Progress Report

Understanding Sources and Sinks
of Nutrients and Sediment
in the
Upper Susquehanna River Basin

February 2007

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Executive Summary

Background

During recent decades, the amount of nitrogen flowing into surface waters and estuaries in the northeastern USA has increased 10-fold or more. In estuaries such as the Chesapeake Bay, such large increases in nitrogen are severely damaging populations of aquatic plants and animals, and also increasing harmful and toxic algal blooms. Most of the coastal waters of the USA are seriously degraded. At the global and national scale, agriculture is the major source of nitrogen pollution. However, atmospheric deposition is also a major source in many regions, and it contributes 25 percent to 50 percent of the nitrogen inputs to Chesapeake Bay.

The Susquehanna River is the largest river east of the Mississippi in the USA, the largest tributary of Chesapeake Bay, and the single largest source of nutrients to the main stem of the Bay. Therefore, better understanding of the sources and sinks of nutrients and sediment in the Susquehanna River watershed will support better management of nutrients and water quality in the Chesapeake Bay. Research is needed urgently to identify the most important targets for nutrient reductions and the most cost-effective solutions.

This research project is designed to increase our knowledge of the sources and sinks of nutrients and sediments in the New York portion of the Susquehanna watershed. Such knowledge will benefit not only the Susquehanna River watershed and the Chesapeake Bay, but will be valuable for improving understanding and management of nutrients in many other portions of the USA.

Program Objectives

- Improve estimates of the amounts of nitrogen, phosphorus, and sediments moving into the upper Susquehanna River, and ultimately to the impaired Chesapeake Bay.
- Determine which factors control nutrient pollution in rural landscapes containing a mixture of forest and agricultural land uses.
- Determine the importance of agricultural sources compared to other sources of nutrient pollution.
- Determine how climate variability and climate change are affecting nutrient pollution.
- Gain knowledge, tools, and techniques that will help maintain agricultural productivity and environmental quality throughout the Northeastern USA and beyond.

Research Strategy

- Improve knowledge of key nutrient cycling processes by funding innovative field and laboratory studies via grants to Cornell researchers. We provide two kinds of funding: "meso-grants" to faculty and "mini-grants" to students.

The Chesapeake Bay Watershed
Hydrologic Units

- Leverage and expand upon existing agricultural ecology research at the Harford Agricultural Teaching and Research Center (see box "Agricultural Ecology Research" on page 3). We fund data collection and synthesis at this site in support of multiple research projects.
- Leverage and expand upon atmospheric deposition research at the Connecticut Hill atmospheric deposition site. We fund the collection of new kinds of data at this site.
- Use computer models to understand nutrient and sediment sources and sinks at different spatial scales: watershed, landscape, farm, field, plot, and micro-scale. We use two models at the watershed scale and provide grants to four modeling groups to model specific processes at finer spatial scales.

Selected research progress highlights from the first year are presented below.

Meso Grants

1) *Determination of Sediment Sources in the Upper Susquehanna Basin.* Field sampling has been completed along the lengths of nine upper Susquehanna tributaries.

2) *The Fate of Nitrate Entering a Coupled Terrestrial-Aquatic Ecosystem in the Upper Susquehanna Basin.* During summer 2006, forest ecosystems were sampled. During early fall 2006, litterfall was collected and water sampling began.

3) *Generating a Dry Deposition Estimate for the Upper Susquehanna.* Two intensive three-week campaigns measuring multiple N species were completed at the Connecticut Hill atmospheric deposition site.

4) *Distributed Denitrification in Northeastern Agricultural Landscapes.* The local hydrology has been analyzed to identify two additional research locations within the watershed.

5) *Effects of Cropping System and Snow Depth on Seasonal Soil N Cycling and N Leaching.* Examine how winter temperature and snow removal affect seasonal nitrogen dynamics and leaching within three cropping systems. Two replicated research plots were established at the Harford Teaching and Research Center.

Modeling Groups

1) *Variable Source Loading Function Model.* We are evaluating the effectiveness of best management practices for reducing non-point source pollution of surface waters at the field, farm, and basin scale in the watershed.

2) *Improving Simulation of Management Practices and Regional Model Comparison.* We are using the Denitrification-Decomposition model to simulate the effect of common field crop management approaches on nitrogen cycling.

3) *Precision Nutrient Management Model.* We are modifying soil temperature, crop growth and nitrogen transformation components of the model to better reflect conditions in the watershed.

4) *Predicting Nitrogen Export from Forested Watersheds.* We are developing improved estimates of nitrogen export in surface waters based on simulations of conditions found in forested regions of the watershed.

Student Mini-Grants

1*)* *Quantification of On-Farm Biological Nitrogen Fixation Across a Fertility Gradient.* Plots on grain farms were established in April 2006 to quantify biological nitrogen fixation of annual and perennial legumes.

2) *Understanding the Role of Polyphosphate Accumulating Organisms in Phosphorus Mobilization in the Susquehanna Basin watershed.* In soil column experiments, over 90 percent of dissolved phosphorus stopped leaching through the columns during the first 24 h, reaching as little as 6.9 mg/L after 10 days.

3) *Mobilization of Phosphate from the Iron-Bound Phosphorus Sink in Freshwater Wetlands.* We compared wetland porewater, soil, and plant tissue chemistry at multiple sites to understand how phosphorus moves through wetlands.

4) *Does Increasing Soil Carbon Promote Nitrogen Retention?* We tested field and analytical methods; collecting, incubating, and analyzing soil from sites with two different land uses near the Connecticut Hill Atmospheric site.

5) *Reducing Nutrient Fluxes by Using Biochar Amendments.* Experiments in soil showed that biochar (charcoal derived from willow) has high adsorption ability for both phosphorus and ammonium.

6) *Measuring Ammonia and Nitrous Oxide Emissions from Manure-Treated Fields.* Laboratory and field studies are being carried out to understand the basic processes controlling ammonia and nitrous oxide emissions from fresh manure and manure-treated soils.

Summary and Future Directions

We are currently in the second year of this research project. As demonstrated in this progress report, we have accomplished a great deal with modest funding in a short time by leveraging ongoing research activities at Cornell University and collaborating with other groups within Cornell University and other institutions. We have developed a large, collaborative team of researchers to investigate fundamental processes controlling nutrient cycling while at the same time integrating basin-wide information with computer models. Also, two intensive research sites are supported, one focused on atmospheric deposition and one focused on nutrient cycling within a large animal research farm. Both sites have very strong historical records of data and research that we can leverage by supporting additional measurement and modeling activities. Finally, student research projects are being supported that will contribute to training future scientific leaders.

In sum, we are achieving our goal of developing new knowledge of basic nutrient cycling processes while at the same time developing new knowledge of nutrient cycling in large watersheds. This new scientific knowledge will provide a considerably more robust platform for effective environmental management of our valuable soil, air, and water resources and the terrestrial and aquatic life that depends on them.

Introduction

Susquehanna River Basin

During recent decades, the amount of nitrogen flowing into surface waters and estuaries in the northeastern USA has increased 10-fold or more. In estuaries such as the Chesapeake Bay, such large increases in nitrogen are severely damaging populations of aquatic plants and animals, and also increasing harmful and toxic algal blooms. Most of the coastal waters of the USA are seriously degraded. At the global and national scale, agriculture is the major source of nitrogen pollution. However, atmospheric deposition is also a major source in many regions, and it contributes 25 percent to 50 percent of the nitrogen inputs to Chesapeake Bay.

The Susquehanna River is the largest river east of the Mississippi in the USA, the largest tributary of Chesapeake Bay, and the single largest source of nutrients to the main stem of the Bay. Therefore, better understanding of the sources and sinks of nutrients and sediment in the Susquehanna River watershed will support better management of nutrients and water quality in the Chesapeake Bay. Research is needed urgently to identify the most important targets for nutrient reductions and the most cost-effective solutions.

AEP Goal

The goal of the Agricultural Program is to increase knowledge about the sources and sinks of nitrogen, phosphorus, and sediment in a large rural watershed of mixed land use, including agricultural and forest lands. The geographic focus is the Susquehanna River drainage basin and its tributaries within New York State (an area of approximately 19,500 km^2), with an emphasis on nitrogen and phosphorus dynamics of the agricultural and forested landscapes of the region.

Specific Objectives

- Improve estimates of the amounts of nitrogen, phosphorus, and sediments moving into the upper Susquehanna River, and ultimately to the impaired Chesapeake Bay.

- Determine the factors controlling nutrient pollution in rural landscapes containing a mixture of forested and agricultural land uses.

- Determine the importance of agricultural sources of nutrient pollution in the context of all sources in the watershed.

- Determine how climate variability and climate change affect the movement of nitrogen, phosphorus, and sediment from the rural landscape.

- Gain knowledge, tools, and techniques that can be used to maintain agricultural productivity and environmental quality throughout the Northeastern USA and beyond.

Fencing near streams can reduce erosion and reduce sediment pollution downstream. Photo courtesy of Greg Nagle, Department of Natural Resources, Cornell University.

Research Approaches

- Fund creative field and/or laboratory studies through grants to Cornell researchers.

- Leverage and expand upon existing agricultural ecology research at the Harford Agricultural Teaching and Research Center (see box "Agricultural Ecology Research" on page 3).

- Leverage and expand upon existing atmospheric deposition research at the Connecticut Hill site.

- Use computer models to understand nutrient and sediment sources and sinks at different spatial scales (watershed, landscape, farm, field, plot, and micro-scale).

Related Activity —
The National Nitrogen Problem

Briefing for the White House Office of Science and Technology Policy

Robert W. Howarth

David R. Atkinson Professor of Ecology & Environmental Biology

Cornell University

November 3, 2006

Conclusions

- Human acceleration of the N cycle over past 40 years is far more rapid than almost any other aspect of global change.

- N fluxes from northeastern US have increased 10-fold or more and from the Mississippi River by 5- to 6-fold.

- Nutrient pollution leads to hypoxia and anoxia, degradation of habitat quality, loss of biotic diversity, and increased harmful algal blooms. Most of the coastal waters of the US are degraded.

- Globally and nationally, agriculture is the major source of N pollution; increase in consumption of animal protein is the major driver; ethanol production will aggravate the problem (corn is a "leaky" crop).

- Atmospheric deposition is a major source in many regions, making up 25 percent to 50 percent of the N inputs to Chesapeake Bay.

- Technical solutions exist and should be implemented, but further research can best target problems and solutions, leading to more cost effective solutions.

- Monitoring programs are not adequate to provide needed information into the future; USGS water quality programs need to be rebuilt and expanded; atmospheric deposition monitoring needs to be greatly expanded (particularly for gas deposition near emission sources).

Agricultural Ecology Research:
Cornell University Department of Animal Science
Harford Animal Science Teaching and Research Center

Site Description

- Research on dairy cattle, beef cattle, and sheep.

- Records from 1973 to present.

- Approximately 526 hectares of cropland which has been in maize and alfalfa since 1979; about 390 ha are used for the dairy operation.

- Located in town of Harford in Cortland County, NY. Landscape typical of much of the Upper Susquehanna River watershed. Valleys are farmed, hills are forested or grassland.

Photo courtesy of the Department of Animal Science, Cornell University.

- The property is on the drainage divide between the St. Lawrence and the Susquehanna. Most of the intensively farmed land is in the Susquehanna.

- Most of the water drainage is ground water in deep gravel outwash aquifers. About 40 percent of the ground water is from the intensively farmed valley floor and the remainder from the surrounding hills.

Ongoing and Historical Data Available (some for 25-30 years)

- Water quality from 15 wells, including nitrate.

- Soil test results (pH, P, potassium, and N availability) and crop yields.

- Manure and fertilizer applications: good records for 20 years.

- Nutrient inputs via animal feed.

- Animal densities.

- Field management.

Photo courtesy of the Department of Animal Science, Cornell University.

Data to be Collected for this Project

- Repair and sample wells monthly for a year; analyze DON, nitrate, ammonium.

- Monthly plus storm event surface samples from drainage creeks and nearby streams; analyze for sediments, nitrite, nitrate, ammonium, TDN, SRP, TDP, and particulate N and P.

- Monitor deposition of ammonia and ammonium along gradients away from the farm site, using both bulk deposition measurements (Fahey et al. 1999) and passive samplers for ammonia gas in the atmosphere.

Meso Grants

In August 2005, the current Agricultural Ecosystems Program began. In September 2005, an open meeting at Cornell was held to explain the project to faculty, staff, and students and to inform the community about the availability of competitive grants.

Subsequently, five meso-grants were awarded. These grants are continuing during the second year. A brief update for each meso grant award is provided below.

Determination of Sediment Sources in the Upper Susquehanna Basin

Principal Investigators: Tim Fahey and Greg Nagle Natural Resources

Our study expands on our previous regional study of sediment sources in central New York by using ^{137}Cs to quantify the relative importance of sediment producing processes in the upper Susquehanna watershed. We are sampling recently eroded sediments in a suite of watersheds in the upper Susquehanna with contrasting historical and current land uses, and differing geomorphic and stream channel characteristics, to identify sub basins with high levels of sediment contributed by bank erosion.

Recent studies in four other Susquehanna watersheds in Pennsylvania have documented sediment loads from channel erosion that are orders of magnitude higher than earlier reports had suggested, with 50-90 percent of the sediment from channel banks. These highly erosion-prone legacy sediments have been found to contain high levels of phosphorus (1.43 lb/ton) and nitrogen (4.41 lb/ton).

Our previous work found high levels of bank derived sediment in streams with severe past impacts from channelization and channel incision and in streams with banks consisting of fine-grained glacial deposits. Although not a prominent contributor in our study streams, high levels of bank erosion were also found along a few stream reaches with concentrations of "legacy sediments " (determined by C-14 dating of buried material) which are deep alluvial deposits of sediment eroded after early Euro-American settlement. Our data indicated the dominant influence of eroding streamside glacial deposits on sediment yield in many central NY watersheds.

Research Update Highlights

- Field sampling along the lengths of nine major tributaries of the upper Susquehanna has been completed. Laboratory analyses of all radionuclide samples from these tributaries are expected to be completed by 12/1/06.

- We are also analyzing samples from these tributaries to examine variations in the concentrations of phosphorus in stream sediment and in stream banks.

- We have analyzed buried wood from three tributaries in order to date alluvial deposits and examined the magnetic susceptibility (MS) levels in a number of alluvial deposits to determine whether MS levels could be used as a sediment tracer, as well as an indicator of the age of the sediment. We have also had total nutrient analyses done on bank profiles in five tributaries in order to date sediment and examine the use of heavy metals as a possible sediment tracer. Final results on this project will be written up by mid January and submitted for publication in a scientific journal.

Photograph courtesy of Greg Nagle, Department of Natural Resources, Cornell University.

The Fate of Nitrate Entering a Coupled Terrestrial-Aquatic Ecosystem in the Upper Susquehanna Basin: A Pilot Tracer Experiment

Principal Investigator: Christine Goodale
Ecology & Evolutionary Biology
with Steve Thomas (University of Nebraska)

Goals and Approach

This field study of coupled terrestrial and aquatic nitrogen retention is following the fate of NO_3 entering Upper Susquehanna forests. After an application of $^{15}NO_{3-}$ and Br- in late April, 2007, ^{15}N will be followed into upland forest ecosystem pools (roots, foliage, wood, soil), down through the soil profile, through the near-stream zone, the stream reach and stream ecosystem pools and in stream water. This study is unique in its integration of terrestrial and aquatic perspectives and will be among the first to assess the relative contribution of watershed subsystems in nitrogen retention, providing a far more comprehensive understanding of the fate and control on nitrogen retention than exists to date.

Background

- Forests cover over two-thirds of the Susquehanna Basin.
- These forests receive some of the highest rates of nitrogen deposition in the country, of which more than half is as NO_3-N.
- Small forested catchments in this region appear to retain or denitrify about 95 percent of atmospheric nitrogen inputs.
- Understanding ***where*** nitrogen is retained within the system is crucial to understanding if or when that pool might saturate.

- Past ^{15}N-addition studies have followed either the long-term fate of ^{15}N in terrestrial ecosystem or the short-term cycling of ^{15}N in stream ecosystems. We are merging strengths of both approaches.

Research Update Highlights

- During the late spring of 2006, potential field sites were identified at Cornell's Arnot Forest (Schuyler County, NY) and permissions were secured to conduct an experimental ^{15}N addition to a 0.25 ha forested area surrounding the source of Pine Creek and continuing 85 m downstream.

- During summer 2006, forest ecosystem pools were sampled on the plot to establish background carbon, nitrogen, and ^{15}N characterization. This sampling included completion of two quantitative soil pits (0.5 m^2) designed to quantify soil, rocks, and roots in 10 cm depth increments to 50 cm depth, as well as five 50 cm deep pits sampled in 10 cm increments for chemistry only. Spatial heterogeneity of soil chemistry was characterized through collection of 54 20 cm^2 x 10 cm deep soil cores distributed evenly across the 0.25 ha plot. All trees larger than 10 cm diameter were tagged, inventoried, and measured for diameter at breast height. Two tree cores were collected by increment borer from each of 22 dominant trees, and green leaves were collected by slingshot from 18 trees.

- During early fall 2006, litterfall was collected in 25 0.24 m^2 litter baskets. Laboratory processing of collected samples (e.g., grinding, elemental and isotopic analysis) is anticipated for Nov. 2006 - March 2007. In addition to the sampling of ecosystem pools, a substantial amount

Spring source (left) and base (right) of Pine Brook. Photos courtesy of Christine Goodale, Department of Ecology and Evolutionary Biology, Cornell University.

of instrumentation was installed during summer 2006 to sample water and solute fluxes through the catchment, including 12 zero-tension lysimeters at 10 cm depth, 12 tension lysimeters (Soilmoisture Equipment) at 50 cm depth, 9 riparian wells, 9 piezometers, and 8 in-stream sampling points. A Tru-Track WT-HR Water Height data logger was established in July 2006 at the base of the stream where it exits the experimental plot.

- After allowing three months' settling time, monthly water sampling from all of these points was initiated in October 2006, to be continued during the snow-free period until and through the experimental ^{15}N application anticipated for late April 2007.

- Two Cornell undergraduates were supported by this project (Abby Jane Golash and Alicia Korol), and one (Golash) has continued in developing a Senior Honors Thesis.

Generating a Dry Deposition Estimate for the Upper Susquehanna
Principal Investigators: Jed Sparks, Tom Butler, and Roxanne Marino
Ecology & Evolutionary Biology

Background and Goals

Understanding of the cycling of any nutrient or sediment within a system requires a robust estimate of the inputs to that system. Dry deposition of nitrogen is not currently accurately estimated in the Upper Susquehanna Basin. We are developing a more accurate estimate of dry nitrogen deposition by leveraging several ongoing activities supported by the core AEP funding (see Connecticut Hill box next page) to expand the measurement of gaseous nitrogen species concentrations with a two-pronged effort described here. The combination of these two efforts will provide:

1) a reasonably well constrained estimate of dry nitrogen deposition,

2) invaluable information to the modeling effort supported by core AEP funding, and

3) a robust dataset for the pursuit of additional funding.

We will use the methodology of atmospheric chemistry, which is traditionally highly detailed, technology oriented, and expensive. However, we will focus on obtaining the information useful for basin-wide ecological modeling.

Measurement of total dry nitrogen concentration at Connecticut Hill

We have now completed two three-week measurement periods at the site (June 6-27, 2006 and September 5-26, 2006). During each of these deployments we used real time measurements (Ecophysics Model CLD 770 Chemiluminescence sensor, custom built gold/H_2 catalyst NO_y converter, and a custom built ammonia decomposition converter) and passive samplers (custom constructed and commercial passive filter units) to measure total NO_y (NO_y = NO; NO_2; N_2O_5; other minor oxidized nitrogen forms; organic forms including peroxyacetyl nitrates, alkyl nitrates, and isoprene nitrates; and HNO_3) and ammonia (NH_3) for the purpose of comparison with CASTnet estimates of dry deposition of total nitrogen (N_t). These data have not been fully analyzed and the CASTNet estimates for September are not yet available.

Our preliminary calculations from the June measurement period suggest the chemiluminesence estimate of N_t is ~ 30 percent higher than the CASTNet estimate and most of this difference is due to oxidized organic forms of nitrogen. We anticipate submitting this work for publication early next spring. We plan to deploy the chemiluminescence system again over the next year to capture additional seasons (primarily during the winter). The passive samplers deployed simultaneously with the real-time equipment have shown some promise for generating independent estimates for NO, NO_2, NO_x, and NH_3 concentration. However, some significant challenges still remain with calibrations at low concentrations and the influence of variable humidity. We plan to address both of these issues this winter in the laboratory.

## Rigorous Calibration of Passive Samplers for Concentration of NO_x and NH_3

In the past year, we have constructed a 50 x 50 cm exposure cell made of Plexiglas lined with Teflon and calibrated passive samplers for NO_x at 25 ppb. The results were promising. The average of 30 samplers exposed for a variety of time periods (1 to 15 days) was 24.8 ± 1.3 ppb. However, our preliminary measurements using passive samplers in the field show much higher levels of variability. We hypothesize this variability is driven by the lower concentrations observed in the field (~ 1 ppb) and the influence of variable humidity. During the coming winter, we will complete two additional fumigation experiments focused on NO_x. First, we will fumigate thirty passive samplers over variable times (7-21 days) at ~1 ppb NO_x. Second, we will repeat this experiment under humidity conditions similar to those observed at the Connecticut Hill field site.

These new experiments, coupled with our previous fumigation, will allow us to generate meaningful correction factors for field NO_x concentration assessment using passive sampler technology.

Connecticut Hill Atmospheric and Precipitation Chemistry Research and Monitoring Facility
Institute of Ecosystem Studies

Site Description

- One of the best studied sites in the U.S. for atmospheric deposition

- Location chosen to be uninfluenced by any local pollution sources such as power plants, urban centers, farms, or highways.

- Six hectare site surrounded by extensive forestlands in the 4500 ha New York State Connecticut Hill Game Management Area, as well as old fields and pastures. Both the landscape and land use are typical of other headwater sections of the Susquehanna River watershed in New York State.

- National Atmospheric Deposition Network (NADP), AIRMoN Site NY67 (wet precipitation quantity and chemistry on a daily basis: NO_3^-, NH_4^+)

- Clean Air Status and Trends Network (CASTNet) site # CTH 110 (weekly dry acidic deposition: HNO_3 vapor, particulate NO_3^-, particulate NH_4^+; weekly ozone)
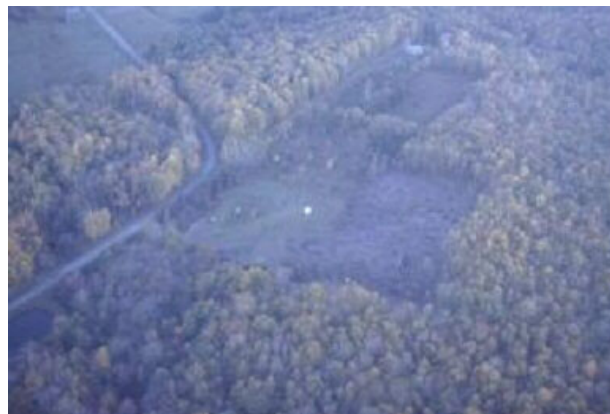
Historical Data Available

- Continuous operation since 1976

- Long-term record of nitrogen deposition (wet and dry)

- One of the original locations to measure regionally representative dry deposition in the U.S. (1987)

- Studies of throughfall versus inferentially measured dry deposition of nitrogen and sulfur species

- Isotopic studies (^{15}N, ^{18}O and ^{17}O) of wet and dry deposition to understand the sources of NO_x deposition (e.g., vehicle emissions vs. non-vehicle sources)

- Impact of changing emissions of SO_2 and NO_x on wet and dry deposition of sulfur, nitrogen, and acidity.

Data to be Collected for this Project

- Improve measurement of dry deposition of nitrogen, especially gaseous NO_2, NH_3. At least 1/3 of the measured total nitrogen deposition at the sites is in the form of dry deposition, but not all components have yet been measured.

- MARGA (Monitoring instrument for aerosols and gases) hourly sampling for gaseous NH_3, HNO_3, and HNO_2, and particulate NH_4^+ and NO_3^-; ThermoElectron 42C-Y chemiluminescence detector for hourly sampling for NO_y

- Passive gas sampler monitoring for dry deposition of NH_3, NO_2, NO_x, HNO_3

- Comparison of data from passive samplers and CASTNet filter packs

- Further tests of spatial variability of dry deposition components

Photos courtesy of (top) Tom Butler, (center) NADP, (bottom) Elizabeth Boyer.

Distributed Denitrification in Northeastern Agricultural Landscapes

Principal Investigators: Todd Walter
Biological & Environmental Engineering
with Peter Groffman of the Institute of Ecosystem
Studies and Sujay Kaushal of the Univ. of Maryland

During this first year we have been installing instrumentation in field sites and learning the "push-pull" technique for measuring denitrification rates. We have instrumented two distinctly different hydrological settings, a headwater riparian area and an upland spring, with nests of mini-piezometers (for push-pull measures) and matrices of capacitance probes (for continuously measuring the shallow water table). We are still analyzing the local hydrology to identify two or three additional monitoring locations that will allow us to best meet our objective to "quantify the distribution of denitrification in Northeastern US agricultural landscapes." Todd Anderson (Ph.D. candidate) visited the Baltimore LTER site for training in the push-pull method. By the end of November we will begin making push-pull denitrification measurements. We will also begin gathering and analyzing water samples to "quantify the distribution of groundwater nitrogen fluxes and flow paths through our monitored field site."

*Areas prone to prolonged saturation during warm periods of the year are likely **hotspots** for denitrification; these spots likely correspond to so-called **hydrologically sensitive areas**. Photo courtesy of Todd Water, Department of Biological and Environmental Engineering, Cornell University*

Related Activity –
The North American Nitrogen Center

In 2004, the North American Nitrogen Center, directed by Robert Howarth, was established at Cornell University as part of the International Nitrogen Initiative (a joint effort of the International Council of Science's IGBP and SCOPE programs) . In the summer of 2006, Alan Townsend, Colorado State University, assumed Directorship, relocating the Center to Colorado. The Agricultural Ecosystems Program, under Robert Howarth, lead principal investigator, continues its work as an activity of the Center.

The goals of the Center are to better understand the sources and sinks of N across North America, to quantify the consequences of N pollution, and to provide scientific support for the development of technical and policy approaches for reducing N pollution (www.eeb.cornell.edu/biogeo/nanc/nanc.htm). The Nitrogen Center has identified an improved understanding of nitrogen sources and sinks in the Susquehanna River Basin as a priority area of study in North America.

Effects of Cropping System and Snow Depth on Seasonal Soil Nitrogen Cycling and Nitrogen Leaching

Principal Investigators: David Wolfe, Horticulture and Janice Thies, Crop and Soil Sciences with Peter Groffman of the Institute of Ecosystem Studies

Results

Replicated research plots (10 x 10 m) were established at the Harford Farm Teaching and Research Center to examine winter temperature and snow removal effects on seasonal nitrogen dynamics and leaching within three cropping systems (alfalfa, corn/winter fallow, and corn/winter rye) selected for their relevance to a large proportion of agricultural acreage within the Susquehanna watershed.

A suite of soil quality measurements have been made on composite samples collected from the 0-15 cm and 15-30 cm depths approximately every 2 to 3 months, beginning with an initial baseline pre-winter sampling on Nov 20, 2005. Soil temperature at the 10 cm depth was monitored during the winter period with HOBO temperature sensors installed in selected plots. Two 200 cm^2 PVC lysimeters were installed at the 45 cm depth in each plot, and leachate has been sampled approximately every 2 – 4 weeks since June 29, 2006. A subsample of corn plants were destructively harvested at mid season (July 20, 2006) and at plant maturity (September 20, 2006) for dry weight, and percent carbon and nitrogen determinations. Natural snow frequency and depth were unusually low in winter 2006, but during periods of snow cover, a significantly higher variability of soil temperature was observed in snow removal treatments. Preliminary data analyses do not indicate a significant snow removal effect on soil quality or corn growth or nitrogen uptake, however.

Snow removal treatment. Photo Courtesy of David Wolfe, Department of Horticulture, Cornell University.

Summarizing some of the soil quality parameters measured, for corn, averaging across treatments, soil depths, and sampling dates (Nov 20, 2005 through June 29, 2006) we found 5.97 percent organic matter (OM), 624.8 mg/kg active carbon, 5.14 µgN/gdw soil/wk potentially mineralizable nitrogen (PMN), and 75.2 percent wet aggregate stability. Aggregate stability was lower, but all other values were significantly higher, in alfalfa plots, with average values of 6.67 percent OM, 847.0 mg/kg active carbon, 10.63 µgN/gdw/wk PMN, and 55.7 percent aggregate stability. For both corn and alfalfa we observed a 20 to 40 percent decline in aggregate stability and a 10 to 14 percent decline in active carbon during the winter period, with further declines in spring. PMN declined by about 20 percent during winter in alfalfa plots but did not change significantly in corn plots. No significant change in percent OM has been observed for either crop.

Winter rye treatment. Photo Courtesy of David Wolfe, Department of Horticulture, Cornell University.

The volume of leachate was about double in corn compared to alfalfa during the summer and early fall period (June 29 to Oct 30, 2006), with values of 1054 and 508 ml/m^2/day for corn and alfalfa, respectively, or, reporting on a per cm rainfall basis, 2994 and 1443 ml/m^2/cm ppt for corn and alfalfa respectively. Leachate nitrate analyses are not com-

pleted for all sampling dates so conversion to nitrogen losses are not possible, but the average nitrate concentrations we measured from early leachate collections was 11.4 and 2.9 mg/L for corn and alfalfa, respectively. Analysis of corn biomass samples to estimate crop nitrogen uptake has not been completed. A winter rye cover crop has been established in the designated corn plots, and a satellite field study, comparing winter wheat and winter rye planted at two dates for effects on crop nitrogen uptake has been established in a field adjacent to the corn experiment.

Continuing Work

We are completing laboratory analyses (e.g., frozen samples for determining microbial carbon and nitrogen) and statistical analyses of Year 1 data. During November and December 2006, in addition to intensive soil sampling and cover crop destructive harvests for biomass and nitrogen uptake determination, we are intensifying field instrumentation with installation in each plot of soil thermocouples at 5 and 15 cm depths connected to a Campbell data logger, frost tubes, soil cores installed for *in situ* nitrogen mineralization rate determination. Plans are also being made for estimates of *in situ* denitrification in spring 2007. A snow fence will be placed around the plots. Leachate measurement continues every one to three weeks depending on rainfall and snow melt events, snow depth will be monitored weekly, and soil sampling and biomass harvests will be conducted as scheduled during winter, spring and summer 2007.

Collaborators — Mann Library Develops Tools for Managing and Curating Research Data

Gail Steinhart
Research Data and Environmental Sciences Librarian

Research programs such as the Agricultural Ecosystems Program Upper Susquehanna project (AEP) develop large, complex data sets that may be valuable to other researchers as well as the public. But managing these data and making them accessible is a huge challenge. Cornell University's Mann Library is collaborating with the AEP to develop new approaches for cataloging, managing, and archiving scientific data, and making data available to researchers via the Internet. A key goal of this research is improving ways to create "metadata" (that is, information about a data set), and make the metadata available in databases that are accessible via the internet. Achieving this goal will allow researchers to locate and access these valuable data sets. This collaboration is part of a broader initiative by the Library supported by the National Science Foundation to explore how university libraries can play a role in curating and managing research data.

Mann Library was solicited by the AEP for assistance in developing documentation for research data collected by the group to: provide a platform for distributing the data over the Internet; create a web site that would provide project information and direct access to that data; and facilitate collaboration by the group. In addition, the AEP sought to document and share thirty years of historical research data. To fill the AEP request, Mann Library began by identifying a method to create a high quality documentation (metadata) for environmental research data. For this purpose, a set of tools was selected that had been developed by a collaborative group that include the National Center for Ecological Analysis and Synthesis and the Long Term Ecological Research Network. This group developed a metadata standard, the Ecological Metadata Language, or EML, which allows for detailed descriptions of data. EML comes with an easy-to-use editor that allows scientists to create their own metadata records.

These tools have been previously tested by David Bouldin, Emeritus Professor of Crop and Soil Sciences, to document thirty years of research data on water quality. A workshop was held for AEP researchers on using these tools to create their own metadata. An exciting aspect of using this particular set of tools is that it allows the group to participate in other, broader data distribution efforts, such as the Knowledge Network for Biocomplexity.

AEP data is now being distributed through DSpace, Cornell University's open-access repository. A web portal was also created by Mann Library that makes this project information accessible to the public, and will offer links to the data deposited in DSpace. Finally, a project wiki — a collaborative web-authoring environment — is being hosted by Mann Library where participants may post documents and other information for sharing within the group.

Mann Library personnel are excited by the challenges and opportunities that managing a curating scientific data present.

Modeling

Whole-Basin Modeling

Two models are being used in the Agricultural Ecosystems Program at the scale of the entire upper Susquehanna River basin: the **SCOPE/NANI model** and the **Regional Nutrient Management model (ReNuMa)**. We will also explore how the insights and output from several finer scale models can improve understanding at the whole watershed scale.

The SCOPE/NANI model is a simple mass-balance model for nitrogen that compares sources of nitrogen in the landscape to riverine nitrogen fluxes. It was originally developed for large regions, such as the combined watersheds of the North Sea or the northeastern US, or the entire Mississippi River basin (Howarth et al. 1996), but has subsequently been applied to watersheds of the scale of the Susquehanna both in the U.S (Boyer et al. 2002) and in Europe (Humborg and colleagues, unpublished). Despite its simplicity, a comparative analysis of many models demonstrated that the SCOPE/NANI model is among the best in terms of error of prediction and assessment of nitrogen source determination (Alexander et al. 2002).

Although the AEP focus is on the upper Susquehanna basin, we are developing estimates of nitrogen inputs to the entire Susquehanna basin in order to compare inputs and outputs from the upper and lower portions of the basin. The SCOPE-NANI model uses a simple mass-balance approach to compare riverine nitrogen fluxes to four categories of net anthropogenic inputs: (1) atmospheric deposition, (2) fertilizer, (3) nitrogen fixation by vegetation, and (4) food and feed imports. To date, we have estimated inputs for the early 1990s. These estimates are spatially-explicit and are stored in a Geographic Information System so that inputs can be examined for any portion of the watershed. Wet and dry nitrogen deposition data were obtained from CASTNet and NADP monitoring stations and interpolated separately using universal kriging after de-trending. Fertilizer application rates within counties were obtained from the literature and weighted based on the proportion of each county in each basin. Nitrogen fixation was derived from leguminous crop area data from the Census of Agriculture multiplied by nitrogen fixation rates from the literature. Net nitrogen import in food and feed were derived from crop and animal data from the Census of Agricul-

Annual nitrogen in fertilizer, circa 1992. Fertilizer application rates within each county were obtained from the literature and weighted based on the proportion of each county in each basin (Battaglin & Goolsby 1994).
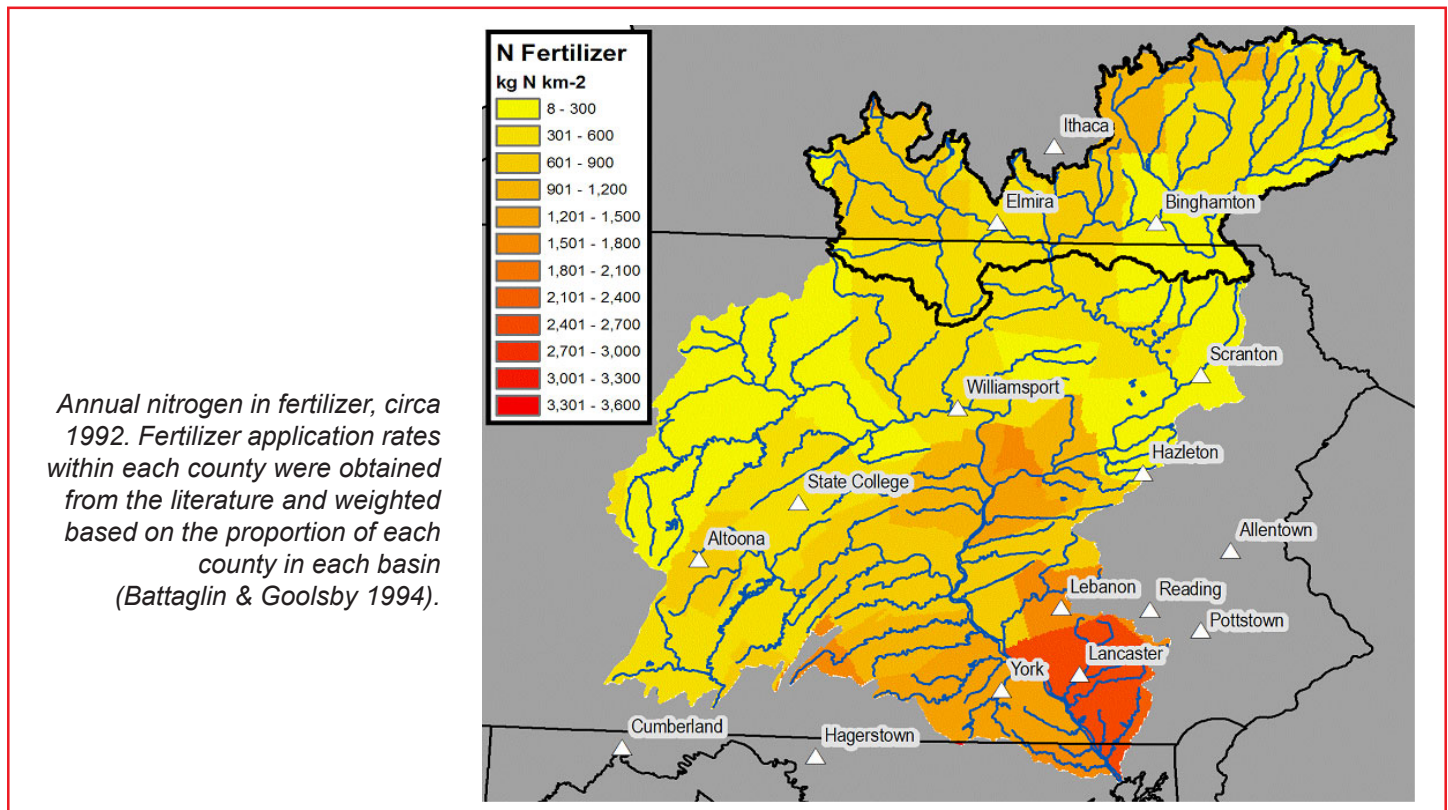
ture and data from the literature on crop and feed nitrogen contents and animal and human nitrogen requirements.

Overall, our draft results were similar for the upper basin and the entire basin, though total inputs were somewhat lower in the upper basin (3188 vs. 3639 kg N km^{-2}). Of these totals, atmospheric deposition contributed 30 percent (upper) and 29 percent (entire). Net import of food and feed contributed 29 percent (upper) and 33 percent (entire). Fertilizer accounted for 16 percent (upper) and 18 percent (entire). Nitrogen fixation contributed 25 percent (upper) and 21 percent (entire). Thus agriculture contributed the majority of anthropogenic inputs to the basin, mostly through net imports of food and feed and nitrogen fixation rather than fertilizer. Only about 25 percent of nitrogen inputs are ex-ported in rivers, with the remainder stored in vegetation, soils, and groundwater, or denitrified.

The following presentation was made on these research results:

• Woodbury PB, Howarth RW, Swaney DP. Modeling nitrogen in the Susquehanna basin (USA) using the SCOPE-NANI approach. Platform presentation at the annual meeting of the Society of Environmental Toxicology and Chemistry, Montreal, Canada, November 5-10, 2006.

The other model we will use at the large watershed scale is ReNuMa, a model designed to allow planners and other stakeholders to explore scenarios for reducing nitrogen fluxes from the landscape. During the second year of the project we will be applying the ReNuMa model to the Susquehanna Basin.

ReNuMa Model: Nitrogen Dynamics
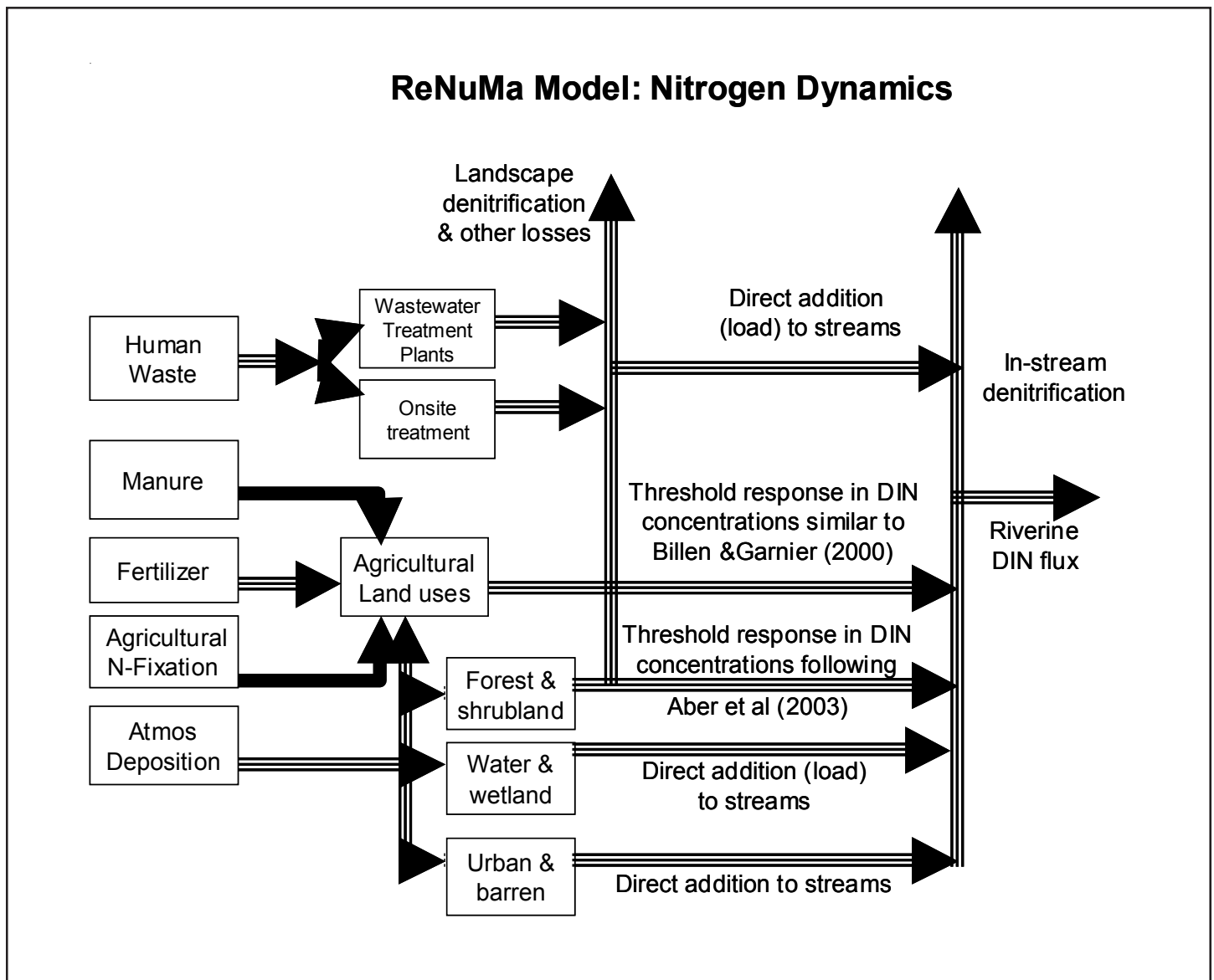
Collaborators:
The Upper Susquehanna Coalition

The Upper Susquehanna Coalition (USC), established in 1992, is a network of county natural resource professionals who develop strategies, partnerships, programs and projects to protect the headwaters of the Susquehanna River and Chesapeake Bay watersheds. The USC is comprised of representatives from 13 counties in New York and three in Pennsylvania.

The USC members are Soil and Water Conservation Districts in NY and Conservation Districts in PA. All USC members have signed a Memorandum of Understanding that reflects their endorsement of the development of non-point-source projects on a watershed basis. Over the last ten years, USC has united its members in a genuinely coordinated effort. Through shared projects and regular meetings, the USC has maintained a remarkable degree of cordiality and cooperation between its members and its many partners.

Strategic Planning

The USC has partnered with the NYS Department of Environmental Conservation to develop New York State Tributary Strategy for Chesapeake Bay Restoration - *An Interim Plan based on the Chesapeake Bay Program Watershed Model, Version 4.3.* This and later versions of this document describe the overall issues and potential solutions to address water quality issues in the USC.

Site-Specific and Process-Specific Models

In addition to these overall basin modeling approaches, we have engaged (on a competitive basis) four different modeling groups at Cornell, to contribute to an integration of modeling across scales, from plots to large watersheds. Progress for each of these four modeling groups is summarized below.

Variable Source Loading Function (VSLF) Model

Lead: Tammo Steenhuis
Biological & Environmental Engineering

Background and Approach

In the Northeast USA runoff is typically produced in locations where soils saturate from below. Such locations are called variable source areas (VSAs) because they expand during a rainstorm. Since these VSAs are primary locations for denitrification and runoff from these areas is the primary transport mechanism for nutrients, locating these VSAs is important for estimating nutrient loads and effects of management practices (see related meso-grant to Walter and others). However, most current models assume that runoff is produced in locations where rainfall intensity exceeds the soil infiltration capacity. Such models predict that runoff occurs along the boundary of the basin. We have developed the Variable Source Loading Function (VSLF) model, which predicts that runoff occurs in areas along the rivers, which better matches field observations. We will implement and validate the VSLF model for selected areas in the upper Susquehanna basin. We will also develop a web-based tool where a user can click on a landscape element and find its probability of saturation.

Research Update Highlights

We are currently evaluating the impact of Best Management Practices (BMPs) to reduce non point source pollution of surface waters at the field, farm, and basin scale in the Upper Susquehanna basin in New York State. Agricultural BMPs are a commonly accepted management tool to reduce P loading to surface water bodies, and we are researching different modeling approaches to determine the extent to which BMPs are able to reduce the pollutant load in the Upper Susquehanna.

- First, we have developed a model termed VSLF (modified from the GWLF model) that can simulate the spatial distribution of runoff producing areas, called Variable Source Areas (VSAs), over the entire watershed, and thus delineate target areas for BMP implementation.

- Second, we are modifying the commonly used Soil and Water Assessment Tool (SWAT) model to predict spatially distributed runoff source areas similar to VSLF. The strengths of SWAT include its ability to run with readily available inputs that do not require significantly complex data gathering for general initialization, and the process based chemistry, and the simple runoff generating algorithms, the ubiquitous Soil Conservation Service Curve Number (SCS-CN) type found in numerous models. We re-conceptualized the SCS-CN equation and divided the watershed into a series of sub-basins (contiguous areas expected to behave similarly), which may or may not contain VSAs. One option was to define the HRU using land use and an index class (TI for example), which would directly incorporate the VSA hydrology into the SWAT framework. Another more physically realistic option was to incorporate the soil characteristics at the index level. There is some evidence that soil variability can be explained by topographic features in glaciated regions. To incorporate soil, we have spatially weighted the
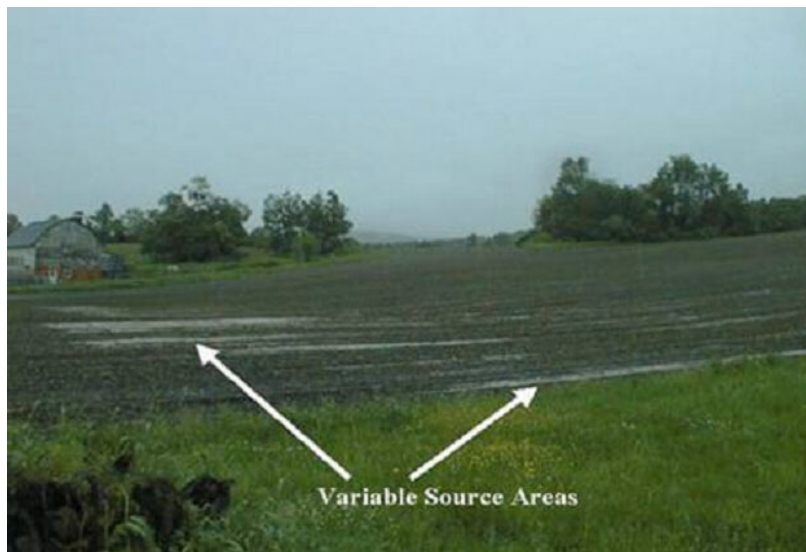

Photo: Steven Lyon, Department of Biological and Environmental Engineering, Cornell University.

SSURGO soils and extracted the required properties with the Soil Topographic Index (STI) for the basin. Delineation of HRUs proceeded similarly to the standard delineation, except that now HRUs are defined by the coincidence of land use and STI.

- Third, we are combining water quality and economic aspects of watershed management strategies to devise a methodology for choice and placement of the BMPs on a farm, which insures that the farmer is using BMP strategies to reduce phosphorus loading in the most cost-effective manner. The area farms differ in both physical characteristics such as size, proximity to water bodies, topography, and runoff source areas, as well as management characteristics, such as crop rotation schedules, manure spreading plans and dairy herd size. In addition to physical differences, different costs are associated with specific BMPs and their placement, and these factor into the farmer's decision-making process. We are using the models (VSLF and SWAT), cost information gathered from a BMP database, and interviews with farmers and farm planners to explore different policy scenarios, and determine the optimal choice and placement of BMPs on farms to decrease phosphorus loading.

Expected Impact

The results of our modeling and cost analysis are expected to provide a more cost-effective means of determining the relative risk of nutrient transport and non-point source pollution for a given management or development scenario. By incorporating VSA hydrology, VSLF and SWAT results will provide farmers and watershed managers more accurate information regarding different zones within their farms which have a high propensity for phosphorus loading, so they can then pinpoint areas on which to focus BMP strategies.

By varying different parameters and delineations, the degree of different potential impacts can be examined. For example, we could arbitrarily divide the STI into 10 equal area intervals ranging from 1 to 10, with index class 1 counting the 10 percent of the watershed area with the lowest STI (i.e. lowest propensity to saturate) and index class 10 containing the 10 percent of the watershed with the highest STI (i.e. highest propensity to saturate). For a more discrete representation of HRUs the index may be divided into more classes or follow a different distribution (i.e., exponential, log normal, etc.).

In addition to different modeling changes, we analyze different BMP scenarios including manure spreading, crop rotation, and riparian buffers and how different combinations can reduce phosphorus loading. Cost analysis will explore the impact of farmer decision-making on water quality outcomes, and how this can affect phosphorus loading. Our combined results will ultimately influence zoning regulations and public policy regarding agricultural environmental management of small and large rural watersheds.

Related Publications

Agnew, L. J., S. Lyon, P. Gerard-Marchant, V. B. Collins, A. J. Lembo, T. S. Steenhuis, and M. T. Walter. 2006. Identifying Hydrologically Sensitive Areas: Bridging the Gap Between Science and Application. *J. Environ. Manag.* 78:63-76.

Easton, Z. M., P. Gerard-Marchant, M. T. Walter, A. M. Petrovic, and T. S. Steenhuis. 2006. Hydrologic assessment of an urban variable source watershed in the northeast US. Water Resour. Res. (In Press)

Gérard-Marchant, P., W. D. Hively, T. S. Steenhuis, 2006. Distributed hydrological modelling of total dissolved phosphorus transport in an agricultural landscape, part I: distributed runoff generation. Hydrol. Earth Sys. Sci.10:245-261.

Gérard-Marchant, P., M. T. Walter, and T. S. Steenhuis. 2005. Simple models for phosphorus loss from manure during rainfall. J. Environ. Qual. 34:872-876

Hively, W. D., P. Gérard-Marchant, T. S. Steenhuis. 2006. Distributed hydrological modeling of total dissolved phosphorus transport in an agricultural landscape, part II: dissolved phosphorus transport. Hydrol. Earth Sys. Sci.10:263-276.

Lyon, S. W., A. J. Lembo, M. T. Walter, and T. S. Steenhuis. 2006. Defining Probability of Saturation With Indicator Kriging on Hard and Soft Data. *Advan. Water Resour.* 29:181-93.

Lyon, S.W., J. Seibert, A.J. Lembo, M.T. Walter, T.S. Steenhuis. 2006. Geostatistical investigation into the temporal evolution of spatial structure in a shallow water table. *Hydrol. Earth Sys. Sci.* 10:113-125.

Lyon, S.W., M. McHale, M.T. Walter, T.S. Steenhuis. 2006. Effect of runoff generation mechanism on estimating land use control of P concentrations. *J. Am. Water. Resour. Assoc.* (in press).

Schneiderman, E.M., T.S. Steenhuis, D.J. Thongs, Z.M. Easton, M.S. Zion, G.F. Mendoza, M.T. Walter, and A.L. Neal. 2006. Incorporating variable source area hydrology into curve number based watershed loading functions. Hydrol. Proc. (In Press).

Srinivasan, M. S., P. Gérard-Marchant, T. L. Veith, W.J. Gburek and T. S. Steenhuis. 2005. Watershed scale modeling of critical source areas of runoff generation and phosphorus transport. J. Amer. Water Resou. Assoc. 41:361-375.

Walter, M.T., E.S. Brooks, D.K. McCool, L.G. King, M. Molnau, J. Boll. 2005. Process-based snowmelt modeling: Does it require more input data than temperature-index modeling? Journal of Hydrology 300: 65-75.

Improving Simulation of Management Practices and Regional Model Comparison
Lead: Christina Tonitto
Horticulture

Background and Goals

Three categories of data will be used to better characterize watershed nitrogen cycling and better parameterize the ReNuMa model. First, a meta-analysis database will be used that quantifies nitrate leaching from paired studies of fertilizer application under bare fallow contrasted to cover crop management, as well as fertilizer application compared to unfertilized systems in which a legume cover crop serves as the nitrogen source. Additionally, data from the literature will be analyzed to quantify the effects of the following management strategies on nitrogen losses: (1) application of nitrification inhibitor, (2) slow release nitrogen, (3) side-dressing, (4) manure application, (5) legume-based rotations, (6) cover crop rotations, (7) pasture, (8) perennial or Conservation Reserve Program systems. We will also use the Decomposition-Denitrification (DNDC) model to simulate organic and inorganic carbon and nitrogen compounds as they move between the atmosphere, the crop, the soil, and the soil leachate. Experimental data from the Rodale Institute in Kutztown, PA on nitrate losses during a 15-year period under different management practices will be used to calibrate the DNDC model. Predictions under various management strategies will be compared to those of the ReNuMa model.

Cover crops can trap nutrients such as nitrogen and prevent them from polluting groundwater and surface water. Photo courtesy of Christina Tonitto, Department of Horticulture, Cornell University.

Research Update Highlights

- Funding from the USDA AEP grant awarded to Cornell University has contributed to the development of the Denitrification-Decomposition (DNDC) model for use in grain rotations common in the Susquehanna drainage. Our work is conducted for silty clay loam soils, high clay soils common to the drainage. Our work assesses the importance of nitrogen-source in determining crop yield and nitrogen loss from agricultural systems by studying three rotations: 1) conventional, inorganically fertilized corn-soybean rotations, 2) legume-fertilized corn-soybean-winter wheat – legume rotations, and 3) manure-fertilized corn-soybean-hay rotations. Long-term data sets from The Rodale Institute in Kutztown, PA have been used to validate model dynamics. Comparisons of modeled and measured flux over the course of a decade demonstrates that the DNDC model accurately models low nitrate flux periods, but does not accurately track observed patterns of peak nitrate flux. Our current research addresses modifying DNDC to simulate high-flux nitrate events.

- Our DNDC work was presented as part of a workshop, "Denitrification modeling across terrestrial, freshwater, and marine systems", sponsored by Natural Environment Research Council and National Science Foundation at the Institute for Ecosystem Studies from November 28-30, 2006.

Precision Nutrient Management (PNM) Model
Lead: Jeff Melkonian
Crop and Soil Sciences

Background and Goals

Small changes in the timing and rate of nutrient applications (fertilizer and manure) for corn production can significantly affect nitrogen losses to surface and groundwater. We developed the PNM model to improve nitrogen use efficiency and reduce nitrogen leaching. This model simulates soil nitrogen and soil water based on the LEACHN model (Hutson, 2003) and maize growth and nitrogen uptake based on the model of Sinclair and Muchow (1995). Climate data are automatically downloaded from the Northeast Regional Climate Center. Higher resolution climate data for New York State are currently being developed, and will allow the model to make separate predictions for each 5 km by 5 km area. The initial focus is on corn production since it is an important row crop in the upper Susquehanna basin and a potential source of nitrogen loads to surface waters. We will use the model to simulate different management, climate and fertilizer and manure inputs to identify management practices that limit nitrogen leaching while maintaining crop productivity. We will

**Example of High Resolution Climate Data:
Range of daily maximum temperatures: 6/1/06**

Cooler

10 degrees C

Warmer

● NOAA Climate Station
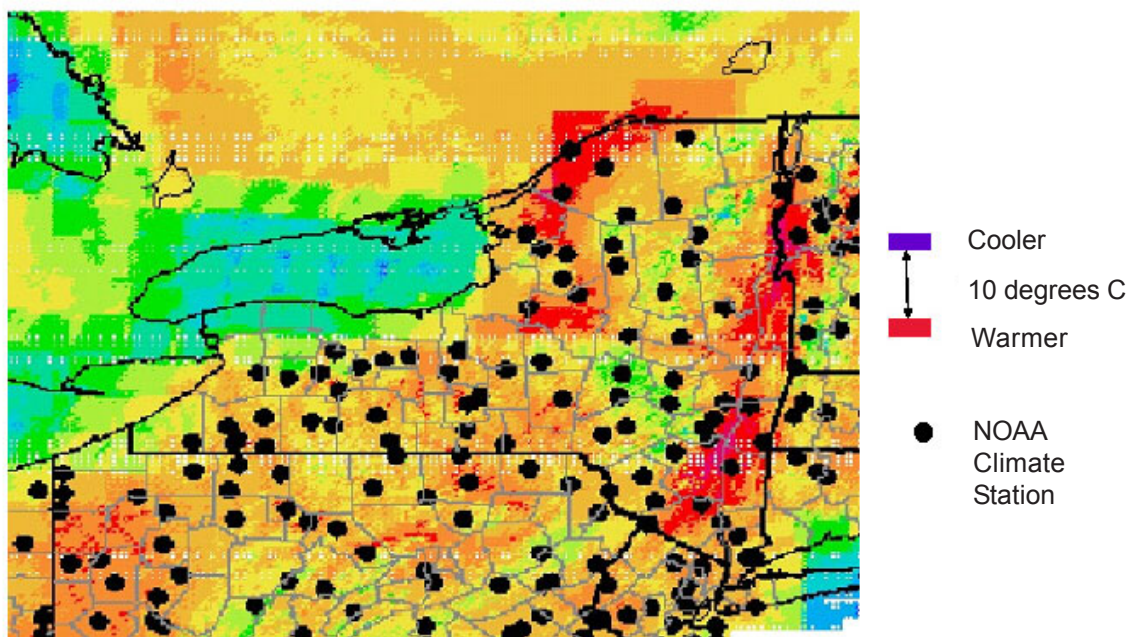
also run simulations to make more precise side-dress nitrogen recommendations, because such recommendations can reduce environmental nitrogen losses by up to 60 kg N ha^{-1} yr^{-1}.

Results

We have modified the soil temperature, crop growth and nitrogen transformation components of the PNM model. These changes improved model performance when tested against nitrogen leaching, nitrogen mineralization, and crop nitrogen uptake and growth data from experiments at different locations in New York State. In particular, simulation of nitrogen losses and crop nitrogen uptake in manured fields was improved by using recently calibrated PNM model nitrogen transformation rate constants. We made progress in the development of a new Nitrogen Leaching (or Loss) Index (NLI) for New York State and a web-based application of the PNM model to improve current nitrogen fertilizer recommendations for maize. The goal of each of these efforts is improve nitrogen-use efficiency in maize production and reduce nitrogen losses to surface and groundwater, including those in the Upper Susquehanna River Basin. The manure and inorganic nitrogen model simulations spanning 40 years of climate data for locations across New York State, including the Upper Susquehanna Basin, have been completed. We are using the results of these simulations to develop a new Nitrogen Leaching (or Loss) Index (NLI) for New York State.

The PNM model web interface for maize nitrogen fertilizer recommendations has been largely redone based on input from colleagues at Cornell. A log-in page and an expanded output page have been added. The output page provides user with additional information on field nitrogen status and weather over the time period of the simulation. Significant progress was made on the development of high resolution precipitation and temperature data by the Northeast Regional Climate Center (NRCC) (Art DeGaetano and Laura Joseph). These data will replace the current weather data (from the Applied Climate Information System) supplied by the NRCC and should significantly improve the nitrogen recommendations provided by the PNM model.

Publications

Sogbedji JM, van Es HM, Melkonian J, Schindelbeck RR. (2006) Evaluation of the PNM model for simulating drain flow nitrate-N concentration under manure-fertilized maize. Plant and Soil 282:343-360.

Presentations

- World Congress of Soil Science / July 9-15, 2006 / Philadelphia, PA, USA
  1) Session 4.3A Land Use Modeling as a Tool to Combat Soil Degradation Oral presentation: "Application of dynamic simulation modeling for nitrogen management in maize" J. Melkonian, H. M. van Es, A. DeGaetano, J. Sogbedji (Université de Lomé, Ecole Supérieure d'Agronomie, Lomé, Togo) and L. Joseph.

  2) Session 1.0 PW. Synthesis, Modeling and Application of Disciplinary Soil Science Knowledge to Soil-Water-Plant-Environment Systems

Model: Predicting Nitrogen flow from Forested Watersheds

Lead: David Weinstein
Natural Resources

### Background, Goals, and Research Update

To predict nitrogen export, the Regional Nutrient Management model (ReNuMa) uses a relationship predicting nitrogen export from nitrogen deposition. I am constructing an alternative method to estimate nitrate export from a forested watershed to increase the accuracy of this prediction. This method uses the model, Simple Nitrogen Cycle [SINIC], to provide a relationship between site conditions and nitrogen export that accounts for more of the variables causing export to vary spatially and temporally. Clustering of the output from the simulations made using data from Hubbard Brook Experimental Forest has identified the importance of topography, temperature, moisture, substrate, vegetation on nitrogen export. I am currently investigating whether this set of variables must be expanded to work as well in the watersheds of the upper Susquehanna. I am establishing a data set for the upper Susquehanna for topography, temperature, moisture, and substrate. I am defining sub-watersheds of the upper Susquehanna based on spatial and temporal categories defined by topography, temperature, moisture, substrate, and vegetation. For a selection of these sub-watersheds, I am producing predictions for inorganic nitrogen export based on the relationship described above.

Presentation

- Weinstein, D.A., "Predicting N flow from forested watersheds in the upper Susquehanna basin", Poster for Agricultural Ecosystem Program All-participants meeting, April 2006.

Upper Susquehanna River Basin
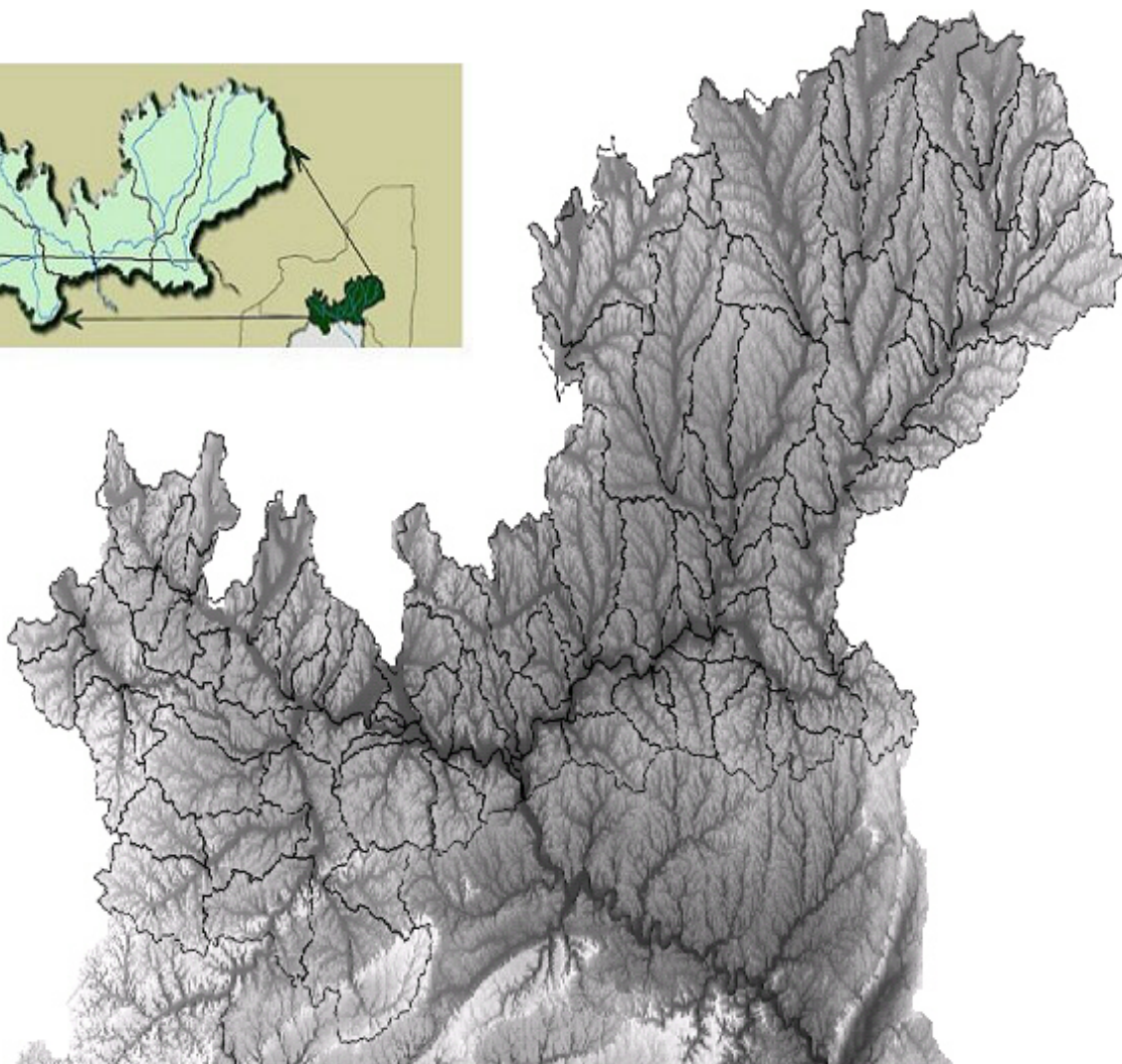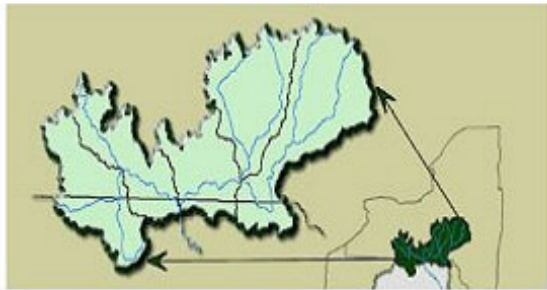
Student Mini-Grants

We awarded 6 mini grants to students in five different departments. These grants range between $1,000 and $3,000 and were for year 1. Progress is reported below.

Quantification of On-Farm Biological Nitrogen Fixation Across a Fertility Gradient

Lead: Meagan Cocke
Horticulture

On-farm field plots were established in April 2006 to quantify biological nitrogen fixation of annual and perennial legumes on grain farms in the Finger Lakes region representing a soil fertility and management gradient. Red clover and field peas in monoculture and mixtures with orchardgrass and oats, respectively, were established on 17 fields. Soil samples were collected in June 2006 and analyzed for nutrient availability and texture. An additional soil sampling was completed in August 2006 for a mid-season assessment of available inorganic nitrogen pools. Plant and soil samples were collected in October 2006 and will be analyzed to quantify nitrogen fixation and to assess labile organic nitrogen pools such as microbial biomass and particulate organic matter. A final sampling of biomass and soils will be completed in spring 2006. Nitrogen mass balances will be developed for all 17 fields using collected yield data and farmer records. More accurate estimates of field-scale biological nitrogen fixation will provide important information for modeling nitrogen sinks and fluxes within the Susquehanna River basin. Integrating nitrogen fixation and soil nitrogen measurements with field-scale nitrogen balances will assist in evaluating the effects of different agricultural management practices on nutrient pollution.

Understanding the Role of Polyphosphate Accumulating Organisms (PAOs) in Phosphorus Mobilization in the Susquehanna Basin Watershed

Lead: Maria Vicenta Valdivia
Biological and Environmental Engineering

Methods

Two undisturbed soil columns, 30-cm diameter by 30-cm deep, were extracted from the Harford T&R Center. Plants were carefully removed from soil columns, and each column was placed on a support base, with one sampling port at a depth of 15-cm and a central drain hole, connected to a tube in order to direct the leachate to a bucket placed at the outlet of each column. Each bucket contained 16 L of water with a phosphorus concentration of about 320 mg/L as K_2HPO_4, normalized at pH 7 using HCl, and equipped with an air pump to maintain aerobic conditions. Water from each bucket was added to each column independently using a sprinkler connected to a pump, in order to simulate rainfall, at a rate of about 250 mL/min, alternating cycles of 15 min of rainfall and 15 min of recess, to allow the columns to drain. The water in the buckets was thus recycled for each soil column over the length of the experiment, *i.e.* 10 days, taking water samples every 2 h for the first 12 h, every 12 h for the first 5 days, and every 24 h until day 10. With the same frequency, water pH and dissolved oxygen (DO) was measured in the effluent and in each bucket. Soil pH, oxidation-reduction potential (ORP) and temperature at the top soil and the sampling port in each column were also measured. Soil samples were taken from the top and the sampling port before and after the experiment, for NMR spectroscopy. Water samples were analyzed for phosphorus colorimetrically and for polyphosphate using solution state 31P NMR spectroscopy.

Results

Results were similar for both soil columns, as expected. About 90 percent of dissolved phosphorus decreased in the first 24 h, reaching as little as 6.9 mg/L after 10 days. Soil temperature remained stable during the experiment, 22.7 C avg. ORP values also remain constant over the experiment, 334 mv avg, with similar values at the top soil and in the sampling port. Effluent DO decreased from 7.3 mg/L to 3.6 mg/L, suggesting increasing microbiological activity, since no plant roots were present and microfauna can be considered negligible. However, 31P NMR results show that no polyphosphate was present in the soil, and thus, there is no evidence of PAOs activity. The breakthrough curves obtained from each column are consistent with phosphorus sorption.

Continuing Work

Trials including saturation/desaturation cycles will be performed with the columns in order to test the effects of an anaerobic phase, if any, in promoting the growth of PAOs in soils. Additionally, small scale sorption experiments will be performed in order to assess the importance of sorption in phosphorus retention in soils.

Mobilization of Phosphate from the Iron-bound Phosphorus Sink in Freshwater Wetlands
Lead: Sam Simkin
Natural Resources

A conceptual model of the study was presented in poster format at a US EPA conference in Washington, DC. Method development focused on analytical techniques that are sufficiently economical to support spatially extensive sampling and subsequent linkage to maps of bedrock chemical composition. Future work will proceed with cross-site comparisons of wetland porewater, soil, and plant tissue chemistry, laying the foundation for experimental manipulations and ultimately spatial interpolation.

Does Increasing Soil Carbon Promote Nitrogen Retention?
Lead: Marissa Weiss
Ecology & Evolutionary Biology

1) Poster Presentation, AEP Spring meeting, May 2006
2) Continuing work: I am currently transitioning from methods testing to collecting, incubating, and analyzing soil. I will collect soils from two different land uses at the Connecticut Hill Game Management Area, forest and old field. I will quantify the content of labile and recalcitrant organic matter in the soils. I will then conduct a lab incubation in which I will incubate paired control and nitrogen fertilized soils. I will measure nitrogen leached from the incubated soils to determine whether soils with more labile organic matter retain more nitrogen.

Reduce the Fluxes of Nutrients in Agroecosystems in the Upper Susquehanna River Basin: Amendment of Willow Char from Renewable Biomass and Energy Production Byproduct
Lead: Chih-Hsin Cheng
Crop and Soil Sciences

- In this project, application of bio-char for mitigating the nutrients losses was studied. Although I started from oak wood bio-char, the ultimate goals will be applying the bio-char, produced from renewable biomass or bio-energy by-products, for solving environmental problems.

- For simulating the fate of bio-char in soils, original bio-char was incubated at different temperatures for 6 months. The results showed that pH values of bio-char decreased from 8 to 6. The FT-IR (Fourier Transform Infrared Spectroscopy) spectra indicated that the decrease of pH values was due to the increases of carboxylic and phenolic functional groups. With more functional groups, the positive charge of bio-char decreased and the negative surface charge increased. The point of zero net charge (PZNC) also showed that original bio-char was at pH 7 and then dropped to pH below 3 when bio-char was incubated at 70°C or 105°C. Future work will proceed with conducting isothermal adsorption experiments of phosphorus and nitrogen in these bio-chars with different properties. I expect that both specific and non-specific adsorption will occur for phosphorus adsorption, while only non-specific adsorption will occur for nitrogen adsorption.

Nitrous Oxide Flux from Organically Fertilized Fields in the Upper Susquehanna River Basin: the Estimates of Spatial and Temporal Variability by Different Scale Measurements
Lead: Marina Molodovskaya
Biological and Environmental Engineering

Agriculture has been implicated as an important source of atmospheric nitrous oxide and ammonia emissions. In dairy areas the main source of nitrogen is due to the spreading of animal waste on the agricultural land. Laboratory-scale studies and field studies were carried out in order to understand the basic processes controlling ammonia and nitrous oxide emissions from fresh manure and manure-treated soils. The laboratory studies estimated the maximum potential and tendencies of ammonia and nitrous oxide emissions from manure impacted by different oxygen availability conditions and tillage conditions.

We found that greater air exchange significantly enhanced nitrification and inhibited denitrification in fresh manure. Soil texture was also a factor that controlled ammonia volatilization and nitrous oxide formation processes in soils. For larger-scale field research, state-of-the-art integrated micro meteorological instrumentation was used for measuring nitrous oxide atmospheric fluxes (eddy covariance method), precipitation, temperature, CO_2 land-atmosphere exchange, and surface energy balance. The instrumentation (Campbell Scientific, Logan, Utah) provided continuous monitoring of the real-time high frequency data. Field and laboratory experiments both show increases in nitrous oxide flux after intensive precipitation events and manure applications and are much greater on the poorly drained hardpan soils than on the well-drained valley soils.

Summary and Future Directions

The amount of nitrogen flowing into surface waters and estuaries has increased 10-fold or more during recent decades in many parts of the USA. This increase has degraded most of the coastal waters in the USA. In estuaries such as the Chesapeake Bay, large increases in nitrogen are causing hypoxia and anoxia, degradation of habitat quality, loss of biotic diversity, and increased harmful algal blooms.

At the national scale, agriculture is the major source of nitrogen pollution, but atmospheric deposition is also a major source in many regions, making up 25 percent to 50 percent of the nitrogen inputs to Chesapeake Bay. The Susquehanna River is the largest river east of the Mississippi in the US, the largest tributary of Chesapeake Bay, and the single largest source of nutrients to the main stem of the Bay. Thus, better understanding the sources and sinks of nutrients and sediment in the Susquehanna River can lead towards better management of nutrients and water quality in the Chesapeake Bay. Technical solutions exist and should be implemented, but further research is needed urgently to identify the most important sources of nutrients and the most cost-effective methods for reducing nutrient pollution. This research project is designed to increase our knowledge of the sources and sinks of nutrients and sediments in the New York portion of the Susquehanna watershed. Our results will provide new information that is useful for many other parts of the US as well as the Chesapeake Bay.

We are currently in the second year of this research project. We have accomplished a great deal with modest funding during a short time by leveraging ongoing research activities at Cornell University, and by collaborating with other institutions. As demonstrated in this progress report, we have created a large collaborative team of researchers to investigate fundamental processes controlling nutrients cycling while at the same time integrating basin wide information by means of modeling. We also support two intensive research sites, one of which focuses on atmospheric deposition and one of which focuses on nutrient cycling at a large research farm with a strong historical record of research in farming methods as well as soil, water, and air quality. We have also supported student research projects that will contribute to training future scientific leaders as well as answering specific scientific questions that will provide a more robust platform for effective environmental management.

Created wetland by the Upper Susquehanna Coalition in the Catatonk Creek Watershed. Photo courtesy of Mary Jane Porter, NYS Water Resources Institute.

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Appendix

Agricultural Ecosystems Program Principals and Participants

Principals

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Johannes Lehmann	Crop and Soil Sciences, Cornell University
Roxanne Marino	Ecology and Evolutionary Biology, Cornell University

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Participants

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