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Effectiveness of a participatory modeling effort to identify and advance community water resource goals in St. Albans, Vermont

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ABSTRACT

Natural resource managers face complex challenges in addressing non-point source water pollution. A participatory modeling approach was applied in the St. Albans Bay watershed to identify the most effective phosphorus control options to achieve the load reductions required by the Lake Champlain Phosphorus Total Maximum Daily Load (TMDL). Stakeholders participated in the collection of data in the watershed, model creation, development of policy scenarios, and interpretation of model results. The participatory modeling approach employed in this study led to the identification of new solutions to an old water resource problem regarding phosphorus loads to streams and St. Albans Bay. The modeling process provided a perceived neutral atmosphere for discussing water pollution issues that have historically been divisive and provided participants with greater understanding of local environmental issues and reduced historic conflict among actors. This study highlights the importance of considering the dynamics of social and technical factors in the use of modeling in natural resource planning processes. The approach led to stakeholder agreement about problems and potential solutions generated in the modeling process. As the process ended, local decision makers were moving forward to implement solutions identified to be most cost-effective.

1. Introduction

In recent years, there has been a shift from prescriptive management of water resources towards policy making and planning processes that require ongoing collaboration among stakeholders, scientists and decision makers. Watershed management affects and is affected by society, especially when non-point source pollution is a primary issue. Participatory modeling is a process of engaging stakeholders, including the public and policy-makers, in an otherwise purely analytic modeling process to support decisions involving complex environmental questions (Hare et al., 2003), or, rather, framing the decision support effort around one or several modeling efforts that structure and formalize the process (Gaddis and Voinov, 2008; Voinov and Gaddis, 2008). As Korfmacher (2001) outlined, the move to involve stakeholders, and citizens more generally, in such modeling efforts can take different forms and be for varied purposes. For example, stakeholders may be asked to comment on the outputs of models, to provide information to include in models, and/or to be involved in developing models. Purposes for participatory modeling include education and improved decision making. In addition, the shift towards more open and integrated planning processes is one way to address potential conflict and misunderstanding. To be effective, participatory modeling requires concerted efforts from stakeholders and scientists, which adopt the scientific modeling process as a backbone for decision making and incorporate community knowledge and values into the analytical tools developed. Modeling tools, appropriately applied, can empower stakeholders to move forward with joint efforts to remediate an environmental problem (Argent and Grayson, 2003), contribute to support for management, and help inform changes in management systems (Cowie and Borrett, 2005).

In this paper, we evaluate the experience of employing a participatory modeling approach in the St. Albans Bay watershed, Vermont to identify new solutions to water resource problems that have historically been locally controversial and divisive. We report on the following objectives of this study:

- Develop a watershed model that incorporates local watershed processes and involves stakeholder input throughout the scientific modeling process;

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- Determine whether participatory modeling in the St. Albans Bay watershed could lead to identification of new solutions to old water resource issues in the watershed;
- Understand the social dynamics of conflict and collaboration throughout the participatory modeling process to see if historic conflict in the watershed could be at least partially resolved using this approach.

These objectives reflect the multidisciplinary character of our research project and team. We drew on knowledge and skills relevant to both the biophysical and social dimensions of the case. We report findings here that span these disciplinary perspectives as these findings relate to the modeling process, its outputs, and implications for management and decision making. Although this article reports on a single case study, it provides insight into what might occur in other settings. In particular, it describes how stakeholders experienced collaborative work across historic lines of conflict, and varied experiences with the technical complexity of the modeling process.

Lake Champlain has received excess nutrient runoff for the past 50 years (VTANR and NYDEC, 2002) due to modern agricultural practices and rapid development of open space for residential uses (Hyde et al., 1994). The effect of excess nutrients has been especially prominent in St. Albans Bay, which exhibits eutrophic algal blooms every August (Hyde et al., 1994). The Lake Champlain Total Maximum Daily Load (TMDL), established by the Vermont Agency of Natural Resources and the New York Department of Environmental Conservation, allocated a phosphorus load to the St. Albans Bay watershed that would require a 33% reduction of total phosphorus input.

Required load reductions identified in the Lake Champlain TMDL were based on regression models employed at the Lake Champlain Basin scale, which do not necessarily account for unique watershed processes in various subwatersheds. Water quality data in the St. Albans Bay watershed were not available for calibration of the TMDL model, which was based on data collected in larger basins draining to Lake Champlain (VTANR and NYDEC, 2002). While this approach was appropriate for the TMDL process, an additional model was required to identify the most cost-effective means of reducing total phosphorus across multiple sources in the St. Albans Bay watershed. Development of such a model, in collaboration with a local stakeholder group was one objective of this study. Details on the specifics of the watershed model are reported elsewhere (Gaddis, 2007).

The extent to which the public or a representative stakeholder group can participate in water resources research and management is determined by the methods employed in engaging stakeholders, inclusion of diverse groups, group size, incorporation of local knowledge and expertise, and the time and funding available for the process to develop (Roberts, 2004). Citizen participation in watershed management can range from simply providing public comments on draft management plans to a more involved process in which stakeholder working groups help guide the development of a management plan from the beginning (i.e. employ a participatory modeling approach). The Lake Champlain TMDL process included a public involvement stage when stakeholders were invited to comment on the TMDL after the modeling and scientific research had been completed. While this is fairly typical for TMDL processes, and probably all that could reasonably be expected at a scale as large as the Lake Champlain Basin, it did not give the opportunity for stakeholders to contribute to the scientific process, including modeling data collection, or monitoring, prior to TMDL development. In addition, water quality data collection in the watershed had been previously conducted primarily by researchers from outside of the watershed and without a formal public involvement process. Following TMDL development, a basin planning process was initiated by the Vermont Agency of Natural Resources that involved a substantial public involvement component to incorporate public feedback on proposed basin plans. However, resources available to this process did not include funds for additional scientific research or modeling. Rather, the intent was for the planning process to draw on previous research and model results. In short, scientific research and modeling in the St. Albans Bay watershed have been historically disconnected from stakeholder engagement and public involvement while the decision making and planning process were somewhat separate from the modeling process. Engaging stakeholders in a watershed modeling process specific to the St. Albans Bay watershed with the hope of identifying new solutions to old water resource problems was a crucial objective of this study.

The watershed feeding St. Albans Bay is dominated by agriculture at the same time that the urban area is growing. In the 1980s, urban point sources of pollution were reduced by upgrading the St. Alban's sewage treatment plant. During this period, agricultural non-point sources were also addressed through implementation of 'Best Management Practices' (BMPs) on 60% of the farms in the watershed at a cost of $2.2 million (USDA, 1991). Despite the considerable amount of money and attention paid to phosphorus loading into St. Albans Bay, it remains a problem today. The historic focus of those working on this problem has been primarily on agricultural practices in the watershed. This has caused considerable tension between farmers, city dwellers, and landowners with lake front property. Participatory modeling provides a means for integrating scientific knowledge with local knowledge and, when executed well, provides a place for a diverse group of stakeholders to share varied forms of knowledge about water resource issues. At the same time it provides a platform for stakeholder interaction and dispute resolution. Adopting a more integrated approach to environmental management, such as participatory modeling, can assist with addressing the complexity of current environmental problems (Pahl-Wostl, 2005). Another objective of this study was to determine if participatory modeling facilitated more cooperation and reduced conflict between stakeholders in the St. Albans Bay watershed. Recognition that effective watershed management requires input through both scientific and social processes is key to developing partnerships between scientists and stakeholders who live and work in a watershed or ecosystem (Rhoads et al., 1999).

2. Methods of participatory research in the St. Albans Bay watershed

We initiated the project, as a group of multidisciplinary researchers from the University of Vermont, in response to the need for watershed specific TMDL implementation planning. The project drew on existing collaborative efforts to resolve water resource concerns in the area. The St. Albans Bay watershed offered a good opportunity for participatory modeling for several reasons: its active stakeholder community, the willingness of the community to embrace the research process, the size of the watershed, data availability, and the stage of the watershed in the basin planning process.

In the St. Albans Bay watershed modeling effort, we followed, to the extent possible, some of the standard guidelines of participatory modeling. These include transparency, continuity of stakeholder involvement, representation, incorporation of stakeholder values and knowledge, and the role of results in management decisions (Korfmacher, 2001).

2.1. Creation of the stakeholder group

A key to success with any participatory approach is that the community participating in the research be consulted from the initiation of the project and invited to help to set the goals for the project and specific issues to be studied (Beirele and Cayford, 2002; Voinov and Gaddis, 2008). Stakeholder participants were involved in the decision making process at various stages, including model selection and development, data collection and integration, scenario development, interpretation of results, and development of policy alternatives. Engaging participants in as many of these phases as possible and as early as possible, beginning with setting the goals for the project, substantially improves the value of the resulting model in terms of its usefulness to decision makers, its educational potential for the public, and its credibility within the community (Korfmacher, 2001).

Varying levels of stakeholder participation often occur in a participatory modeling project. A deep level of participation can be difficult to achieve because it requires a high level of time commitment, which is hard to expect from stakeholders, and usually possible only if the stakeholders themselves initiate the study (as in Participatory Action Research; Wadsworth, 1998). It helps if stakeholders have some expertise in watershed science (hydrology, nutrient dynamics, agricultural management, etc.), although stakeholders can participate meaningfully without explicit expertise in these topics. They can define goals, contribute information and assumptions, develop scenarios, and use the results (Beirele and Cayford, 2002; Webler and Tuler, 1999; Gough and Darier, 2003). Rarely can the level of participation be prescribed in advance for a project. It is determined by the initial and evolving goals of a specific project.

Stakeholders in the St. Albans Bay watershed served an advisory and representative role in the process with an aim of developing a new understanding and consensus on the issue of phosphorus loading to streams in the watershed. This included a clear project goal of informing the opinion of local decision makers and creating interagency cooperation, as compared to only soliciting information and opinions, which is an approach often used in watershed management projects (Carr and Halvorsen, 2001). These characteristics distinguish the participatory modeling approach taken in the St. Albans Bay watershed from other methods of engaging the public in watershed research and management (Duram and Brown, 1999).

We solicited participation through inquiry with known stakeholders and through several open information sessions to converse with particular groups of citizens as well as the public as a whole. We identified and invited the major stakeholders from the St. Albans community to join a working group to develop a watershed model and to help ensure that the model accurately represented processes in the watershed. Citizen stakeholders were identified based on past involvement in the local watershed committee and agency stakeholders were identified based on their influence or involvement in watershed monitoring, implementation, or decision making.

Citizen stakeholders represented the St. Albans Area Watershed Association, the UVM extension service, the local farming community, and the local high school (Bellows Free Academy). Among the interests represented by citizen stakeholders were agriculture, lakeshore property values, water quality, and education. Agency representatives included decision makers from the Town of St. Albans; the City of St. Albans; the Town of Georgia Conservation Commission; the Northwest Regional Planning Commission; the State of Vermont Agency of Natural Resources River Management and Basin Planning sections; the State of Vermont Agency of Agriculture; the Natural Resources Conservation Service (USDA); the Franklin County Natural Resources Conservation District. We made a deliberate attempt to involve members of the business and residential communities without success. Their lack of interest in the process was perhaps because they perceived themselves to have no stake in the outcome. The lack of involvement from the business and residential communities may have biased the study in at least two ways. First, analysis of stormwater load and its associated phosphorus sources was spatial (specific to areas draining to stormwater sampling locations) but did not include a detailed accounting of specific industrial or residential sources of phosphorus. As a result, the solutions identified for these sources were relatively broad-based and focused primarily on stormwater treatment and education of homeowners rather than specific stormwater management plans for areas in the watershed. Second, the funding and implementation strategies identified for the watershed revolved around leverage and funding opportunities available through local, state, and federal agencies, because these agencies were well represented in our working group. Involvement from the business community might have led to other implementation strategies and funding sources. In addition to jointly conducted monitoring efforts, the working group met six times during 2005–2006 (Table 1). The project also maintained a web site (www.uvm.edu/~landmod), where participants could get regular updates on the modeling progress, and see all the data sets involved in the analysis. The web site was interactive and was also used to upload meeting minutes and monitoring results.

2.2. Agenda setting

A critical step, early in the participatory modeling process is the development of research questions and goals of the process. The questions identified should be answerable given the time and funding available to the process. In addition, it is important that all stakeholders agree on the goals of the process such that a clear research direction is embraced by the entire group before detailed modeling begins.

The working group helped outline the goals and agenda of the modeling project during the first stakeholder meeting (Table 1) and agreed on the methods by which concerns would be addressed. This included discussion and active modification at the meeting of conceptual linkage diagrams that capture specific watershed processes and water resource issues in the St. Albans Bay watershed. The following research goals were identified by the stakeholder group at the first meeting:

1. Identify current nutrient and sediment loads to streams from urban, residential and agricultural areas,
2. Identify historical loads versus current loads of phosphorus to streams,
3. Identify which stormwater management policies, methods, and land use practices will help to reduce urban flooding,
4. Identify nutrient management policies and methods, their cost-effectiveness, and their ability to reduce nutrient and sediment loading to streams in urban and agricultural areas,
5. Understand the distributional cost impacts for different members of the community of resolving the issue,
6. Educate and involve community members who are not currently involved,
7. Persuade individuals and towns to participate in pollution reduction activities,
8. Identify an acceptable level of flooding, and
9. Identify the impacts of reducing phosphorus in dishwasher detergent and fertilizers.

Table 1
Summary of stakeholder meetings.

Meeting	Stakeholder groups present													Summary of meeting
	St. Albans Town	City of St. Albans	Town of Georgia	NRPC	VTANR – River Mgmt	VTANR – Basin planning	VT agency of Ag	NRCS (USDA)	NRCD	Watershed association	Farmers	UVM extension	Citizens	
1. Goals and conceptual model, 1/27/2005	X	X		X	X			X		X	X	X	X	1. Agreed on goals of modeling process 2. Developed timeline, methods, and metrics to achieve goals and measure success
2. Water module assumptions, 3/2/2005	X	X	X	X	X	X	X	X	X	X	X	X	X	1. Received feedback on hydrology module assumptions 2. Agreed on assumptions that required stakeholder input
3. Policies and management practices, 5/17/2005	X	X	X			X		X		X			X	1. Discussed current policies and management practices used to reduce phosphorus 2. Discussed how policies could be used to achieve goals and barriers to implementation
4. Phosphorus module, 11/9/2005		X	X			X		X		X	X		X	1. Received feedback on phosphorus module assumptions 2. Agreed on assumptions that required stakeholder input
5. Scenario development, 1/16/2006	X		X	X	X	X	X	X		X	X		X	1. Presented and discussed preliminary model results 2. Agreed on list of phosphorus reduction scenarios to test with the model
6. Presentation of results, 5/10/2006	X	X	X	X	X	X		X		X	X		X	1. Presentation of final model and scenario results 2. Discussed how to move forward with most appropriate solutions 3. Discussed how to present results to the public

X = Present at meeting.

Table 2
Stakeholder derived scenarios. Scenarios in italics could not be evaluated using the models developed for the watershed.

Scenario	Proposed By
Storm sewer separation in city	City of St. Albans
Eliminate or reduce use of road sand (City, other municipalities)	Municipalities
Install decentralized bioinfiltration or retention systems around city	ANR – Basin Planning
Treatment of stormwater with sediment traps	Northwest Regional Planning Commission
Installation of proposed diversion structure on Stevens Brook	Town of St. Albans
Treatment of farmstead discharge	NRCS
Installation of buffers in the agricultural landscape	Agency of Agriculture
Eliminate P fertilizer use on agricultural and developed landscape	ANR – Basin Planning & Watershed Assoc
Reduce manure application on agricultural landscape	UVM and NRCS
Reduce soil erosion to soil tolerance	NRCS
"EAF steel slag barriers for P reduction from non-point pollution (surface runoff)"	UVM
Impact of large scale stormwater treatment	*ANR – Basin Planning*
Restoration of flood plain and natural geomorphology	*ANR – River Management*
Urban riparian buffers	*ANR – Basin Planning*
Impact of new development patterns	*Northwest Regional Planning Commission*

Goals related to flooding (#3, #5, and #8) fell outside the scope of our funding and modeling expertise and were not addressed in this study. The remaining water resource objectives were incorporated into one or several modeling tools with guidance from the stakeholder group.

2.3. Watershed monitoring and data contribution from stakeholders

When this project commenced, recent data regarding the state of the watershed, including water quality, discharge, soil phosphorus concentrations, and spatial information, was limited (most data was from the early 1990s). At the same time, a highly motivated group of citizens organized through the St. Albans Area Watershed Association existed and was eager to begin "doing" something in the watershed. In partnership with this group and the Vermont Agency of Natural Resources, a citizen's volunteer monitoring program was established with 25 monitoring sites around the St. Albans Bay watershed. Stakeholders participated directly in water quality sampling and monitoring. This was an effective entry point to the community because people were ready to 'act' on the water quality concerns in the watershed and were not satisfied with more meetings and discussions of the problem. Over 500 water quality samples and stage height data were collected over two years by a group of fifteen volunteers drawn from the community. The resulting data filled an information gap, and the process engaged a group of local citizens in the research process. This early engagement proved valuable during the latter stages of the project when the stakeholder group was assembled for the participatory modeling exercise. The partnership that grew from the monitoring effort built trust between researchers, watershed activists, and landowners that provided access to streams on their property. Citizen volunteer monitors provided other benefits to the research process. In many cases, they lived close to monitoring sites and had access to private property such that more frequent and more complete monitoring could take place at significantly less cost than would have been otherwise possible. Citizen monitors also gained benefits by becoming more familiar with their watershed, an educational opportunity that was shared with other community members.

In a separate effort, soil test kits were offered free of charge to 300 homeowners in the City of St. Albans. A partnership was formed between the local watershed association, the Lake Champlain Basin Program, a local high school, the UVM Master Gardener extension service, and ourselves. The data was used to develop a soil phosphorus map for the City of St. Albans that indicated many areas of high phosphorus concentration. This map served to educate homeowners that phosphorus fertilizer was not needed for most of the soils in the city, in addition to being a direct input to the watershed model. Homeowners received a copy of their soil test that was intended to help them make better decisions about appropriate lawn care. The collection of urban soil data also demonstrated neutrality to the agricultural community because we were investigating all sources of phosphorus in the watershed, urban and agricultural. The resulting trust that developed between us (University Researchers) and the agricultural community eventually led to a wide array of data and information that is otherwise protected as confidential and would be unavailable to the public.

Other stakeholders contributed existing data to the process and participated in collecting new data. Stakeholders from governmental bodies had access to agricultural, wildlife, and spatial data that were otherwise unavailable. These data, provided to us in aggregate, maintained privacy for landowners in the watershed. In addition, some stakeholders were aware of data sources that were more specific to the watershed such as locally collected climatic data.

2.4. Model selection

Selection of appropriate modeling tools to address questions identified by stakeholders is a critical step in the participatory modeling process. To be useful in a participatory framework models need to be transparent and flexible enough to change in response to the needs of the group. Although participatory modeling incorporates values, the scientific components of the model must adhere to standard scientific practice and objectivity. Thus, while participants may determine the questions that the model should answer and may supply key model parameters and processes, the structure of the model must be scientifically sound.

Model complexity must be dictated by the questions posed by the stakeholder group. Models that are too simple are less precise and explanatory, however, a model that is too complex can lose transparency among the stakeholder group. In many cases a simple model that can be well communicated and explained is more useful than a complex model that has narrow applicability, high costs of data, and more uncertainty. In summary, successful participatory modeling requires appropriate modeling tools and paradigms.

Two specific modeling tools were used to achieve goals outlined by stakeholders in the St. Albans Bay watershed (see Section 2.1). The first one consisted of several simple mass-balance models used to calculate aggregate loads from several sources in the watershed including barnyard runoff, waterfowl, and wastewater treatment. The second modeling tool was the spatially explicit Landscape Modeling Framework (LMF) developed by the Gund Institute for Ecological Economics. The LMF can be used to estimate the relative impact of different nutrient sources on waters throughout a watershed (Costanza and Voinov, 2004; Voinov et al., 2004). The models developed for the St. Albans Bay watershed incorporated the following processes: hydrology (including evapotranspiration, storm runoff, and snow melt); erosion; phosphorus dynamics in urban, agricultural, and forested soils; plant growth; stormwater runoff and conveyance in St. Albans City; wastewater treatment plant discharge; and road sand wash-off. The model was run at a daily time step for 5-year simulations on a raster scale of 30 m grid cells. Details on the watershed model developed in this study are reported elsewhere (Gaddis, 2007). Here we focus on the participatory process and stakeholder involvement.

While these modeling tools did seem appropriate for the study we were also biased towards these tools as we had significant experience with this type of modeling prior to the project.

2.5. Incorporation of stakeholder values and knowledge into model development

All stakeholders come to the process with their own interests, perceived knowledge about the system, vested interests, and priorities. These make them biased and subjective. For example, the dominance of the committee by citizen volunteers and agency representatives led to solutions that would be implemented either through volunteer efforts or funded through existing agency programs. The transparency of the modeling process should reveal these biases and help to find common ground. Giving stakeholders the opportunity to contribute and challenge model assumptions before results are reported can create a sense of engagement in and ownership of the process that makes results more credible in the future. This can only occur, however, if the models developed are transparent and well understood by the stakeholder group and, later, the public. In some cases, it can reduce conflict between stakeholders in the watershed, since model assumptions are often less controversial than model results (Korfmacher, 2001). Furthermore, when local knowledge is incorporated with expert knowledge, researchers may develop more complete watershed models (Habron et al., 2004).

The facilitators of a participatory modeling exercise must be trusted by the stakeholder community as being objective and impartial, and therefore should not themselves be direct stakeholders. In this regard, facilitation by university researchers or outside consultants, if established as a neutral party, can reduce the incorporation of stakeholder biases into the scientific components of the model. It is also essential that stakeholders trust the science used in the project. A track record in the local area and perhaps even recognition of researchers by the local stakeholders based on past research or involvement can be helpful in building relationships between the stakeholders and the facilitators.

We made every effort to make the model development process transparent to the stakeholders. The stakeholder working group discussed and agreed on model assumptions for some parameters and validated other model assumptions during the second and fourth stakeholder meetings (Table 1). Stakeholders were asked to verify assumptions about the dynamics, history, and patterns of the watershed system. This approach is based on the assumption that those who live and work in a system or watershed may be better informed about its processes and may have observed phenomena that would not be captured by scientists who live elsewhere. Farmers and homeowners possessed important local knowledge about the biophysical and socio-economic system. This type of knowledge, when combined with technical knowledge of watershed processes, is key to identifying new and more appropriate solutions to environmental problems (Gough and Darier, 2003; Webler and Tuler, 1999). This two-way flow of information is a key characteristic of successful participatory modeling (Duram and Brown, 1999).

Stakeholders identified processes or pollutant sources that had been neglected in past research for the watershed. For example, farmers identified field drainage of lowland fields as a potentially important process for understanding the flow of water and nutrients through the agricultural landscape. In addition, community stakeholders provided information about typical human behavior in the watershed many of which were important inputs to the simulation model (i.e. frequency of lawn fertilizer application).

2.6. Phosphorus reduction scenarios suggested by stakeholders

Initial model results were reported to stakeholders mid-way through the process and included the relative proportion of phosphorus load from a variety of sources and processes (Fig. 1). The next step in the process was to identify potential reduction mechanisms or solution scenarios to the phosphorus problem in the watershed.

Stakeholders were well placed to pose solution scenarios to the phosphorus load problem. Many of them have decision making power in the community and understood the relative feasibility and cost-effectiveness of proposed solutions. This illustrated how engaging local decision makers in the scenario modeling stage of the research process can lead to development of more innovative and economically sound solutions (Carr and Halvorsen, 2001; Gaddis et al., 2007).

The stakeholder working group developed a list of scenarios of watershed interventions that could be implemented through volunteer and incentive-based actions and/or proposed policy changes that the group deemed feasible (Table 2). Watershed interventions cover both the urban and agricultural sources in the watershed. Scenarios related to in-stream erosion could not be assessed using the modeling tools developed because this process was not identified as a separate source in the original modeling effort, which is reflective of both a limited budget and insufficient model scope to quantify this source. Most of the scenarios addressed sources and processes that were modeled using the landscape model and thus were assessed using this tool. Some spatially referenced scenarios were assessed using the spatial model outputs and interpreted using GIS (Gaddis, 2007).

2.7. Assessing social implications

A qualitative case study approach was used to evaluate stakeholder experiences with the modeling process. This approach was chosen because of the explanatory type questions needed to identify how the modeling process affects stakeholder experiences. Case study methodologies are preferred with current events because they allow researchers to study a "phenomenon in its real-life context" (Yin, 1989). Interviews, our main tool, were semi-structured to allow the interviewer to explore subjects and go beyond baseline interview questions (Maxwell, 1989). The goal was to census all members of the original stakeholder group, a total of fifteen people. Criteria for whom to involve included, a) individuals who had been part of the process from the beginning and who helped define the goals of the process, and b) individuals who attended more than two of the six stakeholder meetings. Thirteen of the fifteen individuals consented to a tape-recorded interview about their experiences with the modeling process. Two participants could not be interviewed due to their time constraints. Interviews lasting from fifteen minutes to an hour and a half were conducted over four months during 2005, with questions focusing on previous instances of conflict surrounding environmental issues and the effects the modeling process had on them personally as well as their relationships with other stakeholders. Participant observation, where we both observed and participated in meetings, took place during all six stakeholder meetings, with detailed notes taken during two meetings.

The primary data analysis for this research project was coding of interview transcripts. The interviews were transcribed and coded for themes using Ethnograph (Qualis Research, 2005), a computer software that supports the management of word-based data. Observations were gathered for all formal stakeholder meetings. In addition, the case study was informed by interactions that occurred before these meetings (e.g., water sampling) and between meetings (e.g., informal meetings to gather information). A preliminary list of codes was developed in the fall of 2005. The final list of codes reflects both initial themes as well as themes that emerged from the interview transcripts. During the analysis process, transcripts were systematically coded for themes related to 1) how a participatory computer modeling process helped stakeholders address sources of conflict and provided opportunities for collaboration, and 2) how stakeholders experienced complexity and integration through

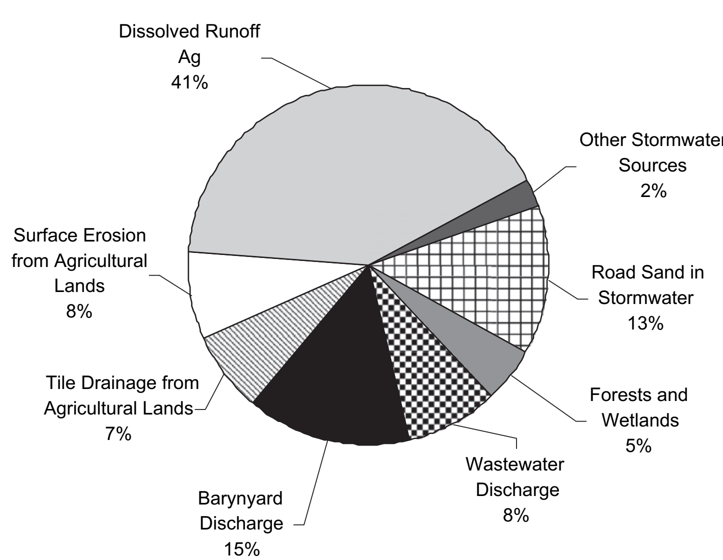

Fig. 1. Summary of percent of the total phosphorus load to watershed streams attributable to each modeled process or analyzed source.

a participatory computer modeling process. Observation notes were used to provide a check against each stakeholder's spoken word.

3. Summary of model results relevant to participatory research

3.1. Current sources of phosphorus load to St. Albans Bay

Detailed results of the spatial model developed for the St. Albans Bay watershed are described elsewhere (Gaddis, 2007). A brief summary is provided here to give context to the social dynamics discussed in the following section. Modeling results suggest that the St. Albans Bay watershed accumulates phosphorus over the long-term, primarily in agricultural soils. Phosphorus load to streams could be significantly higher than previously thought, possibly as high as 10.6 metric tons of phosphorus per year (mtP/year). The majority of the phosphorus load to streams in the St. Albans Bay watershed comes from non-point sources (8.06 mtP/year; 76% of total load) although point sources also contribute a significant load (2.49 mtP/year; 24% of total load; Fig. 1). Of the non-point sources, the most important source and pathway is dissolved phosphorus in agricultural surface runoff (4.37 mtP/year; 41% of total load) followed by road sand wash-off in developed areas (1.26 mtP/year; 13% of total load). Direct discharge to streams from farmsteads also represents a significant load to streams (1.58 mtP/year; 15% of total load) of which the majority comes from barnyard manure runoff and silage leachate. Addressing these three sources with available technology and management practices would result in phosphorus load reductions to streams that could achieve TMDL targets. The wastewater treatment plant has already reduced its phosphorus load significantly, and currently has one of the highest treatment standards in the State of Vermont. It is unlikely that improvements to this facility would be the most cost-effective in achieving reduction targets. Stormwater detention would also reduce in-stream erosion sources, which were not estimated in this study.

3.2. Scenario modeling results

While none of the individual solutions proposed by stakeholders could independently achieve the target reductions outlined in the Lake Chaplain Phosphorus TMDL, the model showed that some combination could have a meaningful impact (Fig. 2). The most effective combination of scenarios to achieve target reductions in the near future would be treatment of farmstead runoff and reduction of road sand using improved sweepers throughout the watershed and in the city. Implementation of these two actions could achieve a phosphorus load reduction of 1.76 mtP/year, equivalent to an approximate reduction of 17% in total phosphorus load to watershed streams. The cost of implementing these changes is estimated to be about $6 million and $680,000 respectively. Achieving a long-term nutrient balance in the watershed requires reduced fertilizer usage in agricultural and urban areas, and reduced manure application rates throughout the watershed. This is despite the fact that short-term load reductions from these actions will be small. This can only be achieved by reducing animal feed to the watershed or increasing the export of nutrients. Because manure has been primarily converted to a liquid waste, conversion of this valuable material to a product that can be exported from the watershed is currently prohibitively expensive.

3.3. Stakeholder response to model results: identifying new solutions

A primary goal of a participatory modeling exercise is to resolve differences between perceived and actual sources of an environmental problem. As observed in other studies, stakeholders may have proposed scenarios based on their perception of the problem but they also may be particularly adept at proposing new policy alternatives following initial model results from a scenario modeling exercise (Carr and Halvorsen, 2001). Other research has found that the participatory modeling process can further facilitate development of new policies through development of a collaborative network between stakeholders throughout the research process (Beirele and Cayford, 2002).

None of the scenarios proposed by the stakeholder group had an impact on two of the largest transport pathways of phosphorus from the landscape to streams: dissolved phosphorus in surface runoff (accounting for 41% of the total load) and phosphorus in field drainage (accounting for 7% of the total load). For a short time, stakeholders were somewhat discouraged that this was the case. However, they had come to understand that the phosphorus loading problem was the result of decades of human behavior and that it would take decades to correct the problem. This was a major educational success of the effort. As a result they took the challenge in stride, recognizing that it was likely that new technologies and innovative management strategies would be needed to target this need. During the last stage of the modeling process a new technology was introduced to the discussion that removes dissolved phosphorus using an industrial by-product from the steel industry called EAF steel slag barriers (Drizo et al., 2006). These technologies show some promise in being able to reduce the non-point source phosphorus load from surface runoff and field drainage. Stakeholders were excited and energized at the prospect that these possibilities for removing phosphorus from runoff might become available in the future. As the modeling process came to a close, they looked forward to working with the engineers to make more substantial progress in reducing phosphorus loading in the watershed.

Overall, many of the modeling results for the St. Albans Bay watershed were unexpected by the stakeholder group. These unexpected results included recognition that stakeholders' initial ideas for action in proposed scenarios would not address some of the most important sources and pathways of phosphorus movement to receiving waters (dissolved phosphorus from agricultural fields, road sand wash-off, and field drainage). This reflects a disconnect between the perceived relative importance of various phosphorus sources by stakeholders and their actual relative contribution to total phosphorus loads in the watershed. Some processes that had previously been considered significant by the stakeholder group, such as stormwater discharges proved not to be a significant direct source of phosphorus to watershed streams. The impact from stormwater appears to be its contribution to in-stream erosion which was not captured by the models developed for the watershed. This provided the stakeholders with a better sense of how the system works and the knowledge that new solutions are needed. Also unexpectedly, the participatory modeling approach employed in this study did lead to the identification of a new solution, the EAF steel slag barriers, to reduce phosphorus load to receiving waters. By the end of the process, it had become clear that the participatory approach had led to greater stakeholder acceptance and utility of model results as evidenced by local decision makers moving forward to implement solutions identified to be most cost-effective at the end of the process.

4. Social dynamics of participatory modeling

Understanding social issues is important to gain knowledge about stakeholders, the way they understand environmental issues, and have discussions of future policy options (Kasemir et al., 2003). Currently there is a gap in our understanding of these social processes in the context of planning initiatives that incorporate modeling.

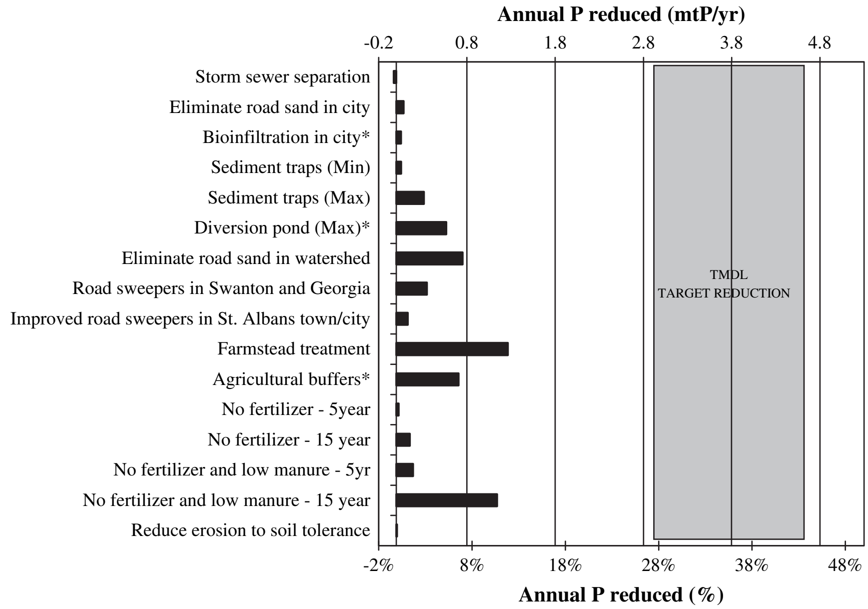

Fig. 2. Estimated phosphorus reduction of scenarios proposed by stakeholder working group. *Scenario also would reduce in-stream erosion, a process that was not quantified in the modeling process.

4.1. Historic conflict and improved collaboration between stakeholders

In assessing social implications of the modeling process, it is important to consider the history of conflict in St. Albans, including primary actors and the sources of conflict over natural resources. Stakeholders all defined the primary actors in conflict as the agricultural community (farmers) and the urban/suburban community. Secondarily, they described conflict between individuals in state and federal agencies and local citizens.

Sources of conflict identified during interviews included uneven expectations and responsibility for environmental problems, regulations and financial constraints, resistance to change, blame, and family history. These sources of conflict were focused primarily through the lens of agricultural versus urban land use and associated landowners. Stakeholders described collaborative processes that emerged during the modeling process, through which they moved beyond some of these conflicts. They felt the process helped them to develop positive conversations about natural resource issues, to become actors in a neutral process, and engage different people (Harp, 2006).

Almost all stakeholders emphasized the positive conversations that occurred. In these conversations, they addressed issues related to regulations and financial constraints as well as options for future planning and management options. Some stakeholders focused on how the model provided a neutral framework for discussion and decision making. This included descriptions of how people moved away from blaming individuals. This is illustrated by the following quotation.

> "It brought people together in a non-confrontational manner. That was key I thought. It wasn't that we were coming together to discuss what the farmers were doing, or what the city folk were doing. We were coming together to just say this is what is happening without any blame being placed on anybody."

Even though participants had conflicting ideas on what should be in the model, two stakeholders found that the modeling process provided a common ground for discussion. Nine of the thirteen stakeholders commented on how the modeling process brought people together to work on environmental issues. Urban stakeholders described learning about agricultural issues as a positive outcome. Similarly, members of the agricultural community described learning about urban issues as positive. Another person commented about how people worked together across levels of government, from city, town, and state government. Communication between stakeholders also improved among individuals working within the urban community. However, another stakeholder did not feel quite as strongly about the modeling process bringing people together but rather described the stakeholder meetings as a "springboard to get a few people together". This may be closer to the reality of this process and reflect the opinions of the external community about the nature of the process. The long-term outcome of the modeling process will provide greater clarity about this issue (Harp, 2006).

One overall observation of stakeholder meetings, confirmed during an interview, was that stakeholder groups were segregated at the beginning and became more integrated through the modeling process. That is, we noted that at the first meeting, people sat next to others who shared their same interest group. This segregation in seating choice changed as people became more comfortable with each other and started to sit next to people from other stakeholder groups. In terms of interactions, we observed increasing levels of collaboration as the stakeholder meetings progressed. These observations were supported by descriptions from all 13 interviewees emphasizing the collaborative processes that they felt had occurred. Overall, the collaboration that occurred through the computer modeling process allowed stakeholders to address several sources of conflict and brought them together across categories of urban and agricultural settings, as well as state and local government.

4.2. Increases in understanding of complexity and integration

As information from various sources and actors was brought to the medium of the model, stakeholders described a greater awareness about the importance of the phosphorus issue, a more accurate sense of how water moved through the watershed, better understanding of non-point source pollution and its causes, and an increased vocabulary that helped facilitate discussion.

The causal relationships between personal actions and increases in pollutants were an important theme for three people. One person described changes that he made after gaining a better understanding of non-point source pollution, indicating that he had started using phosphorus-free fertilizer. One indicated that the model showed how many smaller sources of pollution accumulated in a system and caused larger water quality problems. Another commented that the model clearly addressed the causes and effects of different actions in the watershed. These latter two focused on how the modeling process allowed participants to see the issue from a spatial perspective. This can allow stakeholders to see the bigger issues as well as their role in them.

Several stakeholders highlighted the holistic understanding of the system that they gained through the modeling process. As one stakeholder described it, "tying pieces of information together" was an important aspect of this process. One person emphasized the integration of diverse data sets into the model and indicated that she felt the model was stronger because we sought information from many sources in the community. The identification of modeling as a tool for integrating information is not surprising; it shows that, in this case, the model helped people synthesize varied forms of data.

While some stakeholders handled the complexity of the model well, others saw the complexity and technical nature of the model as overwhelming. While one stakeholder reflected on her experiences at the first stakeholder meeting with the complexity of the model, another said that many of the meetings were too technical for him to understand. He explained that he kept coming to meetings as a show of support for the project rather than with the expectation of understanding the specifics of the discussion. In these interviews, the stakeholders indicated that they believed that the complexity of the model was appropriate for what the community was trying to accomplish even though they did not always expect to personally understand all of the components and discussions. They stayed involved in the process in part because they could contribute to other dimensions, for example, providing information and developing ideas for possible actions. And, perhaps more important, they trusted other participants to manage the complex dimensions of modeling and could see the value of each individual contributing in their own way to the whole effort (Harp, 2006).

In our observations, when modeling discussions became very technical, several of the stakeholders who did not have much to contribute appeared uninterested or distracted by something else. It is important to avoid lengthy discussions of particular problems to keep the attention of the group as a whole. These issues are better resolved in sub-groups or as ad hoc workgroups that can meet separately in person or virtually, and then briefly report the results to the larger group. We also noted that there existed a strong division between stakeholders that represented agricultural interests versus stakeholders who were more interested in urban issues. This reflects the traditional compartmentalization of natural resource issues especially in Vermont. Although there was frustration over the complexity of the issues, the model helped to bring them together, and all stakeholders remained with the process to the end. In the future, it will be of value to investigate whether integration through the modeling process encouraged a more holistic understanding of different phosphorus sources.

4.3. *Incorporation of model results in future watershed management decisions*

Although many of the stakeholders involved in the St. Albans Bay watershed participatory modeling process were decision makers that influence policy and implementation of watershed interventions at multiple scales, there was no direct mechanism by which model results would be used in any decision making process. Through qualitative discussions, however, several stakeholders indicated that they intended to use the information gleaned from the project to direct existing funding sources and adapt policies to the extent possible to address the most significant phosphorus transport processes and sources in the watershed. Clearly, stakeholders are often limited in appropriating money and influence towards new projects, since other projects may have support for other reasons or are mandated by policies developed at higher bureaucratic levels, especially in the case of federally funded projects. Changing programs and policies of governmental agencies, especially to adapt to local conditions and problems takes time.

The issue of future use of the model was a focus of concern during several interviews. Initially the model was going to be put on the internet so that community members could continue to use it after the modeling process. Due to a lack of resources, this did not occur. Although the future use of the model by the community will be extremely limited due to its complexity and lack of continued presence by the University, many of the stakeholders were under the impression that they would be able to use it. Unfortunately, since the end of the participatory modeling process, the stakeholder group has not had the capacity to work with the model. However, they have continued to draw on results from the modeling exercise conducted over the course of the project. Several stakeholders participated in the presentation of model results to the local press and general public in May 2006.

There are several specific examples of watershed management changes that have emerged from this project. In addition several partnerships have been created or strengthened and trust developed between previously opposing groups as a result of the participatory modeling exercises. The municipalities in the watershed have agreed to investigate alternatives to road sand for winter deicing of roads. Recently the St. Albans Area Watershed Association partnered with the City of St. Albans to build a new salt shed that will help address the road sand source of phosphorus. Staff at the NRCS are moving forward with plans to improve treatment of farmstead discharge in the watershed (K. Hakey, personal communication, Spring 2006). The City and Town of St. Albans are undertaking a shared stormwater utility feasibility study (D. Perry, Northwest Regional Planning Commission, Fall 2008). Finally, the findings of this study were incorporated into the recent basin plan for the St. Albans Bay watershed (VTANR, 2008).

In addition to management changes, stakeholders had other recommendations and observations. A new focus on local decision making was suggested by a state employee as well as a town official. A member of the watershed alliance suggested a move away from adversarial relationships with the farming community. Another focus, echoing others' sentiments, is that information should be expressed in terms that people can understand. Several stakeholders suggested that education of the public was necessary in order to make important community wide changes to deal with diverse water pollution issues.

While participants are unlikely to manipulate the computer model in the future, their experience with the process and its results has informed efforts to identify and pursue management options. This dimension of the case illustrates how participatory modeling can contribute to adaptive management settings. As described by Cash et al. (2006) and Olsson et al. (2006), such settings present a range of scale challenges (spatial, temporal, jurisdictional, institutional, management, networks, and knowledge), all of which were present in our case. The participatory modeling process provided ways for participants to explore these challenges and consider implications for management responses.

5. Conclusions

The participatory research approach used in this study provided a transparent modeling process that involved a representative group of stakeholders throughout a two year research process at multiple levels of engagement—water quality monitoring, soil phosphorus sampling, model development, scenario analysis, and future policy development. As in other similar studies (Gaddis et al., 2007; Hare et al., 2003), the modeling process served as a neutral framework to address issues of conflict and to understand the different perspectives held by stakeholders in the watershed, and to work together towards common goals. The watershed model served as a powerful visualization tool that allowed stakeholders to see how pollution moved through a watershed, making it place-based and relevant to their particular spatial location within the watershed. By bringing people together in a neutral process—and, importantly, with the common perception that the process was, in fact, neutral—and discussing with them causal relationships of watershed processes, the participatory modeling exercise in the St. Albans Bay watershed effectively joined scientific research with stakeholder involvement.

Several important scientific findings emerged from this research, which would not have been discovered without the stakeholder involvement achieved in this project. Phosphorus sources and transport processes were identified that are not typically accounted for in watershed models including road sand and direct barnyard discharge. The evaluation of scenarios demonstrated that interventions perceived to be most effective may not necessarily be the most cost-effective mechanisms to reduce non-point source phosphorus loads, whereas interventions that had not been considered previously could achieve significant reductions at a reasonable cost. Although stakeholders were discouraged that scenarios proposed by the group did not curtail the largest transport pathways of phosphorus, dissolved phosphorus runoff from agricultural soils, the modeling process, and discussion during stakeholder meetings, resulted in the identification of new solutions and priorities for reducing total phosphorus to St. Albans Bay.

While the issue of uncertainty haunts many natural resource modeling studies where management decisions are imminent, in our case there was almost no problem with stakeholders ‘not trusting’ the model results or dismissing them because of the associated uncertainties, which, in fact, were large. The joint learning and understanding of the system and allowed everyone to see that we were employing the best available knowledge and data, and that decisions must be made with imperfect information. In essence, the stakeholders were ready to accept what they had helped to build.

Conflict issues in St. Albans provided a challenging backdrop to watershed planning. Collaboration during the modeling process allowed stakeholders to address several sources of conflict and bring them together across distinct planning categories of urban and agricultural settings, as well as state and local government. From interview accounts, the modeling process did provide collaborative opportunities among members of the modeling group.

Another remarkable feature of this study was a close collaboration between modelers and social scientists on this project. While the modelers were taking care of the model development, social scientists were providing important insight about group dynamics and helped identify particular problem areas in stakeholder interactions.

Non-point source pollution is a challenge in natural resource planning. Due to the diverse set of actors involved and multiple sources of pollution spatially distributed across the landscape, an integrative framework is useful for non-point source management. The modeling process allowed for a combination of lay and technical information, local and expert knowledge, as well as diverse perspectives. Overall, this study highlights the importance of considering the dynamics of both social and technical factors in the use of modeling in natural resource planning processes.

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