Participatory Spatial Modeling and the Septic Dilemma

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Abstract: Whereas point sources of nutrients are quite well known and controlled, there is growing concern about non-point sources, especially those that are related to individual homeowners and citizens' practices. They seem to be the hardest to manage and reduce. On-site sewage disposal systems (OSDS) are among the major contributors to the nutrient pollution of surface and ground waters. In Calvert County, Maryland, up to 25% of the non point source nitrogen pollution originates from septic systems. A participatory landscape modeling approach has been used to analyze and visualize the impact of septic systems on the water quality entering the estuary. The landscape model tracks the fate of nutrients released from septic tanks and other non-point sources. A series of stakeholder workshops have been arranged to demonstrate, using the model, how septic discharges contribute to the water pollution in the estuary. Our results suggest that septic tanks are a less significant contributor to surface water nitrogen pollution in the short-term than was previously assumed whereas fertilizer runoff may be more important than previously thought. We are exploring how this participatory process can be used to influence decision-making and management policies in the County to reduce all sources of nitrogen to local waters.

Keywords: Spatial modeling; Sewage disposal systems; Stakeholders; Landscape; Decentralized wastewater

1. INTRODUCTION

A new chapter in environmental management is upon us. Whereas previously the major dichotomy was between point and non-point sources, now the perceived source of environmental degradation shifts from ‘large companies’ and entities, which can be regulated to individuals (us) who make independent choices. The largest source of water pollution in many parts of the United States comes from individual homeowners, small farmers, and small businesses. These non-point sources are more dispersed, and difficult to quantify, than pollution coming from large agricultural tracts. This makes it nearly impossible to regulate. As a result there is a growing need and interest in solutions that engage citizens. Education and participatory environmental management requires tools that can be used for visualization of options and evaluation of complex systems. We believe that modeling tools will be instrumental in achieving good decisions using the participatory management framework.

Excessive nutrient loads to the Chesapeake Bay from surrounding cities and rural counties has led to eutrophication especially in small harbors and inlets [EPA 2002]. The Maryland Tributary Strategies, Chesapeake Bay 2000 Agreement and Calvert County Comprehensive Plan [MDDNR 2000], calls for reductions in nutrients entering the Bay to reduce impacts on aquatic natural resources. Though the goal set for phosphorous appears achievable, reductions in nitrogen lag well behind the goal. Most sewage in rural residential areas in Maryland is treated by on-site disposal systems, or septic tanks. For Calvert County, the Maryland Department of Planning has estimated that 25% of the non-point source nitrogen pollution to local waters originates from septic systems. Therefore it appears that if Calvert County is to meet nutrient reduction goals, then nitrogen from septic systems must be addressed.

The Gund Institute for Ecological Economics has developed a spatially explicit Landscape Modeling Framework (LMF) that can be used to estimate the relative impact of different point and non-point sources of nutrients on waters throughout a watershed [Costanza 2003]. The goal of the current project was to apply this framework to the Solomon’s Harbor watershed, the most densely populated watershed in rural Calvert County. The specific goals of this project include:

1. Understand whether upgrading septic tanks can make a difference in nitrogen pollution of the Harbor in either the short or long-term.
2. Determine how housing density and distribution affects nitrogen loading.
3. Most importantly, engage stakeholders in meaningful dialogue about behavior patterns and local citizen-initiated decisions.

By applying modeling tools we provide visualizations and data in a compelling and clear way. As a result, we hope to support decisions that will help to achieve nutrient reduction goals. These results can then be applied to other watersheds in Calvert County.

2. LANDSCAPE MODELING FRAMEWORK

2.1 Spatial Modeling Environment

The LMF couples the dynamic nature of ecological and hydrologic process models with GIS technology. The modeled landscape is partitioned into a spatial grid of square unit cells. Unit models, composed of existing modules, are run in each cell. Modules are archived and described in a Library of Hydro-Ecological Modules [LHEM 2004]. The hydrology module simulates water flow vertically within the cell. Phosphorus and nitrogen are cycled through plant growth and organic matter decomposition modules (Figure 1).

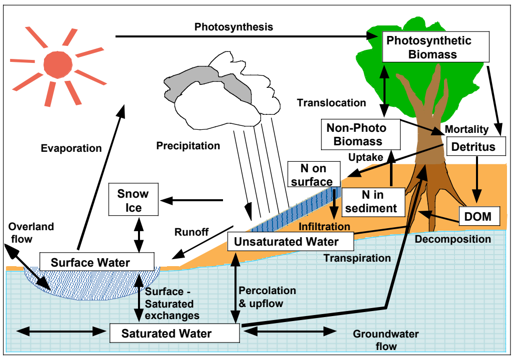

Figure 1. Main variables and flows considered in the unit model.

While the unit model simulates ecological processes within a unit cell, horizontal fluxes are within the domain of the broader spatial implementation of the unit model that forms the landscape model. Such fluxes are driven by cell-cell head differences of surface water and of ground water in saturated storage [Voinov et al. 1999]. Nutrients and other compounds are carried by water transport across the landscape. This spatial implementation is achieved within the framework of the Spatial Modeling Environment (SME) [Maxwell and Costanza 1995, Maxwell and Costanza 1997a, Maxwell and Costanza 1997b, Maxwell and Costanza 1994, SME3 2003]. SME links local unit models with GIS spatial data and algorithms of horizontal transport. 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]. Thus, when run within the LMF, the landscape evolves to reflect changing hydrology, water quality, and material flows between adjacent cells. 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]. Further modules are currently being developed to allow dynamic simulations in terms of economic variables such as social, natural and built capitals.

2.2 Study Area and Case Studies

We have previously applied the LMF to several watersheds in Maryland [Costanza et al. 2002, Voinov et al. 1999a, Voinov et al. 1999b, Voinov et al. 1999], including the Hunting Creek watershed also in Calvert County. In this project we focus on the most densely populated area in Calvert County that drains into Solomon's Harbor (Fig.2). Only a small portion of the watershed is serviced by a sewer system, whereas the rest of the area is entirely on septics.

The existing design of septic tanks provides for practically no removal of nitrogen, and all the discharge is leached into the groundwater. Alternative septic designs are expensive, especially as retrofits. Our challenge was to provide the county and citizens with the information required to make good decisions that would be both affordable and effective at reducing nitrogen loads to the harbor. We used the modeling approach to help compare various scenarios and understand what priorities should be set and how septic tanks, atmospheric deposition, and fertilizer contribute to the nutrient loading of the harbor.

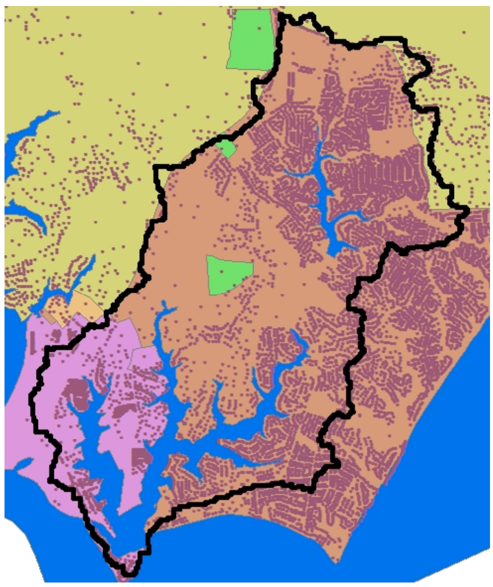

Figure 2. Study area. Dots are individual residences. The lower magenta area is serviced by a central sewer; remaining area is on septic tanks.

2.3 Model calibration and validation

Water quality and flow data were not available to calibrate the model for Solomon's Harbor. Instead, the model was calibrated for the nearby Hunting Creek watershed [Seppelt and Voinov 2002, Voinov et al. 1999a, Voinov et al. 1999b] using flow and nitrogen data collected by the USGS from 1990 – 1995 [USGS 2000]. However, we felt that applying that model to a different watershed should not be used to predict actual nitrogen concentrations, but was appropriate for use in comparing scenarios and relative nitrogen runoff.

3. STAKEHOLDERS AND DECISION-MAKING

From the start of this project we have focused on the application and the use of modeling tools to support decision-making and community education. We have designed a web page and organized a series of community stakeholder meetings to engage residents in the process [OSDS 2004] .

3.1 Stakeholder meetings

Four (of five) stakeholder meetings have been held so far with members of the Solomon's Harbor community. The first meeting attracted almost one hundred people, representing diverse interests of concerned citizens, real estate agents, developers, state environmental regulators, county planners, septic tank companies, non-governmental organizations, and representatives from the team. The meeting focused on discussion of relative sources of nitrogen to Solomon's Harbor and community concerns with respect to water quality. There were several prepared [OSDS 2004] about septic tank processes and nitrogen transport in watersheds, but the group was most eager to engage in active discussion. This discussion was effectively facilitated by the Green Mountain Institute for Environmental Democracy. It is generally agreed in the community that septic tanks are a significant contributor to the nitrogen load in nearby Solomon's Harbor. One of the goals of our modeling research was to test this assumption and determine relative contributions of various nitrogen sources to the harbor.

The second and third meetings were gatherings of a smaller task team (~12 people) that had volunteered to collaborate closely with the modelers during the entire term of the project. This group included several citizens, a real-estate agent, the county planner, and a representative from a septic company. We have focused on the tradeoffs of decentralized wastewater alternatives. One of the main goals of the second meeting was to demonstrate which technologies complete the nitrogen reduction process (nitrification and denitrification). Many septic technologies make claims of nitrogen reduction when they only facilitate the process of nitrification, which does nothing to actually reduce total nitrogen loading (in nitrate form) to groundwater. A simple spreadsheet was developed for selecting alternatives based on the tradeoffs between cost and nitrogen reduction. A survey was distributed to assess citizens' concerns and interest in changing the practice of septic treatment.

3.2 Scenario development

During the third meeting, considerable effort was spent deriving scenarios for septic tank reduction based on survey results, open discussion, and input from all interest groups. An interesting question emerged from this discussion: Given limited resources, is it better to focus on scenarios which we suspect will have the greatest impact on water quality or those scenarios which are most easily 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.

Alternatively, the stakeholders felt that the following scenarios would be more easily implemented and thus should be focused on:

1. Upgrade all septic tanks in houses newer than 1993. (All such houses have 2 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 to test all of the scenarios using the landscape modeling framework.

4. MODELING RESULTS

4.1 Relative nitrogen loads on watershed from anthropogenic sources

Relative loads of nitrogen to the entire watershed were calculated over five years (1990 – 1995) using time-specific data. We have a good estimate of atmospheric deposition [NCDC 2000], septic loading of nitrogen [USEPA 2000], 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

Scott's fertilizer [Scotts 2004] for Kentucky bluegrass 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. 3). Estimates of fertilizer usage determined by the LTER study in Baltimore, Maryland are 15 – 25 kg/ha [Band 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. 3). All of the relative comparisons of scenarios described in the sections to follow are connected to this assumption.

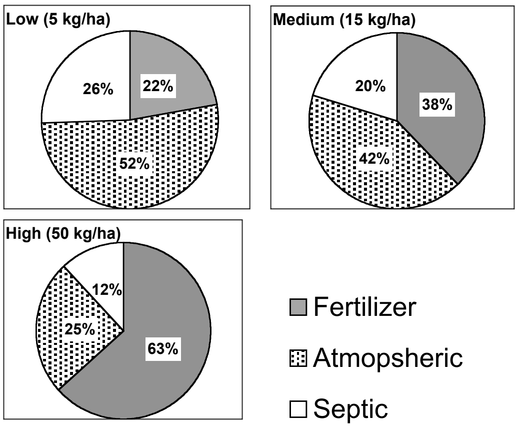

Figure 3. Relative sources of nitrogen to Solomon's Harbor watershed based on fertilizer use assumptions.

4.2 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. Fertilizer on the other hand, is added (theoretically) periodically to the landscape in quantities that provide for plant uptake. As a result, a higher percentage of the nitrogen, which comes from atmospheric deposition, is mobile and likely to runoff into nearby surface waters compared to nitrogen from fertilizer.

Nitrogen deposited from septic tanks is discharged relatively deep in the soil and migrates to shallow aquifers. Migration 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 can be expected to have a smaller total contribution to surface waters in the short-term, including the harbor, than fertilizer or atmospheric deposition. The resulting expectation is that nitrates will accumulate in groundwater, which has been noted in Calvert County. This explains why removal of atmospheric deposition and fertilizer have a greater impact on water quality in Solomon's Harbor over 5 years than does removal of septic nitrogen (Fig. 4).

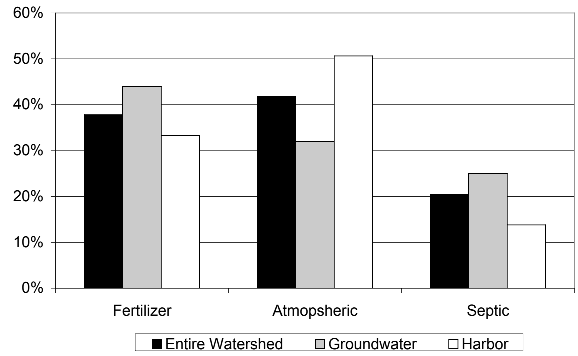

Figure 4. Proportion of nitrogen from 3 sources to Solomon's Harbor Watershed, Groundwater, and Habor over 5 years.

4.3 Results of Scenario modeling

Results of the scenario runs recommended by the stakeholder group are presented in Figure 5. We should anticipate a very small reduction after one year, and an equally small one in year two, unless we upgrade all septics. By year 3 we see a small increase in the reductions, however the maximum reduction in load is less than 13%, when all the septic tanks are upgraded. This delayed response is related to the slow movement of groundwater in this relatively flat watershed.

Upgrading all septics is a very costly plan and it is unlikely that it would be accepted by the public. All alternative scenarios give even smaller effects. We expected distance to closest stream to be an important factor in septic nitrogen loading, as it is for fertilizer 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 septics 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.

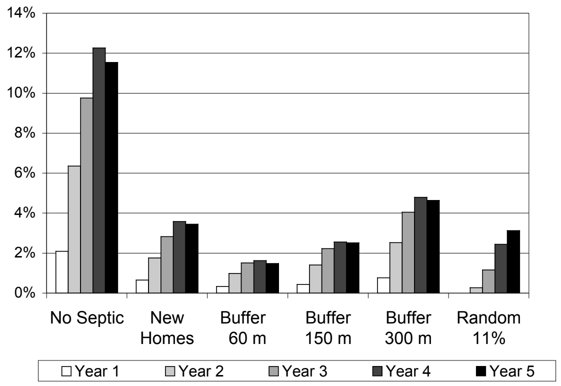

Figure 5. Projected reduction of nitrogen flow to Solomon's Harbor for different scenarios

4.4 Effects of modeling results on stakeholder involvement and policy decisions

An interesting issue with significant impacts on the participatory modeling approach has emerged during this project. As it became clearer that fertilizer and atmospheric deposition have a significantly larger effect (more than the community thought) on nitrogen loads in Solomon's Harbor, we began to wonder whether the expense of any of the proposed septic management scenarios would have a real effect on the trophic status of the harbor. Clearly, cleaning up septic tanks is a good environmental decision regardless since it would improve groundwater quality and to some degree surface water quality.

Atmospheric deposition cannot be directly influenced by local citizens. Fertilizer can be influenced but through educational initiatives rather than policy changes. Ultimately, this requires involvement of other governmental and citizen groups beyond the Department of Planning and Zoning which is currently leading the initiative to reduce nitrogen in the harbor. We are thus faced with the dilemma of presenting our results 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 as meant that water quality has not improved and is now not expected to improve for at least 20 more years. As a result, many residents are quite frustrated.

All this has been discussed during the fourth meeting with the small group, in which results from the modeling exercises were presented. The model itself is too large to run scenarios during the course of a meeting (each scenario takes 2 -5 hrs to run). The general outcome was some sense of confusion since the results presented were clearly not quite expected. The results were in some contradiction with the previous rough estimates performed by W. Boynton [OSDS 2004]. The group was therefore quite eager to help with gathering more information on fertilizer applications and was willing to work on developing best strategies of communicating the results with the larger pool of stakeholders. It is clearly an exciting educational opportunity for stakeholders to be involved in the actual process of fact-finding and decision-making.

5. CONCLUSIONS

From the start of this project we have focused primarily on the applications of modeling tools rather than on their development and refinement. We had a fairly well tested modeling framework, which is flexible enough to apply in different situations. The scope of the project did not offer us much time and resources to fine-tune our tools for the scale and watershed of interest here. It was a challenge to generate some meaningful results in a short time that could be used to make certain changes in management practices, and policies. As a result we are restricted to making comparative conclusions rather than absolute predictions.

Application of modeling results is always a challenge. A model is a simplification of the real world, which always excludes a multitude of factors that may become important for policy development. For example, based on our models we may conclude that the role of septic discharge is actually pretty low. The overall input from septic systems is the lowest among all the anthropogenic nitrogen sources. In addition, the discharge is leached into groundwater, which then becomes contaminated and eventually affects the quality of the surface water. There is a huge buffering capacity of groundwater, which means that it takes a long time for the effects to surface and it also takes an equally long (or even longer) time to see the effect of management policies that decrease the amount of nitrogen in the septic discharge.

Therefore, if we do insist on policies that will mandate improvements in septic tank performance we are likely to end up with a lack of observable improvement, in the short-term. On the other hand, managing septic loads is most feasible to implement at the local level. Atmospheric pollution is clearly the factor that contributes the most nitrogen load to the watershed and harbor, but it is unlikely that local governments can do much to control it. Most of it comes from transboundary long-distance transfer. Fertilizers are clearly the second most important factor (and depending on assumed fertilizer usage could surpass atmospheric), but in a free market democratic society it is practically impossible to mandate fertilizer usage by individual homeowners. We could easily imagine tax incentives or tradable rationing to limit the overall fertilizer application, but this is unlikely to be implemented by the County. The most effective approach is an educational campaign used to convince residents to reduce the amount of fertilizer used on their lawns.

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. 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 Solomon's Harbor.

6. ACKNOWLEDGEMENTS

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