Modelers' Views on the Role of Nitrogen-Loading Models in Watershed Management

A Peer-Reviewed Report by

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Abstract

In interviews with sixteen modelers and outreach professionals in southern New England, we explored themes related to ecological models and their application in local decision making. In specific, we investigated the use of nitrogen loading models in local town-based planning board decisions. A number of themes arose from a qualitative analysis of the interview transcript data. People differentiated between two general types of models: those intended to advance science and those used to advance policy making. We focused our interviews on policy models and asked our interviewees what were the features of good policy models. People remarked that models should be appropriate to the scale of the decision, they should be cautious about invoking powerful metaphors, they needed to be honest about their ability to make predictions, and that there was a danger that models might promote technocracy if they are perceived as being beyond reproach.

Four other major topics arose. The first major topic was uncertainty. There was a great deal of debate over whether or not to provide uncertainty information to users. Some argued that modelers were professionally and ethically obliged to provide uncertainty information. Others suggested that lay users would not be able to interpret uncertainty information correctly and presenting uncertainties would result in loosing credibility with local decision makers.

The second major topic was transferability. People distinguished between ecological transferability—what it takes for modelers to construct a model that would work well in a new locale—and social transferability—what it takes for the local decision makers to accept that a model developed elsewhere would provide meaningful results for a this locale. Questions of ecological transferability centered around model complexity and the availability of local data that could be used to calibrate the model. Questions of social transferability centered around the legal and regulatory process by which a model becomes deemed valid.

The third major theme had to do with the involvement of local decision makers and local citizens in the design and operation of nitrogen loading models. Some argued that involving local people in the calibration of a model would lead to higher social acceptance. There was disagreement about whether or not lay monitoring programs would produce data good enough for modelers to use. Some were skeptical of these data. People also disagreed about whether or not lay publics should be involved in the design of models.

The fourth theme focused on the use of models by lay decision makers. Most of our interviewees agreed that few, if any, lay users would want to run these models themselves. Even if lay users did have an interest in running models, many of our interviewees expressed concerns that model outputs might be misinterpreted. There was resistance to posting models on the World Wide Web where they would be available for anyone to use. Some recommended that “science translators” be the ones who actually run models for users to prevent misuse.

We organize our discussion of these results around three central themes. First is the culture of science in which modelers operate, which shapes the approach modelers take

toward modeling. Second is the important theme of uncertainty information and the best way to handle presenting those data to non-scientists. Finally, we discuss the role of ecosystem models in democratic decision making. We conclude that models can contribute to helping lay decision makers make wise decisions about land-use, but that there are many obstacles to overcome before these models are integrated into local decision making processes.

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1.0Introduction

Computer-based models that characterize ecological function and approximate environmental impacts under different management scenarios are prevalent in the field of water quality management (Thomann 1998, Thieler et al. 2000). More and more they are being called on to serve as policy making tools. This is increasingly so as water quality protection has turned toward a watershed management approach as a strategy to address non-point sources of water-born pollution (Browner 1996). The Chesapeake Bay Community Model is one example of such models (Chesapeake Bay Community Watershed Model 1998).

As these models continue to proliferate, a wider discussion about the proper way they should be used in policy making is emerging (Costanza and Ruth 1998; Shackley 1998; Ewing, Grayson, and Argent 2000; Korfmacher 2001). A key question this literature addresses is: What are the proper roles for citizens, stakeholders, policy makers, and scientists to play in the modeling and policy making processes? Additional questions are: Is there a role for the public in the design, calibration, and operation of these models? What is the appropriate way to deal with uncertainty information? How should models be used to aid policy making?

Costanza and Ruth (1998) argue that models are basically tools to help construct joint understandings, which have the beneficial effect of producing consensus on policy actions. They reported on four cases where systems dynamic models were jointly constructed by stakeholders and modelers. Although the quality of involvement differed in each case, they reported that all four cases produced consensus on policy actions. Korfmacher (2001) studied public participation in watershed modeling from a democratic theory point of view. She concluded that public involvement in all aspects of modeling is consistent with democratic ideals, and producing substantively better models. However, she admits that there are no data to support this claim. In her examination of four case studies where publics were involved in watershed modeling activities, she found that the most cited reason for involving the public was that value-laden assumptions associated with the model ought not be made by experts alone. Surprisingly, however, when publics were involved, it was *not* to provide input on these value-laden assumptions. Korfmacher rates high the benefits from public involvement in model development and use, although the cases she studied did not perform to those ideals.

Although much more research needs to be done to validate these claims about the need to involve stakeholders and citizens in the design and application of models in policy making, one research project in Australia has reported interview data that tentatively supports these claims made by Costanza, Ruth, and Korfmacher (Ewing, Grayson, and Argent 2000). This team reported on a process to design a watershed ecology model as a collaborative effort between modelers and 40 interested participants including government, stakeholder-interest groups, and citizens. Preliminary interviews with all 40 individuals early on in the process reported that the process was effective at bringing public concerns into the decision making process. At time of publication that process was not yet complete, so the final word is yet to come.

The study reported here contributes to this literature, but it starts from a different position. We begin by recognizing that models are being developed for the most part by scientists outside of the policy process. It is actually rare to find in the literature a model, such as the one in Australia or those reported by Costanza, Ruth, or Korfmacher, that is constructed collaboratively among stakeholders and modelers, although the practice seems to be increasing. By in large, it is still modelers who make the model. Additionally, it is rare to find a model that is used by lay people. For this reason we sought to inquire into the views that modelers have toward the models they create. At the same time we recognize another segment of the professional world involved with using models in policy making. State university extension service professionals as well as other “outreach professionals” such as regional planners, staff from federal and state agencies, and leaders of organizations such as national estuary projects or watershed management programs frequently serve in mediating roles between modelers, local decision makers, and publics. They have significant influence over how models are used in the policy making enterprise. They also have input into the design of models.

This study explores the views that scientists and outreach professionals have toward models and the ways they believe the models should be used to assist policy makers engaged in watershed planning. Through face-to-face interviews with modelers and outreach professionals we anticipated revealing insights about how these important players view the appropriate nature and use of models in public policy making. We presume that such insights will prove useful to those who encourage the democratization of ecological models in public decision making.

2.0Methods

The population of people designing and supporting the use of computer-based watershed management planning tools is potentially quite large. We focused our efforts in Massachusetts, Connecticut, and Rhode Island. Within this area much of the work on models centers around marine coastal environments. The Waquoit Bay National Estuarine Research Reserve on Cape Cod is a prominent location where ecological modeling research is being undertaken. In addition, there are several university and extension based centers that have produced and promote the use of such models, including Woods Hole Oceanographic Institute and the Buzzards Bay Project, a former National Estuary Project in Southern Massachusetts, the Narragansett Bay Program, and the NEMO project located in Connecticut. Finally, there is much regulatory attention given to coastal zone planning in these areas at both the state and local level. This region of the country is marked by a politics of home rule. Land use planning is the responsibility of cities and towns and is not imposed by the state. Thus, there are numerous local decision makers and voluntary town boards who could potentially use the models that are being developed.

We interviewed nine scientists and seven extension service outreach professionals (many of whom are natural scientists) in southern New England who produce and support the use of computer models intended directly or indirectly to affect watershed management policy making in southeastern Massachusetts, Connecticut, and Rhode Island. Table 1 summarizes our interview pool, including area of basic expertise, position, and the type of planning tool or model with which they are associated. A wide diversity of modeling approaches and scales are represented, but we focused mainly on nitrogen-loading modeling. Nitrogen loading is a key consideration of land-use planning in coastal communities in southern New England. Narrowing the focus in this way allowed us to gain more depth into the question of how modelers and providers think about the ways these models can aid local decision makers.

The modelers and outreach professionals who we interviewed possess a diversity of experiences regarding users of their models. Some devise their models expressly for other scientists. Others have crafted their models for use directly by the public. Still others work with state and local agencies to integrate models into management processes.

The scientists and extension professionals we interviewed were engaged with a variety of models. We asked them to describe the kind of model they worked with and their replies included the following kinds of models: loading threshold models, biogeochemical estuarine response models, ecosystems models, watershed hydrodynamics models, ecological estuarine response models, critical area identification models, simple loading models, nutrient flow models, nutrient loading models, hydrodynamic models, and GIS-based critical area identification, nutrient loading, and predictive loading models.

Table 1. Description of Interviewees

ID	Modeler or Outreach	Training	Position (at time of interview)	Type of Model
Joe Costa	Modeler	Biological sciences	Director, Buzzards Bay Estuary Project	Nitrogen-loading
Joe Vallino	Modeler	Biochemical engineering	Oceanographic Research at Marine Biological Lab	Ecological systems models
Ed Rastetter	Modeler	Mathematics and Zoology	Ecological Research at Marine Biological Lab	Ecological systems models
Art Gold	Modeler	Hydrology	University Professor and Cooperative Extension, University of Rhode Island	Risk assessment, water quality, nitrogen loading
Jim Kremer	Modeler	Biochemistry and ecosystems ecology	University Professor, model developer, University of Conn.	Nitrogen loading and estuarine response
Roman Zajac	Modeler	Marine coastal ecology	University Professor, GIS analyst, University of New Haven	Nitrogen loading
Linda Deegan	Modeler	Population ecology	Research ecologist, Marine Biological Lab	Estuarine response
Margaret Geist	Outreach	Ecology	Waquoit Bay National Estuarine Research Reserve	Nitrogen loading
Virginia Lee	Outreach	Coastal Management	Director of Sea Grant, Coastal Resources Center, University of Rhode Is.	Nitrogen loading
Jim Lucht	Outreach	Environmental Planning	Research associate for cooperative extension team, University of Rhode Island	Risk assessment, water quality, nitrogen loading model by Art Gold.
Lorraine Joubert	Outreach	Water resources	Outreach/training coordinator for Cooperative extension, University of Rhode Island	Risk assessment, water quality, nitrogen loading model by Art Gold
Mary Tyrell	Outreach	Environmental Science	Director of watershed research institute, Yale University	Nitrogen loading model of Roman Zajack
Scott Nixon	Modeler	Ecology	Professor, University of Rhode Island School of Oceanography	Nitrogen loading and ecological systems models
Gil Pontius	Modeler	Mathematics	University Professor, researcher, Clark University	GIS models for land use and Nitrogen loading
Ed Eichner	Outreach	Water resources planning	Water resources planner, Cape Cod Commission	Nitrogen loading
Chet Arnold	Outreach	Marine Environmental Sciences	Director, NEMO (Non-point Education for Municipal Officials)	Nitrogen loading

The purpose of the interviews was to gain an understanding of the ways that modelers anticipate how their models will be perceived and used by local policy makers. More specifically, we wanted to understand:

- who do they think should be using these models,
- whether or not to include uncertainty information,
- how to include uncertainty information if it is deemed relevant,
- how the model should be introduced to a potential user in local policy making,
- how to verify the model works in this context (ecological transferability),
- how important it is that the model be accurate,
- how important it is that the model be scientifically grounded,
- how important is research on models, in the context of other problems of coastal development and ecology, and
- how should these models be developed? Specifically, is there a role for users in the development stage.

The interviews followed a semi-standardized structure (Weiss 1994) and typically lasted one hour. In most cases they were conducted face-to-face, but a few were done over the telephone. The questions from the interview guide are listed in Table 2.

Table 2. Interview Guide (with probes)

1. Tell me about your model. Is it still under development? Is it finished? Was it designed for a specific site? What is its general architecture? (Is it a spreadsheet? A look-up table? A stochastic model?) What are its inputs (generally) and its outputs (does it include ecosystem effects?).

2. With what other N-loading models are you familiar? (Get names and phone numbers of modelers.) How does your model differ from other models that are out there?

3. How long have you been doing this work? What is your motivation for devising this model? Is it important part of your career? Do you have a lot invested in this work? Or is this a sideline to something much more important to you?

4. What are your hopes about how the model should be used? Did you have a specific user in mind when you designed it? Has that changed over time?

5. Thinking about N-loading models in general, how do you think they should be used and toward what end? Is there a difference between how your model should be used and how other models should be used?

6. *If interviewee says that models should be used by public:* Do you have any thoughts about whether or not there is a role for the intended users to play in the design and development and testing of the model? If so, what

role?

7. What makes a model a "good" model? Probes: How important is the inclusion of uncertainty information? How important is a proven track record? How important is scientific accountability? How important is user friendliness?

8. If a model works in location A, how can we be sure that it will work in location B? Probes: what is your take on validating a model? How can you prove that a model works? What evidence do you need to be convinced that the model is producing reliable, useful outputs? Do you think other intended users of the model will have the same expectations as you?

9. *If the intended user is someone other than the modeler:* Do you have any thoughts on how a model like yours should be introduced to the intended users? How important is follow-up support? Which institutions might play important roles in that process of supporting users of the model?

10. What are some of the most pressing challenges and concerns in your work? Probes: Understanding the ecology? Gathering data? Getting the model made user-friendly? Transferring the model to users? Training users? Preventing the model from misuse?

11. In the bigger context of coastal development and ecology in general, how important would you say it is to put public resources into further model development? Why? What do you hope would come out of this work? What other work do you think is important in this area in general?

To analyze the interview data, three of the co-authors independently read all the transcripts and coded text segments that were specifically related to questions on the interview guide. In addition, we also sought to let important themes or ideas expressed during the interviews emerge by using a constant comparison approach (Glaser and Strauss 1967). This is an inductive approach in which important concepts emerge during the data analysis rather than in advance of the investigation. Data are categorized with respect to relevant similar characteristics in a process called coding. At first, a relatively large number of categories are developed. Then, through iteration these categories are grouped into more abstract categories according to their meaning and significance. Data and categories are grouped according to their relationships with each other. After each of us conducted both types of analyses, we met to compare and contrast our findings.

In the final stages of our analysis we supplemented our interview transcripts with notes from other meetings we had had with certain modelers and extension/outreach professionals. We had met with these people before developing our interview guide, mainly in order to gain a better appreciation of this area. The combination of these data sources allowed us to identify differing perspectives on several salient themes related to the development and use of computer-based models for watershed planning. In presenting the results we also present vignettes from interview transcripts that exemplify our points. In this report, we will be comprehensive in our inclusion of categories and report all, even those with a single interviewee.

The interview data were also supplemented by responses to a survey (see Appendix A) We gave a survey to all sixteen interviewees, despite multiple attempts to motivate them to complete the survey, only eleven returned a survey. Three outreach professionals out of the seven we interviewed and one modeler out of the nine we interviewed did not return the survey. Also, one modeler who did return the survey answered only the first question. In addition, not every person who completed the survey completed all portions of the survey, therefore the number of responses reported for some questions is less than eleven.

The survey included questions about:

- the appropriate goals of nitrogen loading models;
- the appropriate users of these models;
- the appropriate methods for making models available to town officials;
- the obstacles to local officials using models; and
- what features would make a model useful to town officials.

Because of the small number of responses to each survey question, we did not complete statistical tests on the data (e.g., t-tests). However, the survey results are useful for further interpreting the interview data, and are used to illustrate some of the results discussed in the next section.

3.0Results: Views of Scientists and Outreach Professionals on Models and their Role in Watershed Planning.

These results are organized into topical categories beginning with the fundamental perspectives on models that emerged out of our analysis of the interview transcripts. After describing the two basic perspectives, we turn to one of the most salient themes discussed – uncertainty. The way models deal with uncertainty proved to be a major item of interest to many of our interviewees. Following this, we report on results of questions exploring the topic of transferability of models. We reasoned this would be an important theme to ask about, given the fact that it is logistically impossible to design a new model for each and every application. Yet, demonstrating that a model developed elsewhere has validity in another environment is of central concern to many policy makers. Following the topic of transferability, we turn to two applied themes: the inclusion of publics in the design and calibration of models and the appropriate use of models in local environmental decision making. By in large, we have attempted to keep our presentation and interpretation of the results as close to the original data as possible, but at times we feel we are justified making generalizations or extensions that were not explicitly made during the interviews. In these instances we are drawing on our familiarity with the literature and our other experiences with modelers as well as on the interview data. In the instances where we do generalize beyond the interview data, we have tried to make clear to the reader that we are doing so.

3.1 Two perspectives on models

Our analysis of the interviews revealed two basic perspectives toward computer-based models. We have generalized liberally from the interview data here. In the pragmatist tradition, we differentiated these according to use: scientific uses or policy uses. We believe that science and policy are not independent or polar opposite categories. Models are often designed primarily to serve either scientific ends or policy ends, but these need not be mutually exclusive, and many models serve both ends.

3.1.1 Scientific models

‘Scientific models” are made with the purpose of advancing science and their intended users are scientists. Generally, these models aspire to accurately depict how natural systems or processes function. These quotes from our interviews exemplify what our interviewees has to say about these kinds of models:

> Models are a synthesis of what we think we know about the system and what we think is important about the system.[1]

> [It is] a synthetic tool to bring together our best understanding of a complex set of processes along with the measurements we have of them.

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[1] All quotations are taken from verbatim transcriptions of our interviews with the individuals listed in Table 1.

Scientific models can be statistical or dynamic models. They construct a view of reality through deduction and the application of general relationships. Such models summarize and synthesize large bodies of scientific knowledge–theoretical and empirical–and can become massively complex. Scale is an important feature here as these models seek to replicate the salient elements of natural systems. At the smallest scale a model of macro algae formation, for example, may begin with physical and biochemical processes at the molecular level and "build" more complex organisms. At a larger scale, scientific models may rely on empirical correlations of systems variables to model, for example, how fish populations in an estuary are affected by increased nitrogen run-off. Although different scientific models focus on different scales of natural systems, all of them share a reliance on known or assumed causal processes.

The end points of scientific models are determined by the research question that originated the modeling effort. The endpoints of scientific models may or may not have relevance to policy makers because the purpose behind making the model was to explore scientific understandings of how the physical, biological, or ecological system works. The point is that scientific models are tools scientists use to improve understandings of natural processes. One distinguishing characteristic is that they must be falsifiable, according to the scientific paradigm as defined by Popper. In this use, a model makes a prediction about how things will change given a certain stimulus. The experiment is carried out in a "real" physical system and the results compared. Thus, models become hypothesis testing tools to be used alongside experimentation as another way of verifying knowledge claims.

3.1.2 Policy models

The second type of model we call "policy models," although our respondents also called them "decision support aids," "management tools" and "heuristic models." They are designed to serve in the policy making environment. In general, policy models do not aspire to the level of precision or accuracy that scientific models do. [2]

> I firmly believe it's good to have a scientific basis for what you're doing in policy, but you don't need to have it that exact.

Instead, policy models focus on representing the relationships among key variables so that policy alternatives can be contrasted against each other on a range of relevant end points. Policy models are also useful when the problem is not obvious; for example when policy makers are trying to decide where to begin with a watershed management plan.

> What you can do [with policy models] is you can start to decide where to look, where your problems might be and might not be, and give you some conceptual framework to start to look at your own river.

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[2] Scientific models tend *in general* to be very complex, but there is no reason why scientific models necessarily must be more accurate or complex than policy models.

Policy models are also seen as a way to get a quick and lower-cost overview of the problem:

> It’s important to do an initial survey at fairly low cost, without investing a huge amount in a model that may be much more complex, but may not give you much more certainty [...]. It is important to do a broad-brush view and then determine where to spend resources -- and it may or may not be in more modeling at that point.

In this perspective models are expected to help policy makers learn about how proposed development actions are linked to ecological changes and to understand the possible future conditions of a watershed. The results are intended be used for political/regulatory decision making. According to one interviewee, local planners need "some kind of tool to get something to be able to compare different kinds of land use activities and alternatives.” Similarly, "the model itself definitely isn't the assessment, it’s just a small tool.”

The key difference between policy and scientific models lies in the way they incorporate policy judgments about social acceptability of certain outcomes. Speaking of models as ideal types now, scientific models would never include a module that assesses the desirability of scenario outcomes. Policy models frequently do this. One policy-oriented nitrogen-loading model, for example, uses the traffic light metaphor to convey a judgment of the acceptability of ecological conditions in the embayment for which the model is run. A red light means water quality is unacceptable, while yellow means it is marginal, and green means it is acceptable. Scientific models back away from making policy judgments such as these, mainly because doing so requires clear management criteria, which are typically not preexisting, but are more often the result of a highly politicized process that cannot be reliably modeled.

Policy models place less emphasis on describing physical systems than do science models, but they issue much more precise policy advice. They generate management scenarios, evaluate possible policy actions and prioritize them. These prioritization routines can be shaped with local input to reflect the character and preferences of the local community. For instance, if a town wants to not overburden its few remaining farmers, the model can be made to focus more weight on non-agricultural alternatives to reduce nitrogen loading.

3.2 Use and abuse of models in decision making

3.2.1 Promote education and learning among scientists and policy makers

A fundamental distinction that emerged from our interviews was a contrast between using models as aids to help planners understand how the ecological system works versus using models to predict future impacts very precisely. Scientists develop models that quantitatively represent relationships suggested by theory or observation. By running a model under various conditions or assumptions, they can better learn how ecosystems function. Using models in this way was seen as essential to advancing scientific knowledge. In this use:

> The model represents your current understanding put into a quantitative format to see whether or not your understanding matches observations.

But using models to advance understanding was not limited to scientists. One of the extension service people we interviewed spoke adamantly about the necessity for models to educate the public. Models can help people develop a sense of awareness of how environmental policy actions can affect the quality of the watershed.

> The river's not going to get cleaned up by some fancy model that only the academics understand. It's going to get cleaned up by the people in the towns going, "Oh! Ah ha! I see the problem! And I see what I can do about it!"

Models can help scientists *and* policy makers think about the big picture. They can help users to better understand dynamic responses and flows within a watershed. And they can support a decision maker learning about management options and to rank the options on different criteria. According to this view, models can be used as "thinking devices" to help generate new knowledge, new hypotheses, about relationships among ecosystem elements and about ecosystem dynamics, and to generally advance science.

3.2.2 Models can promote democratic deliberation

Several of our interviewees saw another way that models can be used as educational tools. They advocated using models as aids to further along a public conversation.

> I think models should be used to stimulate people to have a discussion. It is really true that the output of a model does not have a societal value until people think about it and decide what they want to do with it. […] I think models are most useful when they stimulate people to have discussions about what their values are in that context.

> Our bottom line is to get these folks to ask the right questions. I think that we can show that we've had a lot of impact and a lot of changes have occurred, based on that premise that we get them to ask the right questions, rather than try to get them so up to speed that they can debate storm water hydrology with an engineer.

> A good model is one that provides the ability to sort of make, generate more questions. I mean certainly you want models to give answers, but you also want them to generate more questions as you go through that process.

> Just being exposed to models will help you think about the process [...] just the fact that the model [result] is presented will get people talking.

Using models to help advance a public conversation is potentially a way of promoting social learning about the connections between human behavior and the ecological quality of the watershed.

3.2.3 Indulge desires for prediction

In addition to these educational uses, models are sometimes used to predict the future. In other words, the model becomes a "crystal ball" to see into the future:

> Models are about the only way we can offer some sort of quantitative analysis of predicting the future.

Knowing the consequences of each decision alternative takes a good deal of the controversy and difficulty out of decision making. People want to know what will happen if they change the town zoning, if they do not require sewer hook-ups, if they impose a 50 foot or 100 foot buffer limit. Predictive models are highly attractive to decision makers. But it is impossible to know whether the predictions of either science or policy oriented models are right. Using a model to predict the future invariably introduces the question of uncertainty. Among the modelers we spoke with there was great resistance to the idea that models could or should be used to give "answers" that defend "right" decisions or policy actions. Designers of scientific models often felt uncomfortable with their models being used in the policy arena at all. Yet they also recognized a dilemma if they do not use their models to predict the future.

> The alternative is to say, “Well we actually don’t trust this model, so I am not comfortable giving an answer. So you should go back to your town council and make a decision without *any* input from scientists.”

To the modeler the choice seemed to lie between the extremes of letting the models be misused in the policy-making domain or withholding them entirely. As the next section addresses, at the core, however, was really the issue of how much resolution and certainty models afford.

3.2.4 All models are imperfect

On one point there was consensus among our interviewees. All models are imperfect. Two dimensions of this were mentioned. First, models are imperfect representations of reality because scientific understandings of biological and physical systems are incomplete. In other words, models can be wrong. By this we mean that models can fail to depict the function of physical and ecological systems they attempt to model. As an example, consider the possibility that a model predicts increased photosynthesis of algae under decreased sunlight. This would be factually incorrect. Of course the kinds of mistakes models are likely to make are much more sophisticated than this example, but our interviewees spoke about the “youthfulness of our science” and the need to advance basic scientific understandings before advances in models can be made. This individual was extremely critical of the adequacy of present ecological understandings of how nitrogen affects estuarine ecosystems, claiming present scientific understandings are incomplete, consequently our models are imperfect as well.

> [names someone] His model, or anyone’s model, isn’t very good at all in terms of how we understand systems.

Second, models are imperfect because they fail to achieve the level of accuracy that users of the models would like. In this instance, the model might be right about the fundamental causalities of the ecological system, but imprecision in the quantitative parameters and relationships might make the model come up short of expectations. The underlying reason for this is complexity. Ecosystems are highly complex and that makes the task of the modeler difficult. Three particular challenges arise. First, there is natural variability to all ecosystems. For instance, rainfall and temperature can vary substantially year to year. A model is expected to “work” under a wide variety of these conditions.

Second, there are exogenous factors that the model must accommodate. These are factors acting upon the ecological system being studied. For instance, how does a model deal with the effects that a hurricane can have on nitrogen loading in an embayment? Exogenous factors make the model's job very difficult. Third, there is the problem of insufficient data. Data collection is time-consuming and expensive. It is rare that scientists have the resources to gather the data they would like to have in order to calibrate their models to the local context. Consequently, informed judgments or guesses must substitute for these data.

> Most models, almost without an exception, compare computed and observed state variables, not rate processes. So they state how much chlorophyll is there and not the rate of photosynthesis. So there is lots of room for mischief. And you can get the rates really weird, but have state variables that look good. So you are getting the right things for the wrong reasons! Then you are really on thin ice.

In some cases, the systems being modeled are so complex that models could never capture that complexity. Models might do a fairly good job of mimicking some variables over a narrow range of conditions. As the scale of the system increases the number of variables and relationships a model needs to assimilate becomes impossibly large.

One modeler put it succinctly,

> Any modeling results will be wrong; it's just a matter of how wrong they will be.

3.2.5 Appropriateness of scale

Generally, concerns expressed about potential pitfalls of using models were related to the use of policy-oriented models. An important theme in the interviews was the appropriate scale at which models can provide useful advice for policy makers. There was a widely held assumption that local planning or health board members want a model to inform decisions about whether a given building lot ought to be allowed to be developed.

In the survey our respondents overwhelmingly voiced disagreement with this objective for models (see Table 3). Only one of our interviewees contemplated the possibilities of using his model to investigate impacts from one house. We also found widespread agreement that present models are not sophisticated enough to determine lot-level development decisions. The issue came up quite a bit in the interviews:

Table 3. Average support for goals of nitrogen loading models (N=9)

Level of resolution model at which model should be accurate	Mean agreement[a] (-2 to +2)
Building lot	0.0
Large land uses (shopping mall, housing developments, farms)	+1.0
Zoning districts	+1.1
Town plan	+1.3

[a] -2 = strongly disagree, +2 = strongly agree

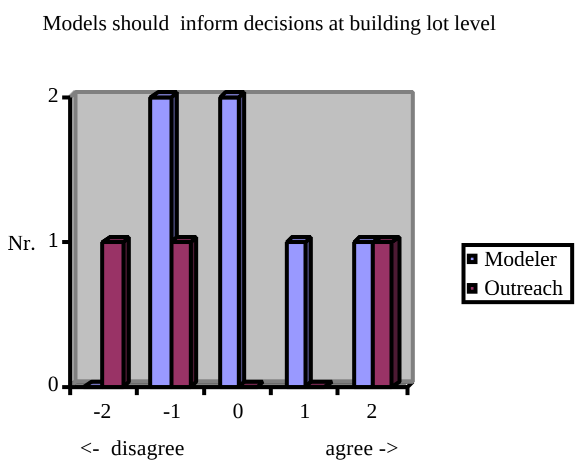
> Board and commission members' scale of decision making, both in time and space, is small. Too small for a model to predict any change.

> [If you ask] does this guy get to build his deck or build a big driveway; well there is no way a model is going to have anything to say at that scale. If there is a housing development with a number of houses

being planned, we probably can help.

Our survey data in Table 3 shows that respondents increasingly supported using models to inform decisions at larger and larger scales of land-use. We asked them to indicate the level of their disagreement or agreement (on an integer scale of –2 to +2) with statements about the goal nitrogen loading models ought to aspire to achieve. The results reflected a general belief that models have good accuracy at the level of the town plan and at the level of zoning districts or large land uses.

While, many people felt that models do not have the capability to distinguish effects based on changes on the level of individual building lots, there was disagreement over whether or not models ought to aspire to that level of precision. One individual (an outreach professional) strongly disagreed with the goal of models being able to inform town board decisions at the scale of the individual building lot. Two other people (one modeler and one outreach professional) strongly agreed with this goal.



On the other hand, some land-use policy decisions address issues beyond the scale of towns. Some of these are decisions that involve incredibly high public investment such that they are basically non-reversible. One local example was the design and placement of the sewage outflow pipe in Boston Harbor. For decisions such as this model accuracy and completeness are clearly critical. One respondent asserted that, in large-scale policy issues, decision makers *should* spend resources building complex and competing models. Under the presumption that a model captures only a piece of the true picture, he advocated decision makers using multiple models to patch together an understanding of highly complex problems.

3.2.6 The allure of complexity, numbers, and fancy graphics

Just as the sirens of Lorelei lured unwary boaters toward dangerous waters with their hypnotic songs, models have the potential to lure policy makers into uncritically accepting model results because of the model's prestige, quantification, complexity, or fancy graphics. Our interviewees saw danger in accepting models uncritically.

An interesting concern that emerged from our interviews addressed the allure of attractive, engaging graphics. An intriguing anecdote is worth elaborating here. One modeler told a story about viewing a model of the Florida Everglades. He described how the model created a dynamic image of water going into the ecosystem and spreading out. When the model was run the effect of this image was to see it as a heart beating:

> And when they showed the revised plans for the Everglades the whole thing pulsed real well, and he [the modeler] said it was like a healthy heart. But when they ran the current conditions, it looked like the heart was fibrillating almost. And the decision makers went crazy over that! That one image, more than anything else, had a bigger effect on what happened with the Everglades decision. […] So I am very aware that people are drawn to images and the substance of the model and the science that goes into it may be secondary.

Fancy graphics, especially when combined with a powerful metaphor such as this, enhance the possibility that users will be impacted by the results of the model. This individual expressed concern that such powerful imagery might bestow more credibility on the model results than a careful, considered assessment of the model's capability may allow.[3]

Models produced at reputed research institutions are often embodied with a degree of credibility that may have more to do with the prestige of the institution than with the merit of the model itself. In other words, the prestige of the institution may convey a suggestion that the model is beyond reproach. The following quote commented on this issue of prestige, but also linked it to concerns about the allure of quantification and complexity:

> I feel that we have got to watch out for this policy of quantification and fooling ourselves – that because the model is complicated and has complicated math, and because it comes out of a fancy university that it is somehow the answer.

Complexity and quantification can conspire to create a wall of misunderstanding that separates the lay audience from the experts in the research institution. Because individual lay policy makers who are not scientists can never be expected to achieve the level of scientific knowledge necessary to understand the inner workings of a model, their acceptance of the model must be based on something other than personal experience. Either they need to trust the reputation of the institution and the scientists who created the model or they need to hire their own experts to examine the model.

> The negative side is that most ecological models are so complex and detailed that you could not explain it to anyone other than another specialist and even then it would take a long time. So that puts the user in the position of being a totally passive receiver and that puts the scientist is this position of being God-like [saying], "I tell you what to think and you have no way to understand it, you just have to take me at face value and either trust me or not."

It is important to mention, however, that many of our interviewees felt that complexity was an impediment for good models. Einstein's famous dictum "make things as simple as possible, but no simpler" was widely advocated in these interviews. The reason give for this was that unnecessary complexity increases the likelihood that something will be wrong with the model.

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[3] For elaboration on this point, especially with respect to GIS models, see: Gregory McMahon III (1995). The role of information in watershed planning: Contributions from critical theory and environmental dispute resolution. Doctoral dissertation. University of North Carolina, Chapel Hill.

3.2.7 Dangers of intimidation

Several modelers familiar with local policy making made candid assessments of how complex scientific models could be used to disable voices expressing policy preferences contrary to those the model output justifies.

> If I come out of company XYZ with a model documented in 15 volumes and I say, "You have to cut nitrogen by 20%." And you are a little old guy in tennis shoes who runs a golf course or something and you want to argue with that decision, that's awfully hard. I mean, how would you even begin to deal with that? "The Model says this." How would you begin? Where is your voice against this?

This quote lucidly portrays how models might intervene in the policy making dialogue. Models potentially provide a huge amount of credibility, which is capable of squashing opposing viewpoints.

3.2.8 Dangers of technocracy

There were strong views about the proper and improper use of models as policy-making aids. Most believed that valuable knowledge could be gleaned through their use, but there was a danger of misuse -- either intentionally or unintentionally. Technocracy—rule by a scientific elite—was raised in three interviews. Some modelers were very candid about their fears that models and modelers are gaining too much power in the policy making setting. Two people expressed concern that decisions normally made democratically might come to be determined by a model instead. Given the inaccuracies of models this could be very damaging. One interviewee sympathetic to models having more influence over decision-making still qualified this view by suggesting that answers should be bracketed in ranges of uncertainty, which would give the democratic decision makers some room for judgment and self-determination.

> The output should not be a point estimate. There should be a middle, a high, and a low. I think if that [uncertainty] information is made accessible it will probably muddy the waters a bit and undermine the power of modelers.

He went on to explain that models contain implicit policy judgments, which often express opinions of the modeler. This is, of course, particularly true for models that assess possible policy interventions, but it is true of all aspects of modeling when there are uncertainties involved. For example, there might be three very good, but different explanations of how macroalgael growth responds to water temperature. Since there are scientific disagreements about which explanation is most correct, choosing among the three cannot be made on scientific reasons alone, but must include other judgments as well. Since these judgments affect the outcome of the model, they potentially affect the policy decisions that are made too. Why should a modeler's opinions have more impact in the decision-making than those of any other person? he asked.

> I don't live in [names town]! I'm not gonna have to live with the decisions that are made. So I don't see why my opinions should count more than the people who are living in the watershed.

In summary, a prevalent concern among our interviewees was that models could often be viewed by local decision makers as more certain and deterministic than they really are, or than they really can be. Many believed that model results sometimes do not merit the certainty which they are given. Issues related to uncertainty are discussed in the following section.

3.3 Uncertainty

3.3.1 Uncertainty is inherent to models

Uncertainty is endemic to models because ecological knowledge is imperfect and because models are simplifications of systems that are inherently complex and dynamic (see Holling 1995). Everyone we interviewed agreed that even the best models of nitrogen loading and ecosystem dynamics contain uncertainties.[4] Since uncertainties in one parameter piggyback onto the next, the overall uncertainty for a model can be extremely high.

> I suspect if you did that [computed uncertainty information for each variable in the model] with most models the results would be pretty unimpressive, given the level of uncertainty you have in almost every coefficient that is in a model. That may be an indication of how useful a model really is to anybody. I don't know if they should believe it. I'm not sure. I don't know.

Another source of uncertainty in scientific and policy models is the adequacy of data. Many believe that available data are not that good. One source of uncertainty is with data that are not "ground truthed." Often it is financially or logistically unreasonable to collect field data from every site where a model is to be applied. When field data are not available estimations have to be made and these introduce uncertainties. This problem can be mitigated is through the use of lay monitoring programs, which offer a cost-effective way of gathering quality environmental data. But even these cannot collect the quantity of data that are needed to calibrate models to new locales.

A third source of uncertainty arises from incomplete scientific understandings of the systems being modeled, including the relationships in dynamic watershed systems and what are the key parameters. These uncertainties may have to do with incomplete understandings of basic ecological science, or they may be more particular to the present application. In either sense, incomplete knowledge translates into uncertainties in the model outputs.

3.3.2 Uncertainty about the uncertainties

To complicate matters, uncertainty is not always straightforward to compute. Several of our interviewees believed that uncertainty really cannot be calculated for complex models. One scientist-modeler remarked very boldly, "We don't have a very good way of capturing uncertainty in any complex calculation." He further remarked:

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[4] In her study of modeling uncertainties, Katrina Korfmacher reported interviewees saying that the best models were accurate within a factor of 3 (Korfmacher 1998).

> You're asking yourself, "Well, how uncertain are you that we balanced the nitrogen budget accurately?" And if I try to think about how well we know what the denitrification rate is in Narragansett Bay, I would not know how to begin to answer that question. Because you have so many scales of error and uncertainty. *And I don't know how well I know any of those things*. (Emphasis added).

Table 4. Response to survey question 8d. "Given the goal of making a model useful to the public at large, how important are each of the following features?"		
Model outputs are expressed as uncertainty ranges around a point estimate.		
Answer	Nr. of modelers	Nr. outreach professionals
Very important	4	2
Important	0	1
Not so important	3	0
* N=10 because one respondent who returned a survey did not answer this question. Other answers (neutral, don't know, not at all important) received no responses at all.		

In other words, modelers are caught in a bind. They know for sure that there are uncertainties, but they do not necessarily know how to compute or assess them. At present the calculation of uncertainty requires many subjective judgments to be made about the type of uncertainty and its magnitude. Thus, there is uncertainty about the uncertainty!

3.3.3 Modelers are comfortable with uncertainties

While there are many questions about the magnitude and significance of uncertainty, modelers claimed to be very comfortable in dealing with it. One interviewee suggested modelers and scientists might be <u>too</u> comfortable in dealing with it:

> I think that scientists have a much bigger tolerance of uncertainty than people who aren't scientists and in fact actually revel in the uncertainty.

The outreach professional who made this statement was highly critical of scientists who refused to take policy stances. Reveling in uncertainty is a way of avoiding sticking one's neck out, avoiding political risks. In the end this essentially protects the status quo interests, which leads to greater environmental damage. Uncertainty, according to this perspective, is an excuse that scientists use to stay out of the public arena.

3.3.4 Uncertainty information and the lay public

One important question dominating our interviews was whether or not models should convey uncertainty information to lay policy makers. By in large, our interviewees felt that the planners and lay policy makers would *prefer* a point estimate to a range that is likely to encompass the actual number. In other words they felt that lay users did not want uncertainty information, given the choice. But, they disagreed about whether it was appropriate to not present uncertainty information. Table 4 summarizes the responses to a survey question about expressing uncertainty information in the model's results. Clearly there was wide disagreement as to whether uncertainty information ought to be presented. Interestingly, all of the outreach professionals who answered the question felt uncertainty information should be included. Modelers were split on this question.

3.3.4.1 Uncertainty information *should not* be shared with the lay public

Interviewees raised three basic concerns about providing uncertainty information to lay policy makers and citizens. First, some expressed a concern that the additional information would confuse people. They were pessimistic about presenting uncertainty information to lay audiences. For example this individual noted:

> I don't think the general public really understands uncertainty issues […] I think it tends to confuse people.

Another modeler, a person who has experience in working with local planning boards, reconciled this difference in the following way:

> People who don't work with the public much want to build in uncertainty levels. And the thing I have learned about the public is, the more you talk to them about uncertainty, the more they are likely to ignore everything we say.

This leads conveniently into the second reason why our interviewees were skeptical about providing uncertainty information to lay people – because it will lead them to ignore the scientists and the regional outreach professionals. Speaking from personal anecdote this modeler noted:

> As I start to talk to them [lay publics] in an honest way about the level of uncertainty, over and over again people say they are shocked at the youthfulness of our science and they are not really sure that can deal with this. And they will turn the decision over to their financial person, and their economic modeler, and their economic development model. And that is what they are going to use!

> You have to explain important caveats or uncertainties but you don't want to dwell on them because you end up undermining yourself.

Another modeler expressed the same concern that including uncertainty information would lead to scientists being ignored, but he couched his statement in a larger context, the context of economic incentives.

> It really seems clear to me that the economic pressures and the free enterprise—the right of the landowner of the developer to make a buck is really all-powerful. And I am worried that good *but uncertain* scientific information won't appear convincing enough against that force.

The third concern about presenting confidence intervals to lay people is similar to the last in that it is concerned with the strategic way the model results may be used. The fear here is that uncertainty ranges create space for political conflict.

> [If we present a range of output values] They [the lay publics] are going to select numbers that are most advantageous to their particular case.

An interviewee felt that local decision makers would tend to drift toward the more restrictive side of a confidence range and hedge on the side of caution. In his experience, communities usually adopted the number most protective of the environment. We note, however, that what a person decides as "cautious" depends on their values. For example, environmentalists might see the safe side as the higher end of the range, on the belief that it is better to overestimate the problem than to underestimate it. Real estate developers of free-market libertarians may take just the opposite view, believing it is more dangerous to over-restrict economic development and expansion than it is to over-protect the environment.

3.3.4.2 Uncertainty information *should* be shared with the lay public

All in all, among all out interviewees there was more disagreement than agreement about whether or not uncertainty information of any kind should be delivered to lay people. On the other side, some argued it was the responsibility of the scientists who present models and the managers who present the information to be up-front and to openly acknowledge all uncertainties. These people were optimistic about the public's ability to comprehend and deal with uncertainty.

One modeler inexperienced with lay policy makers acknowledged that lay people might initially be confused, but he was confident in his ability to explain why uncertainties are present.

> I think it is possible to explain why an uncertainty is there. […] I can explain it to *anybody*!

While many of the outreach professionals adopted the view that uncertainty was to be avoided, there was not consensus. One very prominent person in the field, well experienced in dealing with town boards, strongly advocated including uncertainty information.

> What you will find when you do that [present uncertainties] is that people are very accepting at the local level. They recognize that science doesn't have all the answers and you can't be 100% predictive, especially with complex ecosystems.

Another individual felt that, even if uncertainty information is unpalatable, the public needs to have it. Several justifications were given. One reason was that uncertainty information is essential to make informed decisions, despite what the public did or did not want. This interviewee went on to relate a story about an encounter he had with a local planner:

> I said, "Suppose we told you that this answer was really very uncertain?" And there was this big long pause and then the guy said, "Of course I would have to know that." [...] Clearly he did not even know there was a chance that there was uncertainty and it was staggering for him to realize that someone might not share this information with him. Of *course* he needs to know that.

A second reason for including uncertainty information had little to do with the pragmatics of doing so, but boiled it all down to a moral issue about the professional duties of scientists to be honest. Scientists have a professional obligation to not distort their findings. The principled tone of this argument is caught in this statement:

> Many of my colleagues believe that the public can't cope with the real uncertainties and you have to give them an answer. My response to that is, "I don't care!" If I know that the answer is between 5 and 20 and I can't tell you anything more than that, then I simply refuse to tell you it's 15!

This modeler (who had little experience working with lay people in policy making settings) said:[5]

> I think you have to be fairly honest about the uncertainty and I think that I disagree completely with those that say the public can't handle uncertainty.

Another simply said:

> No scientist worth his or her own weight would say, 'here's my single answer.'

According to this view, including uncertainty information is about being honest and, as one modeler claimed, "people appreciate the honesty." There were pragmatic reasons offered in support of this principal, of course. Excluding uncertainty information involves scientists making judgments about what the lay public needs to know. This may anger lay people and it runs the risk of drawing the modeler into politics, something most modelers deeply wish to avoid. Including uncertainty information, according to this view, absolves the modeler of wrongdoing and makes the decision makers take responsibility for their decisions. Couching answers in uncertainty ranges also protects the scientists' legitimacy from future challenges. Because scientific knowledge is always progressing, today's uncertainties become tomorrow's certainties.

> If we were to say, "Well, here's the answer," then we will always be proven wrong at some point. And we'd loose our jobs.

A third point of view expressed in the interviews was that uncertainty information had a positive effect on lay publics because it leads people to become more skeptical of information sources, including scientists!

> It should not be a point estimate; there should be a middle, a high, and a low. I think if that information is made accessible it will probably muddy the waters a bit and undermine the power of the modelers, but maybe that is a good thing. I don't live in the watershed, I am not gonna have to live with the decisions that are made, so I don't see why my opinions should count so much more than the people who are living in the watershed [...] any modeling results will be wrong, its just a matter of how wrong they will be."

Finally, several of the outreach professionals argued that uncertainty information needed to be included in a format that was easily understood by lay publics. Confidence intervals, error bars, and other mathematical expressions of uncertainty are not understandable, according to this view. What is preferred is a qualitative expression of uncertainty.

> It is much more helpful to say, "We are quite certain about these things and less so about those," rather than adding it all up.

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[5] When interpreting these words it is important to keep in mind that we were asking about town and city planning and health boards at the local level. For the most part the assumption was that the individuals on these boards are not scientists. It is unclear how our interviewees understood the difference, if any, between these board members and "the general public."

3.4 Transferability of models

3.4.1 Ecological transferability

Imperfections associated with models lead to another theme in the interviews - the degree to which models are transferable to different locales. Transferability is associated with four problems: verification, calibration, selection, and generalization. Models are customarily built using empirical data from a specific place. The Waquiot Bay Estuarine Reserve on Cape Cod, for instance, is the birthing-ground to several of the scientific models discussed in the interviews. Scientists have been studying Waquoit Bay for years and have accumulated a tremendous amount of empirical data. These data are useful for calibrating and validating models. But Waquoit Bay is unusual. For most bays very few data are available, making it difficult to know if a model that is custom made for one bay work well in another.

3.4.1.1 Verification

Verification refers to proving the model works. Modelers establish ecological transferability by demonstrating a model works well in a variety of locations. But to validate a model in a given application area requires local data. One of the most challenging obstacles is the lack of local data, without which it may be impossible to know for sure whether the model is working well. Data such as flushing rates, areas of impervious surfaces, flow rates through wetlands, human habitation and land use, weather, and nitrogen inputs to streams would be needed. Gathering these data is expensive, time consuming, and impractical given the number of watersheds to be modeled.

> You can't afford to—for every river—spend all this time testing water quality.

3.4.1.2 Calibration

Calibration refers to the input parameters from the local setting needed to key a model to a place. For example, if a nitrogen-loading model works in three different types of bays (for instance: a bay fed primarily by one large river, a bay fed primarily by several small streams, or a bay fed primarily by groundwater), then one input parameter might be which of these three types the actual embayment more closely mimics. Calibration relies on data about the local setting.

3.4.1.3 Selection

One of the most important ways to make sure the model works well in a new setting is to ensure that the right model is used for the right job. There is no model that is going to work well in all situations. Models each have their own strengths and weaknesses. And finding the right model will mean first knowing what the problem is that the model needs to analyze. For instance, one interviewee mentioned that if the problem were likely to be the amount of impervious surfaces, then NEMO (Non-point source Education for Municipal Officials – a model provided University of Connecticut Extension Service) would be a good choice. On the other hand it would not be the best choice in an undeveloped watershed.

> In places where there is a lot of run-off, use NEMO. In places where you think denitrification will really make a difference, use MANAGE. *But use them when you understand, without a doubt, the place where you are trying to use them* (emphasis added).

In other words: strive to match the method with the purpose. We note that coming up with the right match is one of the places where important judgments can enter the process.

3.4.1.4 Generalization

Believing that any given model produces valid outputs for a setting in which it has not been ground-truthed involves a leap of faith. Local data can confirm that the model got the right answer, but only for the scenario under which local data was collected. If the data were collected during a particularly dry year, it is difficult to know whether the model would still work during a wet year. But some modelers felt lay users needed to remain vigilantly skeptical of what models can tell them:

> We also have to make sure that we do not get stuck in the idea that because a model is tested and working a certain range of conditions that that model is correct and therefore can be used in a bunch of other conditions. And so we've always got to watch out for non-linearity in our models and we also have to remember that our model does not represent truth.

One of the major troubles for models is estimating parameters associated with human activities in the watershed. Some data are available, such as water use rates for individual houses. Other data are more difficult to obtain, such as rates of fertilizer use on lawns. Moreover, these rates and kinds of data do not remain constant, but they change over time. Such information is important because any of these parameters might be essential for the model to get results that match observations.

3.4.1.5 Complexity and Transferability

One theme upon which there was no consensus among the interviewees was the relationship between complexity and transferability. On the one hand greater complexity should be better able to capture the important variables that distinguish one place from another. Therefore, a model that allows different water use rates per household should work well in towns with different numbers of seasonal dwellings. Other interviewees suggested complexity and transferability might be inversely related, mainly because understandings of relationships among large numbers of variables in ecosystems are uncertain. Without these understandings more complexity simply opens the door for more error.

The issue of ecological transferability was more salient for scientists promoting the use of science-based ecosystem models intended to reliably simulate dynamics in a watershed. Others oriented toward using models as policy making tools felt that transferability between ecosystem contexts was measured in terms of how well the model helped policymakers think about the problems in a watershed of concern. This leads to the topic of social transferability.

3.4.2 Social transferability

In addition to ecological transferability interviewees discussed the social transferability of policy models. This type of transferability was only relevant to policy models and it refers to the acceptance of models by different policy makers.

Social transferability is linked in many of our interviewees' minds to a perception that local policy makers will not use a model that has not been proven to work in their particular town. This kind of verification and acceptance can take a tremendous amount of field data, which is costly to produce. People spoke about the need to dispel the notion that every community needs to have its own model. One interviewee explained that simple models that capture simple ideas have the best chance of working in a wide variety of locales.

One of the most interesting insights from this research emerged from an interview with one modeler on this theme of social acceptance of models. He emphasized that, for local decision makers to accept a model, it must first be accepted by a state or federal agency as a legitimate policy making tool. He observed that models achieve political legitimacy through a mechanism similar to case law. A model is more likely to be accepted by regulatory and judicial bodies in a new locale if similar administrative bodies in other locales have accepted the model. In other words, a model becomes legally sanctioned incrementally. Once it obtains this legal legitimacy, the model can be assumed to be ecologically transferable, unless there is a strong and compelling scientific reason to suggest otherwise.

> There are certain models that have been routinely accepted by EPA and once the EPA has accepted them, they then become the basis of decision.

Local decision makers, such as town planning boards,

> are looking to see if this model has been widely embraced by the EPA or by the State agencies.

Of course, models that have legitimacy may not work well in every setting and there can be negative consequences if proponents insist on using them anyway:

> Consultants are using [names model], and there's a lot of debate about its efficacy, but people are using it anyway because that's the only thing there that's blessed by the EPA.

This individual went on to explain that there is caveat in place to protect against harmful misuse of models. A proven and accepted model can be disbarred from operating in a given locale if an argument can be made on the basis of science that the model would not work well given the local conditions. Such an argument would either need to convince regulators or a judge.

In summary, models are born in a specific physical location. Once a model is demonstrated to work properly for that place, it can begin to be taken elsewhere. Ecological transferability is established by building up a number of examples documenting that the model works well in different places. Once enough of these data are accumulated, the next step is to get a regulatory body to endorse the use of the model for a specific type of decision. The final crowning step is when EPA or a state agency "blesses" the model as a valid tool to use for decision making. Local decision makers are much more likely to look to this stamp of approval and less likely to want to determine for themselves whether a given model is appropriate for their application.

The key to demonstrating the social and ecological transferability of ecosystem models lies in collecting local field data to confirm model estimates match reality. These data are expensive and time-consuming to amass. Local data collection efforts may offer an opportunity for lay people to become involved with the modeling effort, a topic we turn to next.

3.5 The public's role in model development and use

One of the major focuses of this research effort was to investigate the questions of whether nitrogen-loading models can assist local decisions makers in land-use planning, and if so, how they can be involved in the development and use of models. In pursuing a line of questions about these topics we spoke generally about "public participation." We used this term to refer to the lay officials elected to serve the community on boards such as the planning board, the board or health, the conservation commission, the selectboard, the zoning board of appeals, and so on. We also used this term to refer to citizens in the community who do not serve on a formal board, but who may become involve in the decision making process.

3.5.1 Reasons to involve publics in model development

3.5.1.1 Involvement as a means to greater acceptance

One of the reasons cited for involving local policy makers involved in the conceptual development of the model was to enhance their acceptance of the model as a policy making aid. This point of view was advanced by one outreach professional.

> It doesn't mean they [local policy makers] need to be involved in the nitty-gritty, but at least involved at the conceptual aspects of what we're doing and why. They are much more likely to believe the results, to want to do something with them.

Note that her claim was that people would not only be more likely to believe the output of the model, but also more willing to actually use those results in policy making.

3.5.1.2 Lay monitoring and data collection

Other reasons why local policy makers ought to be involved in modeling efforts concerned the theme of local knowledge and lay monitoring programs. Some of our interviewees were opportunistic in the sense that, if a community had a planning department that had collected useful data, it was silly not to make use of those data:

> I am all for utilizing any of that available information.

But this same individual saw information gathering as the role for professionals rather than lay publics:

> I don't think it is the general public that is really involved in all of that [data gathering]. I think it is the professional staff that are in a particular town or county.

Table 5. Response to survey question 8t. "Given the goal of making a model useful to the public at large, how important are each of the following features?"		
Community members are involved in the calibration of the model.		
Answer	Nr. of modelers	Nr. outreach professionals
Very important	2	0
Important	1	2
Neutral	1	0
Not so important	3	1
Not at all important	0	0
* N=10 One individual who returned a survey did not answer this question.		

On the other hand, several of the outreach professionals we interviewed believed that local people had valuable knowledge that *needed* to be tapped. One area in which citizen input was mentioned as essential was in the construction of policy scenarios for watershed development. Local people, including real estate developers and planning board members, are likely to have specific ideas (or agendas) about where future development is likely to happen. By tapping into this local expertise the modelers can ensure that the scenarios developed are truly relevant to the community.

Other outreach professionals said they used (or would use) local input, but only toward very specific ends. A few mentioned that they would use local input if it were more expedient than getting the data another way. One person set up a lay monitoring program to collect water quality data only because it was too expensive to hire a consultant. A few interviewees emphasized the role of local users in verifying the data that goes into the model:

> The little things that they [the local public] do, "well this area is wrong, that is right" […] in a sense they really provide a lot of potential for verification or reasons for refuting the model, the results of the model—which is critical.

For many of the scientists, however, local citizens had little to offer in terms of data. One questioned the accuracy of data collected by lay people, saying that he would *not* use local data at face value. Local people are *unlikely* to understand ecosystem processes, he suggested:

> It may be a little bit elitist, but I'm afraid that the average man on the street or the man at the planning committee meeting does not really know very much there, even if he has a strong opinion. [...] It is my job to be skeptical. And it troubles me that, unless a particular community had a person who was a hydrologist and said, "I can help with the groundwater tracks here," and that individual has some credibility [...] I have trouble seeing how they can help us tighten up some of these things we are struggling with.

To conclude, these interviews revealed two polar opposite views about involving lay citizens in data gathering activities. As Table 5 shows, about half our interviewees felt that having the public involved in calibration was important while the other half felt it was not so important.

3.5.1.3 Developing the model itself

Some of our interviewees worked together. One modeler-outreach professional pair mentioned an interesting way of incorporating public feedback into the design of a model. Their model was constantly in a state of evolution, as are most models. But while this modeler did not usually attend the workshops with local planning boards, he would meet regularly with the outreach professionals who were taking the model into communities and they would discuss how appropriately the model seemed to be meshing with local needs. They debriefed after each application about what worked well and what didn't. Several specific changes to the model were guided by the feedback he received from these outreach professionals.

Table 6. Response to survey question 8s. "Given the goal of making a model useful to the public at large, how important are each of the following features?"

Community members are involved in the design of the model.

Answer	Nr. of modelers	Nr. outreach professionals
Very important	2	0
Important	1	1
Neutral	1	2
Unimportant	3	0
Not at all important	0	0

* N=10 One individual who returned a survey did not answer this question.

Involving citizens in model development is not widely practiced. But as Table 6 shows there was a wide variety of opinion about whether or not community members should be involved in the design of the model. However, none of the modelers or outreach professionals who completed the survey chose the most negative response to this question.

3.5.2 Role of public in using the model

3.5.2.1 Lay users need help interpreting the outputs of models

Most models are not designed to be used by local policy makers. In our study we found that this was true for both scientific and policy models. Interpreting the meaning of model outputs can be less than straightforward. Thus one modeler purposed that locals should not use models, instead *science translators* should. This individual likened giving town planning board members a model to dropping them off in a boat to navigate the rapids of the Colorado River without a river guide.

> We need a guide so that they [the publics] do not get fooled by the darn thing. We want to have a translator working with those people.

These "science translators" are, of course, outreach professionals from regional planning agencies, university extension services, and other state or federally-funded projects such as Sea Grant, the National Estuary Program, and so on. These science translators help to make certain that the local decision makers understand the bounds understand that limits of the model being used. Many interviewees agreed that, while technical assistance is needed, the local board members need to be the ones using these models.

A concern voiced in our interviews was that lay users would misinterpret the messages coming out of the model and might misuse the information, either strategically or accidently. In response, one modeler acknowledged that misuse happens, but asserted that it is less a problem than people often believe it is.

In general, those who were inclined toward the view that a model or tool should be used for decision making were concerned about users' understandings of the outputs. They wanted the output to be clear and accessible. Several mentioned the power of *maps* as a way to convey output quickly to people. One approach was to load maps onto the web, so that they would be accessible to everyone at the same time and "serve as a basis for discussion in the decision process with the anticipation that this should level the playing field for the environmental groups and the developers."

3.5.2.2 Getting models into public policy making

A more salient discussion theme arising from the interviews was the extent to which lay publics should be free to use models, either formally or informally. In the survey, we asked people to express their opinion about some different strategies for introducing nitrogen-loading models to town decision-making. Table 7 summarizes the responses. Two strategies received the most support: training outreach professionals to use the model and interpret the results and mailing diskettes of the program to planners experienced with running models and interpreting the results for the publics.

There was lukewarm support for modelers and their assistants doing the outreach and for training local planning board members to run the model themselves. Two people – one modeler and one outreach professional – were strongly opposed to this idea. The least supported alternative of all was making the model available for the public at the town planner's office. Outreach professions all felt this was an inappropriate way of trying to get the model used more in local decision making.

Table 7. Average support for ways to introduce models to town decision-making

Statement from survey	Mean agreement (-2 to +2)
Train state regional planning agencies or state cooperative extension service to run model and disseminate results to communities	+1.6
Send disk copies of the program to planners experienced with running models and interpreting results for public.	+1.3
Modelers run the model and their assistants disseminate the results to local policy makers.	+0.9
Train local planning board members to run the model themselves	+0.3
Send disk copies of the program to interested stakeholders	+0.1
Make the model publicly available on the world wide web.	0.0
Make the model publicly available at the town planner's office.	-0.3

Posting the model on the World Wide Web, where anyone at all could play around with the model, was very controversial. Our respondents were clearly divided into two camps, one that strongly supported making models available on the Internet and one strongly opposed to it. Table 8 summarizes the results for this question and points out that modelers and outreach professionals were both divided on this question.

One argument against making models too widely available was the complexity argument above—it is just too difficult for people to figure out how to use models and interpret their results. Some interviewees expressed a concern that local users would not have adequate time or expertise to learn how to use the models appropriately. Thus there was a real danger of models being misused.

Table 8. Response to survey question.		
Make model publicly available on the world wide web.		
Answer	Nr. of modelers	Nr. outreach professionals
Very appropriate	3	0
Appropriate	0	2
Inappropriate	2	0
Very inappropriate	2	1
* N=10 because one respondent did not answer this question.		

3.5.2.3 Potentials for misuse

There was considerable attention given to the potential misuse of models by publics. Several expressed concern that uninformed users of models could do more harm than good. Another acknowledged that misuse happens, but asserted that it is less a problem than people make it out to be.

Model results could be misused if users do not understand either the way a model works or its outputs. This point was addressed above as the allure of fancy graphics. This modeler put it quite succinctly,

> Images are very powerful for decision-making. So that is something I think we need to look out for particularly today. People can really get fooled into thinking that the quality of what is on the screen equals the quality of the knowledge behind it. You've got to be very careful about that.

Also addressed above was the question of the proper scale at which models should be applied. This outreach professional expressed concern that local decision makers want to use models in inappropriate ways:

> Frankly, we were relieved to learn that they [planning board members] don’t want to run the model, because the first thing that most people want to so is look at the impact of the next subdivision. The very reason that we developed the model was to get away from that myopic view of subdivision-by-subdivision impact, where it’s almost impossible to show a downstream impact from one subdivision.

3.6 Views on the use of models in decision-making by local boards

3.6.1 Would local board members use models?

There was general support among our interviewees for the view that local planning board members would generally *not* be interested in using nitrogen-loading models. We asked: “In coastal towns where nitrogen loading of estuaries is a known problem, what percentage of town planning board members do you think would use the model if it were provided to them on the internet?”

Only three individuals, all of them modelers, felt that anywhere near half of the planning board members would use a model on the Internet. Only two outreach professionals completed this question on the survey and both felt that less than 20% of the board members would use a model provided in this way. Among our very small sample there was no apparent relationship between these responses and individuals' self-reported levels of understanding about the needs, desires, and limitations facing town-planning boards. Nor was there a relationship with individuals' experience in training local town board members how to use models, which is surprising.

When we inquired into the possible reasons why local planning board members would not use a model, lack of time was the consensual response (see Table 9). The secondary explanation, which all but one individual agreed with, was that planning board members are simply resistant to change.

Table 9. Survey Question #7. Why would local planning board members not use a model provided on the internet?

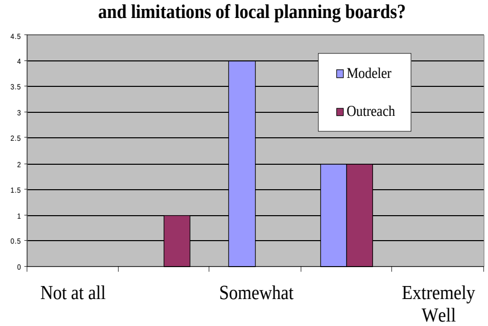
Statement from survey	Mean agreement (-2 to +2)
They are too busy to take the time to learn how to run the model	+1.8
They don't have the time to use it.	+1.6
They are used to doing things in a certain way and are resistant to change.	+1.1
They are uncomfortable using computers	+0.6
They don't believe models are useful.	+0.0
They don't have access to the internet.	-0.3
They don't trust the scientists who made the model.	-0.6

* N=8 Several individuals who returned a survey did not answer this question.

In our interviews and without exception, those experienced with working with the public announced without doubt that, at least with reference to specific models they worked with, local people have no inclination whatsoever to run a model. The reasons focused on time and complexity. This modeler pointed out the time constraint local planners are under:

> These people who work on these boards are just amazing people. Every Tuesday they are down in the basement of the town hall from 6:30 till midnight arguing over someone's lot. I just don't see a lot of them sitting down to use something that would take them a long time to get used to.

Figure 2. How well do you understand the needs and limitations of local planning boards?



Would local planners read up on the strengths and weaknesses of a model before a meeting, if they had the time to do so? A seasoned outreach professional stated that planning board members would not do any homework ahead of time; they will only react to what is being presented. Echoing the famous political scientist, Joseph Schumpeter, he said, "They are like a herd of cattle stampeding off in one direction, then they're stampeding off in another direction."

In answer to a question about whether local planners would use a specific model that his outreach team used, an outreach professional stated unconditionally:

> They would never use it. It's just too complicated to use.

But as the conversation moved away from a specific model, to talk more generally about models, this individual suggested that some planners *would* be interested in using models provided they had graphic interfaces that were easy to understand. In this same vein, another modeler mentioned that models could be made for local planners to use, but:

> The model-developer has to be in tune with that culture, has to know how the planner/manager is going to interpret it.

Another person speaking about his model also stated unconditionally that no local board members would ever want to use his model. But then he went on to tell a story of one board member who happened to be a consultant knowledgeable in models. This consultant took the model and adapted it for the town's needs. The town actually ended up writing a new town ordinance in the subdivision regulations that required the model be run for any new proposed development. But clearly this was the exception to the rule. In his experience no lay people ever showed any interest whatsoever in learning how his model operates.

Although all the outreach professionals and several of the modelers felt very strongly that local people would not be interested in running models, a few modelers were optimistic that local planners would have some interest in experimenting with running different scenarios using the models. One was enthusiastic about having his model available on the World Wide Web:

> Ultimately, any citizen of [town] should be able to turn on his or her computer or go to the library and get on the computer and design their own future scenario.

This model, however, is GIS-based and is likely to rely on maps and images that lay users can readily understand. In that way it is substantively different from models that appear to be more mathematical or scientific on first glance. There was widespread agreement among the interviewees that lay users would have no stomach for complex math or science. Their focus would be on outputs.

3.6.2 Users are focused on output, not on the caveats of the model

Those we interviewed felt that local decision makers are not always astute observers of the finer distinctions among models. First, several noted that lay decision makers were not interested in the logic and limitations of models; their attention is centered on the output:

> I mean for 80-90 percent of the people, and this includes a lot of town officials, the details of the science are not important, as hard as that may be to accept. It's unimportant. The only take home message that they will be looking for is: "Too much nitrogen from lawns or septic systems or whatever source, is going to kill all the shellfish." Or, "I am going to have a lot of smelly rotten algae on my beach." They only care about the end result; they don't care about the nuances of how you came to that conclusion.

> My hunch is that people want an answer. They don't care so much about whether it's the right answer or not, they just want an answer. And the model does that. So managers have discovered models as wonderful things.

While lay users may be on the lookout for simple messages, they are also likely to focus mainly on those messages that reinforce their preconceived beliefs, according to some of our interviewees.

> If they feel in the back of their minds that a certain development is bad, they will be against it and they will look for any scientific reason to justify it. And if our model happens to justify their position, they will embrace it.

Another modeler took this a step further, accusing users of misrepresenting the output of models to match their political objectives:

> You can always twist the output. I think that is what this is all about.

Thus, there was considerable concern that any model could be misused. This is most likely to occur when a user does not understand the internal workings of the model. People expressed concerns that artifacts of the model's calculations can easily mislead lay users. They can be misled by a false sense of accuracy and sensitivity to internal assumptions. They can be misled when experts report nitrogen loading levels as "acceptable" or "unacceptable" without reference to the underlying values, interests, and legal precedents that can inform those terms.

3.6.3 Users need to be educated about how to employ systems thinking

The final theme under the category of use by local decision makers has to do with using models to help lay policy makers think more systematically about environmental impacts. Several people stated that one of the benefits of ecosystem models being used by policy makers is that they would be encouraged to think differently about the consequences of development and that they would begin to connect actions in the watershed with outcomes in the bay.

> I am very uncomfortable with a model being used where the answer is 6.25, is then reported to the committee and [the committee concludes:] "well that is less than 7, so yes." And they vote. [...] They want an answer. But what I really want them to do is realize why the answer is what it is. [...] If we can show the decision makers what the model does and what its shortcomings are, then they are more knowledgeable.

4.0Discussion: The disconnect between models and users

In New England, as well as in other parts of the country, a tradition of home rule leaves local towns and cities with the primary responsibility to regulate land use. But the environmental impacts of nitrogen loading due to land use decisions can be difficult to discern or predict, in part because it can take decades for nitrogen to move from the site of origin to the marine environment. Moreover, towns often face development by an incremental process of lot-by-lot development. Models offer one hope that the future consequences of environmental damage can be predicted early on.

Our interviews with 16 professionals who design models and use them to help communities make better decisions revealed a number of insights about why models are not as influential as many hope they might be.

4.1 Culture of modelers is different from the culture of users

One of the explanations for why models are not used more in local decision making that we discovered during this research has to do with a breakdown of communication between modelers and users. One way to look at this is as a difference of cultures. Modelers come from a different political and organizational culture than the community users. They are scientists who are motivated by the challenge of understanding ecosystems in the language of mathematics or systems theory. They think and talk about ecological problems in a very precise language. And they are rewarded by their cultures for solving abstract problems, not for solving practical problems. Community users, on the other hand, are primarily interested in affecting policy and orchestrating or governing social change. They want to act expediently. They invoke a language that is based on experience and local knowledge and have a pragmatic orientation with little interest in furthering abstract understanding.

Indeed, the leitmotivs of these two groups can be inconsistent. For instance, many scientists feel that to take a stand on a political issue is to jeopardize one’s scientific objectivity. “Their input stops with the database” is how one modeler described some of his colleagues. The stereotype is that scientists abhor politics and prefer an “objective,” unimpassioned discourse. To the contrary, community users operate in a highly politicized environment, one in which motives and often hidden and sincerity questioned. Objectivity is always under scrutiny, perhaps because absolute objectivity is impossible and understanding the base political preferences of the other participants is an important part of the political process.

Modelers are not usually familiar with who the users are, how the users think, what the users care about, or the conditions under which the users have to make decisions. They do not know about every local community where their models might be used. Local planning board users, in turn, typically have no opportunity whatsoever to tell the modelers what they care about, what their concerns are, how they would like to use a model. They do not understand the problems and conditions under which the work of modelers is constrained.

Put simply, there is a disconnect between the tool and the problem the tool is intended to help solve.[6] (We note furthermore that it is precisely this disconnect that outreach professionals are intended to address.)

At the same time it is logistically impossible for a model to be “hand carved” for each community. Every community is indeed different, but it is simply too expensive and time consuming to craft a model that is organic for each town. If they are to build models that are accurate and compelling for local decision makers, modelers need basic information from users – what end points do they care about, what kinds of problems does the community face, what kinds of solutions are likely, which are politically unrealistic? To employ a model for a local problem, these dimensions of community input must be brought into the model in some way.

One solution many be to make a generic model that would be applicable to a certain type of problem, and then to calibrate the model to the local context. During the process of designing this generic template model, there could be broad-based dialogue with community users about their concerns and needs. In turn the modelers could discuss with the users their restrictions. Together the parties could reach agreement on what the model should be able to accomplish.

4.2 The importance of uncertainty

4.2.1 Uncertainty about how the ecosystem works

One thing that stands out from these interviews is how many of the scientists admitted that they do not adequately understand how ecosystems work. One was brutally honest when he said, “We don’t even understand the fundamental underlying ecological processes!” Another modeler asserted that, “We understand so little; models really shouldn’t be used to predict what is going to happen at all! It’s a farce to even try and use these for policy making, they are so fraught with uncertainties.”[7] A recent review article of another type of model was very direct:

> We believe that the applied engineering models currently being used to predict the behavior of beaches in the U.S. are at best poorly founded and at worst invalid (Thieler et al. 2000:65).

It is probably accurate to say that modelers would not say these things to the general public in a policy making context (although they did not ask us to keep it confidential). We believe they were being candid about the level of consensus among scientists who work in this field. Certainly modelers do understand a great deal of how nitrogen enters groundwater, moves to estuaries, and impacts the marine ecology. They do not know everything, however. And, most importantly, they probably know less than most of the general public believes that they know. This is another point of disconnect between the scientists and the lay users. It may reflect different cultures of knowledge. Lay people are

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[6] Although this is beginning to change, as noted at the beginning of this manuscript.

[7] This is a paraphrase not a direct quote.

consistently "shocked by the youthfulness of our science," as one modeler put it. Yet despite the uncertainties, these scientists are still devising models and they are still interested in having their models be used more by local decision makers. The conclusion we draw from this is that, while there are uncertainties about fundamental ecological processes, modelers feel they have fairly good guesses about how these things work. Furthermore, since uncertainty can never be wholly eliminated, operating under conditions of uncertainty is simply a fact of nature.

4.2.2 Uncertainty and the scale at which the model is used

All but two of our interviewees opposed the idea that models should be able to inform local board decisions about the incremental impacts of land use changes at the scale of the individual building lot. Moreover, *all* of the respondents felt that current models are incapable of predicting the incremental impacts of development at the lot-level.

At the same time there was a widespread assumption among these interviewees that what local board members wanted was a model that would let them justify decisions to allow or disallow development of a single family house.[8] This points to another disconnect between the model and its use. At present models are incapable of discerning the impacts that planners are assumed to want to know about.

Given this, should further research in modeling focus on improving the resolution of models to a scale more applicable to local decisions? We are hesitant to make such a recommendation. There is a possibility that modeling incremental change will make it more difficult for local land-use decision makers to regulate development on individual lots. We would prefer to see such a recommendation emerge out of a thoughtful, considered dialogue among local land-use decision makers, modelers, outreach professionals and professional planners. Such a dialogue would enable the parties to explore all possible ramifications of their desires, before having them realized.

4.2.3 Uncertainty about being candid about uncertainty

Uncertainty is prevalent in the modeling of complex phenomena. However, the interpretation of uncertainty is difficult for both the expert and layperson. Modelers expressed concern that uncertainty was impossible to calculate and difficult to estimate. Making subjective estimations of uncertainty was suggested by two of our respondents as a more effective way to convey the extent of uncertainties to lay users.

Modelers and outreach professionals did not agree about whether or not uncertainty information is helpful to local decision makers and whether it should be provided to them at

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[8] A survey we did of local board members in this part of New England verified this perception as accurate. 51 local board officials (response rate = 33%) responded to the question, How appropriate this the goal of making models able to discern incremental changes at the building lot level? 21 people agreed strongly, 15 agreed, 10 were neutral, 4 disagreed, and only one person disagreed strongly. Among the local board members we surveyed, there was overwhelming support for this capability. For results of that survey see (Dietz, Tanguay, Tuler, and Webler, 2001).

all. Some suggested that the presentation of uncertainty information was required by the scientist's professional ethic. Another perspective is that, even if models are only partially correct, provided the uncertainties are understood, anything understanding is better than uninformed judgment. Other people complained that being honest about uncertainty would frustrate users and cause them to abandon the use of ecological models en mass. They were concerned that land use decisions would then be made on purely economic grounds, which would lead to an environmental catastrophe.

One prevalent issue raised in the interviews was whether the non-expert could understand uncertainty information. Some believed that it could and that people would recognize that science does not have all the answers. Others disagreed. Such problems create a tension between the desire to provide models that are "truthful" and models that are meet the presumed needs of policy makers for a point estimate.

4.3 The role of models in democratic decision-making

4.3.1 Promoting understandings of systems

There was widespread agreement among those we interviewed that the models were never highly accurate predictors or representations of reality. This was especially true for policy models, which aim to capture only fundamental relationships among some key parameters. Policy models in particular are highly simplified depictions of complex eco-systems.

None of the models discussed are viewed as providing "answers" in the sense that the model dictates to the local policy makers exactly what they should do. Instead, most of the people we interviewed agreed that models should be used to promote understandings and to help develop within users an intuitive feel for how the ecosystem works. Broadly speaking, our interviewees believe that scientific and policy models should support learning. They should not be expected to determine which land-use activities are allowed and what are prohibited on individual sites. Certainly, models should be used to help local decision makers come up with zoning and development plans for the community. Computer-based tools of all types have been used to help local policy-makers (and other stakeholders) learn about policy options, explore various scenarios, and support the search for consensus. Models are also aides to deliberation that can help inform and enable democratic policy dialogues.

4.3.2 How models may be used in democratic policy making

Two views of how models may be used in democratic policy making at the local level emerged from our study. One view was pessimistic, the other optimistic.

One individual associated the pessimistic view with the libertarian-anarchist tradition in our country. He explained that our political system is an adversarial democracy in which interest groups battle it out for dominance. In this scenario, the model and its results are just one more resource over which political antagonists battle. If the model reinforces one person's position that person will seek to enhance the credibility of the model. Those whose views are not confirmed by the model with attempt to discredit the model. In general our interviewees who spoke about this scenario saw this as negative and discouraging. We note, however, that many political scientists see strengths to this kind of adversary democracy.

Many modelers and outreach professionals we interviewed also held out hope that local planning boards would apply a model to their local situation, would rationally discuss what the models tells them about the problem, and would act to regulate development so that it is less damaging to the environment. In this scenario, the model would not become a football kicked back and forth, but would serve as an aid to rationalize the discussions and to produce consensual decisions. Consensual conflict resolution is gaining prominence in environmental decision-making. According to this view models can form the basis for reasoned political discourse. In other words, they can "get people talking again." These deliberations can yield sane and logical decisions; hopefully ones that lead to sustaining the health of the ecosystems.

4.3.3 Power, policy judgments, and democratic accountability

Our results also warn not to become too enthusiastic about models rationalizing political discourse. Caution is in order too. Several people we interviewed were conscious of the ways models may *undermine* democratic deliberation about local environmental planning issues. This happens when models intimidate or discredit certain voices in the policy dialogue. The image one modeler brought out of the "little old man in tennis shoes who runs a golf course" who didn't have a chance speaking against results of "a model documented in 15 volumes from a fancy university" captured this concern very well. Models have power because of their scientific credibility, especially when presented by modelers who have strong academic credentials. People trust scientists and this translates into power.

Modelers have power by virtue of their expertise. They have an opportunity to impart their subjective beliefs and desires into policy making in two places: in the assumptions they make at the front end of the modeling effort and in the portrayal and interpretation of results emitted from the model. The example raised by one interviewee of the model output designed to look like a beating heart illustrated well just how powerful a metaphor can be. The choice of a metaphor is not a scientific decision. It is laden with value-assumptions and policy judgments. This example shows how subtly policy judgments can be imparted into a modeling application. Whether accidental or strategic, policy judgments are powerful and modelers must be careful about abusing this power. Democratic ends would be well served by having local voices brought into the process where these policy judgments are made.

Despite these concerns, it is clear that there is a need for democratic policy discussions to be informed with knowledge about human impacts on ecosystems. It is impossible to make a model that is purely objective. Instead models should be scrutinized with a watchful eye for policy judgments that are either incorrect for the specific context, or inappropriate from a normative policy making point of view. Both of these contingencies should be the focus of a careful democratic discussion among all involved and affected parties.

4.3.4 Build models or fix problems?

One of the last questions we asked in our interviews was, "How important do you think it is to continue to put public resources into further model development?" Nearly everyone advocated further funding, which was not unexpected. But we were surprised by some of the candid remarks.

One person pointed out that models were important, but they were not necessarily helping to actually solve any of the problems development in coastal areas is causing the marine environment. This modeler stated boldly that money could be better spent:

> I am obsessed with the fact that we can spend a fortune on modeling to come up with a model that is so fantastic it makes people salivate, while if we spent that same money on fixing septic systems, or fixing a cow pasture, we would do a lot to solve our problems.

Another modeler expressed approval of the National Science Foundation (NSF) funding models that promote basic research, but he acknowledged these were unlikely to have any impact on real problems. The physical problems that need to be solved are very specific to a particular watershed, he said. And:

> To really solve a problem you have to get down to tiny details. And that's not the problem NSF is set up to address, first of all because it wouldn't be advancing science.

Finally, two of the outreach professionals we interviewed supported more research into modeling, but only to a limited extent. Their take on it was that models should be developed that allow one to take a broad stroke at depicting the watershed and highlighting some of the more critical problems. Once the problems are identified, there should be a concerted effort among local policy makers and scientists to decide whether more modeling is likely to be productive at that point or not. Modeling for the sake of modeling was contrasted against the priority of enabling policy actions.

5.0Conclusion: Opportunities and Obstacles for Public Involvement in Watershed Planning

Water quality management computer models such as the nitrogen-loading models studied in this project are becoming an increasingly important and prevalent component of watershed management. But there are many unanswered questions about what modelers should aspire to achieve, how models should be used in the policy environment, and how users' concerns and needs should be taken into consideration. In sixteen focused interviews with modelers and outreach professionals in southern New England, this research shed some light on these questions.

Models can best be thought of as educational tools. Whether they are used by scientists to advance science or decision-makers to inform land-use policies, models help people make sense out of the world. Few models are intended to be operated by lay people, but the number of these is increasing as more and more models are posted to the World Wide Web. As this happens, models will need to meet new standards for accessibility and comprehension. They will have to succeed in teaching their lay users the functioning of the ecological system that is modeled.

In the policy domain, models create a difficult dilemma for users. On the one hand, they are imperfect representations of reality, fraught with uncertainties (many of which are poorly understood), and tend to be applicable on only the most general scales. On the other hand, what users want are models that accurately depict reality, with certainty, and are capable of making distinctions between very small changes in land use. At present models cannot meet the expectations or desires of lay users in local governments. Teaching people to understand and accept these limitations has been one of the primary responsibilities of the outreach professionals. These individuals will continue to play a key role in how models influence local policy decisions. At the same time, we must question the direction most modelers are taking. The push is clearly toward building more and more complex models. Complexity can be a handicap for some policy models, as several of our interviewees noted. This concern has been echoed in a recent review article of beach models by Thieler et al. (2000). They noted that it has not been proven that most models work in real-world situations. In fact, post-hoc evaluations of model performance are few and far between. They go on to say, "The 'solution,' however is not to increase the complexity of the model by increasing the number of variables. What is needed is a thoughtful review of what beach behavior questions should or could be answered by modeling" (Thieler et al. 2000:48).

The same advice seems applicable to nitrogen loading models. In the background of these interviews lurked the question: "What do the community users of these models want and need to know?" For the most part this question remains unanswered, because there has been so little communication between users and modelers. There are certainly some exceptions to this and one may be the MANAGE model that the University of Rhode Island Extension Service has used in local decision making many times. Feedback there is channeled by the extension employees back to the modeler. More attention needs to be given to communication between modelers and users so that questions of what can and what should be modeled are answered in ways that serves the needs, abilities, and interests of all involved.

Associated with this disjuncture between capability and goals is the possibility of misuse of models. Models can be misused in numerous ways, some intentional, some unintentional. Modelers need to be vigilant and reflective of the ways that their personal values and policy judgments may enter into the model, making certain that value judgments of any kind are left to legitimately democratic processes. This point has been made by others in the policy making literature (Smith Korfmacher 1998). Outreach professionals are one of the best lines of protection against the misuse of models. They can clarify confusions and promote the proper use of models. As more and more models become directly available to lay users, concerns will heighten about the possible ways these models can be improperly used.

What makes a model acceptable to users is complex. One of the most interesting and compelling explanations heard in these interviews was that models gain legitimacy incrementally. With each additional application the model gains reputation in the public sphere. Models also need to be legitimized by the scientific community, which is signified by publications about the model in peer-reviewed journals. Once a federal or state agency “blesses” the model by writing regulations that specify its use, the model will be widely accepted.

Is there a role for the public in the design and operation of policy models? These interviews suggest that there are several, although there was some disagreement about which were most appropriate. First, there was widespread support for modelers better understanding the needs and concerns of the users. Greater collaboration between modelers and lay users could advance this goal. Second, we found strong support for the idea that users have an opportunity to participate in running the model. There was most support for involving publics in the design of policy scenarios. Doing this would not only help ensure the scenarios are realistic, but also help to draw people into the policy dialogue in a constructive way. When it came to running models in an unsupervised fashion, as with models posted on the World Wide Web, there was concern for misuse or that the results would be mistakenly interpreted. But our interviews did not revolve around models that have been explicitly designed for public use on the World Wide Web and it is feasible that these concerns could be accommodated by good design principles. Third, there was disagreement about how to resolve the question of presenting data about the uncertainty of models. Some feel the best approach is to present uncertainty information and train people how to interpret it. They argued that lay people deal with uncertainty in their everyday lives – for example, in weather forecasting – and it was just a matter of drawing the right analogies. Others felt that uncertainty information was the kiss of death in an adversarial political system such as ours and what people need is plain simple answers.

Computer-based models will continue to play important roles in managing the environmental impacts of human activities. As the scientific complexity and credibility of models continues to evolve, so also must our understandings of how best to integrate the use of these models into democratic discussions at the local level. At cities and towns all along the coast, citizens elected to serve on planning boards, conservation commissions, boards of health, and other administrative bodies are making decisions about land-use and development that will shape the ecology for decades to come. It is reasonable and right that such decisions should be informed with the best scientific knowledge available. Models are a good way to apply expert knowledge to solving local problems in individual communities. But doing so opens the door for many uncertainties. “How well does this model work in our town?” will be a question local policy makers continue to ask for years to come. This and other uncertainties present major challenges for modelers who hope their models will contribute to positive environmental change. The effective and appropriate employment of models in local democratic decision-making is best served by communication between users and those familiar with the models. Models that are designed in cooperation with users are much more likely to meet the needs of those users. Connecting science with democratic policy making demands a form of coordinated communication that little is known about. Future research should continue to investigate how modelers and users can talk to each other and coordinate their efforts toward agreed-upon goals.

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Appendix A. Survey Instrument

Nitrogen Loading Model Survey: For Professionals Involved with Developing or Disseminating Models or Results

Individual results will be kept confidential. Only aggregate results will be presented. For questions or comments call Thomas Webler (413) 625-9046 or email at TWebler@crocker.com

1. We would like you to characterize your activities with regard to nitrogen loading models. For each item below, please indicate to what degree you engage in the activity.

	I don't do it at all ∨			*I do it sometimes* ∨			*I do it a great deal* ∨
Design and develop nitrogen loading models.	0	1	2	3	4	5	6
Design and develop other kinds of ecological models.	0	1	2	3	4	5	6
Provide nitrogen loading models or the outputs of these models to local policy makers or local regulatory boards.	0	1	2	3	4	5	6
Use nitrogen loading models as part of an official position I have in local government.	0	1	2	3	4	5	6

2. Nitrogen loading models are sometimes linked to estuarine response models or GIS based planning or risk assessment models. Models like these can be used to help local governments make better land use policy decisions. We would like to know which of the models you know of (be they nitrogen loading models, integrated assessment models, GIS-based models or some other kind of model) you think would be the most useful aid for local decision makers involved in land use decision making. Please write down the name of the model or its creator. Also describe what you like about the model. (Use the back of this paper if you need more space.)

____
____
____
____
____
____

3. We would like your opinion on the appropriate way that models can aid local policy

making on land use decisions. Use the first column to indicate how appropriate you think it is to use nitrogen loading models or other kinds of models like those described above for the following purposes. Use the second column to indicate how capable current models are at doing this.

	How Appropriate? *Very Inappropriate* *Don't Know* *Very Appropriate*	**How Capable?** *Very Capable* *Don't Know* *Very Incapable*
Improve local policy makers' understandings about how different land uses impact water quality.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Improve local policy makers' understandings of how nitrogen affects estuaries.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Improve local policy makers' understandings of nitrogen loading rates and nitrogen levels in local embayments.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Improve local policy makers' understandings about impacts of growth.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Help local policy makers to think about development issues in an ecological systems way.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Inform local board decisions about land use at the scale of the town plan.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Inform local board decisions about land use at the scale of the individual building lot.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Inform local board decisions about land use at the scale of large land uses (shopping malls, housing developments, agricultural operations, etc).	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Inform local board decisions about land use at the scale of zoning districts.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Justify controversial board decisions at the building lot level.	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3
Other (please specify) ______________________________ ______________________________ ____________________	-3 -2 -1 0 +1 +2 +3	-3 -2 -1 0 +1 +2 +3

4. Models can be used by a number of different people. How appropriate do you think it is that models are used by these kinds of people? Assume that the model is well-documented, has a user-friendly interface, and that users receive a training session.

	Very Inappropriate		Don't know		Very Appropriate
Regional planning agency (or commission) staff	-2	-1	0	1	2
State extension service professionals	-2	-1	0	1	2
Town professional planners	-2	-1	0	1	2
The average citizen	-2	-1	0	1	2
Representatives of stakeholder groups active in coastal zone policy making (environmentalists, recreation boaters, fishermen, real estate developers, etc.)	-2	-1	0	1	2
Town planning board members	-2	-1	0	1	2
Town select board members	-2	-1	0	1	2
Members of town boards other than the select or planning board active in permitting land use activities (conservation commission, board of health, etc.)	-2	-1	0	1	2
Other (please specify) ____ _______	-2	-1	0	1	2

5. There are a number of ways models could be introduced into local (town-based) decision making. What is your opinion on the appropriateness of these different ideas?

	Very Inappropriate		Don't know		Very Appropriate
Train state regional planning agencies or state cooperative extension service to run model and disseminate results to communities	-2	-1	0	1	2
Train local planning board members to run the model themselves	-2	-1	0	1	2
Make the model publicly available on the world wide web.	-2	-1	0	1	2
Make the model publicly available at the town planner's office.	-2	-1	0	1	2
Send disk copies of the program to interested stakeholders	-2	-1	0	1	2

	Very Inappropriate		Don't know		Very Appropriate
Send disk copies of the program to planners experienced with running models and interpreting results for public.	-2	-1	0	1	2
Modelers run the model and their assistants disseminate the results to local policy makers.	-2	-1	0	1	2
Other (please specify) ____ ________________________________	-2	-1	0	1	2

For the remaining questions, please consider the following scenario. Assume that we have a nitrogen loading model (or another kind of estuarine response, ecological integrated assessment or GIS-based impact assessment model) that you think is very good. The goal is to make this model publicly available by putting on the internet where anyone will be able to use the model. For simplicity's sake, please assume that the model does not need to be downloaded, but can be run directly on-line.

6. In coastal towns where nitrogen loading of estuaries is a known problem, what percentage of town planning board members do you think would use the model if provided to them in this way?

No one will use it				Half will use it				Everyone will use it		
0	10	20	30	40	50	60	70	80	90	100%

(If you answered 100% please skip the next question)

7. Please give us your opinion as to which of the following factors might be important in explaining why local planning board members would not use a model provided via the internet.

	Not at all Important		Don't know		Very Important
They are uncomfortable using the internet	-2	-1	0	1	2
They are uncomfortable using computers	-2	-1	0	1	2
They are too busy to take the time to learn how to run the model	-2	-1	0	1	2
They don't believe models like these are useful	-2	-1	0	1	2

	Not at all Important		Don't know		Very Important
They think these models are too complicated for them to understand	-2	-1	0	1	2
They don't trust the scientists who made the model.	-2	-1	0	1	2
They don't have the time to use it.	-2	-1	0	1	2
They don't have access to the internet.	-2	-1	0	1	2
They are used to doing things a certain way and are resistant to change	-2	-1	0	1	2
Other (please specify) ______________________________ ______________________________ ____________________	-2	-1	0	1	2

8. Given the goal of making the model useful to the public at large, tell us how important you think are each of the following features.

	Not at all Important		Don't know		Very Important
Model outputs show nitrogen flows as function of time.	-2	-1	0	1	2
Model reacts to a change at the building lot level (one additional house)	-2	-1	0	1	2
Model considers the spatial distribution of land uses.	-2	-1	0	1	2
Model outputs are expressed as uncertainty ranges around a point estimate	-2	-1	0	1	2
Model outputs are point estimates without uncertainty data.	-2	-1	0	1	2
Model outputs include a sensitivity analysis.	-2	-1	0	1	2
Model outputs document the assumptions that are embedded in the model.	-2	-1	0	1	2
Users can modify assumptions and default values to fit local conditions.	-2	-1	0	1	2
Model outputs include policy options that could help mitigate effects.	-2	-1	0	1	2
Model outputs specify the contributions from different sources delivering nitrogen to bay.	-2	-1	0	1	2
Model outputs show impacts of nitrogen loading on fish.	-2	-1	0	1	2
Model outputs show impacts on end points that users care about.	-2	-1	0	1	2

	Not at all Important		Don't know		Very Important
Model output includes some evaluation of the significance of the nitrogen loading to the bay.	-2	-1	0	1	2
Model outputs include some evaluation of the water quality in the bay.	-2	-1	0	1	2
Model functionality is supported by a long track record of empirical data.	-2	-1	0	1	2
Model was calibrated with local data.	-2	-1	0	1	2
Users can test the impacts of different policy scenarios.	-2	-1	0	1	2
Technical support is provided.	-2	-1	0	1	2
Community members are involved in the design of the model.	-2	-1	0	1	2
Community members are involved in the calibration of the model.	-2	-1	0	1	2
People who want to use the model are offered a training seminar.	-2	-1	0	1	2
Model input parameters include uncertainty information (a range, not a value).	-2	-1	0	1	2
Other (please specify) ________________ ________________ ________________	-2	-1	0	1	2

9. If there are other features you think are important that are not on the list above, please write them here.

10. How well do you feel you understand the needs, desires, and limitations of local planning boards?

Not at all			Somewhat			Extremely well
0	1	2	3	4	5	6

11. What level of participation have you personally had in <u>town-level</u> planning decisions?

None			Some			A lot
0	1	2	3	4	5	6

12. What level of participation have you personally had in <u>regional or state-level</u> planning decisions?

None			Some			A lot
0	1	2	3	4	5	6

13. What experience have you had in training individuals involved with planning or policy making at the <u>town level</u> about how to use computer models of any kind?

None			Some			A lot
0	1	2	3	4	5	6

14. What experience have you had in training individuals involved with planning or policy making at the <u>regional or state level</u> about how to use computer models of any kind?

None			Some			A lot
0	1	2	3	4	5	6

15. What experience have you had in presenting the output of such models to public audiences of local planners or policy makers?

None			Some			A lot
0	1	2	3	4	5	6

Thank you very much for taking the time to complete this survey. Please use the enclosed envelope to mail the survey to:

SERI
P.O. Box 253
Leverett, MA 01054

Questions or comments to: Thomas Webler, twebler@crocker.com
If you would like to receive copies of our publications which include results from this survey, please send an email to Thomas Webler, above, or send a post card to the SERI PO Box above.