5. Conclusions

The real benefit of this modeling effort to those concerned with the watershed is that the model output provides the ability to consider land use decisions without either the cost or the consequences of implementing that decision, and to predict probable effects of a decision at future times. According to King and Kraemer (1995) the advantages of modeling in the policy-making process includes its ability to clarify issues in a debate, enforce a discipline of analysis and discourse, and provide an interesting and powerful form of advice (often what not to do).

We, therefore, encourage critical evaluation of the model projections we have made in order to do all of the above, including planning or assessment of whether a model-predicted outcome is possible in individual towns or subwatersheds, and if so, how it might be mitigated or avoided. Indeed model results should provoke investigation on a subwatershed level to evaluate if mitigation strategies are in place in the most vulnerable ones. However, judgment that either the model is "right" or "wrong", that the data base is or is not adequate, or that adequate strategies are in place could lead to complacency, or worse. If in fact a threat is not deemed imminent by managers in a particular location that has been identified by the model as "at risk" of substantial future water quality declines, one might be tempted to dismiss the model altogether. This would be unfortunate since the overall conclusions of this integrated, in-depth, basin-wide, but subbasin specific study are important. We have shown conclusively that:

Development will continue to happen in the Catskill/Delaware watershed, if not in S10, for example, then somewhere else. Certainty is high with regard to this point based not only on the observed steady long term trend over time that we have deduced from satellite image analysis, but also based on the very real desires of many, both residents and non-residents, for continued development that meets personal (second-home) or economic (jobs/income from land sales) goals. This is manifest in a) the parcelization trends we have documented, b) built structures and driveways that we quantified both remotely and on the ground, c) in the often vehemently expressed views of past and present land owners gathered through surveys, and d) census and tax parcel data bases that record the history of single family home building. Complacency could also derive from the view of many that the NYDEP is buying up enough land to stem the tide (a concept certainly not welcomed by all). But even with increasing forested areas projected at the most recent rates, we have shown that they are not enough to improve or protect water quality in all subwatersheds. Furthermore, buying up land may lead to unintended consequences. Time and again in modeling land use change we have shown that instituting restrictions in one area pushes development into another (Cornell 2000, Hall et al. 2005, Tyrrell et al. 2008) e.g. pristine forest, or makes some land more desirable, e.g. steeper slopes, both of which can produce negative feedbacks to water quality. This is why it is important to focus on the basin-wide trends revealed by the study and not just individual subwatershed or town projections. (Note added in final preparation: we do not know what the recent very different economic trends in the US will mean).

Impervious surfaces have considerable impacts on in-stream nutrient concentrations and subwatershed nutrient exports that eventually are deposited in watershed reservoirs, and that the water quality models are very sensitive to how much impervious surface is added. Although this has been generally accepted and written about for several decades in the water quality literature, no study to date has quantified this relation at this scale and for so many analytes across a region of this size. The ability to incorporate the NLCD 2001 impervious surface cover map in our analysis gave us the ability to do this, and hence add something new to the literature.

The common assumption that forests are nature's best device for protecting water quality is true based on both univariate analysis and some final export coefficient models. However, we have also shown that the forests of the Catskills are neither as pristine nor as abundant as commonly thought, and that they are at risk of continued loss to parcelization and development, the impacts of which are well supported by our statistical analyses of water quality.

Given these major findings, and given the need to protect water quality for both the economic livelihood of, and ecological benefit to, Catskill/Delaware communities, as well as maintain the economic sustainability of clean water provision to 8 million residents of New York City, our findings should lead to critical discussion of the following:

> Where is development in the watershed desirable?
>
> Where can it be managed with minimum impact – villages or rural areas?
>
> How can impervious surfaces be designed and runoff from impervious surfaces managed to reduce nutrient delivery?
>
> How can local land owners get the tax relief they need to keep rural land in rural uses thus reducing parcelization and development of new roads, driveways, houses and barns?

We believe that our modeling approach would be very useful in examining at least some of these questions.

To assess whether we have adequately characterized the relation between water quality and landscape characteristics through the modeling process, it is helpful to evaluate the work with respect to our own goals for a good model. We stated not only in this document but also in meetings with watershed stakeholders at the beginning of this project that a good model should:

> ... be a formalization of our assumptions about a system and therefore,
>
> ... have a hypothesis, sometimes formal, sometimes not;
>
> ... be testable;
>
> ... be easy to access
>
> ... be as easy as possible to understand
>
> ... employ complete, correct and consistent mathematical formulations of ecosystem processes, in this case of land use change dynamics and water quality/land cover interactions

In terms of the formalization of our assumptions about water quality and land use in the watershed, our modeling results support most of our assumptions about the relation between land use/land cover and stream nutrient variability in the Catskill/Delaware watershed, but the overwhelming importance of impervious surface was not expected. When the models did not support our assumptions, as was the case with the nitrogen species, we were sure that atmospheric deposition plays a role based on the work by Lovett et al. (2000), but we had no spatially distributed representation of deposition across the region. To substitute, we decided to include mean elevation assuming that higher elevations might be more prone to higher N deposition. Both the TN and NO3-NO2 models were strengthened by inclusion of this variable. Although one could argue that the mechanism is still not known, i.e. it may be that mature forests at colder elevations are leaching nitrogen, this example, nonetheless, illustrates how a model works as a research tool, more than a predictor. Given our findings, we are able to say that the modeling effort, and in particular the use of a statistical model, was not sufficient to characterize either NH3 or TSS dynamics. The TN model indicated the need for more information than just the 18 landscape factors we assumed important to fully explain variation across the watershed.

To test model validity we assessed model goodness of fit vis-à-vis real-world observations using a variety of validation metrics, not only in building the land use change model, but also in the derivation of nutrient export coefficients and the analyte load prediction models. This was done to determine how much confidence we can have in our 2022 projections. Based on these validation assessments we can report the models of TP, TDP, SRP and NO3-NO2 as highly explanatory. The TN model must be assumed somewhat less robust although all independent variables included were significant ($\alpha = 0.05$) and fairly highly correlated with TN in univariate analysis. The TSS model must be disregarded and no model could be found to explain NH3 variation across the watershed.

The majority of non-point source pollution modeling is done using one of many available non-point source pollution models in which export coefficients are assigned to different land uses. Much of the inner workings of the model are understood only by hydrologists and are only as good as their inputs, e.g. the HSPF-based (Donigian et al. 1995) EPA BASINS model. They are seldom applied to a region of this size, due to their intense data requirements. Or, if they are, as in the case of BASINS, many default coefficients for required parameters are used, rather than locally-derived relations. Furthermore these coefficients are seldom questioned, adjusted, or revised. In this instance model complexity does not enhance system understanding. In sum they are not as easy to understand, are very cumbersome to calibrate adequately and may produce results that do not match local system behavior.

A statistical model, on the other hand, using local data, attempts to explain local conditions, is easily understood and easily communicated to the public. The use of a statistical model of nutrient concentrations and nutrient loads attached to land use change projections is not only a more easily understood model, but also a useful tool to explore the relation between land uses and nutrient loads using recently locally-gathered data, and can also be a first step toward building a more complex process-based model that starts with a model of precipitation-driven runoff, as we had originally proposed for a second phase of this work. One goal of the statistical model approach was to compare locally-calibrated coefficients to those commonly used in the Catskill/Delaware region and elsewhere, i.e. the GWLF model (Haith and Shoemaker 1987) and the EPA Basins Model (EPA 1996), both of which use land use export coefficients from Reckhow and Simpson (1988), which we have been able to do, but only through comparing total loads, since so many of the land use variables were not correlated with the analytes. It was also the most efficient way to derive estimates of future water quality for a region this large. Given that many of the land use/land cover classes were not correlated with analytes cannot help but lead to some critical reflection about the common non-point source modeling practice of using fixed export coefficients for pasture, urban, forest, corn field, etc.

The equations derived to project land use changes in the future are based on algorithms that were tested for their predictive power using in particular, the ROC statistic, overall, user's producer's accuracy, and a number of assessment tools to evaluate both locational and quantity fit between observed and simulated land use change. These assessments gave us higher confidence in the equations selected for future LULC projections. Likewise the tests applied in the construction of the water quality algorithms avoided hyper inflation of model algorithmic output caused by potential collinearity between explanatory factors. Again, this assures correct mathematical formulations to represent system dynamics. And finally, our assessment of outlier influence was important in identifying those models where either independent or dependent variable values from outliers may have had some effect on model reliability.

We were asked before even applying for the funding to conduct this research, “If you predict land use/land cover changes of that magnitude, can you predict potential water quality impacts?” We answered, “yes,” and, in fact, in 2008 are able to report two future loading estimates for the entire watershed, and for 88 subwatersheds, of 4, and to a lesser degree 5, important nutrients that are highly associated with water quality degradation. The second question posed to us was, “When will it be too much?” That is a more difficult question to answer, and something we had proposed to tackle in a second and third round of funding. To do so would require modeling the fate and transport of the increased loads predicted here, both in-stream and in the reservoirs. Even without those sophisticated studies, we can say that the precursors of water quality declines are evident. None of the subwatersheds as of 2022 comes close to the EPA threshold of 10% impervious surface that signals water quality concerns. The highest projection is for the small SKTB subcatchment, which would be over 4% under the high development rate. While this is not of concern, the fact that the median concentration of 31 of the 83 subcatchments sampled between 2001 and 2003 exceeds the EPA TMDL guidelines for phosphorous cannot escape notice (Table 1, section 4.2.2). We do not have the data for recent sampling that has followed WWTP upgrades, so cannot comment on whether improvements have occurred.

In 1983 Dickerhoff-Delwiche and Haith attributed most of the sediment and solid-phase nutrient loading into the Cannonsville basin to corn fields, and the dissolved-phase to waste water treatment plants. Given that agriculture is declining and the waste water treatment plants have been upgraded under MOA requirements it is probable that water quality is improving in this basin. However, on-going research and modeling efforts in the Cannonsville basin that are attempting to build accurately simulated hydrogical response, sediment, and nutrient loading, have not shown basin-wide declines in phosphorous loading since the time of the data set we have employed (Rao et al. (in press); Tolson and Shoemaker 2007; Benaman and Shoemaker 2004 and 2005; Benaman, Shoemaker and Haith 2005; Schneiderman et al. 2002 and 2007). The DEP annual reports for 2005 and 2007 show a range of reservoir loads over the period 2001 to 2007, and although the year 2007 measurement is lower than other years, one year is not sufficient to verify a downward trend (NYC DEP 2005, 2007).

Even with reduced agricultural activity, upgraded WWTPs, and increasing forest cover water quality may still be at risk. Certainly we have shown that to be true under some of our scenarios particularly due to the effect of impervious surface. Others working in the watershed believe that increases in the number and magnitude of storm events, defoliation due to warmer temperature-dependent insects, and changing soil and air dynamics, all due to changing climate as presented by Rosenzweig et al. (2007) may pose more serious threats to a continued supply of clean water than development-driven changes. If they are correct, more impervious surfaces will exacerbate all of the climate change impacts listed above. It is easy to dismiss the results reported here, because as looking out at miles and miles of forest cover one cannot imagine how any time soon there could be enough development to reduce water quality to levels requiring filtration. Forest-complacency syndrome unfortunately often leads to discovery 10 years down the road that things are changing, while one wasn't looking (or was seeing only what one wanted to see). We believe that the work presented here shows convincingly that in another 20 years, under even the least dramatic rate projections, there will be noticeable land cover changes. If these changes continue post-2022 and they are to have no impact on the quality of water coming out of the tap on East 23rd Street, and or that flowing into the famous junction pool on the West Branch of the Delaware, then particular attention must be paid to the management of future impervious surfaces installed in the watershed.

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