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FORUM
The Politics of Participation in Watershed Modeling

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ABSTRACT / While researchers and decision-makers increasingly recognize the importance of public participation in environmental decision-making, there is less agreement about how to involve the public. One of the most controversial issues is how to involve citizens in producing scientific information. Although this question is relevant to many areas of environmental policy, it has come to the fore in watershed management. Increasingly, the public is becoming involved in the sophisticated computer modeling efforts that have been developed to inform watershed management decisions. These models typically have been treated as technical inputs to the policy process. However, model-building itself involves numerous assumptions, judgments, and decisions that are relevant to the public. This paper examines the politics of public involvement in watershed modeling efforts and proposes five guidelines for good practice for such efforts. Using these guidelines, I analyze four cases in which different approaches to public involvement in the modeling process have been attempted and make recommendations for future efforts to involve communities in watershed modeling.

Researchers and decision-makers increasingly recognize the importance of public participation in environmental decision-making. However, there is little agreement in theory or consistency in practice about how to involve the public. Particularly problematic is the question of how to involve citizens in the analysis function of the policy process. That is, to what extent should citizens be involved in the generation of information upon which environmental policy decisions are made?

In this paper, I address this question in the context of watershed management. I argue that because watershed modeling is a social process as well as a technical one, modeling efforts should reflect the goals of public involvement in a democracy. Based on theories of public participation in natural resources decision-making, I develop a framework of guidelines for appropriate public involvement in modeling. Using these guidelines, I analyze four cases in which different approaches to public involvement have been used. I find that public involvement in watershed modeling is its early stages, and that the primary focus of these efforts appears to be on the technical aspects of participation. Relatively little attention has been paid to the politics of this process: who is involved, how they are involved, and what impact they have on decision-making.

There are varied stances on how the public's preferences should influence different stages of the policy process. Whether it is necessary, appropriate, or even possible to involve citizens directly in generating the information upon which public decisions are based is particularly controversial. Democratic ideals suggest that citizens or their elected representatives should be involved in decisions that affect the public. Proponents of direct or participatory democracy argue that involvement should be as direct and local as possible. The goals of participatory democracy have been increasingly applied to natural resource issues in recent years (Moote and others 1997). On the other hand, theories of representative democracy treat public preferences as data to be considered by elected decision-makers. Bureaucratic theory acknowledges that some aspects of these decisions require technical expertise and are best left to agency experts. Yet even in cases of technically complex decision-making, it has been shown that meaningful citizen involvement is possible, albeit costly in terms of time, staff, and other resources (Ozawa 1991, Petersen 1984). Scholars of the sociology of science argue that because the production of scientific information is a social process, it is appropriate for affected citizens to be involved (Tesh 1999).

In addition, it is often debatable whether a given policy activity constitutes decision-making or information-generation. In the past, water quality modeling has been generally viewed as a technical activity, appropriately carried out by technical experts in environmental agencies. However, managers are increasingly coming to agree that "watershed management, although dependent on science and engineering, is fundamentally social in nature" (Rhoads and others 1999, p. 298). With the increased emphasis on participatory watershed management, some modeling efforts are becoming more inclusive.

Watershed management is a relatively tangible issue for the public in part because many citizens are directly affected by watershed management decisions. While watersheds may cover large geographic regions, watershed management involves many decisions that are

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made and implemented at the local level. Whereas traditional water quality management focused on issuing permits to point sources of pollution such as industries and waste water treatment plants, watershed management involves decisions about land uses, farming practices, and allocation of costs and benefits among all users of water resources. Such decisions are simultaneously more complex, more uncertain, and of greater interest to the general public. Benefits of involving the public in making these decisions could include better understanding of public values with respect to the watershed's resources, a more fair allocation of costs, and greater support for implementation. Therefore, it is not surprising that watershed management is one of the first environmental issue areas to embrace citizen participation in a modeling process.

Modeling for Watershed Management

As noted above, water quality management in the United States has evolved from a focus on point sources of pollution toward a holistic, basinwide approach to controlling point and nonpoint sources of pollution (MacKenzie 1996, Knopman and Smith 1993, Doppelt and others 1993). Historically, water quality management in the United States has relied on setting water quality standards for bodies of water, issuing discharge permits to polluters, and monitoring whether the water quality standards are met. In order to determine allowable discharges, agency staff typically applied computer models that predicted how much pollution each point source, such as a waste water treatment plant or industry, may discharge. These waste load allocation models are rather simple and are based on well-understood relationships between the biochemical oxygen demand of discharges and in-stream dissolved oxygen concentrations (Reckhow and Chapra 1983). Although some states have developed more complex models involving multiple pollutants and sources of pollution, most permitting decisions have been made on a case-by-case basis (Korfmacher 1998). The public has seldom taken an active role in this process of modeling and permitting point sources of pollution.

As the point sources of pollution have been better controlled, it has become clear that in many regions nonpoint sources of pollution—such as farms, roads, and residential developments—contribute more to water quality problems than do point sources (Browner 1996, Levitas and Rader 1992). Largely for this reason, many states are now shifting to a system of watershed or basinwide management, in which the impacts of both point and nonpoint sources of pollution are considered (Browner 1996). Whereas point source controls primarily affect wastewater treatment plants and industries, managing nonpoint sources of pollution has implications for land use, agricultural practices, and air emissions throughout the water- and air-sheds. To control these multiple kinds of pollution sources, new management regimes, such as nutrient trading and effluent charges, have been developed with the purpose of minimizing costs of control (Levitas and Rader 1992). At the same time, the focus of environmental managers has shifted from maintaining chemical parameters such as dissolved oxygen to understanding cumulative effects on living resources such as fish.

These new objectives have considerably complicated the task of water quality modeling. Thomann (1998) describes how the practice of water quality modeling has evolved to meet these objectives, resulting in ever more complex basinwide models. Because of these increasingly complex applications and demands, Thomann predicts that by the year 2010, the number of interactive compartments in watershed models may approach 100 million. Along with this complexity, model results have typically become less accurate and more difficult to understand. This is due to the observation that, as models predict more complex outputs and finer scales, accuracy of the predictions tends to decrease (Walters 1986, Reckhow and Chapra 1983).

Watershed models are a central scientific tool in most watershed management efforts. Watershed models are computer models that link the sources and fates of multiple pollutants from both point and nonpoint sources throughout the entire land area drained by a river. A watershed model typically consists of two linked submodels: one that calculates the amounts of pollutants generated in the watershed and one that models the fate of these pollutants once they reach a surface waterbody. In order to capture the complexity of the whole hydrologic system, these fate-and-transport models require immense amounts of data about soil types, slopes, land uses, management practices, precipitation, and point sources. An additional complication is introduced when these models attempt to predict impacts on living resources. By changing the input scenarios, watershed models may be used to predict how changes in land uses, management practices, or point source discharges would affect water quality.

Because watershed management decisions more directly affect a larger portion of the public than do point source controls, basinwide management has increased the number of stakeholders interested in water quality protection. At the same time, public managers have recognized the importance of involving citizens in the watershed planning process. For example, the EPA's guidance documents and policy statements on watershed management emphasize the role of partnerships and stakeholder involvement (Browner 1996). Accordingly, many states have explicitly adopted a participatory watershed approach to controlling point and nonpoint sources of pollution. Thus, watershed management has simultaneously increased the demand for more complex water quality models, as well as the expectation that the public will be meaningfully involved in the management process.

Because watershed management implies increases in both the salience and complexity of the computer modeling exercise, it has raised questions of whether and, if so, how to involve the public in modeling. There have been a variety of responses by watershed management programs. Many agencies have taken the initiative to involve citizens in watershed management efforts, and some of them have solicited citizen participation in the watershed modeling process. In other cases, the public has demanded involvement in modeling for watershed management.

Although there seems to be general support for involving the public in watershed modeling, "involvement" may mean different things to different people. Different cases of public participation vary with respect to mechanism, purpose, and costs. Mechanisms for public involvement can range from interactively exploring a model's output to participating in model development. The purposes for participation may include simply educating the public, eliciting public preferences for decision-makers' consideration, or some authoritative role in the final decision. The time and resources required for participation will obviously vary depending on mechanism and purpose. Based on the characteristics of a particular case, various arguments may be made for and against public participation in watershed modeling.

Arguments for Public Participation in Watershed Modeling

Models are often assumed to be objective, technical inputs to the decision-making process as opposed to being value-laden parts of the policy process itself. The issue of what is and is not science is relevant both to what aspects of policy-making should be in the public's purview and to what role scientists should play (Jasanoff 1990). However, it is widely acknowledged by decision-makers and modelers alike that modeling involves many assumptions and judgments (Korfmacher 1998, Ozawa 1996, Haan and others 1990, Ascher 1985). As Peters (1991, p. 116) notes, "complex simulations are no longer touted as predictive models but as heuristic devices to explore the logical implications of certain assumptions." In addition, decisions such as which alternatives to examine and how good a fit is required between predictions and observations are often made by modelers as part of the modeling process. Thus, modeling is not a strictly technical task, but rather a value-laden part of the political process. Therefore, guidelines for public involvement in public decision-making generally are relevant to public participation in watershed modeling.

Democratic theory offers several rationales for why the public should be involved in public decision-making. There are many different justifications for including the public in policy making. Three types of reasons are commonly cited: democratic, substantive, and pragmatic (Fiorino 1991, Kweit and Kweit 1981). The democratic rationale emphasizes the inherent value of public participation in decisions that affect the public. Recognizing that in some cases citizens may have unique contributions to public decisions, the substantive rationale claims that citizens' values and technical knowledge should help inform the final decision. The pragmatic justification for public participation emphasizes that a public that has contributed to and been educated by the decision-making process is more likely to support the decision outcome and facilitate its implementation. In fact, one of the most widely cited purposes of public participation is to develop public policies that have widespread support and legitimacy (Fiorino 1991). However, there is also widespread acknowledgment that public involvement does not necessarily lead to such support (Kweit and Kweit 1981).

These three rationales provide a set of objectives for involving citizens in watershed modeling. A participation effort motivated by a primarily democratic rationale would likely focus on involving a representative group of citizens. This can present challenges, since researchers have found that the wealthy and directly affected publics tend to participate disproportionately (Verba and others 1993, Gunter and Finlay 1988, Burch 1976). Maintaining representative input in a long-term, scientifically complex ecosystem planning program is especially difficult. A substantive rationale implies that members of the public who have special knowledge should be involved in the decision-making process. For example, local fishermen might be able to contribute their observations about the historic size, health, and locations of fish populations. A pragmatic focus emphasizes both that widespread education is important and that influential opinion leaders should be particularly targeted for involvement. With a pragmatic goal in mind, watershed managers might use the media to increase awareness about the modeling process and also solicit the input of local officials who will be crucial to implementing the recommendations.

In fact, most public involvement efforts blend all three rationales. Elected officials, agency staff, and citizens may have very different reasons for and, hence, expectations of public involvement. For example, an agency might express a pragmatic rationale through educating the public with the hope that greater public understanding would lead to greater support for the resulting policy decision. A citizen's pragmatic reason for participating, on the other hand, might be to change the agency's views and substantially influence the outcome of the decision. To avoid conflict and disillusionment, it is important to be as clear as possible about the various parties' expectations for public involvement. Unless there is a clear reason for favoring one of these goals for participation, it is most meaningful to evaluate the success of a public participation effort with respect to all three rationales (Fiorino 1991, Kweit and Kweit 1981).

Arguments Against Public Participation in Watershed Modeling

While the three rationales described above support public participation in watershed modeling, there are also several potential reasons not to involve the public, including: lack of expertise, risk of biased input, risk of delegitimization, risk of overlegitimization, misrepresentation of consensus, and insufficient influence. These arguments arise from the costs of public involvement in terms of time, resources, credibility, and quality of the modeling process. While these arguments are seldom stated explicitly, they are frequently implicit in the resistance of modelers and agency staff to public involvement in modeling. Any attempt at constructive participatory modeling should account for these potential costs of involving the public.

Lack of Expertise

Modeling requires skills, knowledge, and expertise that most lay citizens lack. It would be very costly to have citizens develop models, because meaningful involvement in water quality modeling requires significant technical training. Providing sufficient training for citizens to understand the technical considerations involved in watershed management can be very time and resource intensive (Rhoads and others 1999). Even with training in modeling processes, involved citizens may not have the experience necessary to properly interpret model results. This is especially true in an age of increasingly complex watershed models. According to this argument, involving the public is a waste of managers, modelers, and citizens' time and money. Involving the public can also put decision makers in an awkward position if the citizens' judgments differ from the modeling experts' (Griffin 1999, Tesh 1999).

Risk of Biased Input

Another argument is that the public cannot be involved in a truly representative fashion. That is, even if participation is acknowledged to be desirable, this argument states that in practice it is impossible to involve the public in a truly representative way. Researchers have found that citizens who believe that their interests will be directly affected by a policy decision are more likely to become involved in policy-making (Verba and others 1993, Gunter and Finlay 1988, Burch 1976). Few citizens are likely to perceive watershed planning and modeling as directly affecting their well-being. Therefore, it is reasonable to expect that only those citizens with the knowledge to understand from the outset how such an exercise might eventually affect them and those with a particular stake in the outcome are likely to actively participate.

Because of such constraints on participation, even if time and money are devoted to involving the public, the modeling results may include the views of a biased subset of the public. If those directly affected by watershed management decisions are more likely to become and stay active in the modeling process, the subset of the public that chooses to be involved may have a vested interest in a particular outcome. If this is the case, it would not be legitimate to claim that the results of such an exercise comprehensively represented public opinion.

Risk of Delegitimization

Decision-makers typically value modeling efforts as credible, objective, scientific inputs upon which to base decisions. Involving citizens in modeling may cast doubt upon the objectivity and scientific merit of the modeling results, lessening the results' credibility as a basis for decision-making. For example, Thomann (1998, p. 100) claims that "it is the scientific and engineering community, not the managers or environmental interests or legal counsels, that determines model credibility." This perspective implies that any involvement by nonexperts could cast doubt upon the reliability of model results.

Risk of Overlegitimization

Decision-makers generally receive technical data from staff scientists or consultants and public values from constituents, election results, etc. Having received these inputs from different sources, they then balance any conflicts between the two based on their own judgment. In contrast, results of a modeling exercise that involve the public are neither purely technical nor purely political. This raises the question of how the decision-maker should use recommendations based on such modeling efforts. One possibility is to assume that the recommendation is the correct decision, because it integrates scientific knowledge and public values. However, as noted above, the involvement process may have been poor with respect to the representativeness of the public involved, the extent or substantiveness of their input, or their understanding of the model. Thus, mixing science and values through public involvement in watershed modeling produces an unusual kind of policy input. Decision-makers unfamiliar with the participatory modeling process may place too much confidence on these recommendations as representing all citizens' views.

Misrepresenting Consensus

This argument relates to the idea of overlegitimizing model results, but goes a step further by saying that not only may the consensus position produced by a participatory modeling process be biased, but also that it may be misleading to claim any such consensus is possible. A commonly stated goal of involving the public in modeling is to develop a consensus about how to manage the watershed. However, due to the diversity, complexity, and conflicts among public values, it may, in fact, be impossible to come to a consensus. In fact, producing and sharing more environmental information can lead to more conflict, not less (Moote and others 1997, Healy and Ascher 1995). Presenting model results as the outcome of a participatory modeling process may imply that engineering constraints, economic costs, and social values have been optimized. This implication hides the fact that model results are inherently uncertain and that diverse public values may not be fully expressed in a single set of recommendations.

Insufficient Influence

According to the rationales for public participation, the public should have substantive input into final decisions. Citizens who have limited resources for participating in a political process will likely select opportunities that make the most significant impact on final decisions (Griffin 1999). Being involved in a complex, lengthy technical process whose product may or may not influence the final decision may appear to citizens to be an inefficient use of their time. Even if being involved makes them better informed, citizens may feel they are more effective by appealing directly to the decision-maker. Activist groups in particular may hesitate to appear co-opted by an agency with which they have an historically adversarial relationship (Wondolleck and others 1996). These factors may also contribute to the risk noted above of biased involvement, since organized interests are more likely to become involved in technical processes than are individual citizens.

Guidelines for Good Practice

While there are several rationales for involving citizens in the modeling process, there are also risks. Applying the rationales for public involvement to the task of watershed modeling provides a conceptual framework for thinking about what is appropriate public involvement in this context, and how best to mitigate the risks described above. Below, I develop this framework and use it to propose five guidelines for good practice in participatory modeling efforts. Because what kind of involvement is appropriate depends on the purpose of public involvement, the modeling task, and the resources available in each case, the applicability of these guidelines may vary. Nonetheless, using these principles as general guidelines could help watershed managers better account for the politics of public involvement in modeling efforts.

As argued above, the democratic, substantive, and pragmatic rationales for participation are all relevant to most real cases of watershed management. The democratic rationale (that citizens should be involved in decisions that affect them) relates to watershed modeling in at least two ways. First, watershed modeling and management requires funding, which is usually provided by taxpayers. Second, choices about modeling affect the quality and certainty of the information base for making management decisions. This implies that the public should be involved in modeling decisions that require trade-offs between cost and accuracy.

The substantive rationale focuses on citizens' specialized knowledge that may augment experts' understanding with respect to both facts and values. Citizens are uniquely able to elucidate public values that may be relevant to the modeling process. For example, assumptions about allocations of costs and benefits among current groups or across generations, judgements about the relative significance of various natural resources, and choices about future scenarios for the population of the watershed may be embedded in the model. Members of the public may also have technical knowledge that is not accessible to modeling experts, such as anecdotal observation of land-use practices or historical trends (Rhoads and others 1999, Lee 1993).

Finally, the pragmatic rationale is that an involved and educated public is more likely to support implementation of resulting policies. This implies that the public should be involved in the modeling process to the extent that it helps them better understand and trust the model results. A full understanding of the strengths, limitations, and uncertainties of watershed models allows participants to judge for themselves the appropriateness of resulting management recommendations.

Thus, applying the theoretical justifications for why the public should be involved to the context of watershed modeling gives some general principles for how the public should be involved. This framework paints a picture of collaborative analysis, in which the public is involved throughout the process of generating knowledge (Busenberg 1999). This does not mean that citizens become modelers, but rather that they are involved in the kinds of modeling decisions that relate to the three goals for participation. Below, these principles for involvement are operationalized as five guidelines for good practice for modeling efforts that involve the public.

Transparent Modeling Process

The model developed or chosen should be user-friendly, open and flexible, easy to update, and well documented. It should produce easily understandable outputs including a clear statement of potential uncertainties. User-friendliness usually refers to ease of changing model inputs, clear interpretation of outputs, and transparency of model processes. As such, user-friendliness can facilitate substantive input by participants and may make it easier for them to learn from the model (a pragmatic justification). Estimates of uncertainty help participants understand that model predictions are not necessarily accurate. In addition, they allow participants to debate trade-offs between the time, cost, and accuracy of the modeling exercise. Finally, because watershed models are inherently uncertain, ongoing technical support should be provided for model updates and incorporation of new information (Bishop and others 1990, Fedra 1990). This strategy is advocated by proponents of adaptive management, who suggest continual reassessment of scientific inputs to the policy process as a way to cope with scientific uncertainty (Lee 1993, Walters 1986). Thomann (1990, p. 12–2) explicitly applies this principle to water quality modeling, where he suggests that the half-life of a model is between one and two years.

Continuous Involvement

The role of the public should be determined by the purpose of the participation. However, it is generally acknowledged that the public can best influence decision-making through ongoing participation (Griffin 1999, Moote and others 1997). Both the substantive and pragmatic rationales suggest that the modeling process should involve the public in as many of the stages of modeling as possible, including model development or selection. The section below describing the steps of watershed modeling gives examples of how the public could meaningfully contribute to judgments made throughout the modeling process. In order to encourage continued participation, modelers should provide feedback about the public's substantive impact at each stage.

Appropriately Representative Involvement

The democratic rationale suggests that careful attention should be paid to who comprises the public that is participating in modeling. That is, what is the full range of interests in watershed management (both direct and indirect), and how may these best be incorporated? Recognizing that directly affected, well-organized stakeholders are most likely to be actively involved, watershed managers should take steps to reach less-involved constituencies. This does not necessarily mean that lay citizens should be recruited as participants. Indeed, as Tesh (1999) points out, citizens are most likely to participate through organized groups, and organization also tends to increase effectiveness. It does imply, however, that watershed managers should consider alternative ways to learn the preferences of less well-organized stakeholders. Possible approaches include widespread education about the potential impacts of watershed management decisions and a variety of opportunities for input. As suggested above, giving regular feedback about the value of the public's input may encourage diverse stakeholders to remain involved.

Influence on Modeling Decisions

The substantive rationale implies that participants' values and knowledge should have a real impact on the modeling process. While there may be situations in which experts' judgments should prevail over that of nonexperts, all participants should understand when these situations arise. Therefore, it should be clear from the outset how decisions will be made at each step of the modeling process. Ideally, participants should come up with and agree upon these decision rules themselves, including a process for resolving disputes (Wondolleck and others 1996). It should be acknowledged that striving for consensus can take longer than voting mechanisms and that it may result in a stalemate. Having a substantive impact also enhances the pragmatic goal of participation, since participants are unlikely to be supportive of a modeling effort in which they felt ignored.

Clear Role of Modeling in Watershed Management

In order to achieve a substantive impact on watershed policy, not only must participants have a meaningful influence on the modeling process, but also the model results must affect management decisions. Modelers may not have much control over how their results are used, but at the least participants should be informed at the outset about the model's potential role in watershed decision-making. Of course, when the involvement is initiated by researchers, citizens, or interest groups without a direct link to the decision making process, it is clearly more difficult to predict what influence recommendations will have than when the effort is initiated by managers. In such cases, it may be especially important to set realistic expectations for what kind of impact the modeling results may or may not have in order to avoid later disappointment by involved citizens. Decision-makers should be honest about how the public's input will be used and what limitations exist to the participatory modeling group's influence. Feedback about this influence should be provided regularly.

Because participatory modeling groups cannot be held accountable for watershed decisions, it will seldom be appropriate for them to have the final say in management decisions. However, there should be opportunities for participants to share their values, views, and knowledge with the ultimate decision-makers. It should also be recognized that failure to reflect participants' input in final watershed management decisions could backfire with respect to the pragmatic goal of participation. Not only might participants be frustrated with the process, but also they could become highly vocal and well-informed opponents of the decision.

In combination, these guidelines suggest how to maximize representative, well-informed, meaningful participation. In the next section, I apply these guidelines to the multiple steps involved in watershed modeling.

Public Involvement in Watershed Modeling

The general guidelines presented above lay out a framework for appropriate public involvement in watershed modeling efforts. However, watershed modeling comprises a set of several interrelated tasks, each of which requires different kinds of expertise, information, and judgments. Theoretically, the public could participate in any or all of the stages of the modeling process. The guidelines set forth above suggest how the public might be appropriately involved at each of these stages.

Reckhow and Chapra (1983, p. 17) delineate six steps of water quality modeling: (1) determine objectives, (2) develop a conceptual model of the system, (3) construct the mathematical model, (4) calibrate the model, (5) confirm the model, and (6) apply the model as intended. The fact that these stages involve different kinds of decisions has implications for appropriate roles for citizens in each case. Each of these steps of modeling is described below and illustrated with some examples of how the public could be involved in that task in accordance with the guidelines proposed above.

Determine Objectives

The first step in developing a watershed model is to determine what the model will predict. For example, water quality models frequently predict dissolved oxygen concentrations for a given space and time. Public input at the objective-setting stage might reveal that the public values aesthetic considerations, like the avoidance of nuisance algal blooms, which modelers otherwise would not have included as model outcomes. This stage should also include preliminary discussions of what level of accuracy is required for decision making. It should be noted that watershed modeling efforts frequently make use of existing models, rather than constructing an entirely new model structure. In such a case, decisions about outputs, scope, and accuracy are embedded in the choice of models (Ozawa 1996). The modeling effort then typically skips to the fourth step, with relatively little examination of the desired objectives, concepts, and construction of the model being used.

For each of these initial decisions, feedback should occur between participants and the modelers about what is desired and what is feasible. For example, participants might state that they are interested in how many fish are likely to be killed by low oxygen levels in a typical year. In this case, modelers might respond that they cannot predict fish mortality with meaningful accuracy, but could predict quality of fish habitat with relatively high certainty. The dialogue should continue until a feasible set of outcomes is selected that reflects public values.

Develop a Conceptual Model of the System

A watershed model tries to simulate the important characteristics of the hydrologic cycle and human activities in the watershed that affect water quality. In addition to point sources of pollution such as wastewater discharges, nonpoint sources of pollution must be included. To predict nonpoint source pollution, information is needed about what kinds of land uses take place in different parts of the watershed. For example, runoff from forests, fields, and residences contains different concentrations of nutrients, sediment, and other pollutants. In addition to knowing the proportions of different kinds of land use in the watershed, it is important to know where in the watershed they take place, since distance from the stream affects how much of the runoff actually reaches the watercourse. Because of such considerations, watershed models are complex and data-intensive. As complexity increases, the amount (and expense) of data required increases and accuracy often decreases. Depending on the purposes of modeling and resources available in a given case, a more complex model may not be preferable to a simpler one. Thus, the conceptual design of the model incorporates decisions about cost and accuracy to which the public should contribute.

Construct the Mathematical Model

Constructing a mathematical model on a computer requires technical skill, yet is not a purely technical exercise. Many decisions are made in the process of constructing a model that require professional judgments. For example, nonpoint source pollution is often predicted using export coefficients. Export coefficients express the amount of a pollutant (such as phosphorus) that has been measured in runoff from different kinds of land uses under different slopes and soil types. Because of the enormous variability in conditions and uncertainty in these measurements, export coefficients are provided in guidance documents as a range of values. The model builder generally chooses an export coefficient from the range provided based on his or her knowledge of local conditions. While the public may or may not be better qualified to make these choices (for example, through first-hand knowledge of land practices), participation at this stage might educate them about the uncertainties involved in watershed modeling. According to Haan and others (1990, p. 347), "input estimation is one of the most difficult, and often the most frustrating aspects of many modeling activities. Those using models must understand the difficulties inherent in the estimation process if they are to make informed judgments about the desirability of modeling and the accuracy of model predictions." This stage of the modeling process also includes deciding how to measure and express the uncertainty of the model's predictions. The guidelines for good practice suggest that uncertainty analysis is an essential component for the public to understand.

Calibrate the Model

To apply a model properly, it is necessary to have at least two sets of data. Typically, the first set of data is used to calibrate the model and the second set is used to confirm it (see below). For a watershed model that predicts dissolved oxygen concentrations, the data will include independent variables such as precipitation and the observed dissolved oxygen concentrations for a specified time period. The model is run using the input variables from this first set of data, then the predicted dissolved oxygen concentrations are compared with observed concentrations. If the model's predictions are substantially different from the observed concentrations, the modelers change input parameters (such as the export coefficients) so that the model predictions better match the observed data. There is no generally accepted standard among modelers for what constitutes an adequate fit between predictions and observations. Since there are many kinds of land use and a wide range of choices for the parameters, there are many ways to adjust the model to obtain a better fit (Korfmacher 1998). The public might assist in decisions about which parameters are most uncertain and should be altered to improve the model's fit. For example, based on their experiences in the watershed, citizens might have a more accurate estimate than modelers of how widely applied are certain agricultural best-management practices. Being involved in such decisions would make participants more aware of the kinds of uncertainties and judgments included in the model. Citizens could also participate in the decision about when the match between predictions and observations is acceptable.

Confirm the Model

While calibration insures that the model can predict the behavior of the system under one set of conditions, it does not indicate whether the model will work for different conditions. Therefore, a second set of data is needed to confirm the model. Using the parameters selected and modified in the calibration process, the model is again run and its predictions are compared to the observed conditions. This stage is sometimes called verification or validation, but these terms have fallen out of favor with modelers because they tend to create overconfidence in model capabilities. There have been extensive philosophical arguments in the literature about why it is impossible to verify or validate a model (Oreskes and others 1994, Konikow and Bredehoeft 1992, Reckhow and Chapra 1983, p. 17). Because of this, most modelers prefer the terms "confirmation" and "history matching," which more accurately represent the uncertainty of model predictions (Parker and others 1995). As with calibration, there is no commonly accepted standard for what constitutes adequate confirmation. Public involvement at this stage should include deciding whether or not the confirmed model predicts results well enough to be used in decision making and, if so, with what confidence model results should be treated.

Apply the Model Appropriately

Application of the model consists of designing and running scenarios using different assumptions about state variables and management alternatives. At this stage, the public might be involved by selecting input variables for probable scenarios to explore. These decisions clearly involve judgments that may be influenced by individual values. For example, participants might have widely varying hypotheses about probable future land uses, agricultural practices, or industrial discharges. Uncertainty of model predictions may also be tested at this stage through sensitivity analysis. Depending on earlier decisions about model construction, an overall statement of certainty may or may not be presented along with model results.

The above discussion shows there are multiple decision points throughout the modeling process that incorporate values and judgments. Theoretically, nonmodelers could be involved in each of these steps. Although their role would vary from one step to the next, citizens' involvement at each stage could substantively influence the modeling process. In the next section, I present several cases in which efforts have been made to involve the public in watershed modeling. These cases provide a basis for exploring how well the guidelines for good practice are addressed in current approaches to participatory modeling.

Cases of Public Participation in Watershed Modeling

The four cases described below represent a range of current approaches to involving the public in watershed modeling. Although there have been many attempts to make models more user-friendly and more accessible to state or local managers, these four cases attempt to reach beyond professional managers to citizens and stakeholder groups (McMahon 1995). Below, each case is described with respect to the characteristics identified by the guidelines for good practice described above: user-friendliness of model, continuity of involvement, representativeness of participants, influence of participants on modeling decisions, and role of model results in decision making. Table 1 summarizes these characteristics of the four modeling efforts. In order to clarify the nature of participation in each case, Table 2 specifies which steps of the modeling process involve the public. Because of differing policy contexts, variation in how far the modeling effort has progressed to date, and the limited information available on each of these cases, some of these descriptions are more complete than others. The case descriptions presented below are compared and analyzed in the following section.

Chesapeake Bay Community Watershed Model, Chesapeake Bay Program

The Chesapeake Bay Program has one of the most extensive watershed modeling efforts in the country. Approximately $1 million is invested in this effort annually, plus around twice that for data collection and monitoring. The modeling regime connects a watershed runoff model, an airshed model (for estimating atmospheric pollution), and a complex hydrodynamic/water quality model of the bay. One of the primary purposes of the model is to predict the impacts of nutrient reductions in the watershed on nutrient concentrations in and the environmental health of the bay.

The Chesapeake Bay Program has a long history of active public participation (Fraites and Flanagan 1993). However, although the modeling subcommittee's meetings are open to the public, citizens have not participated directly in the program's modeling efforts. Recently, the Chesapeake Bay Program Modeling Subcommittee designed a community watershed model that can be downloaded from the internet onto users' computers (Chesapeake Bay Community Watershed Model 1998). The modeling subcommittee saw this as one way to make their work open to and be held accountable by the public. However, because the model is so complex, current participants are primarily academic researchers who have an interest in developing different aspects of the model and state managers who wish to explore the implications of certain model assumptions for management options within their state. For example, users are able to alter input files, run individual segments of the model, and experiment with different management scenarios. Thus, the model is transparent and widely adaptable, but only for the select group of participants who are able to access and understand the model.

Table 1 Guidelines for good practice as implemented in four participatory watershed modeling efforts

	WARMF Catawba River, NC and SC	Chesapeake Bay Community Watershed Model MD, VA, and PA	Patuxent Watershed, MD	ModMon, Neuse River, NC
User-friendliness	User-friendly interface, but model is "black box"	Model transparent, but difficult for nonexperts to use	Graphical model, easy to understand	Participants not directly involved with model
Continuity of involvement	Participants apply model, alter assumptions and explore output	May download and alter existing model	Involved throughout process	Focus on involvement in setting end points
Representation	Stakeholders	Anyone may download, but to date only experts/researchers	Stakeholders	Stakeholders; surveyed underrepresented groups
Influence on modeling decisions	Model scenarios/ results based on vote by participants	Existing public input channels to Chesapeake Bay Program's modeling subcommittee	Model structure and scenarios reflect consensus of participants	Expect modelers to consider input about model end points
Role in watershed management	Expect decision makers to consider model recommendations	Modeling informs CBP decision making on an ongoing basis.	Expect state-level decision makers to consider model recommendations	Expect model results to influence state's water quality management

Table 2 Participation in stages of watershed modeling: Characteristics of four cases[a]

Modeling effort	WARMF Catawba River, NC and SC	Chesapeake Bay Community Watershed Model MD, VA, and PA	Patuxent Watershed, MD	ModMon, Neuse River, NC
Define objectives	N	N	Y	Y
Concept of model	N	N	Y	Y
Structure model	N	N	Y/N[b]	N
Calibrate	N	Y	Y/N	N
Confirm	N	Y	Y/N	N
Apply	Y	Y	Y/N	N

[a]There is incomplete information about some of these cases. In cases where the modeling effort is not complete, the assessment in this table reflects the modeling program's expectations.

[b]In this case, "experts" develop the structure, equations, and data for the model; however, there are interactive workshops with the stakeholders to update them on progress and, presumably, solicit input.

Although there is no specific plan for incorporating participants' suggestions into the program's official modeling efforts, the researchers who access this model could produce new information that challenges current management strategies. In addition, it is theoretically possible for citizens to educate themselves about watershed processes and model predictions by accessing this model. Such knowledge could enhance their input through existing channels for public participation in the Chesapeake Bay Program. It should be noted that the modeling subcommittee hopes to develop a more user-friendly model that will serve as a tool for widespread education about watershed processes in the future. Thus, the community watershed model currently serves as more of an educational/research tool than as a venue to incorporate widespread public input into ongoing modeling efforts.

Watershed Analysis Risk Management Framework (WARMF) in the Catawba River, North Carolina

The WARMF is a watershed model that was explicitly designed to meet the needs of emerging participatory watershed planning and management efforts. Its designers recognize that the shift from command-and-control regulation of point sources to a watershed approach "provides local stakeholders greater flexibility to manage point and nonpoint source pollution so that water quality criteria can be met through more cost efficient means. Management alternatives must be evaluated according to their effectiveness at resolving water quality problems, costs, and ability to satisfy varied stakeholders" (Chen and others 1997, p. 75). The model itself may be run by any interested citizen on a personal computer and has a user-friendly interface; however, the mechanisms of the model are an inaccessible "black box."

WARMF was developed in the Catawba River basin, with the intent of making the software available to other watershed planning efforts in the future. The public is involved in the modeling process through a series of meetings to explore various scenarios and alternatives. Thus, while participants are not involved in constructing the model, they have multiple opportunities to explore its predictions. For the application on the Catawba River, over 50 stakeholders were identified. These stakeholders included the Duke Power Company, which operates numerous dams on the river, as well as "regional planning agencies, conservation organizations, federal, state, and local agencies, wastewater dischargers, drinking water users, and citizens' groups, which often provide enthusiastic individuals to discuss ideas and share their concerns" (Chen and others 1997, p. 76).

Although the stakeholders are not involved in model development, they do make many modeling decisions through a well-defined process. The involved stakeholders may change scenarios about land use and management options, view input variables, and compare predicted to observed water quality conditions. In addition, uncertainty analysis is incorporated into the model to provide the stakeholders with an estimate of the risk that a given control strategy will not accomplish the desired objectives (Chen and others 1998). In order to come to resolution about model-based recommendations, the involved stakeholders vote. According to model developers, the model itself "provides a road map to guide stakeholders through the decision making process to arrive at effective, cost-efficient water quality management options for the entire watershed" (Chen and others 1997, p. 78). Although the Catawba River application has not yet been incorporated into a management process, the recommendations of the WARMF process are expected to be adopted and implemented by the relevant agencies and local governments.

Patuxent River Watershed, Maryland

In the context of the overall Chesapeake Bay restoration efforts, several individual states are modeling subbasins to refine management decisions. In Maryland's Patuxent River watershed, an effort was made to involve stakeholders in a process called "dynamic modeling" to guide "sustainable ecosystem management at the watershed scale" (Costanza and Ruth 1998).

Costanza and colleagues have used dynamic modeling in scoping and developing solutions to environmental problems in many contexts. Using STELLA graphical programming language, the models are designed in an interactive process with stakeholders. These models are intended to be user-friendly and flexible. The general process consists of three steps. First, the group constructs the basic model structure graphically as a series of stocks and flows with connections defined between them. Second, experts collect data for calibration and define the equations behind the existing structure. At this stage, the whole group is involved through "workshops and meetings to discuss model progress and results" (Costanza and Ruth 1998, p. 187). Third, the entire group is once again involved in exploring various scenarios and management options. The importance of adaptive management—revisiting the model scenarios as new data become available—is also emphasized.

This process was used to develop a model for the Patuxent River watershed. The model was developed using "workshops involving the full range of scientific, government, and citizen stakeholder groups to develop initial scoping models, to communicate results, and to refine and adapt the research agenda" (Costanza and Ruth 1998, p. 191). Descriptions of the model imply that consensus among stakeholders is sought at each stage of the modeling process.

In addition to the watershed model, economic submodels are being developed to assess the costs of various management options. The goal of the integrated model is to "allow stakeholders to evaluate the indirect effects over long time horizons of current policy options" (Constanza and Ruth 1998, p. 192). Although these results have not yet been used in a policy context, the modelers intend to provide their recommendations to state and local decision-makers to inform their watershed management decisions.

Neuse River Estuary ModMon, North Carolina

The water quality of the Neuse River in North Carolina has been the focus of recent concern, particularly since several spills of waste from industrial hog farm lagoons caused large fish kills in the summer of 1995 (Maloney and others 1999). The Neuse River is designated as Nutrient Sensitive Waters under North Carolina state regulations. This designation requires a special focus on reducing nitrogen and phosphorus inputs to the system from both point and nonpoint sources. In 1997, the North Carolina Water Resources Research Institute (WRRI) began an effort to develop a decision support system for nutrient reduction decisions. This integrated effort of monitoring and modeling is called the Neuse River Estuary ModMon (modeling and monitoring) project (Water Resources Research Institute 1998).

Part of this project is a decision support system that consists of several linked models, with the goal of developing "a completely open system that can grow and develop to meet the long-term needs of stakeholders" (Dodd and others 1997). This system links models of runoff loadings, agricultural nutrient management, atmospheric depositions, riparian buffers, in-stream water quality, and costs of nutrient reductions. It is not expected that participants will have a direct role in development of the model, so user-friendliness was not a relevant criterion for modelers. However, it should be noted that particular attention was paid to uncertainty calculations in the modeling efforts (Water Resources Research Institute 1998).

As part of the modeling effort, meetings were held with stakeholders to elicit their input about appropriate end points (objectives) for the models. Because the meetings did not draw a representative group of stakeholders, researchers also sought input from underrepresented groups through surveys and interviews. The purpose of these surveys and interviews was to collect public views so they could be considered in designing the model structure. It is clear from these studies that stakeholders valued a significantly different set of endpoints than professional modelers. For example, input from the meetings indicated that the public is more interested in the economic outputs of the model (cost, efficiency, allocation, etc.) than in the biological and chemical indicators modelers traditionally focus on (Maloney and others 1999). The models have not been finalized, so it is not clear to what extent or whether the participants' views will affect decision making. The final models are expected to be used in basinwide management decisions by the North Carolina Division of Water Quality, including Total Maximum Daily Load allocations.

Good Practice?

The examples described above demonstrate several current approaches to involving the public in modeling to support watershed management. Although these cases are clearly still in their early stages, it is possible to analyze their progress to date with respect to the five guidelines for good practice proposed above. Below, I comment on how these efforts have performed with respect to the good practice proposed above: transparency of the modeling process, continuity of involvement, representativeness of involvement, clarity of participatory process, and influence on decision-making.

Transparent Modeling Process

These cases show a variety of approaches to how directly participants interact with the model's structure and outputs. For example, the WARMF is a black box to participants. They can interact with the model and run scenarios, but are not necessarily aware of how the model functions. The Patuxent case participants probably developed an awareness of the model's structure, since they were involved in its creation. The Chesapeake Bay community watershed model allows participants to change and run the model independently, which requires a working knowledge of how the model functions.

These three scenarios highlight a paradox of participation in watershed modeling: as the models become more complex, it is more difficult for nonexperts to fully understand them. This implies that simpler models may be more appropriate for participatory modeling exercises. However, complexity is often equated with legitimacy, so using a simpler model may detract from the credibility of the modeling effort (Korfmacher 1997, 1998). One way to deal with this conflict is to create a user-friendly model interface. The creators of WARMF have used this strategy. An essential component of such an interface should be educating participants about the assumptions made by the models and to provide them with information about the uncertainty of model results. None of the efforts described above appear to have clearly explained the model's assumptions, dynamics, and resulting uncertainty to participants.

Another area these cases have not fully addressed is updating and adapting the model. Perhaps because these efforts have not reached the decision-making stage, the future of the modeling effort is not emphasized. One strategy would be to plan for ongoing monitoring of the system (preferably incorporating citizen monitoring efforts) and periodic evaluation of the watershed model. None of the cases examined laid out a specific plan for regular adaptation of the model, ongoing monitoring, or incorporation of new data into updated recommendations.

Continuous Involvement

These cases vary with respect to the stages of modeling in which the public is involved. Some watershed modeling efforts, like the Patuxent River cases, involve (or plan to involve) the public in every stage of the modeling process. The Neuse ModMon program emphasizes stakeholder input about the objectives of the model. In other cases, like the Chesapeake Bay Community Model and the Catawba River WARMF, the participants are assisted in exploring an existing model, but are not involved in model development (see Table 2). This approach is probably much less costly to both the modelers and the involved public in terms of time, training, and resources. As a result, however, these models may not predict the variables of interest to the public, may not use the public's substantive knowledge, and may produce outputs that participants do not fully understand. Thus, there seems to be a trade-off between the quality of input and the costs of involvement.

Appropriately Representative Involvement

Most of these cases involved a rather small number of directly involved stakeholders. These stakeholders were primarily agency staff, industries, and representatives of organized interest groups. The Neuse ModMon case was an exception because researchers used multiple methods (surveys, interviews, and workshops) to actively seek out the perspectives of underrepresented and less well-organized groups. Although this case shows it is possible to get input from greater numbers of participants using different techniques, in general only those stakeholders with a direct interest in the outcome of watershed management decisions will invest the effort to become educated about the model and give their input. This is especially true if, as with most of these cases, involvement requires participation in several workshops over a period of time. Therefore, there may be a trade-off between the extent of involvement and the representativeness of participants. Decision-makers who use the recommendations of these efforts should understand who was and was not involved in the modeling process and how the involvement took place.

Influence on Modeling Decisions

These cases also vary with respect to how decisions were made at each stage of the modeling process. The Patuxent River and Neuse River modeling efforts apparently aimed for a consensus among stakeholders on modeling choices. This occurred through a dialogue between modeling experts, managers, and stakeholders about what is desirable versus what is possible. Involvement in the Chesapeake Bay modeling effort is so diffuse that there is no standard pattern for influence; however, it is possible that researchers and participants from outside the program could influence the program's modelers through presentation of their findings.

The Catawba River WARMF process, while intended to promote consensus, actually uses a voting procedure to produce singular recommendations. Thus, the recommendation represents the majority view among a group of stakeholders and may not include all interests or be proportionately representative. Because a single decision must be reached at each stage of the modeling process, differing opinions or concerns by a minority of the involved stakeholders may be hidden by the apparent unanimity of recommendations. In such a case, it may be wise to encourage participants to submit their own interpretations of and any concerns about model results, even if they agree with the consensus recommendations.

Clear Role of Modeling in Watershed Management

Regardless of how influential the recommendations are, it is important to inform participants of their potential role in decision making, as well as limits to this role. It is not clear from the case reports whether or not participants were fully aware of plans for using modeling recommendations. Because the management decisions that these modeling efforts support have not yet been made, it is impossible to know what effect the participatory modeling recommendations will have. However, in all of the cases examined the modelers expect that the modeling recommendations will be taken into account by a final decision-maker.

Thus, these four cases show that there is great variation in what is meant by participatory modeling and to what extent the five guidelines proposed above are reflected in current practice. Each of the cases improved participants' understanding of watershed processes, whether by involving them in model development or by creating user-friendly model interfaces. Some of the cases made significant efforts to involve participants early in the modeling process, whereas others simply allowed participants to explore alternate scenarios using an existing model. Relatively little attention seems to have been paid to representativeness of the participant group, with the exception of the Neuse case in which researchers consciously sought out underrepresented group members. Although three of the four efforts strove for consensus in their decision processes, only the Catawba-WARMF case paid specific attention to how disputes would be resolved (e.g., voting). Finally, although it is too early to assess these efforts' ultimate effects on decision-making, it does not appear that participants in any of these cases had a clear sense of how the modeling process would or would not influence final management decisions.

Recommendations

As a key tool in watershed management, watershed models provide managers with a way to explore possible outcomes of complex decisions. These decisions are often of great interest and consequence to the public. Participatory watershed modeling has the potential to contribute to the three goals of public involvement in policy-making: democratic representation, substantive impact, and pragmatic support. However, from the four cases surveyed here, it is clear that there is much to be learned about how to achieve these goals for public involvement in watershed management. Paying attention to the five guidelines for good practice proposed above could help modeling efforts meet these goals.

An important first step in implementing these guidelines would be to improve our understanding of the current practice of participatory modeling. This could be done by surveying watershed groups, agencies, and researchers and compiling a comprehensive database of cases in which the public has been involved in watershed modeling. This would be a significant undertaking, because participatory modeling is occurring in diverse institutional settings, few of which have been recorded in the literature.

Nonetheless, such a database could provide the empirical basis for investigating several important research questions. First, it is important to carefully document what kinds of impacts broadened participation actually has on modeling efforts. Second, an important research question is what kinds of participation are most productive and least costly in terms of time, resources and staff. Third, these experiences could be analyzed with respect to their influence on the politics of watershed modeling. That is, what effects have participatory modeling efforts actually had on watershed management decisions? Fourth, it would also be helpful to determine what constitutes evidence to participants that they have had an impact and that their input influenced the modeling recommendations.

A final aspect of the politics of watershed modeling that should be examined is whether public involvement has positively or negatively impacted the legitimacy of the modeling effort. If public involvement does appear to erode model credibility, watershed managers could take steps to minimize the risk of delegitimization. One approach might be to obtain regular review by external modeling experts to confirm that the modeling process itself was sound. Another strategy is to emphasize monitoring and feedback to document the predicted and actual response of the system to management changes. The adaptive process should be open and well-publicized to promote awareness that the model is being continuously improved.

Thus, there is much we still need to learn about the evolving practice of public involvement in watershed modeling. The research strategies suggested above could produce information needed to further refine the guidelines for good practice suggested in this paper.

Conclusions

Participatory modeling opens up a new area of public decision-making to input by citizens. If care is taken to balance this input with other forms of participation, more broadly informed watershed management decisions may result. Given the opportunity, the public may substantively shape the structure, scope, and results of the modeling efforts. Public involvement also has the potential to build wider support for watershed management decisions through giving stakeholders a better understanding of watershed processes, appreciation for the strengths and limits of watershed models, and a sense of ownership of the decisions. However, there are risks to involving the public. For example, some groups may be disadvantaged through underrepresentation, modeling efforts could lose credibility, and stakeholders could become disillusioned by the process. Following the guidelines for good practice proposed above could maximize the benefits of participation while minimizing potential risks.

It is particularly important that citizens, modelers, and watershed managers pay close attention to questions of how participatory modeling results are used in decision-making. As discussed above, participatory modeling results are neither a purely technical input nor full a representation of public interests. While public input may be extremely valuable in increasing the breadth of perspectives, information, and alternatives considered in the modeling process, participants are neither appointed experts nor elected representatives. In other words, stakeholder participants cannot be held accountable for watershed modeling recommendations. In addition, participation is unlikely to be representative, especially of indirect public interests. Because of this, managers must avoid the temptation of assuming that by involving members of the public in modeling, they have "checked the box" of citizen participation in watershed management. Perhaps because public involvement in watershed modeling is a relatively new practice, little attention has been paid to such political implications. Applying the guidelines for good practice proposed above could help managers focus on the political aspects of this type of public involvement.

As noted above, watershed management is one of the first areas in which an attempt has been made to involve stakeholders in environmental modeling. This is likely due to the fact that watershed processes are relatively easy to understand, are of a geographic scope citizens can relate to, and have direct impacts on landowners' lives. In the future, participatory modeling may be increasingly proposed for even more complex environmental problems such as regional air pollution or global climate change. The issues of involving a representative public, training participants to understand the model, and using recommendations appropriately in decision-making are likely to be even more complicated in these applications than they are for watershed modeling. Therefore, developing guidelines for how public involvement can most effectively, efficiently, and equitably influence watershed modeling processes may have widespread implications for future participation in environmental management.

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