Report for 2000NY5G: A Watershed-Scale Biogeochemical Loading Model for Nitrogen and Phosphorus

- Book Chapters:
  - Howarth, R. W.; R. Marino; D. P. Swaney; and E. W. Boyer, 2002, Wastewater and watershed influences on primary productivity and oxygen dynamics in the lower Hudson River Estuary, In: J. Levinton (editor), The Hudson River. Academic Press, NY. In press.
- Conference Proceedings:
  - Howarth, R.W., A. Sharpley and D. Walker, 2002, Human Acceleration of the Nitrogen Cycle: Drivers, Consequences, and Steps Toward Solution, IN: Choi, E. and Yun, A. (eds.), Proceedings of the IWA Symposium on Strong Nitrogenous and Agro-wastewater, June 11-13, 2003, Seoul, Korea, Vol 1, pp3-13.
  - Boyer, E.W., August 1, 2003, Atmospheric Deposition. Presentation at the Annual Conference of the Universities Council on Water Resources, Washington, DC.
  - Boyer, E.W., R.W. Howarth and J.N. Galloway, September 14-18, 2003, Riverine Nitrogen Export From the World's Watersheds. Presentation at the 17th Biennial Conference of the Estuarine Research Federation, Seattle, WA.
  - Howarth, R.W., June 11-13, 2003, Human Acceleration of the Nirogen Cycle: Drivers, Consequences and Steps Toward Solution, Presentation at the International Water Association Speciality Symposium on Strong Nitrogeneous and Agro-wastewater, Seoul, Korea.
  - Howarth, R.W., August 1, 2003, The Need for a Nationally Consistent Nutrient Input-Output Information System, Presentation at the Annual Conference of the Universities Council on Water Resources, Washington, DC.
  - Howarth, R.W., R. Marino, W.E. Boyer and D.P Swaney, September 14-18, 2003, Potential Consequences of Climate Change on Delivery of Nutrients to Estuaries, Presentation at the 17th Biennial Conference of the Estuarine Research Federation, Seattle, WA.
  - Howarth, R.W., 2003, Human acceleration of the nitrogen cycle: drivers, consequences, and steps toward solution, IN: Choi, E and Yun, Z (eds), Proceedings of the IWA Symposium on strong nitrogenous and agro-wastewater, June 11-13, 2003, Seoul, Korea, vol 1, pp. 3-12.
- Other Publications:
  - Boyer, E.W., 2003, Atmospheric Deposition, Presentation at the Annual Conference of the Universities Council on Water Resources, Washington, DC, August 1, 2003.
  - Howarth, R.W., 2003, The need for a nationally consistent nutrient input-output information system, Presentation at the Annual Conference of the Universities Council on Water Resources, Washington, DC, August 1, 2003.
  - Howarth, R.W., R. Marino, E.W. Boyer and D.P. Swaney, 2003, Potential consequences of climate change on delivery of nutrients to estuaries, Presentation at the 17th Biennial converence of the Estuarine Research Federation, Seattle, WA, Septemer 14-18, 2003.

- Swaney, D.P., 2004, Linking statistical and semi-empirical modeling approaches for watershed-scale nutrient fluxes, Presentation at the Institute of Applied Environmental Research (ITM), Stockholm University, Stockholm, Sweden, March 24, 2004.
- Swaney, D.P., R.W. Howarth and E.W. Boyer, 2003, ReNuMa: A regional scale nutrient loading model for management, Poster presentation at the 17th Biennial conference of the Estuarine Research Federation, Seattle, WA, September 14-18, 2003.

- Articles in Refereed Scientific Journals:
  - Alexander, R. B.; P. J. Johnes, E. W. Boyer; and R. A. Smith, 2002, A comparison of methods for estimating the riverine export of nitrogen from large watersheds, Biogeochemistry 57:295-339.
  - Boyer, E. W.; C. L. Goodale; N. A. Jaworski; and R. W. Howarth, 2002, Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA, Biogeochemistry 57:137-169.
  - Howarth, R. W.; E. W. Boyer; W. Pabich; and J. N. Galloway, 2002), Nitrogen flux in the United States from 1961 - 2000 and potential future trends, Ambio, 31(2):88-96.
  - Howarth, R. W.; D. Walker; and A. Sharpley, 2002, Sources of nutrient pollution to coastal waters in the United States: Implications for achieving coastal water quality goals, Estuaries 25(4B):656-676.
  - Scavia, D. J.; C. Field; D. Boesch; R. Buddemeier; V. Burkett; D. Canyan; M. Fogarty; M. A. Harwell; R. W. Howarth; C. Mason; D. J. Reed; T. C. Royer; A. H. Sallenger; J. G. Titus, 2002, Climate change impacts on US Coastal and marine ecosystems, Estuaries 25(2):149-164.
  - Seitzinger, S. P.; R. V. Styles; E. W. Boyer; R. Alexander; G. Billen; R. W. Howarth; B. Mayer; and N van Breemen, 2002, Nitrogen retention in rivers: model development and application to watersheds in the northeastern US, Biogeochemistry 57:199-237.
  - Mayer, B.; N. Jaworski; E. Boyer; R. Howarth; C. Goodale; L. Hetling; S. Seitzinger; G. Billen; R. Alexander; N. van Breemen; K. Paustian; D. van Dam; K. Lajtha; and K. Nadelhoffer, 2002, On the feasibility of using the nitrogen and oxygen isotope ratios of nitrate for describing the origin of riverine nitrate and N transformations in large watersheds, Biogeochemistry 57:171-197.
  - Smith, S. V. ; D. P. Swaney; L. Talue-McManus; J. D. Bartley; P. T. Sandhei; C. McLaughlin; V. C. Dupra; C. J. Crossland; R. W. Buddemeier; B. A. Maxwell; and F. Wulff, 2003, Humans, Hydrology, and the Distribution of Inorganic Nutrient Loading to the Ocean, Bioscience 53(3):235-245.
  - Mayer, B., E.W. Boyer, C. Goodale, N.A. Jaworski, N. Van Breemen, R.W. Howarth, S. Seitzinger, G. Billen, K. Lajtha, K. Nadelhoffer, D. Van Dam, L. J. Hetling, M. Mosal and K. Paustian, 2002, Sources of Nitrate in Rivers Draining Sixteen Watersheds in the Northeastern US: Isopotic Constraints, Biogeochemistry 57/58:171-197.
  - Swaney, D.P., R. W. Howarth and E.W. Boyer, (In preparation), Implementing A Management Oriented Nutrient Loading Model in Excel/VBA, Ecological Modeling.

- Van Breemen, N., E.W. Boyer, C. Goodale, N.A. Jaworski, K. Paustian, S. P. Seitzinger, K. Lajtha, B. Mayer, D. Van Dam, R.W. Howarth, J.J. Nadelhoffer, M. Eve, and G. Billen, 2002, Where Did All the Nitrogen Go? Fate of Nitrogen Inputs to Large Watersheds in the Northeastern USA, Biogeochemistry 57/58:267-293.

- unclassified:
  - Van Breemen, N.; E. W. Boyer; C. L. Goodale; N. A. Jaworski; S. Seitzinger; K. Paustian; L. Hetling; K. Lajtha; M. Eve; B. Mayer; D. van Dam; R. W. Howarth; K. J. Nadelhoffer; and G. Billen, 2002, Nitrogen budgets for 16 watersheds draining to the northeastern US coast: storage and losses of nitrogen inputs, Biogeochemistry 57:267-293.
  - Boyer, E. W., R.W. Howarth, and J.N. Galloway, 2003, Riverine nitrogen export from the worlds watersheds, Presentation at the 17th Biennial conference of the Estuarine Research Federation, Seattle, WA, September 14-18, 2003.

Report Follows

A Watershed-Scale Biogeochemical Loading Model for Nitrogen and Phosphorus
Problem and Research Objectives

Two recent reports from the National Academy of Sciences have concluded that eutrophication is the biggest pollution problem in the coastal marine waters of the United States (NRC 1993, NRC 2000). Eutrophication lowers biotic diversity, leads to hypoxic and anoxic conditions, facilitates harmful algal blooms, causes dieback of seagrass beds, and can lead to changes in ecological food webs that lower fishery production (NRC 2000). Over 40% of the estuaries in the country are degraded from eutrophication, with the problem being particularly severe in the northeastern and mid-Atlantic regions (Bricker 1999). For most estuaries in these regions, eutrophication is caused primarily from over-enrichment with nitrogen; phosphorus is a secondary contributor (Howarth 1988; Nixon 1995; NRC 2000). Most of the nitrogen delivered to coastal waters in the US, including the northeastern and mid-Atlantic regions, comes from non-point sources in the watershed (Howarth et al. 1996). Agricultural sources are important in some watersheds, dominating the flux in the Mississippi River basin and contributing to the flux of some estuaries in the mid-Atlantic region, but atmospheric deposition of nitrogen from fossil-fuel combustion is an even greater source of nitrogen to estuaries for most of the mid-Atlantic region and for the northeastern US (Howarth et al. 1996; Smith et al. 1997; Jaworski et al. 1997; Goolsby et al. 1999; NRC 2000).

In regions subject to changes in land use and in atmospheric deposition of nitrogen, the processes that control nutrient loads to the coastal zone are complex. Variability of these hydrological and biogeochemical processes is increasing as weather and climate change. Understanding how these processes affect the magnitude and transformations of the nutrient loads is necessary in order to manage the environmental resources of the coastal zone. Further, it is important for those living in and managing coastal watersheds to understand the impacts of their activities and policies on these nutrient loads. A relatively simple modeling tool that can estimate the impacts of various activities in the watersheds can greatly enhance, at low cost, our ability to manage these regions effectively and to communicate the effects of human activities and environmental processes on nutrient loads. The report of the National Academy of Science s Committee on Causes and Management of Coastal Eutrophication concluded that no model currently available to managers fulfills this need for estimating the controls on nitrogen loads (NRC 2000).

They noted in particular that most models used by watershed and estuarine managers fail to deal adequately with nitrogen deposition onto the landscape with subsequent export downstream, even though this is the number one input of nitrogen to many estuaries. The Committee further concluded that the development of such a model particularly one that deals with atmospheric deposition -- is one of the most pressing priorities for solving the problem of coastal eutrophication (NRC 2000). Our aim has been to develop such a model.

To mitigate the effects of human activities on the supply of nutrients to surface waters, managers are tasked with gaining an understanding of the landscape source areas delivering nutrients to receiving waters. We have developed an easy-to-use model for calculating loads of N and P to coastal watersheds, targeted toward management applications. The model describes transport of water, sediment and nutrients from the landscape to receiving waters. Our goal has been to create a model structure that will be used widely; thus we have developed the model in a commonplace platform: the Excel workbook. This version of the model, GWLFXL1.0, runs as a Visual Basic for Applications (VBA) program with an Excel interface.

Model Summary
In its current form, the model uses the event-based dynamics of a simple, lumped hydrologic model (Generalized Watershed Loading Function (GWLF) (Haith and Shoemaker, 1987) GWLF is a parsimonious, event-based model that has been used successfully to analyze the hydrology, sediment, and nutrient loads of several mixed watersheds in the United States, including the New York City reservoir system, the Hudson River (Howarth et al., 1991; Swaney et al., 1996), the Tar-Pamlico (Dodd and Tippett, 1994), and the Choptank River drainage of the Chesapeake Bay (Lee et al., 2000). We have added additional functionality to handle atmospheric deposition of nutrients, simple estimates of denitrification rate, and changes over time of the areas of different landuse/land cover categories. The original model used daily historic or synthetic temperature and precipitation data to simulate monthly discharge, sediment load, and nutrient transport. We have developed a separate stand-alone weather generation package (also Excel/VBA based) to allow the user to generate alternate climate scenarios in a format compatible with the model.

New Features
Model Input/Output After the "port" of GWLF code to Excel was achieved, several features of i/o were radically redesigned in the interest of flexibility:

- Model simulation options are now controlled primarily from an Excel pulldownmenu (GWLFXL) which appears when the workbook is loaded.
- Model parameters can now be read either from existing GWLF input files (ie textfiles) or from parameter worksheets embedded within the workbook.
- Model output is now organized into several output worksheets, depending upon the time scale desired (ie annual, monthly, or daily). Worksheets that group the output by land use category are also generated at the option of the user. An advantage of organizing model output by worksheet is the ready creation of graphics within Excel from the tabulated values, or further user-generated statistical analyses of model scenarios.

Model Calibration Mode. A major addition to the package is the model calibration mode which utilizes the Solver addin feature of Excel to obtain a least-squares fit of a selection of model parameters to monthly streamflow, sediment flux, or nitrogen flux data. Model parameters are selected and calibration datasets are entered in the calibrate worksheet. The desired calibration mode is chosen from the pulldown menu. Solver then drives the model, iteratively changing the selected parameters, until model best matches the data in a least-squares sense. Up to 5 parameters may be selected, though as of this writing, the procedure appears to work best with one or 2 parameters at a time.

Parameter Uncertainty Analysis. Another new mode of using the model is parameter uncertainty analysis, in which the effect of uncertainty about parameter values on model output is estimated quantitatively. The process occurs in 3 steps:

- In the "stochastic" worksheet, the model parameters to be investigated are assigned probability distributions, together with estimates of their mean and variance, etc
- The user chooses the number of replicate runs desired for the analysis, and then draws the corresponding parameter values from their individual distributions; this option is selected from the pulldown menu
- The user runs the model in uncertainty mode, repeating the simulation for each realization of the parameter values, and the mean and standard deviation of the model outputs are stored in the "uncertainty" worksheet. When the runs are complete, the user can plot the time series of means and confidence intervals for any model variable corresponding to the selection of parameters evaluated.

Project updates and website

The current version of the model and associated documentation and tutorials can be downloaded from the project website: http://www.eeb.cornell.edu/biogeo/usgswri/usgswri.htm. Model updates, fixes, and future documentation will be made available here as well. While the VBA module containing the code is currently password protected to prevent tampering, the code is provided in Appendix 1 of the project report at the above website. Interested researchers can obtain the password by contacting Dennis Swaney at dps1@cornell.edu.

Current and future research directions in follow-on projects

Although the USGS/WRRI funded phase of the project has ended, we have obtained additional funding from an EPA star grant to pursue model development. We are currently engaged in adding more functionality to the model, aiming in particular at refining the descriptions of watershed biogeochemistry and hydrology, writing a model description for publication in a peer-reviewed journal, and beginning to evaluate the model against estimates of nitrogen load for 16 northeast US watersheds (Boyer et al., 2002). Links to further progress with the model development will be reported at the above website.