocation of loading goals among state-level jurisdictions
3. Design of the WIP(s) and allocation of sub-state loading goals
4. WIP Implementation
5. Effectiveness and Future Challenges

We recorded detailed notes during each interview, although interviews were not recorded in any other way. Qualitative coding of the notes documents was conducted using the Atlas.ti software (ATLAS.ti Scientific Software Development GmbH, 2023). Each document was assigned attributes based on sampling information (e.g., batch) and participant information (e.g., jurisdiction, expertise, level of experience, etc.). We coded at both the document and the "block" levels. A block is a distinct statement, mention, or grouping of text from the interviewee. A few basic document-level variables were coded first: 1) interview round or batch, 2) jurisdiction, and 3) adjacency to the Chesapeake Bay. The block-level coding process associates (or "tags") sections of the document with descriptive codes. The software then identifies the number of occurrences, overall co-occurrences (how often two codes occur in proximity to each other), and co-occurrences by document-level variables. Codes were then analyzed in the Atlas.ti and R software environments (ATLAS.ti Scientific Software Development GmbH, 2023; R Core Team, 2022) to assess the prevalence of different themes across a range of topics and further broken down by respondent characteristics (e.g., jurisdiction, general role, etc.) to assess patterns of narratives, with attention paid to the convergence and divergence of opinion within the sample. A full report investigating additional dimensions of the qualitative findings may be found online (Webster, 2022).

Given the relatively limited number of interviews, it is infeasible to perform robust statistical analyses that would otherwise require larger datasets for meaningful interpretation, especially when responses are allocated across multiple dimensions or categories. However, the rich qualitative data extracted from these interviews allow us to draw more general inferences and discern overarching sentiments about the underlying processes and use of CAST and the effects of the CPMP. If our interviews had exclusively focused on CAST and its related uses and functions, our results would likely differ. However, the aim of the interviews was to more fully understand the policy processes in the CBW, and in speaking with decision-makers, the importance of CAST was commonly mentioned. Thus, the responses detailed below reflect the views of those who felt strongly about these issues. Respondent concerns remain important, however, and the absence of statements indicating enthusiastic acceptance of the model or modeling process is notable. As the CBW community is tight-knit, we do not provide direct quotes from respondents in order to protect interviewee anonymity. However, the narratives derived from our interviews can shed light on broader patterns and perceptions, crucial in the context of our study.

4. Results

Our interview results provide evidence that the CPMP is occurring in the CBW, though more research is needed as described in our conclusion. First, there is clearly a widespread perception that the modeling process—indeed, the entire policy process—is politicized. Second, many respondents questioned the salience, credibility, and legitimacy of the model, though some were more positive in their comments. Third, and most importantly, respondents linked perceived shortcomings in the model to politicization, indicating that conflicts over distributional aspects of model design eroded their belief in the usefulness of the model for both environmental protection and equitable distribution of the costs of pollution reduction.

4.1 CAST as a political tool

As elaborated above, the CAST watershed model is used by actors for multiple tasks, including allocating loading goals among the jurisdictions (TMDL), planning WIPs (Design), implementing and accounting for best management practices (Implementation), and finding resources needed for implementation (Funding). For each model-related process, we coded the number of blocks that framed the process as participatory, political, or technocratic. The framings are non-exclusive – a respondent may view the use of the model as technocratic in one context and political in another. As shown in Figure 2, respondents indicated that all major components of this policy process were impacted by political factors. In contrast, framings that the process was participatory were low for both the whole system and modeling process-related statements. Interestingly, respondents also did not describe the modeling process as highly technocratic, or simply following pre-set technical rules. These results are a stark contrast to the literature on CBW governance described above and suggest to us that the CPMP is likely affecting the system.

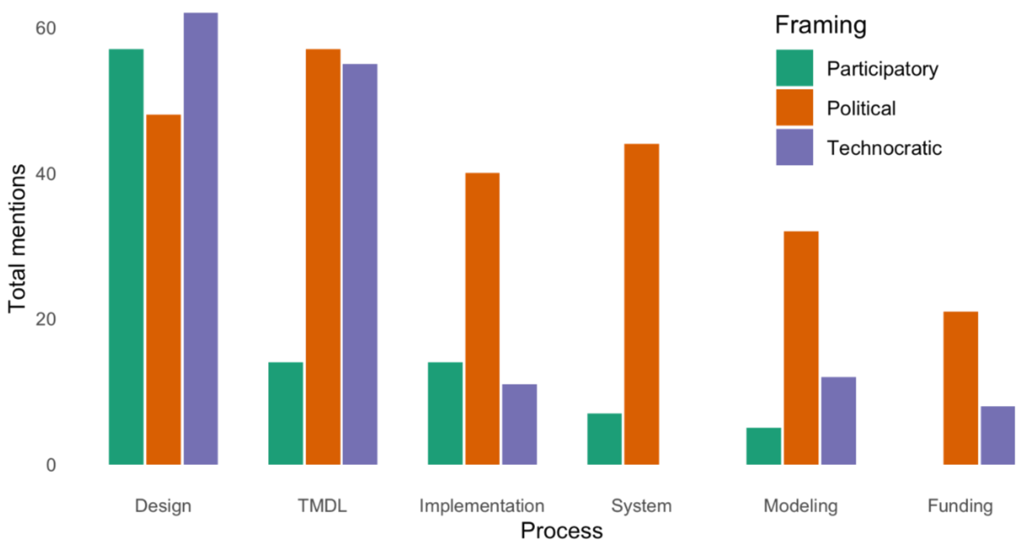

Figure 2: Total blocks containing mentions of model processes by how the processes were framed by respondents. The design process was most mentioned and is perceived through participatory, political, and technocratic frames. Conversely, the TMDL and other processes are substantially less participatory.

Among these descriptions of the modeling process as "political", the vast majority focused on contestation over the distribution of loading goals among states. That is, during the collaborative modeling process, representatives from the member jurisdictions can assert positions that would produce better outcomes for their constituencies. In this context, "better" specifically refers to the idea that changes to the parameterization of CAST would result in higher loading goals (i.e., the jurisdiction would not need to reduce their nutrient load as much) or higher credits against loading goals for preferred BMPs and therefore lower costs for participating in the TMDL. If we look at the broader challenges and opportunities identified by the respondents, negotiations among states over loading allocations were mentioned as factors that reduce policy effectiveness in 29 blocks of text while lack of local engagement was only mentioned 7 times. There was some concern about politicization at the local level, but this usually referred to the use of CAST, rather than its development.

As noted above, we would expect the CPMP to be more prominent in systems that are already complex and highly politicized with entrenched distributional issues. In considering the whole CBP system, respondents recognized 44 major types of challenges for governance as a whole. Among these, nine types were categorized as problems with partnership organization and function (e.g., lack of leadership, lack of local engagement, legal constraints, etc.) and 14 were categorized as generally political (e.g., lack of political will, lack of legitimacy/trust in all government agencies, local political systems, etc.). Only three system-level challenges can be directly tied to the models, but these were mentioned fairly often, accounting for nutrient reductions (61), changing data/models/loads (21), and negotiations among states (29). The latter was mentioned above, and others will be discussed in greater detail below.

4.2 Modeling process

Some evidence for the CPMP comes from the structure of the governance system itself. Although lauded as participatory, the CBP modeling process largely engages federal and state-level decision-makers, with input from local-level actors largely funneled through state organizations or non-governmental organizations. Voting members on the committees that make decisions about the models are appointed by states, including members of the expert committees who decide how to parameterize changes in load allocation associated with specific BMPs. At-large members are drawn from, "nongovernmental organizations, quasi-governmental organizations, Federal Agencies, academic institutions, and other local practitioners that have a role in water quality improvements" (Chesapeake Bay Program, 2021, p. 2), but they are always a minority compared to state-appointed members. The Water Quality Goal Implementation Team (WQGIT) is the highest-level committee with direct oversight over model development, and the importance of distributional issues is clear in the last paragraph of its governance procedures:

> "*Any WQGIT Workgroup decision that has cross-sector implications will come before the WQGIT membership for final approval of that decision rather than as informational briefings. This will help ensure that all partners are aware of the issue at hand and potential impacts to every sector are considered before approval*" (Chesapeake Bay Program, 2021, p. 4).

We see these effects of the focus on distributional issues reflected in our interview results. We first look at influence over the modeling process, then the timing of the modeling process, and finally describe perspectives on its legitimacy. Very few respondents mentioned local government or stakeholder influence on the CAST modeling process, and those who did indicated that the process was "top-down" and lacked transparency. Of the statements regarding influence over the modeling process, 53% indicated the state-level jurisdictions had influence over the models, 25% indicated the EPA and/or CBP had influence, 18% indicated experts had influence, and only 4% indicated local government had influence. Farmers or other stakeholders were not mentioned when respondents were describing influence over the modeling process.

We aggregated responses from interviewees regarding the development and parameterization of CAST into three categories: 1) is the model legitimate, 2) is the model challenging to use, and 3) is the model improving? Understanding the politicization of the modeling process is important because it is linked to dissatisfaction with the models and can point to areas where improvement has occurred or could occur in the future. As shown in Figure 3, respondents expressed concern regarding the legitimacy of the model or the modeling process. While some statements did indicate positive legitimacy, there were no statements indicating enthusiastic acceptance of the model or the modeling process. However, some respondents did mention that the science and models (such as CAST) that come from the CBP benefit water governance in the region as they lend scientific credibility to the process.

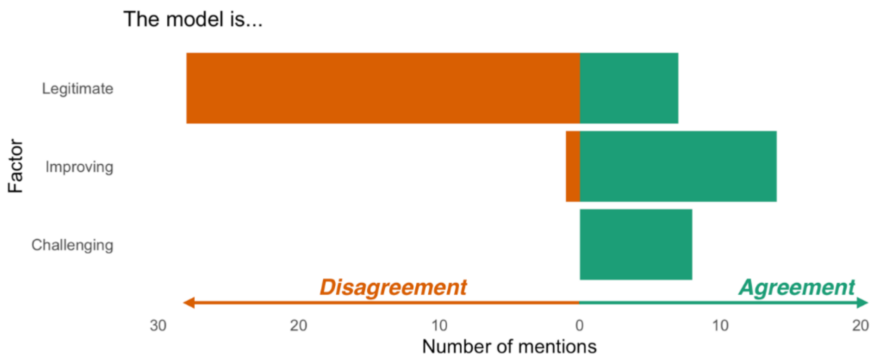

Figure 3: The number of times respondents mentioned whether CAST is legitimate, improving, or challenging to use. Responses were coded based on whether interviewees agreed or disagreed with the statement. Most found the model to not be legitimate, to be improving, and to be challenging to use.

Despite questions of legitimacy, some blocks indicated that the model has been improving, especially with the transition to a simpler version of the model that could be used by states and potentially by other stakeholders. However, other responses state the model needs improvement (14 blocks), while another 72 blocks suggested that the modeling process could be improved. While some of these were general statements, others provided specific recommendations (e.g., the model needs new components such as co-benefits). Of those respondents commenting on the use of the model or on navigating the modeling process, all found it to be challenging.

4.3 Planning and the use of CAST

As elaborated above, the CAST watershed model is used by actors for multiple tasks, including planning WIPs, prioritizing BMP implementation, and accounting for practices that have been verified "on the ground." However, the intended use of CAST by interviewees is as a planning tool, and their use is influenced by input from advisors, special interest groups, and other stakeholders, among others. To be specific, state-level jurisdictions use CAST to evaluate "decks" of BMPs to 1) ensure that their watershed implementation plans will allow them to meet their loading reduction goals if fully implemented and 2) design an efficient WIP that minimizes the economic and political costs of compliance with the TMDL. For the most part, respondents indicated that CAST was only used by a few experts and was too complicated to be used by other stakeholders. Each state differs in its level of engagement with stakeholders during the WIP design process.

We can observe some indications of the CPMP in the structure of the TMDL and WIP-creation system. Although the overarching goals of the TMDL are multi-faceted and include multiple water quality indicators, the TMDL ultimately only regulates nitrogen and phosphorous loads, so CAST was designed to estimate how BMP implementation would affect those loads at edge of tide (in 2025, the purported final year of the TMDL). Of course, focusing on only a few indicators is also simpler computationally and is easier to defend legally, so this itself may not entirely reflect the CPMP but it has certainly lent itself to politicization as described above. At the same time, CAST contains data on nearly 300 BMPs of varying effectiveness and costs, which reflects both the complex nature of the system and the political benefits of having many levers to manipulate to alter distributional outcomes.

As CAST is the canonical estimator of the load reductions proposed in WIPs, it is unsurprisingly the primary tool for planning and WIP design across the CBW. Its centrality suggests that the model is necessarily salient to jurisdictions – CBP uses CAST to estimate the impacts of WIPs and credit their implementation. However, this does not necessarily mean all jurisdictions and users find it to be legitimate despite its salience. For example, some jurisdictions have developed supplemental tools, heuristics, or institutional knowledge leveraged in the planning process. Figure 4 plots the percentage of respondents indicating the factors that influence their general process when designing a WIP for their jurisdiction, regardless of their use of CAST.

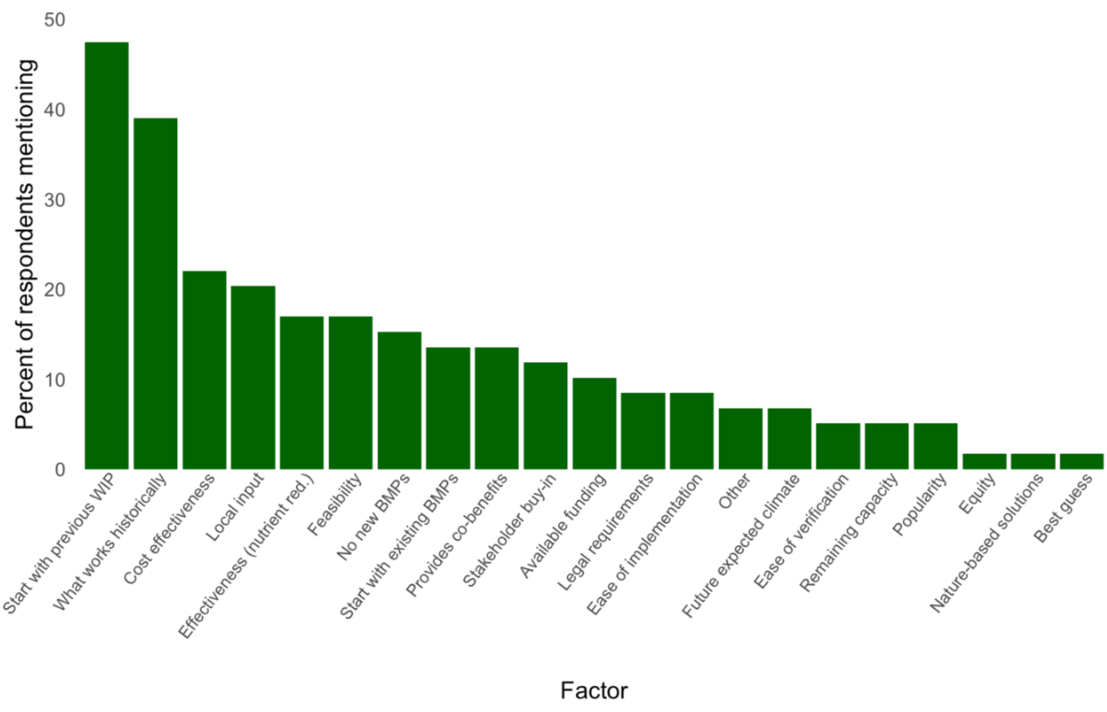

Figure 4: The percentage of respondents that mentioned various factors that affect the planning process in their jurisdiction. Factors are not mutually exclusive. The data indicate that factors related to past planning experience are the most important factor influencing WIP design.

The data indicate that past experiences (i.e., factors "Start with previous WIP" and "What works historically") are by far the most important factors influencing the planning process. Almost 50% of respondents remarked on the importance of previous WIPs, and about 40% noted that historical effectiveness influences the design process. Note that respondents could comment on the importance of as many factors as they wished. The frequency of mentions generally follows a power law distribution, with most factors having minor influence on the planning process. Further, a large majority of these factors do not interface with CAST directly. Of the noted factors, only the "Start with previous WIP", "Cost Effectiveness", and the "Effectiveness [of BMPs on load reductions]" are current features of the modeling system, though many are supplemented by expert knowledge or other tools and databases maintained by CBW jurisdictions. These supported features are among the more common factors reported by our interviewees, as well. However, the utility of these features is somewhat mixed, as five respondents explicitly stated they do not use costs from CAST in planning. Other factors such as ease of implementation, co-benefits, or future climate have some support among interviewees, but are highly dependent on geographic context and would require substantial data to parameterize.

Table 1 presents cross-tabulations of respondents' views on planning legitimacy with the centrality of CAST in the planning process. While not all respondents commented on either the legitimacy or the centrality of CAST, some trends emerged from our interviews. Over 42% of respondents (or 71% of those who commented on CAST) said that the WIP-based planning process is a "paper process", an umbrella term we use to include responses covering statements indicating that jurisdictions design a plan that would allow them to meet their loading goals (as calculated by CAST), but which could or would not be implemented effectively. In some cases, respondents noted that the WIP was only "good on paper", or that it was not possible to implement the plan as written. In other instances, the respondent's sentiment was that partial implementation of the WIP was "the best they can do", and that although the jurisdiction was willing to implement its plan, they lacked the funding, political will, or other resources necessary to realize their intentions. The number of skeptical respondents is approximately two-and-a-half times greater than respondents indicating that WIP design is legitimate (i.e., *not* a paper process).

Nearly 40% of interviewees (or 88% of those who commented) indicated that CAST is central to the planning process, which is as expected. Statistical tests of the interactions between the perceived legitimacy of the planning process, and the centrality of CAST in that process were not significant, likely due to the relatively small number of respondents once they were allocated to each of the nine categories in Table 1. However, overall, substantially more respondents both question the legitimacy of the planning process *and* find CAST to be central to that same process.

Table 1: Interactions between respondents' perceived legitimacy of the planning process and the centrality of CAST in that process. Overall, more interviewees find CAST to be central and view planning as an illegitimate "paper process".

	CAST is central	CAST is not central	Did not comment on CAST centrality	Total
WIP is a paper process	13.6%	3.4%	25.4%	42.4%
WIP is not a paper process	6.8%	1.7%	8.4%	16.9%
Did not comment on WIP legitimacy	18.6%	0%	22.1%	40.7%
Total	39%	5.1%	55.9%	100%

4.4 Implementation and verification/accounting

BMP implementation is a continuous process, and one we expected to be largely removed from the use of CAST. However, CAST was mentioned often (n = 26) when respondents described the implementation process, as the model is also used for "accounting," or determining the amount of 2025-equivalent load reduction that states can count against their loading goals once implemented BMPs are verified. Multiple interviewees described difficulties collecting data, entering data into the National Environmental Information Exchange Network (NEIEN) (Exchange Network, 2023), or otherwise verifying BMPs so that they could be accounted for in CAST. These are all negative evaluations of the salience for CAST in the verification stage of the policy process.

Some interviewees also expressed concerns regarding the effects of verification on accounting, particularly whether BMPs on the ground were under-verified (meaning that more was being done than could be verified and therefore CAST was under-estimating the load reduction for a given state); over-verified (meaning that less was being done on the ground than was being verified, so that false verifications were leading to an over-estimation of load reduction for a given state); or correctly verified (meaning that all BMPs on the ground were verified and so estimates of changes in load reduction appropriately accounted for implementation of BMPs). Over half of the respondents that commented on verification issues indicated that BMPs were under-verified, as opposed to over-verified or "about right". These verification issues (or their perceptions) may contribute to an undermining of CAST's credibility and legitimacy.

Concerns for receiving credit for BMPs were also a minor factor in the reasons why specific BMPs are (not) chosen by local "on the ground" stakeholders from the sets of BMPs laid out in the WIPs. Figure 5 plots the top 10 reasons mentioned by respondents as factors for prioritizing implementation, including the direction of the effects. The co-benefits (e.g., flood protection, local water quality) of BMPs in addition to their impacts on nutrient and sediment transport to Chesapeake Bay is the top reason why BMPs would be considered. The popularity and preferences of local jurisdictions are both positive and negative influences on BMP selection, and it appears those responsible for implementation take a pragmatic approach to what can be accomplished. Resource constraints and cost concerns are collectively an important factor in why BMPs are not prioritized as well.

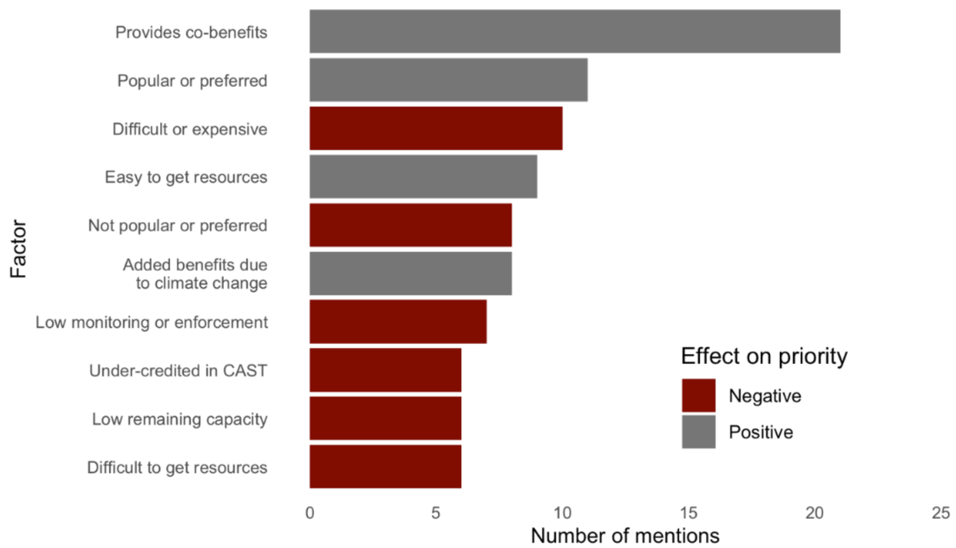

Figure 5: The top 10 factors mentioned by respondents for prioritizing specific BMPs for implementation. Co-benefits and popularity are the most common positive reasons for including BMPs in their implementation priorities. Expense, resources, and negative popularity are reasons why BMPs would be excluded from plans.

5. Discussion

The role of CAST as a load estimation model, planning tool, and BMP accounting instrument has evolved over time as features have been added (and removed) and as it has become central to achieving the TMDL (Lim et al., 2023). The use and integration of models such as CAST into the planning and implementation processes underscores the evolving landscape of model governance. Our results demonstrate that while CAST is regarded as central in the planning process, stakeholders view it as a political as well as technical tool, and are skeptical regarding its salience, credibility, and legitimacy. The irony is that decision-makers still invest considerable time and effort to influence the modeling process, as reflected in the widespread perception that model development and parameterization have been politicized. This is likely because the distribution of the costs of water quality governance is indeed highly salient to those decision-makers who engage directly with the modeling process. Thus, we see that collaborative modeling has, paradoxically, led to reduced salience, credibility, and legitimacy of CAST precisely because of its use as a political tool.

We see the effects of the CPMP in several other sections of our data. First, respondents generally view WIPs as good "on paper"—responsive to TMDL targets and based on CAST projections—but unable or unlikely to be fully implemented due to resource constraints or a lack of political will. Furthermore, this use of the model is linked to perceptions that it is not a legitimate component of the system. This reflects findings from Cash et al. (2003), who argue the legitimacy of scientific information is important for it to be considered in decision-making processes. When models are seen as illegitimate, their outputs and recommendations may be disregarded. This tension aligns with similar discussions regarding indicator models in Turnhout et al. (2007), who noted that even if models are widely used and technically sound, their legitimacy may still be contested if they are not perceived as serving the interests of all stakeholders. Indeed, Cash et al. (2002) note that while trade-offs among salience, legitimacy, and credibility may be necessary in working with diverse stakeholders, there is a requisite minimum threshold of each dimension for the successful integration of information into decision-making. In the case of the CBW, questions of trade-offs and thresholds are complicated by the multiple uses of CAST in the various planning, implementation, and accounting processes that take place in the constituent jurisdictions. For example, and as we have shown, the model's legitimacy is viewed differently depending on use and geography. The legitimacy questions raised in our interviews may be rooted in the politicization of the creation of the model itself, which can erode their credibility and acceptance in the eyes of decision-makers (Hulme & Mahony, 2010).

Despite concerns over its legitimacy, CAST maintains a central position in the planning processes across the CBW, but its use to optimize BMP selection is perfunctory. Our findings indicate that respondents commonly favor previous plans and outcomes over model outputs in working through the WIP planning process. This inclination towards historically effective practices, while understandable, hints at potential distrust in predicted costs from CAST and an over-reliance on tried-and-true practices, potentially at the expense of innovative solutions. This further suggests a level of comfort with what has been done before, reinforcing the importance of experience and local knowledge in the decision-making process (Lemos & Morehouse, 2005). This aligns with the "salience challenge", which is a phenomenon where decision-makers commonly prioritize experiential knowledge over modeled forecasts (Raymond et al., 2010). Conversely, this reliance may point to opportunities for CAST – or perhaps the planning process more broadly – to integrate past experiences in how it estimates the potential impacts of BMPs on load delivery to the estuary. If data on the outcomes of previous BMPs could be quantified, one could imagine a modeling system that more accurately calculates the uncertainty of load reduction coefficients, for example. This would require additional data collection and monitoring, but it could help validate stakeholder decisions – or provide motivation for other novel practices. However, this may be further complicated by groundwater legacies, which will likely ensure changes in loading will not be realized for decades (Chang et al., 2021). It may also provide other pathways for politicization, as evidenced by the CPMP.

With respect to implementation, CAST estimates the effectiveness of suites of BMPs, supplemented by generalized data on the costs of some practices. However, our findings show that the prioritization of BMPs are in part based on their co-benefits – many of them local – which reinforces the multifaceted nature of decision-making. This aligns with the literature on multi-objective decision-making, suggesting that stakeholders often prioritize co-benefits when implementing environmental practices (Bryan et al., 2010). Further, it is unsurprising that stakeholders involved in implementing BMPs would focus on those practices that are popular or preferred by residents of their local jurisdictions, as many practices involve recruiting private landowners (e.g., farmers). Future work may wish to unpack the tension between the popularity and effectiveness of some BMPs. Responses regarding BMP implementation highlight the nuanced role of CAST beyond mere planning. The concerns around practice verification – whether under, over, or properly verified – suggest there is a possible disagreement between how jurisdictions perceive conditions "on the ground" and CAST's parametrization. While no model, including CAST, is perfect, it has certainly proven useful in reducing water quality problems in the Bay.

While respondents raised concerns regarding the legitimacy of CAST, many respondents indicated improvements in the model, especially with newer, simpler versions. Responses regarding the model being challenging to use point to classic trade-offs among utility, complexity, and user-friendliness (Oreskes et al., 1994). Accordingly, CAST's continued movement towards simplification demonstrates the utility of simpler emulation models that reduce complexity and can improve user experiences (Lim, 2021). Many of the noted technical challenges in how stakeholders use and interpret the model likely reflect difficult model implementation problems (e.g., interface design, formats of input/output data, visualization, training), especially in the context of diverse stakeholders. However, we believe the push towards simpler models also reflects the CPMP because simpler models are easier to manipulate for distributional gains (Lim et al., 2023). For example, the design of CAST, like much of CBP's work, is the result of design-by-committee. This requires the participation, if not always the full agreement, of the partner jurisdictions, who then take the opportunity to politicize the modeling process as shown by the perceptions that states have substantial influence over the modeling process and that contestation over loading implications is a major challenge for the CBP. Of course, the CPMP is not the only factor at work. Accounting for nutrient loading is a wicked problem, and CAST is designed to help meet the requirements of the TMDL, which requires a model that forecasts future (2025) levels of nutrient pollution reaching Chesapeake Bay.

The mandated focus on the estuary at times conflicts with more local priorities of the planners, implementers, and stakeholders who influence model design. This disconnect (Webster, 2015) or spatial scale mismatch (Cumming et al., 2006) in the governance system is reflected in the findings of our study. Meeting the nutrient and sediment limits set by the TMDL (US Environmental Protection Agency, 2023) requires substantial and expensive actions. Engagement with stakeholders can only go so far towards securing acceptance of the models when costs are so substantial. Thus, it may not be that the collaborative process has itself undermined the model's legitimacy, but rather the incentives of a wide array of actors brought into highly inclusive processes that do not want to bear the costs of pollution reduction. A focus on the co-benefits may be a way to bridge the power disconnect between people who live on the Bay, increase the salience of sometimes costly practices, and therefore benefit directly from improvements in Bay water quality, and those who live inland and benefit less from investment.

6. Conclusion

The responses from the interviewees summarized in this paper demonstrate the multifaceted challenges of integrating technical models into broad stakeholder-driven processes. The study underscores a tension between CAST's importance in the allocation, planning, and implementation processes across CBW, and its perceived salience, credibility, and legitimacy among stakeholders and decision-makers. Paradoxically, CAST remains important in part because of the same factors that undermine its use for management: it is a political tool as well as a technical support mechanism.

Our research aggregates the views of many of the most deeply connected and highly educated stakeholders across the CBW governance system. It demonstrates how qualitative research can uncover underlying disconnects in the system and can identify opportunities for improving collaborative governance at multiple scales. Clearly, substantially more research is required to better understand the effects of the CPMP and other barriers to effective participatory modeling. Our interviews were designed to elicit a general understanding of the entire policy process, though more targeted data collection could shed additional light on the factors that undermine the salience, credibility, and legitimacy of models in highly politicized contexts like the CBW. Systematic literature reviews, process tracing of model development, and other in-depth research could help to untangle the effects of the CPMP from other modeling challenges such as system complexity. Ultimately, we need to develop a better understanding of how context influences participatory modeling to ensure that it does not become a false panacea (Young et al., 2018).

This research has practical as well as scholarly importance. First, it identifies certain design characteristics that may make it more difficult to politicize a participatory modeling system. One approach to addressing this issue, supported by the array of factors we identified as impacting planning (Figure 4) and recent developments within the CBW modeling community, would be to move away from the narrow targets of the TMDL and develop a multi-criteria system that incorporates data on co-benefits, past experiences, and local preferences to tightly connect technical and contested modeling to local knowledge, improving transparency and perhaps legitimacy. This could make it more difficult to game the modeling system by increasing the number of model outputs, but it might also increase the opportunities to manipulate inputs and further delegitimize the model. As noted above, more research is needed to fully articulate the possible design approaches to mitigating the CPMP.

Second, our findings highlight the fundamental fact that we cannot always circumvent political aspects of policymaking through participatory approaches or design principles. In other words, political problems often require political solutions. Further, a collaborative modeling system that allows space for divergent beliefs to be expressed and explored through political means may increase the legitimacy of the process in the eyes of stakeholders, supporting model salience and credibility and leading to more convergent decisions in the long run. As the case of the CBW shows, attempts to de-politicize the policy process may simply restrict opportunities for political negotiation to the modeling process itself, amplifying the CPMP. Navigating this paradox requires addressing those political issues head-on, even when they appear to be intractable. This is why it is important to consider not only design principles but also precursors to governance, or the dynamic processes that a system must go through to ensure that participants are willing and able to design and implement effective governance—or, more to the point for this paper, constructively engage in participatory modeling (Webster et al., 2022).

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Supplementary Material

The Supplementary Material for this article can be found online at https://sesmo.org/article/view/18677/18143.

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