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Participatory modeling and the dilemma of diffuse nitrogen management in a residential watershed

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Abstract

Whereas point sources of nutrients are well understood and controllable, there is growing concern about non-point sources, especially those that are related to individual property owners. Modeling tools were used to analyze and visualize the fate of nitrogen from three anthropogenic sources: septic tanks, atmospheric deposition, and fertilizer. Our results suggest that septic tanks may be a less significant contributor to surface water nitrogen pollution in the short-term whereas fertilizer used at the home scale is a more significant source than previously thought. Participation in the study was solicited from community stakeholders who were instrumental in understanding how models could be applied to local decision making, in making appropriate model assumptions, and in developing politically feasible scenarios. Stakeholders used the model results to develop recommendations for the Calvert County Board of Commissioners. Recommendations include mandating nitrogen removal septic tanks for some homes, intensive citizen education about fertilizer usage, local regulation of fertilizer sales, reduction in automobile traffic, and cooperation with regional regulatory agencies working to reduce regional NO_x emissions. We explore how the participatory process can be used to influence decision-making, management policies, and citizen education in Calvert County, MD, to reduce all anthropogenic sources of nitrogen to local waters.

Keywords: Spatial modeling; Onsite sewage disposal systems; Septic systems; Stakeholders; Landscape; Decentralized wastewater; Nitrogen; Water Quality; Residential fertilizer use

1. Introduction

In the past 30 years the quality of fresh waters in the US has improved dramatically, in large part due to the widespread implementation of secondary and tertiary wastewater treatment systems, as required under the Clean Water Act (USEPA, 2000a). Remaining point sources of pollution are related to monetary and regulatory problems rather than technology shortfalls. As a result, research in water quality protection has shifted to issues of non-point source pollution. Unlike point-source pollution, in which the source is identifiable and thus controllable, non-point source pollution is an aggregation of pollution that comes, often inadvertently, from residences, farms, and businesses. The identification and quantification of non-point source pollutants and transport mechanisms have proven difficult and have thus limited the implementation of appropriate and effective solutions. Currently, most management plans that address non-point source pollution are driven by dissociated economic, political and ecological interests that are difficult to reconcile. As a result non-point source pollution is typically not well regulated.

Excessive nutrient loads to the Chesapeake Bay from surrounding cities and rural counties have led to eutrophication especially in small harbors and inlets (USEPA, 2002). The

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Maryland Tributary Strategies, Chesapeake Bay 2000 Agreement and Calvert County Comprehensive Plan (MDDNR, 2000), calls for reductions in nutrients entering the Bay in order to reduce impacts on aquatic natural resources. Though the goal set for phosphorous appears to be achievable, reductions in nitrogen lag well behind the target. Most sewage in rural residential areas of Maryland, such as Calvert County, is treated by onsite sewage disposal systems (septic systems). Almost all of the nitrogen pollution that enters local waters from Calvert County comes from non-point sources, of which the Maryland Department of Planning estimates 25% comes from septic systems. In this project we focus on the most densely populated watershed in Calvert County that drains to Solomons Harbor (Fig. 1). Despite high population densities, only a small portion of the watershed is serviced by sewer. There are no major point sources of nitrogen in the watershed.

Integrated watershed management aims to protect and improve water resources while considering economic and social concerns in the community. This is often best accomplished by engaging stakeholders and residents in the research process. Participatory environmental management requires tools, such as landscape models, that can be used to visualize and evaluate complex systems and the collective role of individuals. The goal of this project was to apply modeling tools to the Solomons Harbor watershed, while engaging citizens and stakeholders. This is especially important at this stage in the clean-up process in the Chesapeake Bay area because point-source polluters (wastewater treatment plants) and large non-point sources (i.e. large farms) are already being effectively mitigated (Morgan and Owens, 2001). The remaining non-point sources will require cooperation from homeowners, especially in rapidly developing medium-density watersheds, where nitrogen comes from septic tanks and application of fertilizer to lawns (Law et al., 2004). Therefore the specific goals of this project are:

1. Understand the relative impacts of septic tanks, atmospheric deposition, and fertilizer usage on nitrogen loads to the Solomons Harbor.
2. Determine how housing (thus septic tank) density and distribution affects nitrogen loading, by evaluating proposed septic tank policy changes using a landscape model.

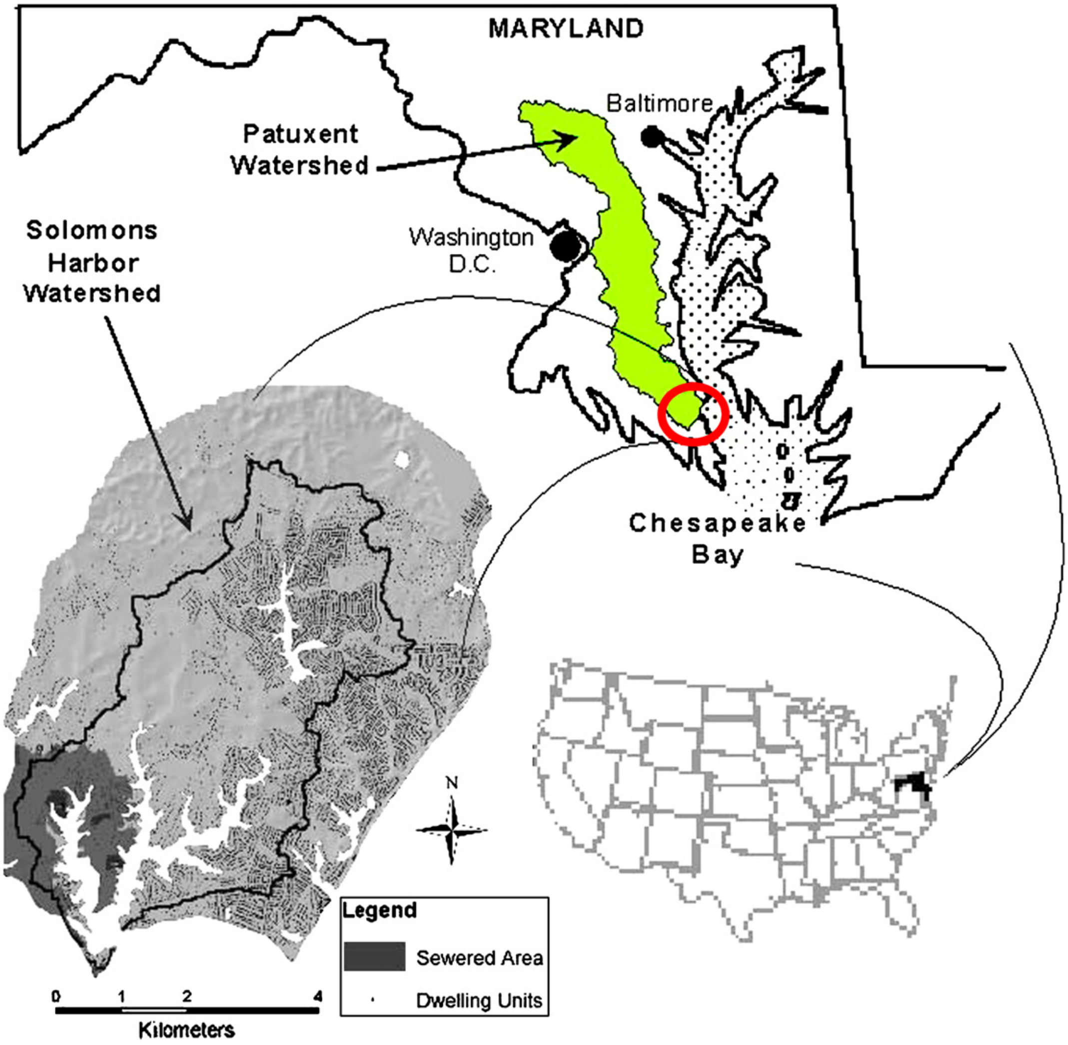

Fig. 1. Population density in Solomons Harbor watershed.

3. Engage stakeholders in meaningful dialogue about behavior patterns (i.e. fertilizer usage) and citizen initiated decisions.
4. Provide stakeholders with meaningful and understandable results such that they can derive effective policy recommendations to achieve their goals of reducing impacts on local water resources.

Two modeling tools in particular were used to achieve these goals. The first is a simple dynamic model of a septic tank and leachfield system using Stella™ software, which allows the user to evaluate alternative septic technologies. The second modeling tool is 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).

Modeling tools are useful in communicating complex processes, spatial patterns, and data in a visual format that is clear and compelling. Modeling also serves as a backbone for concerted efforts of stakeholders empowered by scientific knowledge. The importance of public participation in research related to science and public policy has developed under the umbrella of Participatory Action Research (PAR) (Wadsworth, 1998). PAR is a bottom-up, community and stakeholder driven investigation, which is usually initiated by social activists to solve particular local problems (Kemmis and McTaggart, 1998). In our case, there were no such existing PAR activities launched as of yet thus our approach was initiated by scientific researchers and the local Director of Planning and Zoning, rather than by the citizens themselves. The participatory approach that we advocate is an application of Post Normal Science (Funtowicz and Ravetz, 1993, 1994), which dictates that in problems characteristic of highly complex systems, when facts are uncertain, values in dispute, stakes high and decisions urgent, there is no one correct, value neutral solution. Under such circumstances, standard Western scientific activities are inadequate and must be reinforced with local knowledge and iterative participatory interactions in order to derive solutions which are well understood, politically feasible, and scientifically sound. Our participatory modeling approach is quite similar to the Companion Modeling approach (Barreteau, 2003), in that we aim both to develop a better understanding of a complex environmental system as well as to engage stakeholders and support their decision-making process.

Participatory modeling has become an important means by which stakeholders are engaged in the scientific process. There are many stages in the modeling process in which stakeholders can engage including model development, data collection, model assumptions, scenario development, interpretation of results, and development of policy alternatives based on model results. For example, the Mediated Modeling approach (Van Den Belt, 2004) assumes an intensive course of stakeholder involvement in both model building and model use, with several days of workshops and many hours committed to the effort, usually possible only if there is an established group of stakeholders that is clearly interested in the problem. This was not possible in our case, as the project was organized by our research team in conjunction with the local department of planning. We formed a working group of interested citizens and stakeholders who devoted time to attend five meetings but who provided valuable feedback and recommendations throughout the process. This study does not include a stakeholder process for building a model although stakeholder input was critical in making some key parameter assumptions (i.e. fertilizer usage behavior for homeowners). Instead, models were primarily used to support discussion about local water quality problems and proposed solutions. To this end, the final step in the project was a presentation to the Calvert County Board of Commissioners, which we hope will lead to new more informed policy decisions for the watershed.

2. Stakeholders driven objectives

In this project, we focused on the application and use of modeling tools to support decision making and community education. We designed a web page and organized a series of community stakeholder meetings to engage residents in the process (OSDS, 2004). Five stakeholder meetings were held with members of the Solomons Harbor community. The first and last of the meetings consisted of ~100 and ~35 people respectively, representing the diverse interests of concerned citizens, real estate agents, developers, state environmental regulators, county planners, septic tank companies, non-governmental organizations, and representatives from the research team. Three other meetings consisted of a small working group that volunteered to collaborate with us during the modeling phase of the project. Henceforth, this small team of stakeholders is referred to as the ‘working group’ and included several citizens, a real estate agent, the county planner, and a representative from a septic company. We refer to ourselves as the ‘research team’ to distinguish our contributions from those of others in the working group. The Green Mountain Institute for Environmental Democracy effectively facilitated the discussions. The issues raised and addressed in these meetings are presented in the sections to follow, whereas the chronology of meetings is summarized in Table 1.

2.1. Septic alternatives

Many technologies make claims of nitrogen reduction when in fact they only facilitate the process of nitrification, which does not reduce total nitrogen loading (in nitrate form) to groundwater (USEPA, 2000b). The representative from a septic tank company raised this issue during the first small working group meeting. Nitrogen reduction requires both nitrification and denitrification. The marketing and description of some technologies is confusing to the average consumer, as well as to some members of the working group. Alternative septic tank designs can also be quite expensive. The working group asked us, the research team, to develop a tool that they could use to easily evaluate the actual effectiveness and costs of different septic technologies and

Table 1
Chronology of stakeholder meetings

Meeting	Stakeholder Groups Present								Goals	Conclusions/Decisions
	Citizens	Developers	State Regulators	County Planner	NGOs	Septic Company	Researchers	Attendance		
1	▨	▨	▨	▨	▨	▨	▨	100	*Presentations:* Septic tank processes for nitrogen removal and nitrogen transport in watersheds *Discussion:* Relative sources of N to Harbor and concerns about water quality.	*Stakeholders:* 1. Agreed septic tanks were a sig. contributor of N to Harbor 2. Asked for comparison between septic systems
2	▨	▨		▨		▨	▨	12	*Presentations:* Stella model and spreadsheet demonstrate differences between septic technologies	*Stakeholders:* Decided to distribute survey to assess citizens' interest in replacing septic systems
3	▨	▨		▨		▨	▨	12	*Presentation:* Survey results suggest there is local interest in finding a solution *Discussion:* Given limited resources for modeling is it better to focus on scenarios which we (researchers) suspect will have the greatest impact or scenarios which are most easily implemented politically?	*Stakeholders and Researchers:* Derived scenarios for septic tank reduction based on survey results, open discussion, and input from interest groups present.
4	▨	▨		▨		▨	▨	12	*Presentation:* 1. Preliminary report of modeling results showing % N from septic, fertilizer, and atmospheric sources. 2. Effects of septic scenarios on N loading to local waters. *Discussion:* Modeling results and uncertainty were discussed. Stakeholders explored new innovative solutions to the problem	*Stakeholders:* Asked modelers to run a few more scenarios, changing the assumptions made about fertilizer usage.
5	▨	▨	▨	▨	▨	▨	▨	35	*Presentation:* Project results to the whole community *Discussion:* Solutions to both fertilizer and septic problem.	Presentation to Calvert County Board of Commissioners.

leachfield designs in order to help homeowners make good decisions that would be both affordable and effective at reducing nitrogen loads to the harbor.

2.2. Relative nitrogen loads on watershed and to surface waters from anthropogenic sources

In early discussions with the working group and the larger meeting of stakeholders it became clear to us that the community genuinely was concerned about water quality especially in Solomons Harbor and that there was a perception that septic tanks were a significant contributor. This perception is derived from a past study (Wood et al., 1998), well referenced in the community, that estimated the relative loads of atmospheric deposition, septic tanks, and fertilizer usage. The working group asked us to look at the relative importance of each of these on nitrogen loads to the harbor, taking into account the processes in the watershed. Thus, a major goal of our modeling research was to determine the relative contribution of various nitrogen sources both to the watershed as a whole and to track the transport of nitrogen from each of these sources to the actual harbor.

2.3. Scenario development for evaluation with landscape model

The working group developed policy scenarios, which would address the nitrogen contributed from septic tanks based on results of a mail-in survey of community members (conducted by the working group to assess willingness to implement septic tank upgrades) and open discussion. An interesting question emerged from this discussion: Given limited resources for modeling, is it better to focus on scenarios which we, the research team, suspect will have the greatest impact on water quality or those scenarios which are most easily and therefore likely to be implemented politically? Scenarios are very different for each perspective. For example, scenarios, which are likely to have the greatest impact on water quality are:

1. Upgrade or remove all septic tanks (central sewer).
2. Upgrade all septic tanks for nitrogen removal within a specified distance (60 m, 150 m, and 300 m) from surface waters.

However, the working group felt that the following scenarios would be more easily implemented and thus should be focused upon:

1. Upgrade all septic tanks in houses newer than 1993. All such houses have two chamber tanks, which permit a less expensive upgrade.
2. Upgrade all septic tanks at the time a home is sold (11% per year).

A consensus was reached through discussion to test both sets of scenarios using the Landscape Modeling Framework (LMF). The model itself is too large to run scenarios during the course of a meeting (each scenario takes 2–5 h to run). Thus, scenario modeling was carried out between meetings and the results of scenario runs were presented to the working group.

3. Modeling tools

3.1. Septic–leachfield model

We developed a dynamic model of a septic system with a leachfield using the Stella™ modeling software to represent the processes for nitrogen conversion and removal that occur in current and alternative septic technologies and leachfield designs. A user interface allows users to input one of eleven septic technologies and one of three leachfield designs and evaluate the nitrogen leaching from their property over the course of a typical year as well as the capital and operational costs associated with these decisions. The model is accompanied by a septic technologies ranking tool developed in MS Excel (OSDS, 2004).

A list of alternative septic technologies was obtained from the US Environmental Protection Agency (USEPA, 2004). The treatment mechanisms used in these innovative systems include extended aeration, trickling filters, fixed film reactors, and constructed wetlands. These options include those that nitrify and/or denitrify as well as standard technologies that do not remove nitrogen. Manufacturers of each technology were contacted by email or telephone, and asked questions regarding the operation, maintenance, and performance of the various systems. The model differentiates the loss of ammonia versus nitrate in the leachate. Both user defined inputs and geographically determined variables can be easily changed by the user. The Stella™ model can be downloaded by users (OSDS, 2004) and run using the free run-time Stella™ software.

3.2. Landscape Modeling Framework

The Landscape Modeling Framework (LMF), developed by the Gund Institute for Ecological Economics, couples the dynamic nature of ecological and hydrologic process models with GIS software in a distributed landscape partitioned into a spatial grid of square unit cells (Costanza and Voinov, 2004). Process models are built from modules composed in Stella™ and implemented within each grid cell in the landscape (Voinov et al., 2004). The transparency of modules developed with the Stella™ software is helpful in exploring complex systems captured by the LMF in the context of a participatory modeling process. The use of this software also allows us to build new modules to capture processes identified in the participatory process.

Existing modules, archived and described in the Library of Hydro-Ecological Modules (LHEM, 2004), were used to capture processes related to hydrology, plant growth, organic decomposition, and nutrient transport within each cell on the landscape (these processes can also be described as ‘local’ or vertical processes). For example, the hydrology module simulates water flow vertically within the cell. Phosphorus and nitrogen are cycled through plant growth and organic matter decomposition modules (Fig. 2). Although each module is composed separately in Stella™, they are linked together to form a ‘local’ model of hydro-ecological processes, implemented with unique spatially referenced parameters for each grid cell in the landscape.

The linking of modules together to form a local model to simulate ecological processes *within* each cell in the landscape as well as the spatial horizontal fluxes *between* cells are accomplished with the use of the Spatial Modeling Environment (SME) software (Maxwell and Costanza, 1995, 1997a,b, 1994; SME3, 2003). SME automatically links and converts the Stella™ generated modules into a C++ driver, allowing the user to run the modules as one complete process model which is replicated in each cell of the landscape at every time step (usually daily). Horizontal fluxes of water and nutrients are accounted for with cell–cell head differences of surface water and groundwater (Voinov et al., 1999a). Nutrients and other compounds are carried by water transport across the landscape. SME executes the simulation of landscape processes by reading spatial data layers in the form of maps prepared in GIS and time-series (i.e. climatic) data. A database of parameters serves as input to assembled models, which represent different habitat types within a landscape, including those dominated by human activity (Voinov et al., 2004). The Spatial Modeling Environment essentially executes multiple models across a landscape and calculates all of the horizontal transports at a user defined time step (usually daily). Feedbacks among the biological, chemical and physical model components are important structural attributes of this framework (Maxwell, 1999; Maxwell and Costanza, 1995; Voinov et al., 2004). A simulation run within the LMF gives a visual representation of the landscape as it evolves over time reflecting changes in hydrology, water quality, and material flows between cells. The LMF has been applied previously to several watersheds in Maryland (Costanza et al., 2002; Voinov et al., 1999a, 2004, 1999c), including the Hunting Creek watershed also in Calvert County.

3.3. Landscape model application

The implementation of the Landscape Modeling Framework for this project was done on a spatial scale of 30 m × 30 m grid cells and a daily time step. Water quality and flow data were not available to calibrate the model for Solomons Harbor. Instead, the model was calibrated for the nearby Hunting Creek watershed (Seppelt and Voinov, 2002; Voinov et al., 1999a, 2004) using flow and nitrogen data collected by the USGS from 1990 to 1995 (USGS, 2000) (Fig. 3). We achieved an r^2 of 0.62 in our calibration exercises, and believe that remaining discrepancies are related to the accuracy and resolution of available climatic data. The model is driven by daily climatic data, thus subdaily heterogeneity (i.e. rain intensity) is not available in the data that drive the model but is captured in the stream gauging data (used in calibration), since stream flow responds differently to an intense storm compared to a light but longer storm. Furthermore, the climatic stations are located almost 45 km from the Hunting Creek watershed.

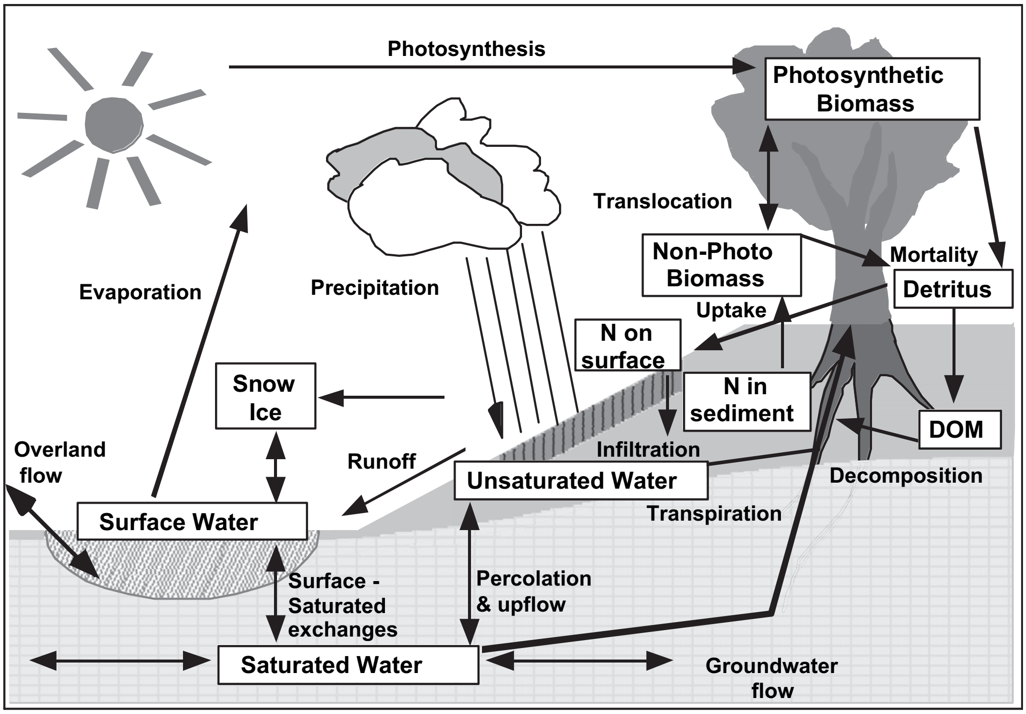

Fig. 2. Main variables and flows considered in the unit model.

Considering these factors, we believe our calibration results are quite good. However, because calibration was not done explicitly on the Solomons Harbor watershed we felt that we could only apply the calibrated model for use in comparing *relative* nitrogen loads from three sources, rather than for predicting *actual* nitrogen loads.

3.4. Scenario modeling

The landscape model, described above, was first run for a 5-year simulation, using climatic data from 1990 to 1995, to determine current system conditions. The relative contribution of atmospheric deposition, septic tanks, and fertilizer

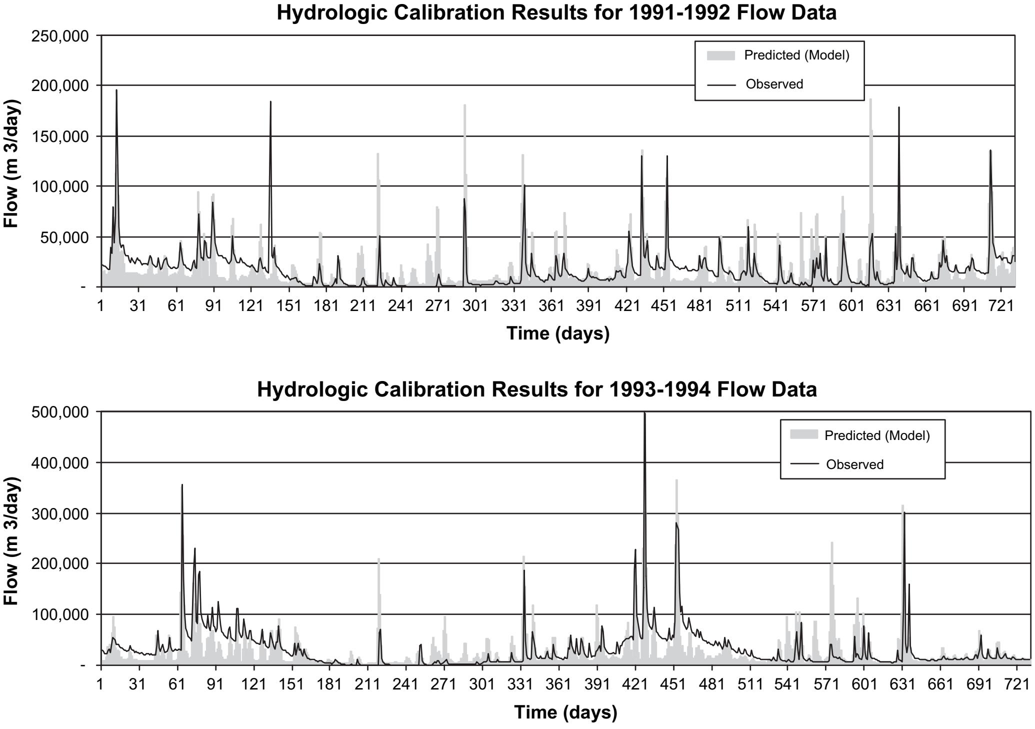

Fig. 3. Hydrologic calibration for Hunting Creek using 1991–1994 data.

were assessed by turning each of these off in the model and evaluating the change in nitrogen load to the entire watershed, to groundwater, and to the harbor over the same 5-year period. In addition, each was turned on in isolation to evaluate synergistic effects from multiple sources. Individual septic tank scenarios, developed in conjunction with the working group, were evaluated by creating alternative septic maps. The current septic map was derived from a housing density map multiplied by average people/dwelling unit for each block group in the watershed. Scenario maps simply removed selected houses (depending on the scenario) from the map. The model was then rerun and compared to the base (current) condition. Individual paired *t*-tests (SPSS) were used to evaluate whether the change in estimated nitrogen load was significantly different from the base condition.

4. Modeling results

4.1. Septic–leachfield model

The simple septic-leachfield model was used to pre-run all of the technologies for a typical climatic year with a standard leachfield design, based on the nitrogen produced by a typical family of four. Total nitrogen exported from the system ranged from 1.1 kg/year to 25.5 kg/year. Capital costs ranged from $3000 to $9200 and included both new and retrofit options. Operational costs ranged from $0 to $365. The most expensive systems did not provide for the highest level of nitrogen treatment, although they may have other benefits related to leachfield life-time.

4.2. Relative nitrogen loads on watershed from anthropogenic sources

Relative loads of nitrogen to the entire watershed were calculated over 5 years (1990–1995) using time-specific climatic data. We have a good estimate of atmospheric deposition (NCDC, 2000), septic loading of nitrogen (USEPA, 2000a,b), and fertilizer usage by farmers. It is considerably more difficult, however, to estimate fertilizer use by residents in suburban neighborhoods. An original estimate had been 5 kg/ha, which would correspond to 22% of the total load of nitrogen to the watershed. This is a relatively low estimate, and to test this assumption, we examined the recommendations listed by Scotts® fertilizer (Scotts, 2004) for Kentucky blue grass in Maryland. In order to be relatively conservative, we assumed that only 1/4 of the residents in the county followed these recommendations and that 1/5 of the residential area was covered with lawn. Based on these assumptions residential fertilizer usage could be as high as 50 kg/ha, thus accounting for 63% of the total nitrogen load to the watershed (Fig. 4). Estimates of fertilizer usage per unit of residential landuse determined by the LTER study in Baltimore, Maryland, is approximately 27 kg/ha (Law et al., 2004). Thus, a medium level (15 kg/ha) of fertilizer usage was assumed for the purposes of running the scenarios. This would account for 38% of the total nitrogen load to the watershed (Fig. 4). The working group was very helpful in determining this particular, very important, model assumption. All of the relative comparisons of scenarios described in the sections to follow are based on this assumption of local fertilizer usage.

4.3. Effects of each nitrogen source on total loading to surface waters

The proportional contribution of nitrogen from anthropogenic sources to the entire watershed differs from the proportional contribution of each source of nitrogen that migrates *to the harbor*. Nitrogen from atmospheric deposition, for example, is deposited on the surface of the landscape, most often during rain events. Residential fertilizer on the other hand, is added periodically to the landscape in quantities that provide for plant uptake of some nutrients. As a result, a higher percentage of the nitrogen that comes from atmospheric deposition is mobile and likely to runoff into nearby surface waters during a storm compared to nitrogen from fertilizer. This is the case, unless of course it rains immediately following a fertilizer application. Nitrogen deposited from septic tanks is discharged relatively deep in the soil and migrates to shallow aquifers. Transport of nitrogen via this pathway is dependent on the movement of groundwater, which can be quite slow especially in the relatively flat and homogenous area of Calvert County. As a result, nitrogen from septic tanks has a smaller total contribution to surface waters in the short-term, including the harbor, than fertilizer or atmospheric deposition. Thus, we would expect to see accumulation of nitrates in groundwater. This has indeed been documented in some parts of Calvert County (Brownlee et al., 2004). This explains why removal of atmospheric deposition and fertilizer has a greater impact on water quality in Solomons Harbor over 5 years than does removal of septic nitrogen (Fig. 5).

The research team decided to also track the long-term trends of groundwater quality (Fig. 6). When there is no additional incoming pollution to groundwater (no anthropogenic scenario), nitrogen in the groundwater decreases over time. Removal of any one anthropogenic source (septic, fertilizer, or atmospheric) simply reduces the rate at which nitrogen in the groundwater accumulates. The nitrogen that humans add to the system results in a gradual increase in groundwater pollution, since there is no removal mechanism except for dilution by cleaner water.

4.4. Results of septic scenario modeling

Model results of different septic upgrade scenarios indicate that, with the exception of upgrading all septics, none of the proposed scenarios is likely to result in substantial reduction of nitrogen loading to the harbor in the first 2 years (Fig. 7). In year 3 we could expect slightly more substantial reductions, however the maximum reduction in load is less than 13% over 5 years, when all the septic tanks are upgraded. This delayed response is related to the slow movement of groundwater in this relatively flat watershed. All alternative scenarios give even smaller effects. We expected distance to closest stream to be an important

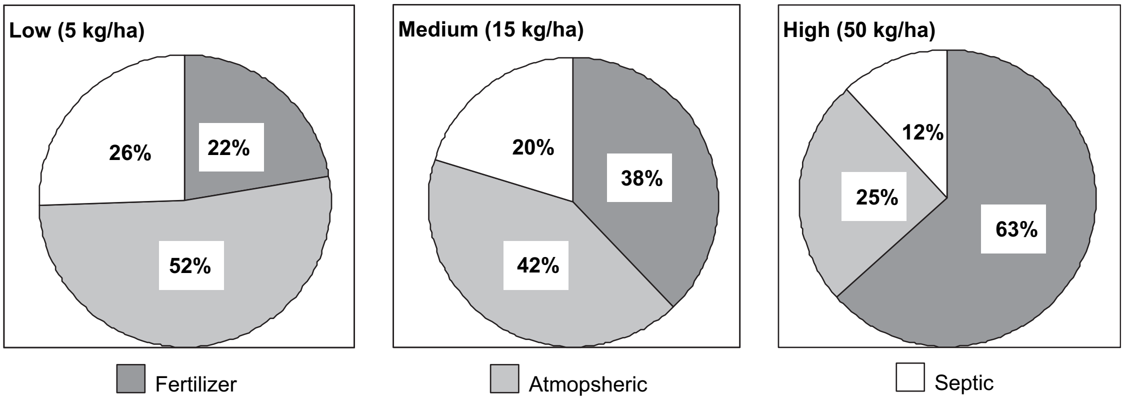

Fig. 4. Relative sources of nitrogen to Solomons Harbor watershed based on fertilizer usage assumptions.

factor in septic nitrogen loading. However, this appears not to be the case. The reduction in nitrogen as a result of extended buffers from surface waters appears to be the result of the total number of houses taken off of septic systems rather than their relative distances from surface waters. This is in part because, unlike surface water runoff, groundwater accumulates nitrogen but has no mechanism for reduction.

5. Stakeholder response and policy recommendations

An interesting issue with significant impacts on the participatory modeling approach has emerged during this project. Fertilizer and atmospheric deposition have a significantly larger effect (more than the community thought) on nitrogen loads in Solomons Harbor, whereas none of the proposed septic management scenarios are likely to have a real effect on the trophic status of the harbor, in the short-term. Nonetheless, upgrading septic tanks is still a good environmental decision since it would improve groundwater quality and, in the long-term, affect surface water quality. Furthermore, it is the only regulation that can be easily and immediately implemented at the local level. The recently adopted ‘‘flush tax’’ in Maryland provides funds for implementation of such local policies.

The model results were first presented to the smaller working group over two meetings and were a severe test of participant confidence, since our results were somewhat contrary to previous estimates (Wood et al., 1998). The working group took a very positive and constructive approach, eager to help gather more information (i.e. on fertilizer applications) and willing to work on developing best strategies for communicating the results with the larger pool of stakeholders. In addition, while realizing the inherent uncertainties in the modeling process, they began to explore new solutions and policy recommendations. This response is similar to the social learning process employed in Europe (Pahl-Wostl and Hare, 2004).

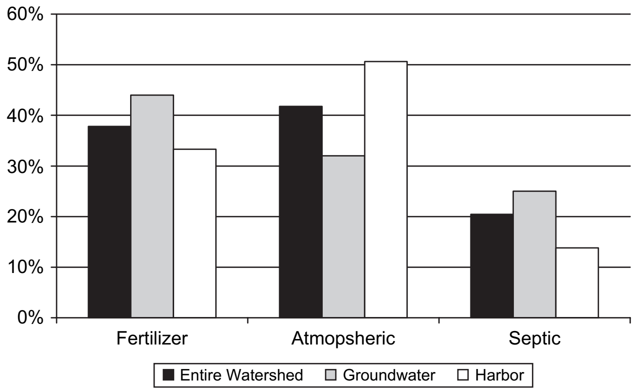

Fig. 5. Proportion of nitrogen from three sources to Solomon’s harbor watershed, groundwater, and harbor over 5 years.

5.1. Recommended management decisions

The working group felt that upgrading all septic systems, a very costly proposal, is unlikely to be accepted by the public. However, they determined that selective upgrading would receive public support even though it is unlikely to result in attainment of water quality goals in the short-term. We are thus faced with the dilemma of presenting this recommendation such that residents are not made to feel helpless toward the situation but also such that we do not give false hopes of improved water quality due to the upgrade of select septic tanks in the watershed. A similar situation arose in the small town of St. Albans, Vermont, which has been dealing with the problem of phosphorus runoff to nearby St. Albans bay. In the 1980s, the community spent large amounts of money to install a wastewater treatment plant to remove phosphorus, and loads have been significantly reduced. However, the continued non-point source loads as well as the internal loading from historic sediments in the bay has meant that water quality has not improved and is now not expected to improve for at least 20 more years, leaving some residents frustrated and confused (Smeltzer, 2003).

This issue was discussed at length with the working group. Rather than abandoning the proposed policies to reduce nitrogen from septic tanks, the working group chose to expand its policy recommendations to include all sources of nitrogen to the watershed. The research team found this to be a distinctly positive outcome of the participatory modeling exercise. The working group came up with the following conclusions about the types of policy options that are realistic and available to

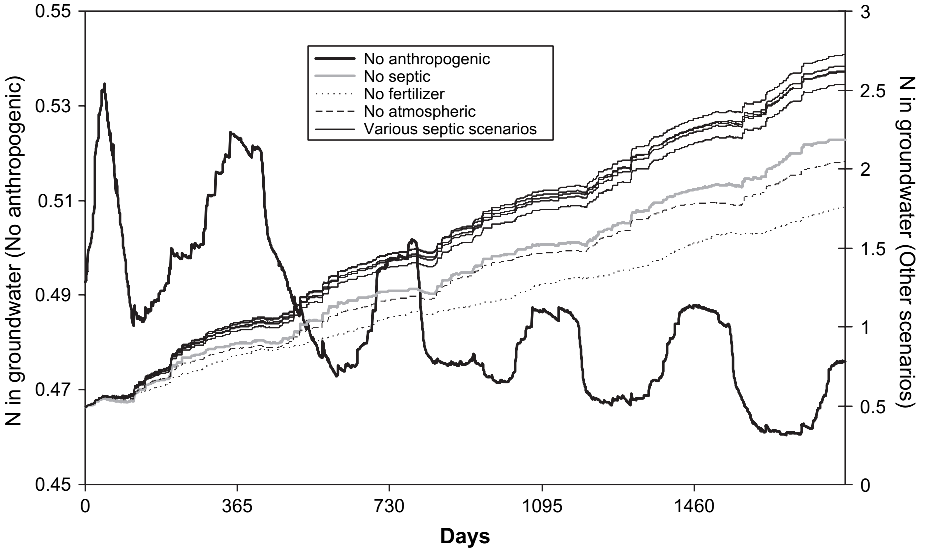

Fig. 6. Change in nitrogen concentration in groundwater for a variety of scenarios over 5 years. Removing anthropogenic sources (left axis) of nitrogen leads to a gradual decline in groundwater concentration, whereas all other scenarios reduce the rate of increase (right axis).

the Solomons Harbor community. Atmospheric deposition cannot be directly influenced by local citizens, except through reduction of local traffic and lobbying regional officials to reduce NO_x emissions from coal-fired power plants. Fertilizer usage could be most easily influenced through educational initiatives since policy changes would require involvement of other governmental and citizen groups beyond the Department of Planning and Zoning which is currently leading the initiative to reduce nitrogen to the harbor.

Two members of the working group then presented their recommendations to the larger stakeholder group following a presentation of the modeling results by one member of our research team. This was the last of all the stakeholder meetings and included a large group (∼35) of citizens in addition to members of the working group and several representatives of local and state government. During this meeting David Brownlee, the Director of Planning and Zoning for Calvert County solicited feedback on proposed policy recommendations and later refined them for a presentation to the Calvert County Board of Commissioners.

5.2. Recommendations to Calvert County Board of Commissioners

The Director of Planning and Zoning and a representative from one of the largest homeowners associations presented the following policy recommendations to the Calvert County Board of Commissioners. We emphasize that the role of the research

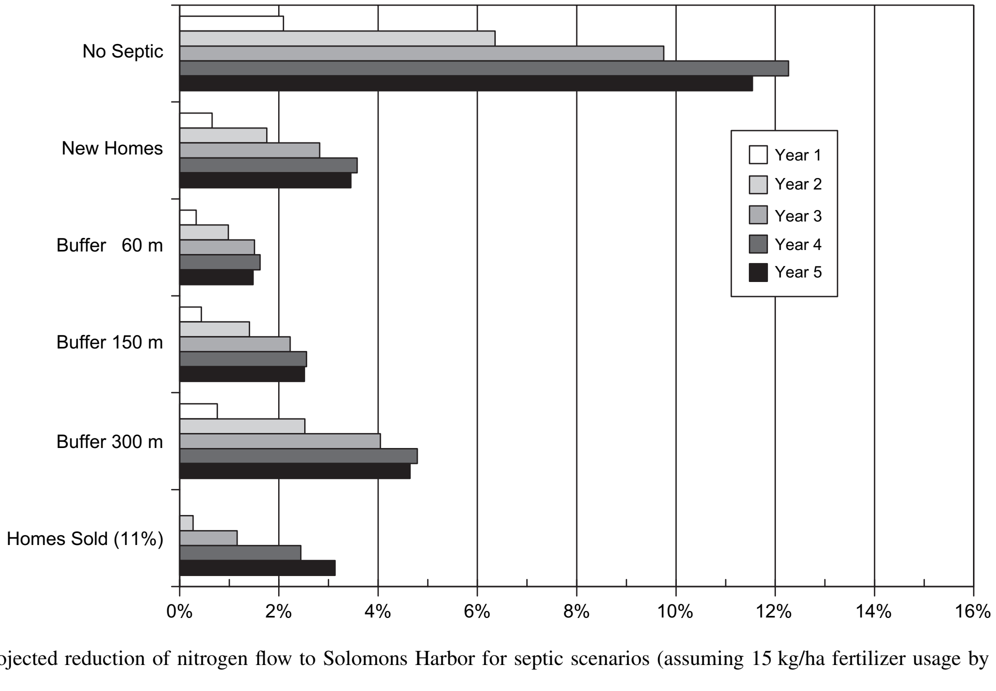

Fig. 7. Projected reduction of nitrogen flow to Solomons Harbor for septic scenarios (assuming 15 kg/ha fertilizer usage by residents).

team in this process was to support the discussion rather than to recommend our own policy ideas. One member of the modeling research team was present to answer questions regarding the conclusions arrived at with use of modeling tools.

With respect to septic tank nitrogen loads to groundwater and surface water, the working group recommended that nitrogen removing septic tanks be mandated for all new homes, all replacement septic systems, and replacement of existing systems at time of sale of property. Funding for some retrofits could come from the Chesapeake Bay Restoration Fund in which all septic system users pay $2.50/month into a fund. Although, the Chesapeake Bay Restoration Fund Advisory Committee determines how funds are spent, it is understood that 60% of the funds are available to subsidize installation of nitrogen removing systems. The working group also recommended that long-term wastewater treatment planning include exploration of other alternatives such as community ‘cluster’ wastewater treatment systems. In addition, it was recommended that the commissioners revisit legislation that makes installation of composting toilets prohibitive (a conventional septic system is still required even if composting toilets are installed).

The working group also recommended that legislation be changed to limit the types of fertilizers sold in Southern Maryland. Recognizing that this policy change may take some time to advance, the working group also recommended that low nitrogen fertilizers be promoted and made available in the short-term.

The lack of public education and outside funding was recognized as one of the primary obstacles to implementation of the recommended policies. Thus, the working group recommended specifically that funds be made available immediately to hire a watershed coordinator for the Solomons Harbor watershed. A watershed coordinator would be responsible for organizing watershed groups, searching for funding for watershed projects, and facilitating communication between citizens and county, state, and federal agencies. A central part of the watershed coordinator’s position would be to develop a public education campaign that includes use of nitrogen-removing septic tanks and reduction in the use of lawn fertilizers.

The working group recommended that the County Commissioners work through the Metropolitan Washington Air Quality Committee (MWAQC) to reduce transboundary atmospheric deposition of nitrogen. A current court order would reduce nitrogen oxide discharges from coal-fired power plants by 65% by 2010. The working group recommended that the County Commissioners support this initiative through communication with regional officials.

The County Commissioners agreed to consider these recommendations but have not yet made any definitive decisions about any of them. It was decided that the watershed coordinator’s position will be evaluated during the budget review process.

6. Conclusions

This project focused primarily on the application of modeling tools rather than on their development and refinement. We used a well-tested modeling framework, which is flexible enough to apply in different situations. Nonetheless, we were restricted to making comparative conclusions rather than absolute predictions. The modeling tools we employed allowed us to successfully accomplish all of our stated goals.

We successfully determined the most important causes of nitrogen loading to the harbor. Atmospheric pollution, primarily from transboundary sources, contributes the most nitrogen load to the watershed and harbor, but local governments have less control over this factor except through their influence on regional bodies. Fertilizers proved to be the second most important factor (and depending on assumed fertilizer usage could surpass atmospheric). Based on our model results we concluded that the overall input from septic tanks is the lowest among all the anthropogenic nitrogen sources. In addition, the discharge is leached into groundwater, which affects surface water quality in the long-term. The large buffering capacity of groundwater means that changes made to septic systems will take longer to materialize into surface water quality improvement. We found that housing density (the total number of homes in the watershed) was the most important criteria to consider when developing septic related policies. The distribution of these homes surprisingly had relatively no effect on total nitrogen loads to the harbor. Managing septic loads is most feasible to implement at the local level. Policy recommendations to the County Commissioners reflected these findings and included mechanisms to reduce nitrogen from all three anthropogenic sources.

Throughout the project we effectively engaged stakeholders in meaningful dialogue about behavior patterns and the effectiveness of politically feasible solutions to the nitrogen loading problem in Solomons Harbor. We have found dynamic spatial modeling tools to be an effective tool in stakeholder discussions of complex non-point source pollution issues. The tools allow stakeholders to visualize and assess the tradeoffs between short-term and long-term pollution issues and their relative costs and difficulties. The interaction with the stakeholder community was an exciting experience that led us to several insights especially in terms of deriving politically feasible scenarios and the openness with which our results were incorporated into current planning and policy efforts. Based on the community support of this project, we hope that the educational and policy changes derived from the results of the modeling experiments will result in real change in nitrogen loads to Solomons Harbor.

We believe that the results gathered and the methods employed in this study have potential applications in many other watersheds. There is a growing interest in stakeholder engagement in the decision making process. Various software tools have been developed to provide access to data and models in a user-friendly and interactive way (Argent and Grayson, 2003; Pereira et al., 2005). We rely primarily on the visualization tools provided by the SME viewserver (SME3, 2003) and the Stella™ (ISEE, 2004) GUI that is used to develop modules. Our experience is that each stakeholder group can handle only a certain amount of complexity and scientific sophistication and it is important to maintain the right balance between providing model details and fostering an overally understanding of the system and the modeling results. A group can easily loose interest and then, often, trust in the model if its description becomes overly complex. While the visualization and interpretation tools are essential, it is really face-to-face discussions and interactions that seem to matter most in advancing the decision making process and incorporating local knowledge into the modeling process.

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