New York State Water Resources Institute Annual Technical Report FY 2005

Introduction

The New York State Water Resources Institute (WRI) devotes most of its resources to research and outreach to assist in state and local government problem solving and demonstration projects. Staff and many cooperating Cornell faculty have been enmeshed in New York States (and more recently New York City) water resources management processes, focusing on the most scientifically demanding water problems.

WRIs FY2005 competitive grants program was operated jointly with the New York State Department of Environmental Conservations (NYS DEC) Division of Water, with the assistance of other NY State Departments. NYS DEC contributed $50,000 of Clean Water Act section 319 funds to support additional projects by higher education. Projects were solicited competitively from about 50 academic entities in NY. Projects were evaluated and selected for funding by a panel consisting of agency representatives on the New York State Nonpoint Source steering committee, and a SUNY academic representative.

Project oversight is primarily through submission of project reports for the annual technical report to USGS. Feedback from project clintele to NYS WRI is an additional factor in evaluating project principals requests for later funding.

Research Projects

WRI FY2005 activity under the Federal Water Resources Research Act consisted largely of research and information transfer projects funded from FY2003 through FY2005. One national 104G project, nine state 104B projects, and the NYS WRI Directors Office information and transfer project are included in this report.

The FY2003 104G project, which did not begin until May 2005, examines statistical patterns in low streamflows. Four FY2004 104B projects were delayed in starting and have carried over to FY2005. Urban stormwater management, development of water quality tools to identify high runoff risk areas, assessing nitrate-nitrogen in surface and groundwater, and measuring the effects of wetland and riparian zones on water quality, were the focus of the four projects.

Five FY2005 projects resulted from NY competitions reflecting WRIs long-term priority on nonpoint source pollutant management. The focus of these concerned the: export of atmospheric nitrogen deposition from forests; GIS-based riparian buffer management for phosphorus and sediment; water resource protection under changing climate conditions; water quality protection for Cayuga Lake; and addressing nutrient excesses for improved water quality on farms.

Research Program

An Assessment of New Advances in Low Streamflow Estimation and Characterization

Basic Information

Title:	An Assessment of New Advances in Low Streamflow Estimation and Characterization
Project Number:	2003NY33G
Start Date:	8/1/2003
End Date:	7/31/2006
Funding Source:	104G
Congressional District:	25
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Water Use, Non Point Pollution
Descriptors:	risk assessment, geographic information system, watershed hydrology, statistical
Principal Investigators:	Chuck Kroll

Publication

1. Zhang, Z.; C.N., Kroll, 2005, A Closer Look at Baseflow Correlation, submitted to the ASCE Journal of Hydrologic Engineering, July 2005. Decision Pending.
2. Hirabayashi, S.; C.N., Kroll, 2006, Automating Regional Descriptive Statistic Computations for Environmental Modeling, resubmitted to Computers and Geosciences, January 2006. Decision Pending.
3. Zhang, Z.; C.N., Kroll, 2005, Estimation of Low Streamflow Statistics at Ungauged Sites Using Baseflow Correlation, in American Geophysical Union Conference, New Orleans, LA.
4. Hirabayashi, S.; C.N., Kroll, 2005, Developing a Geopatial Data Model to Derive Watershed Characteristics for Low Streamflow Prediction, in American Geophysical Union Conference, New Orleans, LA.
5. Matonse, A.H.; C.N., Kroll, 2005, Stimulation of Baseflow and Low Streamflow Statistics Using the SAC-SMA Model and a SAC-SMA/Hillslope- Storage Boussinesq Model, in Fall AGU meeting, San Francisco, CA.
6. Kroll, C.N.; Z., Zhang; S., Hirabayashi, 2005, A Comparison of Regional Regression and Baseflow Correlation for Estimating Low Streamflow Statistics, in Fall AGU meeting, San Francisco, CA.
7. Zhang, Z.; C.N., Kroll, 2006, Estimation of Low Streamflow Statistics Using Baseflow Correlation

With Multiple Gauged Sites, in American Geophysical Union Conference, Baltimore, MD.
8. Hirabayashi, S., 2005, Examining the Impact of Raster Datasets on Floodand Low Streamflow Regional Regression Models Using a Custom GIS Application, MS Thesis, Faculty of Environmental Resources and Forest Engineering, College of Environmental Science and Forestry, SUNY-ESF, Syracuse, NY.
9. Zhang, Z., 2005, Advances in Low Streamflow Statistics Estimation Using Baseflow Correlation, PhD Thesis. Faculty of Environmental Resources and Forest Engineering, College of Environmental Science and Forestry, SUNY-ESF, Syracuse, NY.
10. Luz, J., 2005, Investigating Improvements in Low Streamflow Regression Models, PhD Thesis. Faculty of Environmental Resources and Forest Engineering, College of Environmental Science and Forestry, SUNY-ESF, Syracuse, NY.

PI Chuck Kroll
Title: An Assessment of New Advances in Low Streamflow Estimation and Characterization
Principal findings or significant results:
Research on this project began in May 2004, and thus we have completed 2 years of this 3 year project. We have focused our primarily research on two data sets: the USGS's Hydro-Climatic Data Set (HCDN) and a study area encompassing eastern Tennessee and western North Carolina that was chosen by personnel from the USGS's Reston, VA office. Using these study areas, the following has been found:
1. Most of the underlying assumptions of the baseflow correlation technique appear to be valid for the continental United States.
2. The baseflow correlation technique can be improved if multiple sites are used to transfer information to the ungauged site. These improvements are greatest when less than 8 baseflow observations are available, and diminish with more than 8 observations.
3. In the eastern Tennessee/western North Carolina study area, lowflow regional regression models were greatly improved by inclusion of mapped values of the baseflow index. These findings have encouraged us to pursue an investigation of spatial interpolation of watershed hydrogeologic characteristics.
4. The horizontal resolution of the DEM employed to derived watershed boundaries had little impact on the quality of the derived watershed characteristics. This may have to do with the large horizontal resolution of the raster datasets employed in this study.
5. The use of raw MODIS data appears to have some predictive information for hydrologic modeling, though interestingly it appears to have more of an impact on floods than droughts. We are further investigating this issue with multi-band remotely sensed indexes.
6. Regional regression and baseflow correlation perform similarly in the eastern Tennessee/western North Carolina study area, with regional regression outperforming baseflow correlation, especially when the baseflow index is included in the regression models.
We are now beginning research in Idaho, where the USGS has been performing numerous low streamflow investigations. We also hope to select a more arid study region, as low streamflow estimation typically performs poorly in these areas.
Notable Achievements:
This research has resulted in two notable achievements. The first is the development of a GIS tool to automate the calculation of descriptive statistics from multiple raster datasets across watersheds in a region of interest. This tool was created to be of use with any polygon coverage, and thus can be employed with state, county, city, property, or any other boundaries of interest. Such flexibility makes this tool of wide interest to many researchers, not only hydrologists. The tool is freely available to the public and can be downloaded at www.esf.edu/erfeg/kroll. A tutorial has been created to aid users of this tool. The second notable achievement is that this research has inspired the creation of an International Association of Hydrologic Sciences (IAHS) Prediction at Ungauged Basins (PUBs) low streamflow work group. This group is currently being formed as a joint venture with the Northern European Flow Regimes from International Experimental and Network Data (NE FRIEND), and will focus on international cooperation and information exchange with respect to low streamflow estimation. Through this group, a number of low streamflow study areas will be created throughout the world. These study areas will be the focus of long-term low streamflow research. Research from this group will help us better understand the performance of various estimators of low streamflow statistics at ungauged river sites in different hydrologic setting, as well as the uncertainty associated with these estimators.
Student support:
1. Zhenxing Zhang, PhD, Area of Study: Water Resource Engineering, PhD Topic: Baseflow Correlation.
2. Satoshi Hirabayashi, MS, Area of Study: GIS and Water Resources, MS Topic: GIS Tools Watershed Characterization.

3. Adao Matonse, PhD, Area of Study: Water Resource Engineering, PhD Topic: Hillslope Models for Low Streamflow Prediction.
4. Satoshi Hirabayashi, PhD, Area of Study: GIS and Water Resources, PhD Topic: Advanced Mapping Techniques to Aid in Low Streamflow Prediction.

Export of atmospheric nitrogen deposition from forests at the top of the Susquehanna watershed

Basic Information

Title:	Export of atmospheric nitrogen deposition from forests at the top of the Susquehanna watershed
Project Number:	2005NY64B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	22
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Acid Deposition
Descriptors:	None
Principal Investigators:	Christine Goodale

Publication

Export of Atmospheric Nitrogen Deposition from Forests at the top of the Susquehanna Watershed.

Principal investigators:

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Collaborators include: Robert Howarth and Alex Flecker, Department of Ecology & Evolutionary Biology, Cornell University; Tom Butler, Institute of Ecosystem Studies, Millbrook, NY; and Elizabeth Boyer, formerly SUNY-ESF, now University of California, Berkeley.

Duration: Mar. 2005 – Feb. 2006
Federal Funds received: $24,981
Non-Federal (Matching) funds: $32,100 (128% of federal funds).
Congressional District: NYS District 22.

Abstract: We proposed that chronic exposure to some of the highest rates of atmospheric NO_3^- deposition in the country might have led to elevated NO_3^- exports from central NY forests at the top of the Susquehanna Basin, and to decreased uptake of atmospheric NO_3^- by plants and microbes in these ecosystems. Monthly sampling of stream N chemistry in 16 small streams over March 2005 to February 2006 and dual isotope analysis ($\delta^{15}N$ and $\delta^{18}O$) of select stream NO_3^- samples suggests that contrary to expectations, central NY forests retained the vast majority (89-99%) of atmospheric N deposition. Estimated annual stream export of NO_3-N from wholly forested catchments was 0.1 to 0.7 kg N ha^{-1} y^{-1}, of which direct contributions of atmospheric NO_3^- were small (4-20% of annual export) and confined to the snowmelt period. The apparent contribution of atmospheric NO_3^- during the March 2005 snowmelt sampling (11 to 59% of stream NO_3^-) appears to be an unusually high delivery for intact forest ecosystems. Despite the low estimated annual NO_3^- export, summer NO_3^- concentrations were exceptionally high compared to other Northeastern streams. Seasonal patterns of NO_3^- concentration (summer peaks, spring and fall minima) were contrary to most other snow-dominated catchments, for reasons that can only be speculated at present, but may provide useful information about controls on N exports from these catchments.

Statement of Critical Regional or State Water Quality Problem:

This work addressed several priority research topics identified by the NY Nonpoint Source Coordinating Committee for FY2005, with particular emphasis on the goal to "Improve understanding of the sources and impact of nutrients including the significance of atmospheric sources and deposition."

Introduction

The Susquehanna River supplies about three-quarters of the nitrogen (N) delivered annually to Chesapeake Bay. Primary productivity in the Chesapeake Bay is nitrogen limited, and so the added N drives processes of eutrophication and subsequent hypoxia. In turn, these conditions impact seagrass beds and shellfish populations and other indicators of coastal ecosystem health. The majority of the N inputs to the Susquehanna watershed are from agricultural sources, including fertilizer (15%), N-fixing crops (27%), and import of animal feed, yet atmospheric deposition of fixed N ("N deposition") provides a major contribution (27%) to the watershed's total N loading (Boyer et al. 2002).

Two-thirds of the Susquehanna basin is in forest land cover, for which atmospheric deposition provides virtually all of the N inputs. In forested catchments, N deposition can lead to acidification of soils and surface waters, nutrient imbalances in vegetation, and decreased biodiversity (Aber et al. 1998, Driscoll et al. 2002). Furthermore, the delivery of exported N downstream can contribute to coastal eutrophication (Howarth et al. 2000). The New York portion of the Susquehanna Basin receives some of the highest rates of N deposition in the country, with total (wet + dry) inorganic N deposition exceeding 10 kg N ha^{-1} y^{-1} (Butler & Likens 1995, Butler et al. 2003, Sheeder et al. 2002). Recent syntheses of the effects of N deposition on temperate forests indicate that stream NO_3-N exports often increase sharply as N deposition increases above a threshold of approximately 8 kg ha^{-1} y^{-1} (Aber et al. 2003). However, variability in stream N export increases as well; that is, some, but not all watersheds increase N exports with increasing N inputs. Variability among watersheds receiving comparable rates of N deposition can be quite large, with stream inorganic N exports ranging from 2% to 50% of inorganic N inputs (e.g., Lovett et al. 2000, Goodale et al. 2000). Factors driving variation among watersheds may include differences in tree species composition (Lovett et al. 2000), past land-use history (Goodale et al. 2000), and variation in hydrologic flowpaths across watersheds or through time (Creed & Band 1998). Forests of the Adirondacks and Catskills have the highest N export of forests in the Northeast, yet even basic surveys of N export from forested catchments in the New York portion of the Susquehanna basin had been lacking. Uncertainty over the magnitude and causes of forest export of N derived from atmospheric deposition has been a major source of uncertainty in quantification of nonpoint source N loading for the upper Susquehanna watershed. The North American Nitrogen Center (NANC, www.eeb.cornell.edu/biogeo/nanc) has identified improved understanding of the roles of atmospheric N deposition and forest retention of N deposition in the Susquehanna Basin as a major focus for needed research.

This project obtained information on the quantity and immediate source of N exported from forested catchments at the top of the Susquehanna Basin, a region where human activities have increased rates of N deposition to levels ~8-10 times greater than those occurring during preindustrial conditions. Monthly surveys of stream N concentrations from 16 small forested catchments allowed estimation of landscape variation in N export. In addition, this project used the power of stable isotopes ($\delta^{15}N$ and $\delta^{18}O$) to estimate the direct contributions of atmospheric deposition of NO_3^- to stream NO_3^- export from these forests. The isotopic signatures of both nitrogen ($\delta^{15}N$) and oxygen ($\delta^{18}O$) differ in nitrate derived from various sources. The $\delta^{18}O$ signature of NO_3^- is particularly useful for discriminating between atmospheric-derived NO_3^- and NO_3^- that has been cycled by microbes in soils or sediments (Durka et al. 1994, Kendall 1998, Spoelstra et al. 2001, Williard et al. 2001, Burns & Kendall 2002, Pardo et al. 2004).

The overarching hypothesis tested here is that chronic exposure to highly elevated quantities of atmospheric N deposition has led forests of the Upper Susquehanna region toward N saturation. Hence, we expected that:

(H1) Watershed N exports balance a large fraction of N inputs from deposition, and

(H2) A large fraction of atmospheric NO_3^- passes directly through the soil without uptake by plants or microbes.

We tested the first hypothesis by measuring monthly stream N concentrations, estimating stream N exports, and comparing these fluxes to N loading in deposition. This approach focuses on the mass balance between atmospheric inputs and hydrologic losses, allowing some consideration for internal cycling of atmospheric N. We tested the second hypothesis by determining the dual isotopic signature of NO_3^- ($\delta^{15}N$ and $\delta^{18}O$) in stream water and comparing it to the signature of NO_3^- in wet deposition. This approach focuses on discerning the amount of atmospheric NO_3^- that passes directly to the stream without any microbial processing. Specific objectives include:

1) Quantify forest N balance for a range of forested catchments in the Upper Susquehanna Basin.

2) Identify the direct contributions of atmospheric NO_3^- deposition to forest N export through use of the $\delta^{18}O$ and $\delta^{15}N$ signal of exported NO_3^-.

Methods

Site Description. Landscape level variation in forest export of atmospheric N deposition was assessed through monthly surveys of stream N concentrations (NO_3^-, NH_4^+, and DON) in 16 mostly first-order streams (Table 1). These streams are located within 20 km of Ithaca, NY (42.48 °N, 76.47 °W), and within 25 km of the Connecticut Hill atmospheric deposition monitoring site (CTH110, 42.40 °N, 76.65 °W, 501 m elevation), site CTH110 within EPA's Clean Air Status and Trends Network. All streams have wholly forested catchments free from human habitation or paved roads, although there may be some contributions from agriculture to the upper part of the catchment of stream at the Connecticut Hill deposition station (#16, IES). All streams are within the Susquehanna Basin except for the Connecticut Hill station, which drains north into the Finger Lakes and the St. Lawrence system.

Climate and Deposition. Mean (1961-1990) annual temperature at Ithaca, NY is 7.7 °C, with mean monthly temperatures ranging from -5.8 °C in January to 20.3 °C in July. Annual precipitation averages 899 mm/yr, with greater mean monthly precipitation in summer (80-96 mm/month) than winter (46-65 mm/month).

Atmospheric deposition has been monitored continuously at the Connecticut Hill air pollution station since 1978 on a daily or event basis, and the atmospheric concentration of HNO_3 and fine particulate NH_4^+ and NO_3^- has been measured weekly since 1987 (Butler & Likens 1995). The sum of these forms of atmospheric deposition averaged about 10 kg N ha^{-1} y^{-1} in the early 1990s, decreasing to about 8.5 kg N ha^{-1} y^{-1} in the late 1990s and early 2000s (Butler & Likens 1995, CASTNet online: www.epa.gov/castnet/sites/cth110.html). Wet deposition of NO_3^- makes up 3.2 kg N ha^{-1} y^{-1} of this total (2000-2004; http://nadp.sws.uiuc.edu/nadpdata/).

Table 1: Stream abbreviation, name and general location, and GPS location.

Abbreviation	**Stream**	**Lat. (°N), Long. (°W)**
1. CYT	Unnamed (Cayutaville Rd., CT Hill State Game Mgt. Area)	42.38742, 76.69048
2. SWN	Unnamed (Swan Rd., CT Hill State Game Mgt. Area)	42.31928, 76.71058
3. UCC	Upper Carter Creek (CT Hill State Game Mgt. Area)	
4. WCC	West fork, Carter Creek (CT Hill State Game Mgt. Area)	42.34632, 76.66477
5. ECC	East fork, Carter Creek (CT Hill State Game Mgt. Area)	42.34421, 76.66002
6. CNA	Unnamed (Cornell Natural Area, Connecticut Hill)	
7. WOV	Unnamed (west fork, Overlook Trail, Rt. 224)	
8. EOV	Unnamed (east fork, Overlook Trail, Rt. 224)	42.25241, 76.64994
9. PYN	Pine Creek (Arnot Forest)	42.27222, 76.63621
10. BAN	Banfield Creek (Arnot Forest)	42.27534, 76.64227
11. MIH	Michigan Hollow (Michigan Hollow Rd., Danby State Forest)	42.29859, 76.48425
12. EMH	Unnamed (Eastman Hill, Coddington Rd.)	42.33775, 76.39951
13. HPT	Unnamed (Honeypot Rd., Shindagan Hollow State Forest)	42.31672, 76.31396
14. BRY	Unnamed (Braley Rd., Shindagan Hollow State Forest)	42.32413, 76.35123
15. BMT	Unnamed (Bald Mountain, Shindagan Hollow State Forest)	42.34045, 76.35107
16. IES	Unnamed (CT Hill Air Monitoring Station / Institute of Ecosystem Studies)	

The isotopic composition of atmospheric N deposition to this site is being measured through a NYSERDA-funded project led by Elizabeth Boyer (Univ. California Berkeley) and Carol Kendall (USGS, Menlo Park, CA), with work still in progress as of June 2006.

Vegetation and Soil. Forests are composed of mixed hardwood species including red oak (*Quercus rubra*), sugar and red maple (*Acer saccharum* and *A. rubrum*), white ash (*Fraxinus americana*), basswood (*Tilia americana*), American beech (*Fagus grandifolia*), and black birch (*Betula lenta*) with occasional inclusion of some conifers, including eastern hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*) or planted red pine (*P. resinosa*). Most forests are second-growth, re-grown after harvest or cultivation ~60-100 years ago. Two of the catchments (BAN – Banfield Creek, and BRY – Braley Rd.) included recent partial harvest. Soils are mostly inceptisols (Dystrochrepts and Fragiochrepts) developed in glacial till composed largely of locally transported Devonian shales.

Field Methods. Stream samples were collected monthly from March 2005 to February 2006 from 15 small streams, with a 16th stream from the Connecticut Hill atmospheric deposition site added in June 2005. Sampling dates targeted the middle of each month, although sampling was usually delayed when coinciding with high-flow events. Water samples were filtered with Luer-lok, 60 mL polypropylene syringes in the field through Whatman 0.7 μm pre-combusted glass fiber filters into six sample bottles designated for NO_3^- (30 mL), NH_4^+ (2 × 30 mL opaque polyethylene bottles), DOC and DON (60 mL high-density polyethylene bottles), and dual-isotope NO_3^- analysis (60 mL) analyses, as well as an archive sample (60 mL).

Analytical Methods. Ammonium was analyzed within 24 hours of return from the field using the sensitive fluorometric method (Holmes et al. 1999) with a Turner Designs Aquafluor. The rest of the samples were frozen until analyses up to 9 months later. Nitrate, chloride, and sulfate were measured on thawed samples using a Dionex ion chromatograph. After acidifying and sparging to remove dissolved CO_2, dissolved organic carbon (DOC) and total dissolved nitrogen (TDN) were measured using high-temperature oxidation with a platinum catalyst using a Shimadzu TOC-V analyzer. Dissolved organic nitrogen was calculated by difference as DON = TDN – (NO_3^--N + NH_4^+-N).

Samples for simultaneous analysis of $\delta^{15}N$ and $\delta^{18}O$ of NO_3^- were shipped frozen to the Casciotti lab at the Woods Hole Oceanographic Institution for separation and analysis using the microbial denitrifier method (Sigman et al. 2001, Casciotti et al. 2002). Analytical cost precluded dual isotope analysis of all streams by month combinations. To maximize characterization of spatial and temporal patterns of $\delta^{15}N$ and $\delta^{18}O$ of NO_3^-, we selected two months (March, July) to be analyzed for 9 of the 16 streams, and two streams to be analyzed for most months. March and July 2005 were chosen for the cross-stream comparisons to represent snowmelt and growing-season conditions, respectively. Dual isotope analyses were conducted for most months for two streams – Pine Creek, Arnot Forest (PYN) and West Fork Carter Creek, Connecticut Hill State Game Management Area (WCC) – for all months except for those autumn samples where NO_3^- concentrations were too low (<14 μg N/L) to conduct the analyses (Oct. for WCC and Oct., Nov., and Dec. for PYN).

<u>Estimates of N Flux and Retention</u>. Stream N export was estimated for the 15 streams with a year's worth of monthly stream chemistry by combining these chemistry measurements with measurements of monthly discharge at Fall Creek near Ithaca. With a catchment of 326 km^2, Fall Creek is many times larger than the streams sampled here, but is the smallest stream nearby with a USGS gauge. Nitrogen retention was estimated by comparing these estimates of N export to measurements of atmospheric N deposition to the region, obtained for the Connecticut Hill air pollution site for 2001-2004 (http://nadp.sws.uiuc.edu/nadpdata/).

<u>Istotopic Separation of Nitrate Sources</u>. The contribution of atmospheric NO_3^- to stream NO_3^- export was estimated through use of $\delta^{18}O$-NO_3^- values, assuming that the observed stream $\delta^{18}O$-NO_3^- values were a proportional mix of atmospheric and microbial-derived NO_3^-. Atmospheric values of $\delta^{18}O$-NO_3^- in the Northeast US and Southeast Canada typically fall ~50-60‰. By contrast, microbially cycled nitrate is expected to have $\delta^{18}O$ values around -5 to 2‰, based on the assumption that one of the three oxygen atoms in NO_3^- are derived from atmospheric O_2 ($\delta^{18}O$ = 23.5‰) and two are from soil water ($\delta^{18}O$ = -25 to + 4; Kendall 1998). The percentage of stream water derived directly from atmospheric NO_3^- was calculated as:

$$(\delta^{18}O\text{-}NO_{3\,Stream}^{-} - \delta^{18}O\text{-}NO_{3\,Microbial}^{-}) / (\delta^{18}O\text{-}NO_{3\,Precip.}^{-} - \delta^{18}O\text{-}NO_{3\,Microbial}^{-}) \times 100$$

Table 2: Isotopic ratios (‰) of $\delta^{15}N$-NO_3^- and $\delta^{18}O$-NO_3^- in precipitation and microbial nitrification in soils. Values indicate mean (range) in the literature for the Northeast US and southeast Canada.

Site	$\delta^{18}O$ Precip.	$\delta^{18}O$ Microbial	$\delta^{15}N$ Precip.	$\delta^{15}N$ Microbial	Reference
Turkey Lakes, ON	50 (35-59)	*-2 to +0.5**	-2 (-4 to +0.8)	0 to +6	Spoelstra et al. 2001
Mid-Appalachia, PA-WV	57 (17-76)	3 to 10 *(-0.8*)*	Not meas.	Not meas.	Williard et al. 2001
Biscuit Brook, NY	51 (35-70)	13 to 16 *(-0.7 to +2.4*)*	-0.1	+1.5 to +16	Burns & Kendall 2002
Huntington Forest, NY	54-82	1.2 to 11 *(-0.2 to +2.5*)*	-3 to + 3	-1 to +2	Campbell et al., In press
Sleeper's River, VT	90	-2 to -4	Not reported	Not reported	Ohte et al. 2004
Hubbard Brook, NH	62 (44-77)	*-5 to +15**	-2 (-5 to +2)	Not meas.	Pardo et al. 2004

**Calculated assuming that 1/3 of the O in NO_3^- derived from air (O_2), and 2/3 derived from soil water.*

This approach assumes that atmospheric deposition and microbial nitrification are the only processes that provide NO_3^- to these streams. Because direct measurements of $\delta^{18}O$-NO_3^- are not yet available at the local Connecticut Hill atmospheric deposition station, we used mean (60‰) and range (40-80‰) values from the literature (Table 2) to constrain the possible contribution of atmospheric NO_3^- to stream NO_3^- export. Microbial NO_3^- was assigned a mean (-3‰) and range (-5 to 0‰) based on both literature values (Table 2) and the minimum $\delta^{18}O$-NO_3^- values observed here.

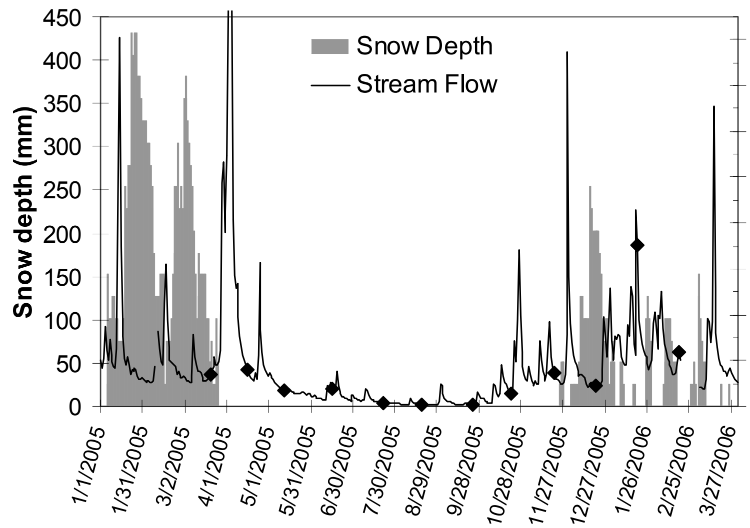

Figure 1: Snowpack depth (grey bars) at Ithaca, NY (http://met-www.cit.cornell.edu/climate/ithaca/) and streamflow (solid line) of Fall Creek at Forest Home, Ithaca, NY (http://nwis.waterdata.usgs.gov/ny/nwis/).

Results and Discussion

Climate and Streamflow.
The year spanning March 2005 to February 2006 received near-average precipitation at Ithaca, NY (962 mm), but included an exceptional summer drought and wet autumn. Summer 2005 was the driest and third hottest in the period of record since 1879: June through August temperatures were 2.8 °C warmer than average, and only 46 mm of rain fell within the two-month period of July 1 to August 29, 26% of average for this period. The drought was relieved by remnants of Hurricanes Katrina and Rita at the ends of August and September, respectively, followed by a series of fall storms that combined for an October total rainfall (185 mm) 223% of average. The winter of 2004-5 was slightly (0.6 °C) colder than average, leading to development of a large snowpack that held until late March. By contrast, the winter of 2005-6 was 2.7 °C warmer than normal, including a mean January temperature above freezing (0.1 °C) and consequent unstable snowpack throughout January and February 2006 (Figure 1). Streamflow peaked in response to events of both precipitation and snowmelt. Flows were very low during July, August, and September 2005 in response to the drought (Figures 1, 2). Lack of surface flow precluded sample collection at 4, 10, and 7 of the 16 streams during these months, respectively.

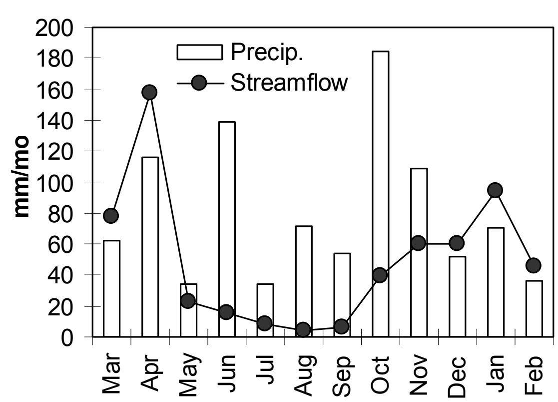

Figure 2: Precipitation (bars) at Ithaca, NY (http://met-www.cit.cornell.edu/climate/ithaca/) and streamflow (dotted line) of Fall Creek at Forest Home, Ithaca, NY for March 2005 to Feb. 2006 (http://nwis.waterdata.usgs.gov/ny/nwis/).

Stream Chemistry. Nitrate concentrations in all streams demonstrated an unexpected seasonal pattern of peak concentrations in summer (July – Sept.) and lowest

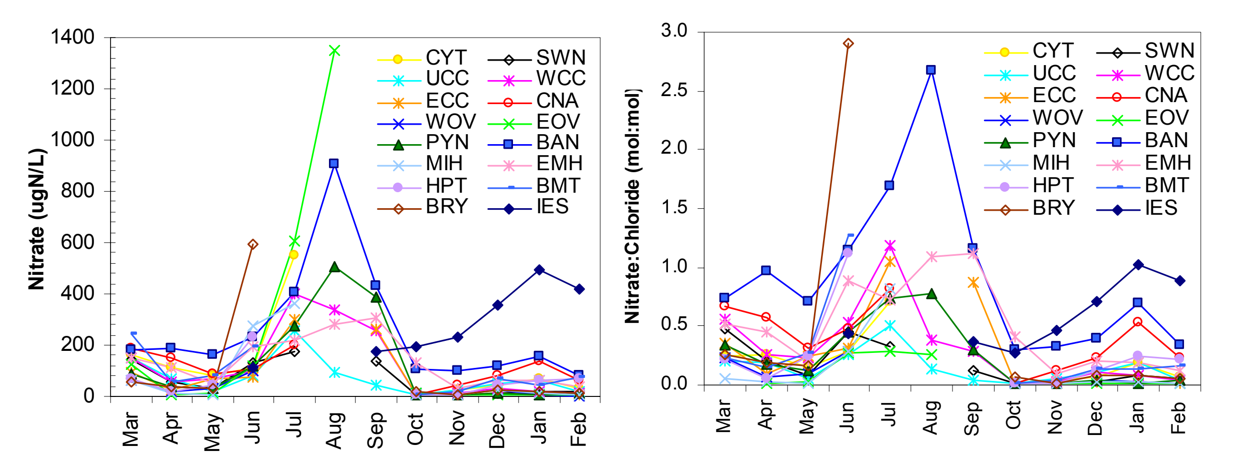

Figure 3A (left): Seasonal pattern of nitrate concentrations in 16 small forested catchments in central NY, and 3B (right), seasonal patterns of NO_3^-:Cl^- molar ratios.

concentrations in spring (April, May) and autumn (Oct., Nov.) (Figure 3). Ammonium concentrations were consistently low, and will not be discussed further: median concentrations were 1 µg/L with a maximum of 11 µg/L in one sample. The seasonal pattern of NO_3^- contrasts with the expected dormant season and spring snowmelt NO_3^- peaks and growing-season minima typical of most snow-dominated catchments (e.g., Stoddard 1994, Likens & Bormann 1995, Campbell et al. 2000, Goodale et al. 2000, Lovett et al. 2000). A similar pattern of summer maxima and spring and fall minima has been observed in southern streams, where the pattern was attributed to expected peaks in in-stream biotic demand for N at a site in Tennesses (Mulholland 2005) or to lags induced by deep geological flowpaths at a site in North Carolina (Swank & Vose 1997). The NO_3^-concentrations we observed exceeded those in Tennessee by a factor of 3 to 28 (e.g., summer maxima of 150 to 1400 µg/L v. ~50 µg/L). Some of these summer peaks are among the highest concentrations reported among comparable forested catchments in the Northeastern U.S. (cf. Aber et al. 2003).

We speculate that the cause for the unexpected seasonal pattern we observed may be due to a combination of climatic, hydrological, and biological factors. Seasonal patterns of the ratio of NO_3^- to Cl^- (Figure 3B) suggest that evaporative concentration during the summer drought (July – Sept.) may have partly driven the high late-summer NO_3^- concentrations observed in several streams (EOV, CYT, WCC, PYN). However, NO_3^- to Cl^- ratios more clearly illustrate strong seasonal patterns in NO_3^- concentration beyond those that can be explained by evaporative concentration alone. These seasonal patterns are characterized by modest increases at snowmelt, spring dips, summer maxima, and dips at leaffall (Figure 3B). The dips in May and October may be due to biological uptake of N for autotrophic (May) or heterotrophic (Oct.) demand. Hydrological factors may also play a role if, for example, deep flowpaths during the summer drought essentially decouple groundwater nutrient supply from surface biological demand (e.g., Burns et al. 1998, Schiff et al. 2002). Land use practices from agriculture (IES) or forest harvests (BRY and BAN) may explain the relatively high nitrate concentrations in these three streams (Figure 3A).

Stream N Export. Estimated NO_3^- export fluxes were consistently low, with a median value of 0.3 kg N ha^{-1} y^{-1} (Table 3). Although stream NO_3^- concentrations were surprisingly high during summer, streamflow was so low during the June to September period (6% of the annual flow) that these high NO_3^- concentrations contributed little toward elevating annual NO_3^- fluxes. Over

Table 3: Annual stream DON and NO_3-N export estimated by multiplying monthly flow from a gauged stream (Fall Creek, mm/mo) by measured monthly stream chemistry at the streams in this survey. Percent retention estimated by comparing stream export of NO_3-N with atmospheric deposition of inorganic N measured at Connecticut Hill (8.5 kg N ha^{-1} yr^{-1}). The amount of annual stream NO_3^- flux derived directly from atmospheric deposition of NO_3^- (uncycled) was estimated assuming an atmospheric $\delta^{18}O$ value of 60‰ (range 40-80‰) and a microbial value of -3‰ (range -5 to 0‰) (e.g., figure 3), weighted by the monthly flux of NO_3^-. These fluxes of atmospheric NO_3^- were then compared with total stream NO_3^- export and atmospheric NO_3^- deposition (3.2 kg N ha^{-1} y^{-1}).

Stream	Stream N Export (kg ha^{-1} y^{-1})		DIN Export / Deposition	Stream NO_3-N Derived Directly from Atmospheric Deposition		
	DON	NO_3-N	%	kg ha^{-1} y^{-1}	% of Stream NO_3^-	% of NO_3^- Dep.
1. CYT	0.7	0.5	6%	0.07 (0.05-0.12)	15% (10-24%)	2% (2-4%)
2. SWN	0.6	0.3	3%			
3. UCC	0.7	0.4	5%	0.05 (0.03-0.09)	14% (9-23%)	2% (1-3%)
4. WCC	0.6	0.4	4%	0.07 (0.05-0.11)	20% (14-32%)	2% (2-4%)
5. ECC	0.6	0.2	2%			
6. CNA	0.5	0.7	8%	0.05 (0.03-0.10)	8% (4-14%)	2% (1-3%)
7. WOV	0.6	0.1	1%			
8. EOV	0.4	0.2	2%			
9. PYN	0.7	0.2	3%	0.04 (0.03-0.06)	16% (11-25%)	1% (1-2%)
10. BAN	0.4	1.0	11%	0.06 (0.03-0.12)	6% (3-12%)	2% (1-4%)
11. MIH	0.6	0.2	2%	0.01 (0.01-0.02)	8% (5-14%)	0% (0-1%)
12. EMH	0.6	0.6	7%	0.02 (0.01-0.05)	4% (1-8%)	1% (0-1%)
13. HPT	0.6	0.3	4%			
14. BRY	0.5	0.2	3%			
15. BMT	0.5	0.5	5%			
16. IES	0.1*	1.1*				
Median	0.6	0.3	4%	0.05 (0.03-0.09)	11% (7-18%)	2% (1-3%)

* Period June 2005 – Feb. 2006, only.

half of the estimated annual NO_3^- export in most streams occurred during March and April, driven by modestly elevated snowmelt NO_3^- concentrations (Figure 3) or high April streamflow (Figure 2). Differences among streams in NO_3^--N export were small, ranging from estimated lows of 0.1-0.2 kg ha^{-1} y^{-1} and highs of 0.6-0.7 kg ha^{-1} y^{-1}. The one stream with a NO_3^--N export greater than 1.0 kg ha^{-1} y^{-1} (during June – February alone) was the small stream at the Connecticut Hill atmospheric deposition station (IES), which was also the one stream with likely contributions of non-forest land cover in the upper part of the catchment. These NO_3^--N export values are lower than median export fluxes observed elsewhere in New York in the Adirondack (2-3 kg ha^{-1} y^{-1}; Ito et al. 2005) and Catskill Mountains (ca. 3.4 kg ha^{-1} y^{-1}; estimated from Lovett et al. 2000), but are roughly similar to median NO_3^--N export rates observed in the White Mountains, New Hampshire (Campbell et al. 2000, Goodale et al. 2000). Both New York mountain ranges have slightly higher rates of atmospheric N deposition (9-12 kg ha^{-1} y^{-1}) compared to the ~8.5 kg ha^{-1} y^{-1} received in both central NY and the White Mountains. Past work has suggested an N deposition threshold of around 8-10 kg N ha^{-1} y^{-1} below which there is near complete N retention, and above which N export increases sharply (Aber et al. 2003). The streams sampled in this study hover right around this threshold and demonstrate near complete N retention, averaging about 96% (range 89-99%; Table 3).

Sources of Stream Nitrate. Values of $\delta^{18}O$-NO_3^- were used to partition streamwater NO_3^- into contributions from atmospheric deposition and from microbially produced (or microbially recycled) NO_3^- (Table 3, Figure 4). Although we lacked field-measured $\delta^{18}O$-NO_3^- end-members for atmospheric deposition and microbial NO_3^-, consideration of a wide range of values from the literature (Table 2) provided relatively tight constraints on the contribution of direct atmospheric deposition to stream NO_3^- export (Table 3). Very little ($\leq$ 4%) atmospheric NO_3^- deposition passed through the forest ecosystem directly, and the preponderance of the NO_3^- exported in streamwater (80-96%) derived from microbial nitrification (Table 3). This result is consistent with most previous $\delta^{18}O$-NO_3^- measurements in forested catchments which have found that atmospheric deposition typically contributes less than 10% of the NO_3^- in streams during baseflow conditions, with somewhat greater contributions (up to 20-30%) during snowmelt or other high-flow events (Spoelstra et al. 2001, Williard et al. 2001, Burns & Kendall 2002, Pardo et al. 2004). As an exception to this pattern, precipitation contributed 39% (range: 16-100%) of the NO_3^- in springs in a declining forest stand in Germany exposed to high rates of atmospheric deposition (Durka et al. 1994).

The small amount of atmospheric NO_3^- deposition that did pass through these central NY forests occurred entirely at snowmelt, particularly in March 2005, when $\delta^{18}O$-NO_3^- values indicated that 12% (EMH) to perhaps 59% (WCC) of stream NO_3^- in the March samples derived directly from atmospheric deposition (Figure 4). Values of $\delta^{18}O$-NO_3^- during the early snowmelt in January and February 2006 suggested much smaller direct contributions from atmospheric deposition in 2006 than in 2005. Because each stream had only one sample per month, it is unclear whether the relatively high fractions of atmospheric NO_3^- contributed in March 2005 were a result of the large snowpack development that year or to melt conditions particular to that sampling date. Values of $\delta^{18}O$-NO_3^- can vary substantially throughout the course of snowmelt. High-frequency (daily to 3-6 hours) sampling during snowmelt in 2003 at Sleepers River, Vermont, revealed high $\delta^{18}O$-NO_3^- values (18‰) at the start of snowmelt, with a substantial drop in within a day or so down to modestly elevated levels (~5‰) sustained throughout the rest of snowmelt, eventually dropping to about -3‰ by the time the snowpack had melted completely (Ohte et al. 2004). Ohte et al. (2004) suggest that the first phase of snowmelt includes melt water from snow directly covering the channel, a process that might have

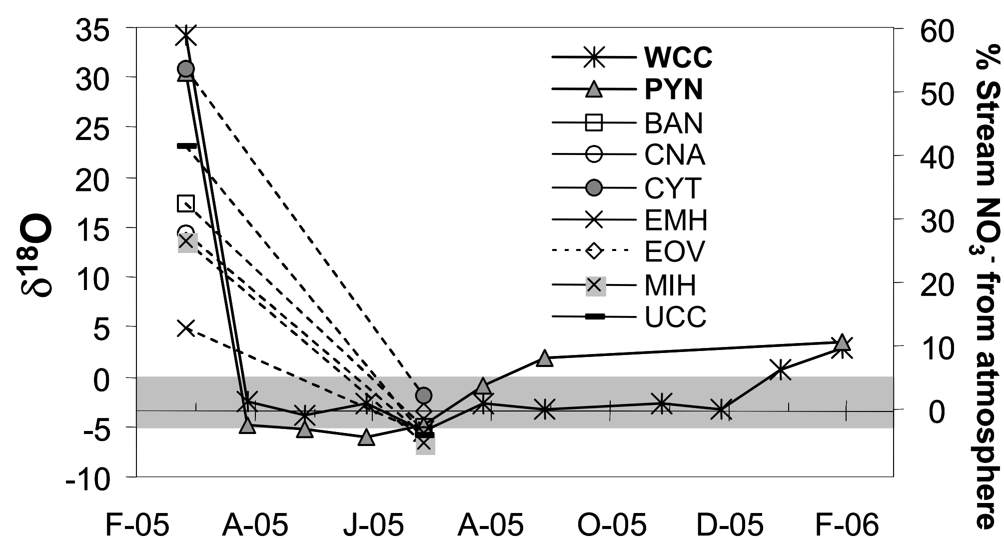

Figure 4: Seasonal pattern of $\delta^{18}O$-NO_3^- values and corresponding estimates of the fractional contribution of atmospheric NO_3^- to stream NO_3^-, assuming an atmospheric $\delta^{18}O$-NO_3^- value of 60‰ and a microbially-derived value of -3‰. Dashed lines connect streams sampled in only two months (March and July 2005).

occurred during the March 2005 sampling at the central NY streams measured here, as snow did cover many channels on that date. Interestingly, several of the March 2005 $\delta^{18}O\text{-}NO_3^-$ values observed here (up to 34‰, Figure 4) exceeded the maximum value recorded at Sleepers River sampled over the full course of snowmelt (maximum of 18.3‰; Ohte et al. 2004), and suggest some of the highest direct contributions of atmospheric NO_3^- ever reported in North America, although forthcoming measurements of $\delta^{18}O\text{-}NO_3^-$ in atmospheric deposition for the Connecticut Hill deposition station will help confirm that result.

Student Training, Publications, and Facilitated Grants

This project provided funding for two undergraduate assistants, including one full-time assistant in summer 2005 (Robin Schmidt, Bard College), and one part-time assistant during the academic year (Kimberly Falbo, Natural Resources major, Cornell University). Both students learned methods of stream water collection and analysis, and were exposed to other areas of research in forest ecosystem ecology in central NY forests.

In addition, co-investigator Steve Thomas led a Cornell graduate student workshop on stream ^{15}N tracers which involved an experiment in fall 2004 on nitrate and DOC interactions in one of the streams sampled here (WCC). Continued sampling of the chemistry of that stream through this WRI project has provided significant context for the original experiment. Results from that experiment are in preparation for submission for publication (Thomas et al., in prep.), and have been presented at three meetings: the 2005 North American Benthological Society annual meeting, the 2005 Gordon Conference on Catchment Biogeochemistry, and the 2006 BIOGEOMON Conference.

The results described here in detail are now in preparation for a separate submission for publication expected in fall 2006, anticipated for *JGR-Biogeochemistry*, *Hydrological Processes*, or similar journal.

Finally, the preliminary stream chemistry enabled by this WRI grant made possible the submission of a successful research proposal to the competitive "Mesogrants" program within Cornell's Agricultural Ecology Program (AEP) to assess contributions of atmospheric N to the Upper Susquehanna River. The new project provides $60,000 to Goodale and Thomas over two years to follow the movement of an added $^{15}N\text{-}NO_3^-$ tracer through the upper part of one of the catchments described here, Pine Creek in Arnot Forest (PYN). We anticipate that the new project will both complement the WRI project, and will serve as a pilot experiment for an anticipated submission to NSF in July 2007 or January 2008.

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GIS-based riparian buffer management optimization for phosphorous and sediment loading

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GIS-BASED BUFFER MANAGEMENT OPTOMIZATION FOR PHOSPHOROUS:

A Field Test of Whether a Topographically-Based Phosphorous Model Can be Used to Locate Best Management Practices

by

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ABSTRACT

A study of phosphorous runoff was undertaken in the Black Creek watershed to determine if a topographically-based loading model could be used to regulate buffer width and assign best management practices. Field measurements of overland flow and chemistry were undertaken at 12 sites over a one month period. The results suggest that while the model correctly identified the presence of some important areas of concern, it can't be used to rank these areas without additional field verification. The data indicate that four sites (Paul Rd, US 20 North, Casswell N and Byron Rd East) could be significant sources of phosphorous. All of these sites have a direct surface connection to Black Creek. Other sites that had measurable phosphorous loads and should be considered for best management practices include Clipnock Rd, the tributary at Casswell Rd which should be buffered, and the site at Rte 33.

Topographic based loading models are attractive for guiding best management practices in theory, but several technical issues need to be overcome before they can be used for this function without field verification. These issues include the resolution of available digital elevation model which is too large, DEM quality which impacts the location and size of flow accumulation, tile drains which can significantly modify surface flow paths, and historic modification of the topography which is not always reflected in the DEM.

INTRODUCTION

It is well known that sediment erosion can have detrimental impact on the water quality of estuarine and lake ecosystems. In addition to the changes in geomorphic processes caused by additional sediment loads, many pollutants (phosphorous, metals, some pesticides) are carried in particulate form. As a consequence it is essential to identify where in a watershed these sediments come from and where they are likely to be carried into the stream transport network. Contemporary modeling techniques (SWAT, AGNPS, GWLF) widely used in TMDL studies to identify areas of concern, treat the sediment transport phenomenon as a nonsource problem in which the type of soil and landcover are assumed to generate a more or less uniform flux of sediment. This allows us to rank parcels in terms of their propensity for generating sediment based on landcover and soil information. It is well established that this is a gross oversimplification.

Erosion in fact occurs in specific areas where the distribution of water energy, substrate and topographic characteristics causes enhanced erosion and transport. Such sites are considerably smaller in scale than the size of the parcels with which soil and landuse information is collected in. Inherent in the practice of predicting erosion from soil and landcover maps is an assumption that the frequency and distribution of micro-erosional environments is uniform within particular landcover-soil associations. This has never been tested, furthermore the size of the spatial assessment (parcels) is too large to locate structural best management practices (BMPs) in anything but the grossest way.

Our working hypothesis is that contemporary loading models commonly used in TMDL work are inadequate to identify areas of concern because of their course resolution and the difficult and arbitrary way that parameters for them must be supplied by contemporary GIS data. One way of enhancing contemporary loading models and improving buffer management is to use topographic information to identify locations within parcels that, by virtue of their slope and aspect receive the most material. This could allow a more accurate determination of buffer widths required for successful NPS regulation. It may in fact be possible to buffer specific areas to obtain an acceptable level of protection for the stream network. Several types of hydrologic models that consider topographic information which could be used for this purpose exist; TOPMODEL (Beven and Kirkby, 1979); weighted flow accumulation (Richards and Campbell, 2002); (Endreny and Wood, 2003) and ANSFOR. In the simplest of these models (weighted flow accumulation algorithm, Richards and Campbell, 2002) phosphorous (or sediment) load is calculated from a rainstorm using soil and landuse information. A "flow accumulation" analysis is than applied to the digital elevation model (which is weighted to the result of the phosphorous model) to yield locations of sites where slope and aspect are likely to cause significant phosphorous and sediment transport. The next level of complexity is the TOPMODEL approach where this flow accumulation is carried out using a topographic index, derived from a Darcy treatment of flowpaths extracted from gridded elevation data. In the original model (TOPMODEL), only water flow is calculated, however more sophisticated versions of this model exist which incorporate chemical interactions to estimate sediment and phosphorous loads. The model by Endreny and Wood (2003) is an example of one of these models that use the topographic index approach in conjunction with event mean concentration data to compute phosphorous loads. It is possible that these innovative terrain modeling techniques can be used to develop better approaches for identifying areas of concern from easily obtainable GIS data. Such sites will be places where structural BMP's will significantly reduce sediment loads, and in particular, reduce the size fractions of mobile sediments that are carrying the most detrimental kinds of pollutants. It is possible that a combination of targeted BMP emplacement and variable width buffer management strategies may reduce extent of buffering required for significant nonpoint source pollution reduction. A process that greatly reduces the costs for successful watershed management.

The purpose of this study was to apply one of these models to the Black Creek watershed to develop a starting point with which to prioritize stream segments for BMPs. The second objective of this study was to conduct an exploratory field survey of overland flow to test how accurate the model was. Do they provide information that is really accurate with the current best resolution of available GIS and gridded elevation data (10 meter for the latter in New York State). Would a more advanced model do a better job with the resolution of available GIS data? At what scale should management decisions be made and are there field observations that might be more useful than the modeling for guiding management decisions?

METHODOLOGY

Research Plan Design

Our methodology was to apply the (phosphorous) weighted flow accumulation model in Black Creek watershed to identify the extent and spatial distribution of (high) phosphorous flow paths. Twelve sites representative of different levels of phosphorous flow transport were instrumented with runoff collectors (Figure 1) to estimate water and chemical (including Phosphorous) fluxes over a one-month period. The limited resources for the project didn't allow us to precisely measure fluxes, however, we were able to measure instantaneous volumes with simple runoff collectors and field observations after every rainfall event to be able to estimate the following load-related variables for each site:

Approximate volume of overland flow and total phosphorous
Mean concentration of phosphorous
Frequency of active overland flow

These field variables are then used to rank sites for their propensity to deliver phosphorous load. Two simple tests for the usefulness of these topographically based loading models for making management decisions are:

1) Does the model correctly predict the presence of overland runoff paths?
2) Does the model rank these sites in the same order as what the field data suggests?

If the rankings do not agree, the model's usefulness for the latter is called into question. In addition to comparing the field results to the modeling, this study also collected associated information from each site in order to elucidate why the model doesn't work. Is it a scale issue where the resolution of the GIS data prevented the model from assessing the site, a flaw in the model cause by not considering one or more crucial parameters, or some combination of both. Auxillary information we collected at each site to help us interpret our results included:

Catchment area associated with the runoff flowpath
Slope of the dominant flow path measured at two different scales
Depression Storage
Land cover
Soil texture
Soil moisture changes after the event
Duration of ponding after the event

A nonparametric statistical correlation between the phosphorous model and our flux-related independant variables was conducted to determine if the model has predictive value in identifying areas where buffer width should be modified. The methodology of the field runoff assessment, including how these above parameters were measured, are discussed in the following sections.

Synoptic Survey

To guide our selection of sites, a field survey and GIS assessment of 25 sites took place throughout the Black Creek Watershed. Sites were photographed, located by GPS and then evaluated by overlaying the phosphorous model on 2002 aerial photographs. Local crop cover was noted from field observations and the type of topography (straight hill slop, convex, concave) was identified. Using this information, 12 sites were selected for the field analysis. These sites were chosen because they have a broad range of different model phosphorous transport rates, and are representative of the topographic and landcover characteristics of rural stream segments in the Black Creek Watershed. Sites are located in the heavily farmed southwestern portion of the watershed (Figure 1).

Phosphorous Modeling

The model (Richards and Campbell, 2002) identifies locations in the watershed where topographic and land cover characteristics cause them to receive large quantities of total phosphate. These locations are sites that, by virtue of their slope and aspect, intercept runoff flow paths from large areas. The key to identifying these sites is to isolate parts of the watershed where flowpaths drain areas that produce high phosphorous loads. Such areas will be places where urban/agricultural land cover cause high event mean phosphorous concentrations. Overland flowpaths are mapped on the surface by analyzing a digital elevation model (DEM), a matrix of numbers that describes the elevation of the earth along evenly spaced intervals. Such intervals can be thought of as cells. An analysis of elevation differences between adjacent cells can be used create a "Flow direction grid" which describes the azimuth that runoff takes as it flows across the ground. Further analysis of the flow direction grid can be used to determine the total number of cells that flow through every cell. This concept is called "flow accumulation". In a routine flow accumulation procedure every cell is given the same weight (1) so that the value represented by a flow accumulation grid is the number of cells that ultimately flow into it. The model modifies the flow accumulation procedure by weighting each cell by the amount of phosphorous that was eroded. The result is a grid that represents the total amount of phosphorous that passes through every point.

Total phosphorous in the model is calculated by determining the amount of runoff shed from the cell by a 1 year return storm event and multiplying this quantity with the average concentration of phosphorous that is characteristic of water in the vicinity of the cell's soil and land cover. For the Black Creek watershed a 1 year storm event is expected to yield 2.3 inches of precipitation in 24 hours (DEC, 2003). Runoff is determined by computing the fraction of the cell that covered by directly-connected imperviousness and using two separate equations to determine the contribution of runoff from the directly-connected imperviousness and non-impervious parts of the cell. Precipitation intercepted by directly connected imperviousness is assumed to completely runoff. The SCS curve number procedure (SCS, 1986) is used to determine runoff from the rest of the cell. To identify the amount of imperviousness in each cell, we used average values of total imperviousness characteristic of the type of land use determined by the Rouge River Project from aerial photography (Klutenberg, 1994). Directly connected imperviousness was computed from total imperviousness using a function suggested by Alley and Venehuis (1981). Flow weighted event mean phosphorous concentrations were obtained from field studies of stream chemistry in the Rouge River. GIS data used in this analysis are 10 meter 1:24k USGS digital elevation models, a 1992 landcover dataset that was improved by Autin et al (2003) and county level SSURGO soil data.

Land cover and soil data were gridded into 10m by 10m cells for the project area and runoff was computed from each. Phosphorus loads were calculated by multiplying the runoff from each cell with its characteristic phosphorous concentration and a conversion factor that transforms inches of runoff from each cell into liters. Since the units of the concentrations data are in mg/liter the resulting erosion computations are in units of mg per cell per day. A digital elevation model gridded in the same manner as the soil and land cover data was weighted by phosphorous erosion after which the flow accumulation procedure was applied. The resulting data is plotted on a map of the Black Creek watershed and color coded by the total kg of phosphorous transported through each cell. The best way to interpret the data is to highlight cells that have low (<0.2kg/day) phosphorous transport loads and identify where they intersect with streams. Cells with higher loads are usually natural stream segments.

Topographic Analysis

The loading model was supplemented with a topographic analysis to determine the extent of internally drained areas. The PCSA algorithm (Richards and Brenner, 2004) was used to map the extent of large-scale internally drained depressions in the watershed (Figure 2). Areas outside of these depressions are directly connected and are capable of delivering sediment and phosphorous to the stream network. Although not explicitly used in the assessment of the phosphorous model, the results of this analysis will be useful for prioritizing BMP strategies in the Black Creek Watershed.

Field Runoff Assessment

Sites were instrumented with runoff collectors (Figure 3) to measure the volume of active overland flow. Runoff collectors were located in a topographic lows showing signs of drainage in the vicinity of where the phosphorous model determined a high phosphorous transport path exist. The small size of the runoff collector containers caused them to overflow on occasion, requiring visits to the site shortly after rainfall events to measure flow rates by hand. These measurements were made by measuring the flow rate through the runoff collector tube and over the back edge of the runoff collector using a graduated beaker and stop watch. Sites were visited and measured daily after the event until active runoff stopped. The duration of ponding in front of the runoff collector was also observed. Typically the first flow measurement was made within 18 hours of the event. To estimate total flow during the event we assumed this measurement was made at the peak flow and that overland flow did not occur before the event. A simple triangle was used to integrate the runoff during the active runoff period which is assumed to be 24 hours. This approach is crude and underpredicts the true volume of overland flow, however since the timing of observations was frequent and regular we could rank sites relative to each other qualitatively by counting the number of times the runoff collector was active. Small rainfall events did occur where some of the runoff collector did not overflow. From this information we could further rank sites in their propensity for generating overland flow. Site A whose runoff collector did not overflow obviously received more runoff than site B whose runoff collector overflowed in the same storm.

Samples were taken for chemistry from both the runoff collectors and active flow measurements. Electroconductivity and pH were determined in the lab. Water samples were filtered and analyzed with a Dionex Ion Chromitograph to determine dissolved SO4, NO3 and Cl. Unfiltered samples were dissolved in nitric acid and analyzed in a Inductively Coupled Plasma Spectrophotometer for Total Phosphate.

The length of significant ponding in front of the runoff collector was determined from field observations. Significant ponding is defined as visible ponding in greater than 75% of the area around the dominant flow path. Length is measured parallel to the dominant flowpath from the front of the rainfall collector. Soil moisture measurements were taken at 10 foot intervals along the dominant flowpath using a Campbell Scientific TDR probe. Measurements are in units of % volumetric water content and are representative of the top 12 cm of the soil profile. Three measurements were taken at each length interval and then averaged to determine the soil moisture content. The TDR is accurate within the range of soilmoisture contents of the factory calibration curve, however in ponded and saturated situations it determined the soil moisture content to be less than 100%. The measurements however were very reproducible. For each site the soil moisture content at total saturation (fully ponded conditions) was determined.

Catchment Area

The drainage area associated with each runoff collector was computed from an 0.5 meter contour map developed from the digital elevation model. To evaluate the contributing area, the drainage area associated with the runoff collector was digitized onscreen using the contours as background. A polygon topology was built from this feature using ArcGIS to estimate the drainage area.

Soil Properties

Soil properties were obtained by locating the site on the Genesee County Soil Survey. Seven surface samples of soil were also taken at 10 foot intervals along the main flow path. Time and resources ran out before we could analyze these samples for grainsize, soil texture and average phosphorous concentration.

Depression Storage

Depression storage was estimated from surface microtopography digitized with a roughness clinometer (Figure 4). Depression storage was measured 6 times at 10 foot intervals along the main flowpath upslope of the runoff collector. Storage was evaluted for each topographic high using an algorithm that determines the equation of a line that extends horizontally from the topographic high to a point where the line intersects with the ground surface. The area between this line segment and the ground surface is estimated numerically using the trapezoidal approximation. Storage associated with all topographic highs were summed and divided by the length of the roughness clinometer to obtain depression storage volume, per unit width, per unit length of flowpath. The dimension of this parameter is a simple length unit that is comparable to mm of rainfall. Thus, a depression storage of 5.6 means that the equivalent of 5.6 mm of rainfall can be stored in the surface without any runoff happening.

Slope

Percent slope of the dominant flowpath into the runoff collector was determined using the DEM and the roughness clinometer. The latter was computed by taking an average of six slopes measured by the roughness clinometer. Measurements were taken at 10 foot intervals along the dominant flowpath.

RESULTS

Site characteristics

Figures 5-11 present detailed aerial photographs with modeled P flowpaths, runoff collector locations and runoff collector catchments superimposed. Mean depression storage varied from 5.7 to 15.6 mm with a typical standard deviation of 3.5. Furrows caused by plowing were a major cause of the depression storage. The PCSA algorithm determined that a significant portion of the watershed is internally drained away from the stream network (Figure 12). A closeup sample of the results of this model are presented in Figure 13. Slopes as measured by the roughness clinometer ranged from 0.6% to 4.7% at the runoff collector sites.

TABLE 1 **Characteristics of the sites determined from GIS data**

Site	Drainage Area (ha)	Soil Musym	Soil Hydro Group	Land Use	% Slope
Byron East	9.72	La	D	210	0.5
Byron West	18.22	La	D	210	0.2
Casswell N	0.53	La	D	210	1.1
Casswell NW	6.04	CaA	D	210	0.9
Casswell S	0.08	La	D	210	0.5
Casswell SW	0.11	CaA	D	210	0.5
Clipnock Rd	0.07	MoB	B	210	0.5
Paul Rd	9.68	Ma	D	210	0.3
Rte 20 N	7.82	Ee	B	310	1.5
Rte 20 S	0.04	Ee	B	310	1.6
Rte 33	0.06	LmB	B	200	2.2
Searls	0.06	MmB	B	210/300	1.4

Table 2 **Field characteristics of the runoff collector sites**

Site	Crop cover	Number of Measurements	Average Depression Storage (mm)	Stdev Depression Storage (mm)	% Slope
Byron East	Alfalfa	17	5.9	2.7	1.2
Byron West	Alfalfa	9	7.8	2.6	0.6
Casswell N	Alfalfa/Soy	15	4.2	1.9	2.7
Casswell NW	Alfalfa/Soy	6	8.7	4.0	2.9
Casswell S	Corn	6	11.4	5.9	3.5
Casswell SW	Corn	6	12.5	2.8	1.3
Clipnock Rd	Cabbage	6	15.6	4.9	4.7
Paul Rd	Corn	n/a	n/a	n/a	n/a

Rte 20 N	Weeds/Fallow	5	5.7	2.2	1.7
Rte 20 S	Weeds/Fallow	6	8.9	5.1	1.5
Rte 33	Fallow/Wheat	6	6.4	3.3	2.6
Searls	Soybean	6	7.6	3.3	1.4

Runoff Assessment

During the survey, a total of 3.99 inches of rain fell during the approximately 38 day period of assessment (the observation period varied between sites depending on when the runoff collector was installed). This rainfall occurred as 6 significant storm events and 4 smaller (<0.30 in) rainfall events that had no significant hydrologic impact (Figure 14). Observed overland flow discharge rates varied significantly between the twelve different sites, ranging from 0.006 l/sec to 21.6 l/sec. For the two sites where active flow measurements were abundant (US20N and Paul Rd), instantaneous flow measurements could vary as much as 4 orders of magnitude within the site implying significant temporal variability. Total runoff volumes were normalized by the total period of observation at each site to make the sites comparable. Flow measurements taken by current meter from Paul Rd (3 measurements) and Byron East (1 measurement) had to be adjusted by multiplying by a ratio of the width of the runoff collector over the width of the flow measurement. This needed to be done to make the values comparable to runoff collector measurements since flow measurements made by the current meter represent a larger width of the flowpath.

Table 3 **Flow estimates and saturation parameters for the sites**

Site	Period of Observation (days)	Log Runoff Volume (Liters/day)	Fraction of period when overland runoff occurred (days/days)	Ave. Length of ponding (ft)
Byron East	38	+ 2.0	0.29	13.3
Byron West	37	+ 0.9	0.22*	3.3
Casswell N	44	No runoff	0.00	0.0
Casswell NW	34	+ 2.1	0.12	23.3
Casswell S	37	+ 0.4	0.11	3.0
Casswell SW	34	+ 0.2	0.09	23.3
Clipnock Rd	33	+1.8	0.15	10.0
Paul Rd	31	+5.0	1.00**	86.7
Rte 20 N	30	+ 3.4	0.40	7.7
Rte 20 S	31	No runoff	0.00	0.0
Rte 33	33	+ 0.6	0.12	2.7
Searls	31	-1.3	0.06	0.0

*May be caused by groundwater inundation

**Active overland flow was observed on every visit to this site even during dry conditions.

Chemistry

Electroconductivity varied significantly between sites as well as flows within one site. The highest electroconductivities appeared to be associated with samples taken from the runoff collector. As these samples are biased to water at the start of the event, they include sediment washed off during “first flush”. This material may have contributed to the high electroconductivities. Measurable levels (0.3 - 2.4 mg/l) of total phosphorous were found at all sites. Dissolved nitrate levels were fairly low (< 1 ppm) for most sites, except for Casswell SW and Clipnock Rd which had 10.3 and 7.6 mg/l respectively.

Table 4 **Overland flow chemistry**

Site	Number of Samples	EC	Ave. diss. Cl (mg/l)	Ave. diss. SO_4 (mg/l)	Ave. TP (mg/l)	Ave. diss. NO_3 (mg/l)
Byron East	13	1660	199	12	0.6	0.1
Byron West	6	2243	325	97	0.4	0.1
Casswell N	0	n/a	n/a	n/a	n/a	n/a
Casswell NW	3	418	9	23	1.5	1.0
Casswell S	4	255	17	34	2.4	0.3
Casswell SW	2	192	17	21	0.9*	10.3
Clipnock Rd	5	491	65	13	1.0	7.6
Paul Rd	7	430	15	35	0.3	0.4
Rte 20 N	10	610	70	28	0.4	0.5
Rte 20 S	0	n/a	n/a	n/a	n/a	n/a
Rte 33	3	117	3	3	0.7	0.4
Searls	1	n/a	0.5	3	1.53	0.5

* Only 1 sample analyzed for Phosphorous

Two sites (Byron E and W) had unusually high chloride, sulfate concentrations and electroconductivities. These sites were believed to be heavily influenced by groundwater. The runoff collector at Byron West in particular was located near the water table. The water table rose above the inlet tube for the runoff collector 4 days after the 10/26 storm event, this is long after the watertable dropped below the inlet of the Byron East collector. The berm associated with Byron rd, which is several feet higher than the ground, effectively prevents any surface runoff from the drainage area associated with Byron West. The homeowner who lives across the street from the site says that the site becomes a large pond for much of the early spring. Byron east has a culvert which enables surface runoff to leave the site. The chemistry is much more concentrated between Byron west and Byron east, despite their similarities in soil type, bedrock geology, and landuse. This suggests that the water collected by the Byron West runoff collector is more heavily influenced with groundwater than in Byron East. The high concentrations are not believed to be road salt contamination since both sites are upgradient of the road. Cl concentrations are interpreted to be caused by deep groundwater brines originating from a fracture associated with the Clarendon-Lindon fault. This feature has been mapped directly underneath the Byron road sites.

Field and Modeled Phosphorous Flux Estimates

Using are overland volume estimates and the chemistry data, we computed phosphorous fluxes for the period of observation when all sites were operating correctly (10/18 - 11/18; 32 days). Due to the crude nature of the overland flux measurements discussed previously, these values should only be used in a comparative way between sites.

Table 5 **Overland Phosphorous Flux Calculations**

Site	Log total P (g)	Log total P (g/day)	Log total P (g/day/ha)	Modeled total P Log (g/day)
Byron East	0.4	-1.1	-2.1	-1.7
Byron West	-0.9	-2.4	-3.6	-0.5
Casswell N	No Load	No Load	No Load	-1.9
Casswell NW	0.8	-0.7	-1.5	-0.3
Casswell S	-0.6	-2.1	-1.0	-2.0
Casswell SW	-1.3	-2.8	-1.9	-0.4
Clipnock Rd	0.3	-1.2	-0.0	-2.0
Paul Rd	+ 3.0	+1.5	+ 0.5	-1.4
Rte 20 N	1.5	0.0	-0.9	-2.4
Rte 20 S	No Load	No Load	No Load	-2.7
Rte 33	-1.1	-2.6	-1.4	-1.4
Searls	-2.6	-4.1	-2.9	-0.7

Modeled flux estimates were made by identifying the pixel nearest the runoff collector with the highest 24 hour phosphorous load. In some sites the DEM was poorly aligned with the stream coverage and aerial photograph, requiring an estimate of where the runoff collector ought to be in the phosphorous model results.

DISCUSSION

Overview

We found the model was useful in the field to identify the presence of ephemeral flowpaths, however the features were not always in the exact location. Bringing small plots of the phosphorous model superimposed on aerial photography in the field was found to be an effective way to find areas prone to flooding. Location errors were commonly larger than the spacing of the DEM (10 meters) indicating registration problems with the DEM or aerial photography. In some situations, the flow paths exist but are blocked by an anthropogenic feature or topographic high that is smaller than the resolution of the feature. Even the absence of finding the feature where the model said it should be was useful, because it indicated major flowpath changes occurring upslope. The geologic explanation for these aberrations often have significant implications for watershed management.

Site Rankings

For sites with active flow observations, flux calculations allow them to be ranked. Although we do not know the precise shape of the hydrograph, we can estimate it as a simple triangle and have assumed a time ordinate of 24 hours. We realize this is only semi-quantitative, however we believe the order of magnitude differences observed between sites enable us to use this technique to enable relative comparisions between sites. Sites with no active flow observations where the runoff collector overflowed are problematical because it is not possible to determine the volume of overland flow that occurred. We only know that the volume is larger than a gallon (the maximum amount of runoff held by the runoff collector) and smaller than the volume of flow required to sustain active overlandflow when the site was assessed (typically 12 to 36 hours after the event). To rank sites that only had runoff collectors that overflowed, we used three additional criterion to rank them relative to each other:

Fraction of days where overland flow was active
Extent (length) of ponding upslope of runoff collector 1 day after the event
Average soil moisture content relative to saturation 1 day after the event
Total estimated phosphorous flux

Table 6 shows the ranking of the sites from highest to lowest based on the above criterion. We feel confident of the top three rankings because of the large differences in total phosphorous loads. Byron East was ranked higher than Clipnock road because it was active at twice the frequency. Casswell S has 30% greater load than Byron West but the latter was active twice as much, although some of this activity may have been caused by groundwater inundation. Rte 33 was ranked above Casswell SW by virtue of the latters lack of overland flow activity. Searls, US20 South and Casswell North were ranked last because of the low phosphorous load and absence of overland runoff activity.

Table 6 **Site Ranking based on the observed field criterion**

Site	Log total P (g/day)	Fraction of period that overland flow was active (days/days)	Average length of ponding (ft)	Average Ø/Øsat after the 10/26 event
Paul Rd	1.5	1.00**	86.7	sat
Rte 20 N	0	0.4	7.7	0.84
Casswell NW	-0.7	0.12	23.3	0.86
Byron East	-1.1	0.29	13.3	0.89
Clipnock Rd	-1.2	0.15	10	0.70
Casswell S	-2.1	0.11	3	0.77
Byron West	-2.4	0.22*	3.3	0.85
Rte 33	-2.6	0.12	2.7	0.74
Casswell SW	-2.8	0.09	23.3	0.91
Searls	-4.1	0.06	0	0.58
Rte 20 S	No Load	0.00	0	0.56
Casswell N	No Load	0.00	0	0.65

*May be caused by groundwater inundation
**Active overland flow was observed on every visit to this site even during dry conditions.

According to the phosphorous model, the sites are ranked in the following sequence (Table 7) for their propensity of contributing phosphorous to streams.

Table 7 **Sites ranking based on the GIS-based Phosphorous Model**

Site	Log modeled total P (g/day)
Casswell NW	-0.3
Casswell SW	-0.4
Byron West	-0.5

Searls	-0.7
Rte 33	-1.4
Casswell N	-1.9
Clipnock Rd	-2.0
Casswell S	-2.0
Paul Rd	-2.5
Byron East	-2.7
Rte 20 S	-2.7
Rte 20 N	-3.5

Site Rankings Compared to the Phosphorous Model

The second question addressed in this study was to determine the effectiveness of a GIS-based phosphorous model in ranking sites appropriate for BMP's. From the practical point of view these models are benefitial for making BMP decisions if they can rank sites in a relative sense accurately. Precise flux calculations are not necessary. To determine this from our field data we performed a Kendall's Tau analysis between our flux parameters and the P model. Kendall Tau is a nonparametric significance test for correlation suitable for small (<20) datasets with outliers. What is evaluated in this test are to what degree the rankings (not the values) are correlated between our variables of interest. Like the Pearson correlation, a Kendall's Tau correlation ranges from -1 to 1 with 1 being a strong correlation between the rankings of the model and the field sites. A good model for making management decisions should have a high positive Kendall Tau between ranks. One would be perfect and indicate the order determined by the model is the same as the order determined by field data. A Kendall Tau correlation was found to be -0.17, a very weak negative correlation. A Z-test (dF = 12, α=0.05) for this test reveals this correlation to be not significant. The site rankings from the field observations do not follow the rankings interpreted from the phosphorous model. What could be the cause of the differences?

In the Byron Road case, the site at east Byron shows considerably more runoff and phosphorous flux then west Byron, despite the prediction of the model. Catchment area supports the phosphorous model assessment ranking for these two sites, with west Byron catchment area being twice as large. Since the landcover, soil hydrologic group are the same (Alfalfa and D, respectively), Byron West should deliver more phosphorous. One possibility may be the existence of tile drains, which according to George Squires (personal communication) could be taking material away from Byron West's drainage basin. The berm of Byron road effectively blocks any surface drainage from Byron West to Black Creek though the model does not detect it. Locating a BMP here is completely unnecessary. In contrast Byron East is directly connected to a drainage ditch that empties into the main stem of Black Creek.

In the Rte 20 case, the model correctly predicted that US20 S would not be a significant source of phosphorous and ranked it as unimportant, however it incorrectly ranked US20 N which field evidence suggest is the second largest contributor of the 12 sites. The cause was the presence of a small tile drain under a driveway which greatly extended the catchment area west of the site. Inspection of aerial photography and field observations suggest that drainage runs east along the road to the US20 N runoff collector. While a contour map of the DEM does show a gradual upslope grade and we were able to define by hand a large catchment for this runoff collector, the region immediately to the west was too low-sloped for the flow direction algorithm in the model to identify a large catchment for this runoff collector. Low slopes are problematic for flow direction algorithms because at the scale of the DEM, adjacent cells are sometimes given the same elevation. With the absence of a significant pour point or several pour points of equal value, the software will incorrectly assign it a flow direction which in this case led to a model catchment area that was significantly lower than the actual one. It is tempting to suggest a higher resolution DEM could have improved the model, however the driveway to the west of the runoff collector would still give the model issues because it is located on a high berm.

The model incorrectly ranked the site at Paul Rd which was found to be the largest contributor of phosphorous of all of the sites in the study. Inspection of aerial photography suggests the flow at Paul Rd was running along an abandoned channel that runs diagonal through the corn field. Black creek appears to have been rerouted historically to flow along the eastern edge of the crop field. The topography must have changed since the data for the DEM was acquired. In this case the DEM did not reflect historic changes in the topography which caused the model to incorrectly identify the position of an important source path of phosphorous.

The sites at Caswell Rd show mixed results. Casswell NW was ranked by the model as the most important contributor of phosphorous. In the observed data it was also ranked high (3rd largest contributor). The other sites were miss-ranked significantly. The rankings within the Casswell sites themselves were also misranked except for Casswell NW At the Casswell site all soils are soil hydrologic group D, thus the result of the model was controlled primarily by the area of flow accumulation. The performance of the model was interpreted to be caused by poor DEM registration and functional limitations (the model does not account for depression storage or slope, which vary significantly between the sites). Average depression storage was about 0.48 inches for Casswell SW compared to 0.16 inches for Casswell NW. These minor differences may have an impact on the response of these sites to small precipitation events. There was another odd aspect of the DEM at Casswell Rd, the slope computed from it was much lower than the slopes measured in the field. The poor quality of the DEM in the vicinity of Caswell rd has clearly limited the usefulness of the model for predicting precisely where the phosphorous flowpaths intersect the stream network.

Implications for Watershed Management

The results seem to indicate that the phosphorous model, while correctly identifying the presence of phosphorous transport paths, has limitations in identifying exactly where they are in the field and whether there is a direct hydrologic connection to the drainage system. While these models theoretically have to work, the 10 meter DEM we used doesn't seem to represent the slope and topography of hydrologically-relevant scale. Some of the problems stem from poor registry between the DEM and aerial photographs used in the analysis, as well as offsets between valleys in the DEM and the real position of stream valleys. Another problem is anthropogenic modifications in topography which occurred after the data for the DEM was collected or are too small to be captured by the resolution of the DEM. Our study suggests these subtle features can have a tremendous impact on surface drainage. It is important to note that the more advanced hydrologic models that utilize topography for routing overland flow are also subject to the same problems that made our model inaccurate. It makes no sense to apply these more sophisticated models when our simple phosphorous accumulation model will probably deliver the same result.

Tile drains, ubiquitous in the watershed, are problematic because they can greatly increase or decrease the effective catchment area associated with the flow path. USDA conservation districts commonly maintain detailed records of tile drains. Tile drain maps should be consulted when making onsite BMP decisions and when interpreting the results of topographically based loading models. Road berms which over many years of maintenance can build up in elevation. These features may block flow paths and can reroute overland flows over long distances. They may also impact the average watertable depth which can influence surface drainage. Byron W site is a good example of this. Topographically-based models should use DEMS that specifically take these into account. DEM's developed from some of the older 24K USGS contour maps (such as this study) will NOT reflect the subtle but significant changes in elevation caused by roads and other transportation infrastructure.

Besides the academic findings of the study, this research has identified four sites of concern that should be addressed with BMP's in the watershed. They are (in descending order of importance): Paul Rd West, US20 N, Casswell N and Byron East). The sites at Clipnock Rd, Casswell S, Casswell SW and Rte 33 are also contributing significant amounts of phosphorous. In the case of the Casswell sites, the Black Creek tributary has very little buffering. All are capable of contributing measurable loads of phosphorous and sediment to Black Creek. While this phosphorous model appears to be useful for identifying the presence of areas of concern, it does not appear to be capable of ranking sites relative to each other without extensive field observations. Regulating buffer widths based on this model without field checking seems unwarranted. It appears the best way to apply this phosphorous model is to use the output to identify multiple sites of concern, follow each up with field observations to winnow down the sites to the important ones and then address each site with the unique set of geomorphologic and field conditions that governs its hydrologic response. Each site should be evaluated for connectivity to the stream network. There is no point in regulating a wide buffer zone in a site where a road berm effectively stops all overland flow. Much can be learned by identifying through aerial photography or field observations, what kinds of anthropogenic features (roads, etc) intersect phosphorous flowpaths predicted by the model. So while the model is often inaccurate in identifying the location of phosphorous transport paths, understanding why it is wrong provides us with valuable information that is useful for assigning effective best management practices. Our model and field results have been presented to the Black Creek Watershed Coalition in digital form. We hope they find it useful as they prioritize best management practices for this watershed.

CONCLUSIONS

A field and modeling study of phosphorous was undertaken in 12 sites in the Black Creek watershed to determine if a phosphorous model could be used to regulate buffer width and assign best management practices. The study suggests that while the model correctly identified the presence of some important areas of concern, it can't be used to rank these areas without additional field verification. Measurements of overland flow and chemistry indicate that four sites (Paul Rd, US 20 North, Casswell N and Byron Rd East) could be significant sources of phosphorous. All of these sites have a direct surface connection to Black Creek. Other sites that should be considered for best management practices include Clipnock Rd, the tributary at Casswell Rd which should be buffered, and the site at Rte 33.

Topographic based loading models are attractive for guiding best management practices in theory, but several technical issues need to be overcome before they can be used for this function without field verification. These issues include the resolution of available DEM which is too large, DEM quality which impacts the location and size of flow accumulation, tile drains which can significantly modify surface flow paths, and historic modification of the topography which is not always reflected in the DEM.

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Impacts

Funding from the grant was also used to design the hardware and software of the Roughness Clinometer, a device used to measure depression storage, roughness and slope in the field. Details of the device can be found in:

http:\\vortex.esc.brockport.edu\~pauljr\inventions

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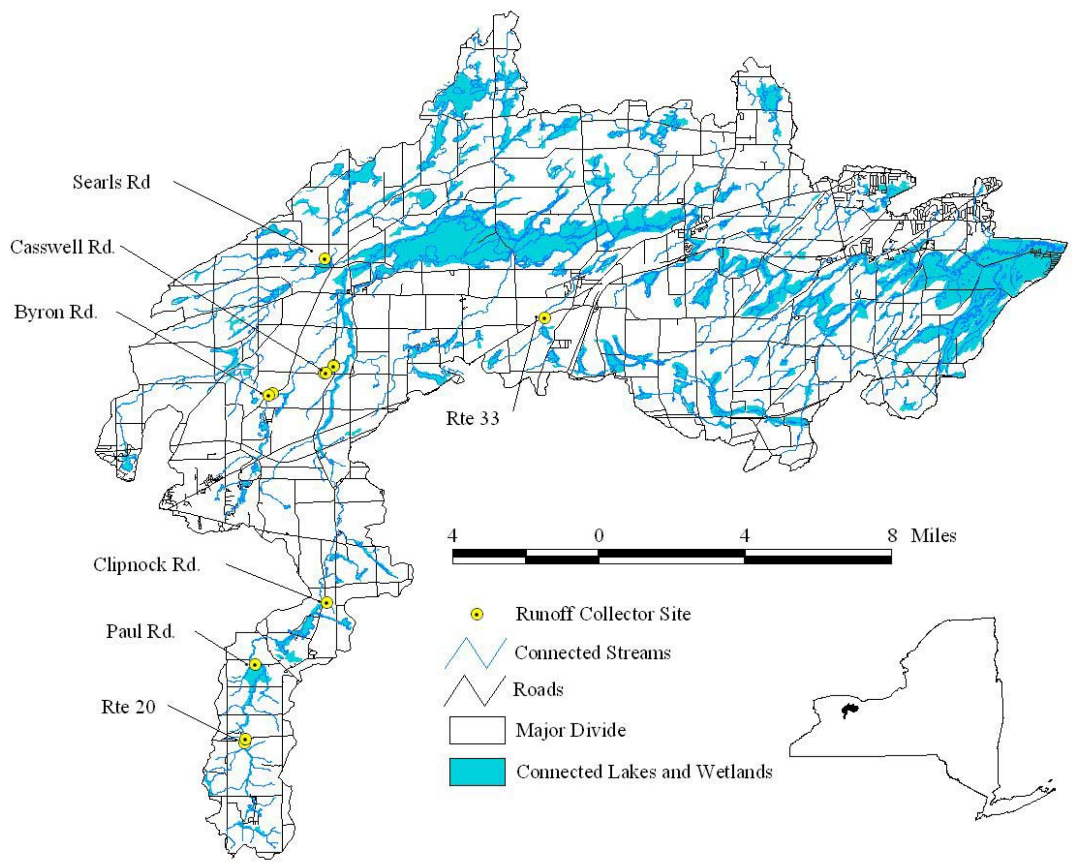

Figure 1 The study area, Black Creek Watershed, is located in western NY. A topographically-based phosphorous loading model was run over the entire watershed to identify sites on streams where, by virtue of slope and aspect, receive greater than normal phosphorous loads. The idea was to target stream reaches at these sites with wider buffers or other appropriate best management practices. Field measurements of overland flow and phosphorous fluxes were conducted on 12 of these sites to determine the validity of the model.

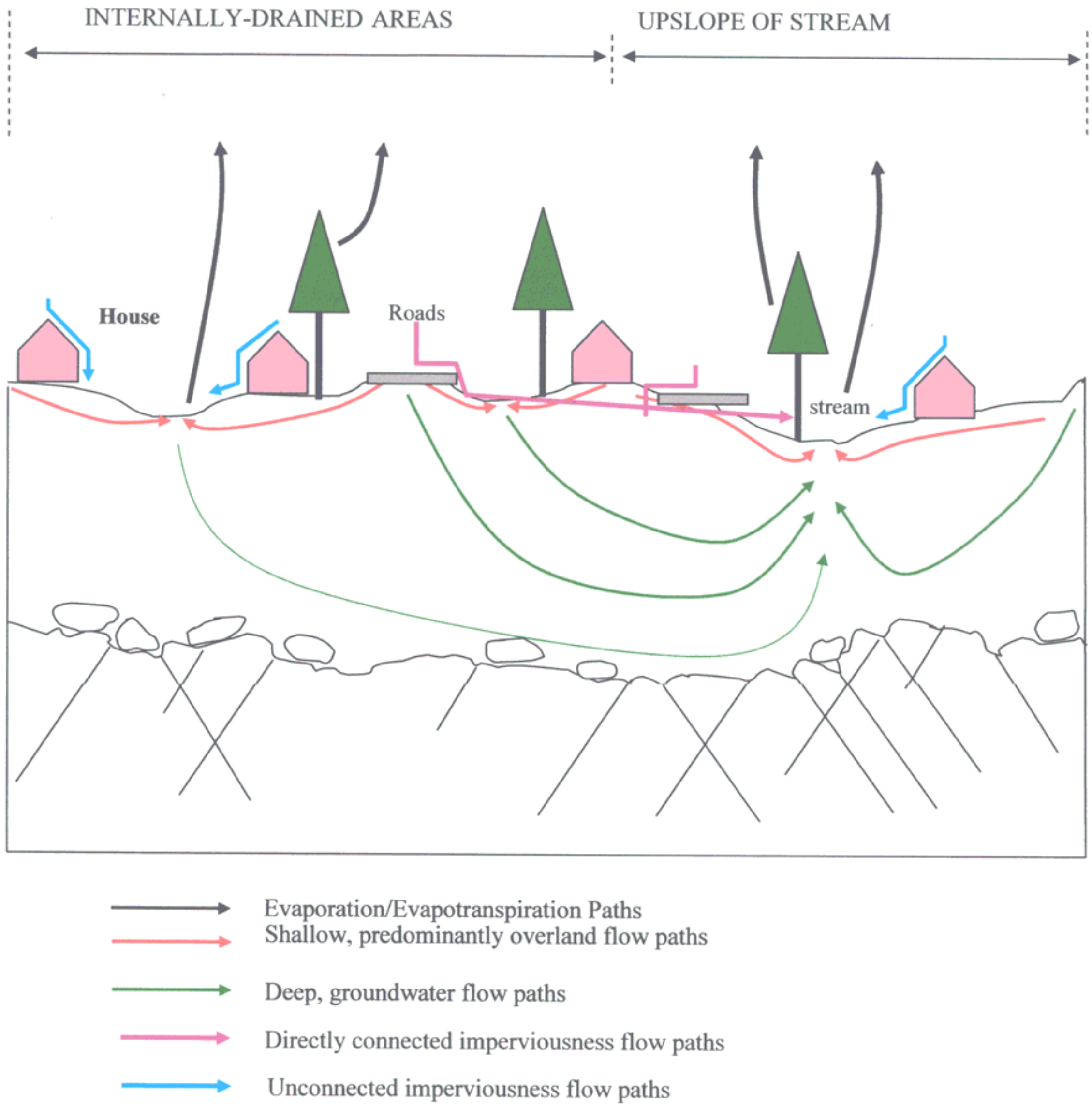

Figure 2 Schematic of watershed profile showing flowpaths associated with Internally-drained and directly-connected areas. These areas were mapped in the watershed using the PCSA algorithm (Richards and Brenner, 2004) to identify topographically connected areas where sediment and particulate phosphorous fluxes can possibly reach the stream network. Internally-drained areas are also important because they can be areas of enhanced groundwater recharge.

Figure 3 Runoff collectors designed for this study that were used to estimate overland runoff volumes. Overland runoff enters the hole at the front of the rain shield, flows through a collection tray and then into a 1 gallon water jug which is located in a 12 by 12 by 14 inch hole underneath. These collectors are accurate for small < 4.3 liter overland flow events. Higher volumes overflow into the hole. The design of the collector facilitates accurate measurements of active overland flow by allowing the user to measure discharge with a beaker and stopwatch.

Figure 4 Device (roughness clinometer) designed for this study that was used to measure depression storage and slope at runoff collector sites. The device is placed into the ground along the direction of maximum slope and dowels are lowered to touch the ground. Measurements of dowel displacement are then processed with software (rough4.exe, available at http:\\vortex.esc.brockport.edu\pauljr) to calculate depression storage, slope and surface roughness. Prior to using the instrument, the site is cleared of sticks and dead vegetation. Details of the device can be found in Richards and Grimm (2005) as well as on the above web site.

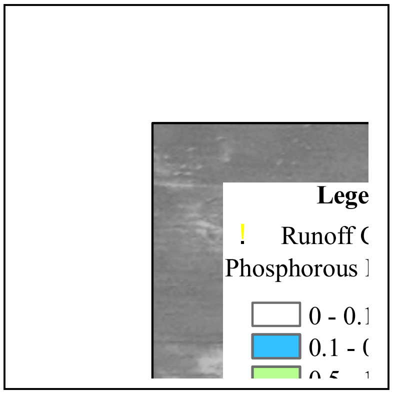

Figure 5 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Byron Rd sites. Runoff collectors for Byron East and Byron West are indicated. Note the drainage ditch that directly connects Byron East to Black Creek. Byron Rd effective blocks surface drainage from Byron West.

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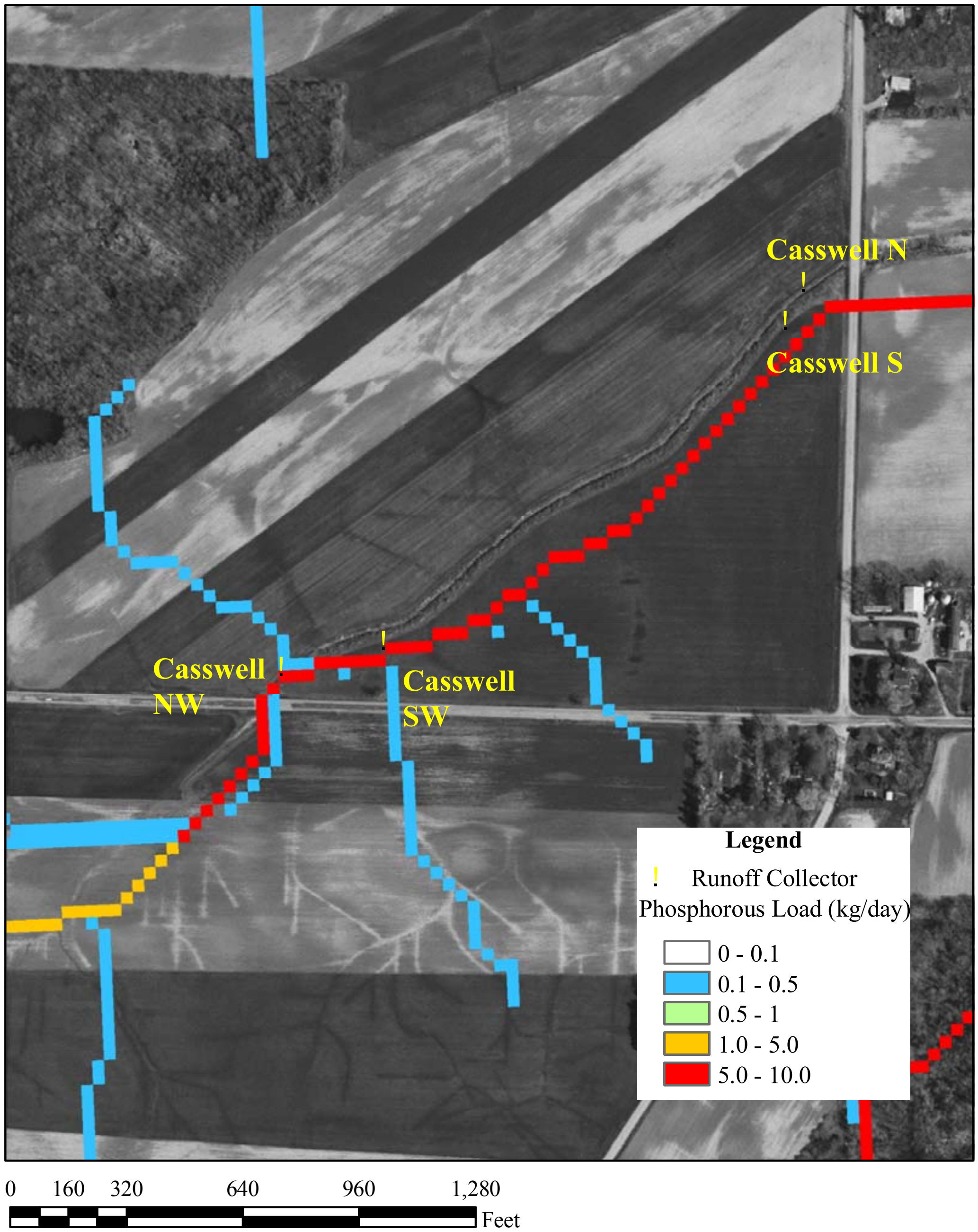


Figure 6 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Casswell Rd sites. Runoff collectors for Casswell N, Casswell NW, Casswell, S and Casswell SW are indicated. Note the offset of the model below the stream.

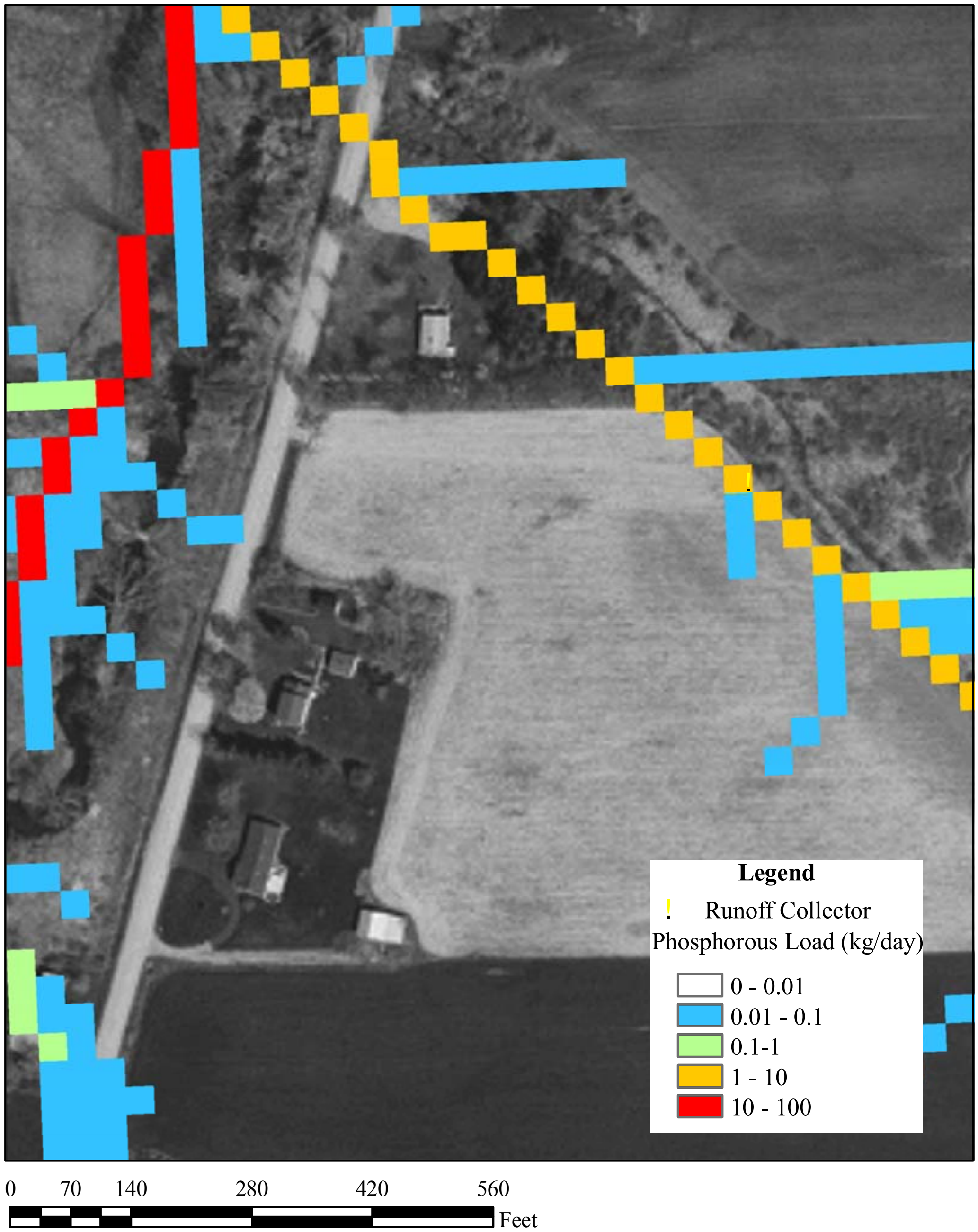
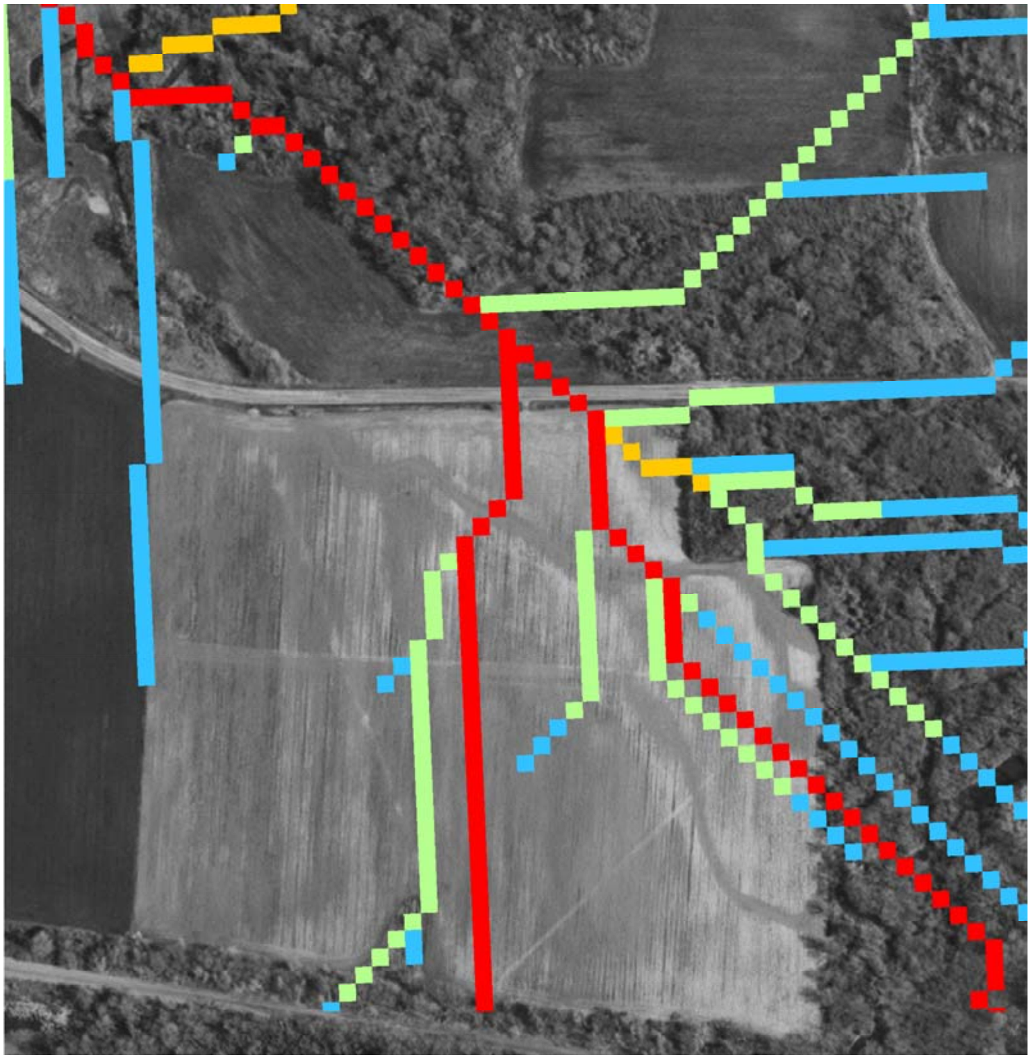


Figure 7 Modeled phosphorous flow paths superimposed on a 2002 aerial photograph of the Clipnock Rd site. The runoff collector for Clipnock Rd is indicated.



Protecting future quantity and quality of New York State's water resources under changing climatic conditions

Basic Information

Title:	Protecting future quantity and quality of New York State's water resources under changing climatic conditions
Project Number:	2005NY69B
Start Date:	3/1/2005
End Date:	2/28/2006
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Congressional District:	22
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Focus Category:	Climatological Processes, Nutrients, Water Quantity
Descriptors:	None
Principal Investigators:	Tammo Steenhuis, Arthur T. DeGaetano, Michael Todd Walter

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Protecting Future Quantity and Quality of New York State's Water Resources Under Changing Climatic Conditions

Control of phosphorus and nitrogen (P and N) loss from agricultural landscapes is important because P is widely recognized as a primary cause of eutrophication of inland waters and N has a direct effect on the degradation of costal waters. Moreover, although the northeastern US receives sufficient rainfall in most years in drought years many regional municipalities face a severe shortfall in drinking water. Protecting our water resources in the future will require comprehensive understanding and knowledge about how foreseeable climate extremes will affect both water quality and quantity. Since essentially all the current water quality models were developed for Midwestern US conditions, these models need to be adapted to the hydrologic and climatic conditions of the Northeast to be trustworthy in New York State.

This research is especially important for New York City (NYC) since eight million people depend on water collected in the Catskills. Moreover, the in the Catskills region of New York State, excessive P loading to the Cannonsville Reservoir, which supplies drinking water to New York City, has led to wastewater discharge restrictions that limit economic development in local communities. This scenario is indicative of many of the region's municipalities.

The overall goal of the proposed work is to contribute to the improvement of surface and ground water quality in the northeastern US and to study the effects of possible future climate changes on water quality and quantity. The proposed research will be carried out in the Cannonsville Reservoir Basin, of which the Town Brook and Trout Creek watersheds are representative subwatersheds that the project team is currently monitoring. These watersheds, in the NYC drinking water source system, are typical of the northeastern US.

Accomplishments

The past year we have formulated in cooperation with both USDA-ARS (Penn State) and NYCDEP, watershed models that are valid for the unique characteristics of the northeastern US, including variable source area (VSA) hydrology. These models, developed at several levels of complexity, are capable of evaluating the temporal and spatial distribution of water and nutrients within the watershed. The model that is conceptually the simplest is based on the SCS-curve number (CN) equation that is used in many water quality models to predict storm runoff from watersheds based on an infiltration-excess response to rainfall. However, in humid, well-vegetated areas with shallow soils, such as in the northeastern US, the predominant runoff generating mechanism is saturation-excess on variable source areas (VSAs). We re-conceptualized the SCS-CN equation for VSAs, and incorporated it into the General Watershed Loading Function (GWLF) model. The new version of GWLF, named the Variable Source Loading Function (VSLF) model, simulates the watershed runoff response to rainfall using the standard SCS-CN equation, but spatially-distributes the runoff response according to a soil wetness index. We spatially validated VSLF runoff predictions and compared VSLF to GWLF for a sub-watershed of the New York City Water Supply System. The spatial distribution of runoff from VSLF is more physically realistic than the estimates from GWLF. This has important consequences for water quality modeling, and for the use of models to evaluate and guide watershed management, because correctly predicting the coincidence of runoff generation and pollutant sources is critical to simulating non-point source (NPS) pollution transported by runoff. The results of this effort are written up in Schneiderman et al (2006) which is in press

A more complicated procedure is the Soil Moisture Routing and Distribution model. This is a physically-based, fully-distributed, GIS-integrated model, developed to simulate the hydrologic behavior of small rural upland watersheds with shallow soils and steep to moderate slopes. The model assumes that gravity is the only driving force of water and that most overland flow occurs as saturation excess. The model uses available soil and climatic data, and requires little calibration. Funding was used for running the SMDR model to simulate runoff production on a 164-ha farm watershed in Delaware County, New York, in the headwaters of New York City water supply. Apart from land use, distributed input parameters were derived from readily available data. Simulated hydrographs compared reasonably with observed flows at the watershed outlet over a eight year simulation period, and peak timing and intensities were well reproduced. Using off-site weather input data produced occasional missed event peaks. Simulated soil moisture distribution agreed well with observed hydrological features and followed the same spatial trend as observed soil moisture contents sampled on four transects. Model accuracy improved when input variables were calibrated within the range of SSURGO-available parameters. The model will be a useful planning tool for reducing NPS pollution from farms in landscapes similar to the Northeastern US. The paper was published for discussion by Gerard Merchant et al. (2005). Based on these discussions the full paper is now in press as Gerard Merchant et al. (2006)

In addition a spatially distributed model of total dissolved phosphorus (TDP) loading was developed using raster maps covering a watershed with 164-ha dairy farm. Transport of TDP was calculated separately for base flow and for surface runoff from manure-covered and non-manure-covered areas. Soil test P, simulated rainfall application, and land use were used to predict concentrations of TDP in overland flow from non-manure covered areas. Concentrations in runoff for manure-covered areas were computed from predicted cumulative flow and elapsed time since manure application, using field-specific manure spreading data. Base flow TDP was calibrated from observed concentrations using a temperature dependent coefficient. An additional component estimated loading associated with manure deposition on impervious areas, such as barnyards and roadways. Daily base flow and runoff volumes were predicted for each 10-m cell using the Soil Moisture Distribution and Routing Model (SMDR). For each cell, daily TDP loads were calculated as the product of predicted runoff and estimated TDP concentrations. Predicted loads agreed well with loads observed at the watershed outlet when hydrology was modeled accurately (R2 79% winter, 87% summer). Lack of fit in early spring was attributed to difficulty in predicting snowmelt. Overall, runoff from non-manured areas appeared to be the dominant TDP loading source factor. More information can be found in Hively et al. (2005). The full paper is in press (Hively et al. 2006)

Impact

The procedures were included as part of the highly-sophiscated computer technology, NYCDEP is developing and applying land (terrestrial) and reservoir models to support long-term watershed management and ongoing reservoir operations. Terrestrial models simulate water and nutrient loadings from the land area draining into the reservoirs, and apply relevant site conditions such as weather, watershed soils and topography, land use and watershed management. Reservoir models simulate in-lake water levels and flows; vertical temperature ranges; and nutrient and chlorophyll levels as a function of weather, reservoir depth, and nutrient loadings. Linking the two models provides a powerful tool for simulating the effects of weather, land use, watershed management, and reservoir operations on water quality in the City's 19 reservoirs

Students involved

Zacharay Easton Floriculture. PhD. 2006
Steve Lyon BEE PhD. 2006

Demonstration assessment of innovative water quality protection options for Cayuga Lake: Fall Creek and Cornell campus

Basic Information

Title:	Demonstration assessment of innovative water quality protection options for Cayuga Lake: Fall Creek and Cornell campus
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Focus Category:	Non Point Pollution, Nutrients, Sediments
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Principal Investigators:	Michael Todd Walter

Publication

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DEMONSTRATION ASSESSMENT OF INNOVATIVE WATER QUALITY PROTECTION OPTIONS FOR CAYUGA LAKE: FALL CREEK AND CORNELL CAMPUS

PREPARED BY: M.Todd Walter and Stephen B. Shaw
Biological and Environmental Engineering

STUDENT PARTICIPANTS

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EXECUTIVE SUMMARY

Despite its small volume in relation to inflow (~0.0003 m^3 volume/m^3 annual inflow), paired sediment samples taken upstream and at the outlet of Beebe Lake indicate an average sediment trapping efficiency of 30%. And, with nearly 6200 metric tons (mt) of sediment captured in the lake each year, the amount retained is an order of magnitude greater than the estimated sediment load from the Cornell campus, 73 mt. These findings suggest that with more routine dredging and enhancement of flow patterns to eliminate hydraulic dead space, trapping in Beebe Lake could be further increased to offset sediment loads from Cornell, thus utilizing Beebe Lake as a centralized stormwater management structure. However, we caution that before such a plan is adopted, the nature of the two sediment sources, Cornell campus vs. watershed above Beebe Lake, needs to be considered. For example, it is possible that sediment generated from Cornell's abundant parking lots may be more highly concentrated with heavy metals than the largely agricultural sources from further up in the watershed.

FINAL REPORT

INTRODUCTION

Beebe Lake is an on-line impoundment of Fall Creek situated near the discharge point of the 326 km^2 Fall Creek watershed into Cayuga Lake. With the current lake dimensions established in 1896 after construction of the Triphammer Dam, the lake surface covers 5.4 hectares and has a depth of approximately 1 m based on soundings taken in November 2005. The most notable characteristic of Beebe Lake is its small volume in relation to its upstream contributing area. For instance, the ratio of total volume (m^3) to total annual 2005 inflow (m^3) is only on the order of 0.0003. Despite, this seemingly minor capacity for trapping sediment, the lake has required periodic dredging with two major dredging events in its lifetime, one in 1929/1930 and another in the late 1980's (Smith 2003). While the need for dredging has generally been considered a maintenance nuisance, in light of recent regulatory requirements in controlling non-point source pollutant loads (US EPA 1993), we can consider sediment captured in Beebe Lake to be sediment that would otherwise have ended up in Cayuga Lake. Therefore, the focus of this report is to quantify Beebe Lake's capacity to retain particulate matter and its associated pollutant load.

While impoundments such as reservoirs and storm water detention basins clearly capture sediments (water resource managers will readily attest), there is surprisingly little standardized information on predicting sediment capture rates. Partially, this dearth of information is due to the wide range of hydrologic inputs, sediment size distributions, and basin hydraulic characteristics. In particular, there is virtually no information for the capture capacity of an impoundment that has a such a small volume to inflow ratio; empirical curves relating the volume/inflow ratio to trapping efficiency typically estimate an efficiency of zero for values less than 0.001 (Verstraeten and Poesen 2000).

Objectives of this work were to:

1. Quantify the sediment trapping efficiency of Beebe Lake using paired samples taken above the lake and at the Triphammer Dam.
2. Estimate the total amount of sediment generated from the Cornell campus and compare to the annual load captured in Beebe Lake.
3. Compare the feasibility of retrofitting campus with localized pollutant management structures or enhancing the trapping efficiency of Beebe Lake to manage sediment originating from the Cornell campus.

Furthermore, in this report we discuss additional research needed to better understand sediment trapping mechanisms within Beebe Lake.

METHODS and ANALYSIS

Sediment Collection

Approximately 75 pairs of 1-liter water samples were collected upstream and at the discharge point of Beebe Lake using a submersible, depth integrated sampler. Sampling frequency varied with more frequent sampling conducted during storm events (Figure 1 – note, a sampling day may include multiple samples). The upstream sample was taken from the Forest Home Drive Bridge (Figure 2), approximately 50 m upstream of a USGS stream gauge (NY 04234000). Conveniently, this sampling location is just downstream of a small waterfall in an area of turbulent flow, thus the sample is considered representative of total suspended solids (TSS) across the entire water column as well as bedload material small enough to fit in collector. The downstream sample was taken at the intake to the hydroelectric facility on the northwest corner of Beebe Lake.

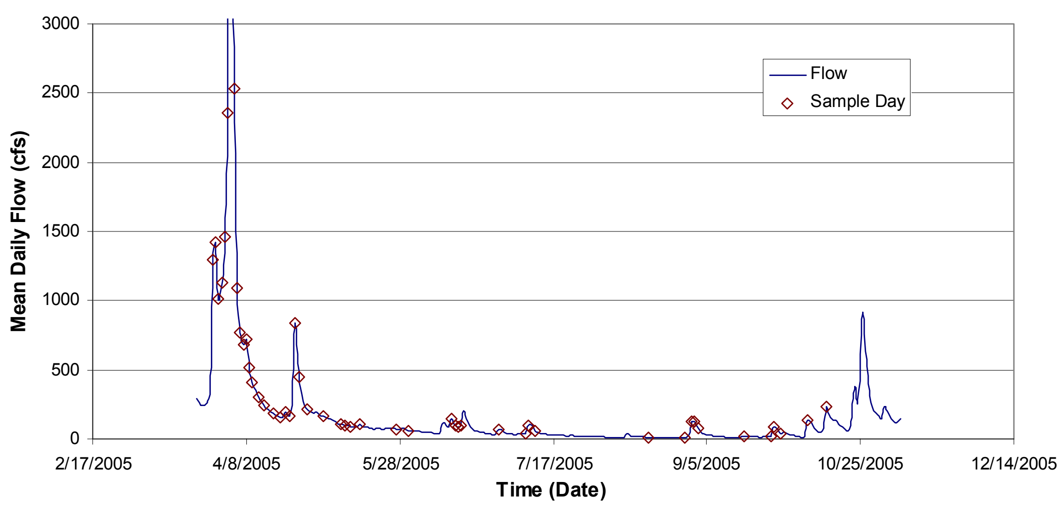

Figure 1. Sampling days superimposed on Fall Creek streamflow at Beebe Lake. Note, multiple samples may have been taken on a sample day.

TSS was determined by filtering the stream sample through a weighed Whatman 934-AH glass fiber filter and the residue retained on the filter dried to a constant weight at ~105º C (APHA Part 209C).

These recent data were supplemented with TSS data for Fall Creek collected from the Forest Home Drive Bridge by Dr. Dave Bouldin during the 1970's.

Figure 2. Sample site locations overlayed on Beebe Lake aerial photograph, circa 1996. Note, more recently, the more southerly island shown in the photo has been removed.

TSS Concentration Analysis

Two primary analyses were conducted on the TSS data: 1.) a comparison of concentrations above and below the Beebe Lake and 2.) the development of TSS rating curves relating TSS and stream flow. In both cases, we found that more predictive relationships could be developed if TSS samples were grouped by the flow conditions at the time of sampling.

Thus, in the case of TSS concentrations above and below Beebe Lake, data were grouped by storm and interstorm periods (Figures 3a and 3b, respectively). Naturally, storm events generate the largest flows, so storm TSS data inherently include the largest flow events and similar results were found if grouped by flow alone (e.g. >100 cfs). Fitting a linear least -squares regression line to the relationships, we find that TSS at the dam is typically 67% of that measured upstream during storm events and 80% of that measured upstream during interstorm periods. An actual retention efficiency was estimated on a mass basis as discussed later. Also, indicated on Figure 3, is a 1:1 line. During storm events, TSS at the dam is always lower than as measured upstream while during interstorm periods, the dominant TSS concentration is less consistent.

For development of the rating curves, TSS samples were grouped among rising hydrograph, falling hydrograph, and interstorm period. For each grouping, linear least-squares regression relates TSS to hourly flow (Figure 4a and 4b). Notably, as shown in Figure 4b, at low flows, flow alone is not a strong predictor of TSS. Complicating factors are likely to include a lag in response in Beebe Lake in comparison to rapid changes in streamflow as well as mixing processes within Beebe Lake that may stir up sediments. However, since low flows contribute a minor amount of the total overall load to Beebe Lake, we did not investigate these processes in this study.

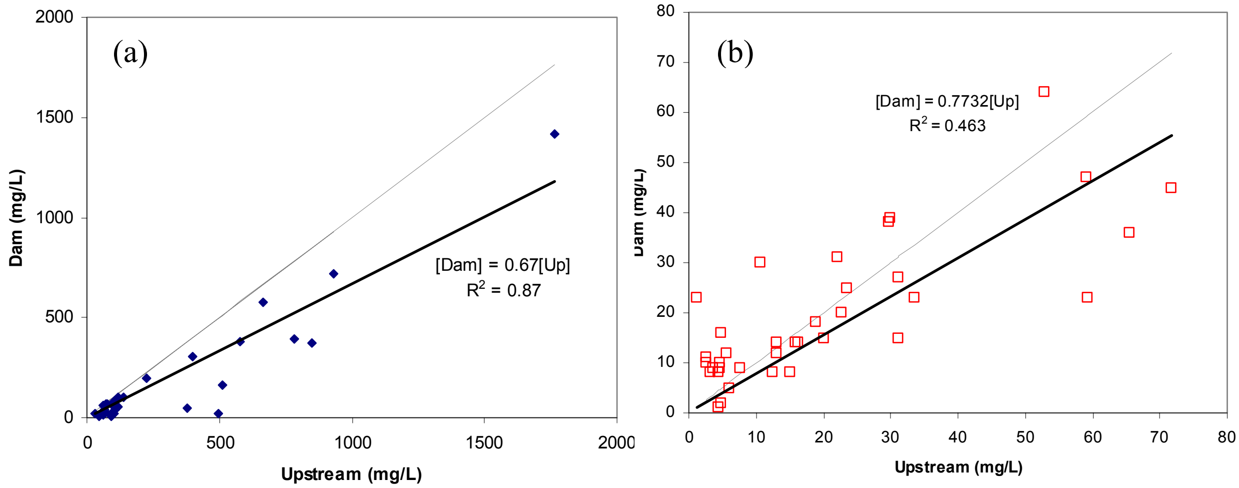

Figure 3. Correlation between TSS concentration upstream and at dam for paired samples taken at same time. Figure 3a. is the relationship during storm periods and Figure 3b is the relationship during interstorm periods. The gray line indicates a 1:1 ratio.

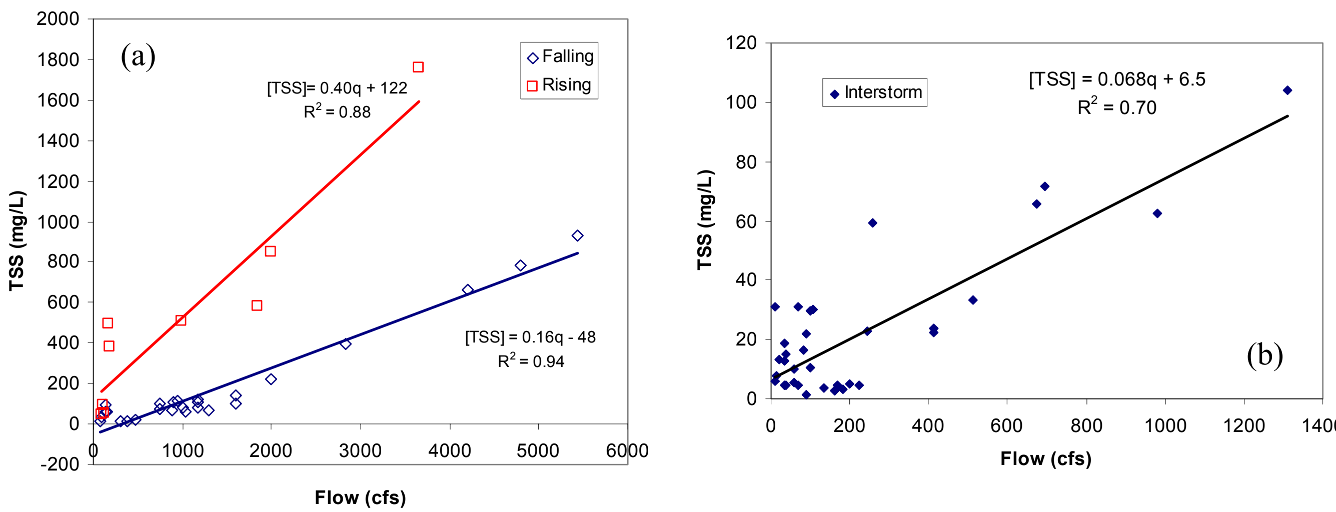

Figure 4. Rating curves relating TSS to Fall Creek flow.

Actual loads to Beebe Lake are dependent on the frequency distribution of flows. To estimate loading, we carried out an hourly time step simulation using 2005 hourly Fall Creek along with the rating curve equations presented in Figure 4. For each hourly time step, we classified the associated flow as being either within a rising, falling, or interstorm period. The hydrograph was considered rising if the flow at T_{i+1} was 5% or greater than the flow at T_i. The hydrograph was considered falling if the flow at T_i was 5% or greater than the flow at T_{i+1} or if the flow on the rising limb was within five hours of its peak (This five hour lag seemed representative based on an analysis of 5 storm events for which frequent samples were taken). Other cases were considered interstorm periods. The mass captured in Beebe Lake was determined by scaling stream concentrations by the regression coefficients portrayed in Figure 3. Hourly TSS load as predicted fro this simulation is shown overlain with flow in Figure 5.

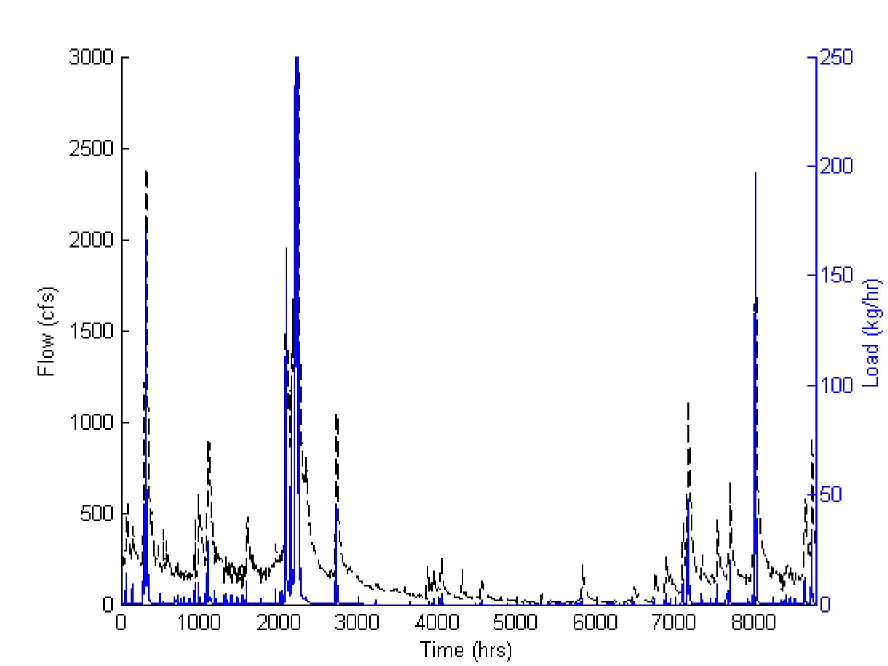

Figure 5. Simulated hourly TSS load overlain by hourly flow on Fall Creek. Note, the flow and load on April 2, has been truncated.

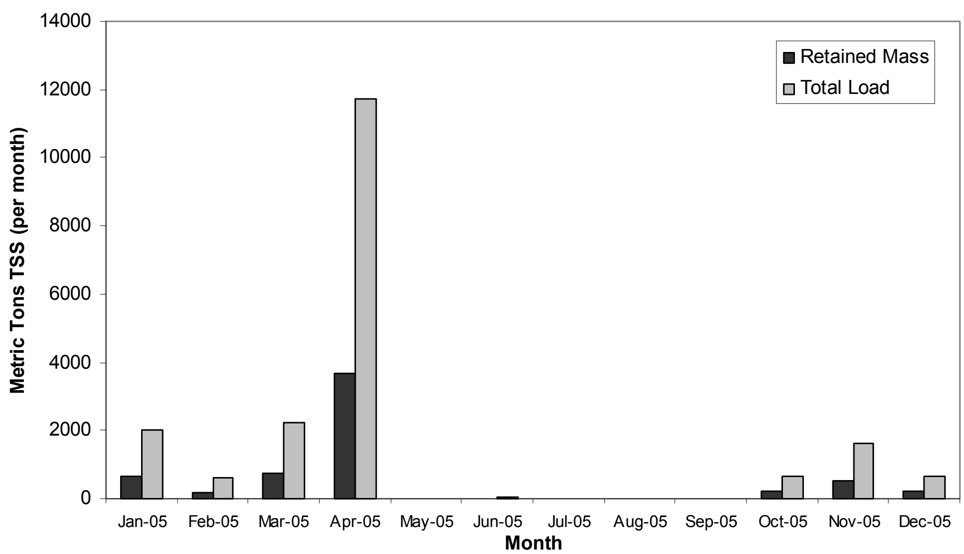

Figure 6. Monthly TSS mass loads entering Beebe Lake and retained within Beebe Lake.

Aggregating to a monthly interval, the TSS load entering Beebe Lake and the mass of TSS retained were determined (Figure 6). As apparent in Figure 6, loading was highly variable through the year, with the highest loads primarily correlating on periods of largest streamflows.

The annual TSS load entering Beebe Lake in 2005 is approximately 19600 metric tons (mt) while the total amount retained is approximately 6200 mt. As a back-of-the-envelope check, we assume TSS sediment has a density of 1.5 mt m^{-3}. Thus, if spread evenly over the 5.4 ha Beebe Lake, the water depth would decrease annually by about 8 cm, a seemingly reasonable amount.

NPS Campus Load Estimates

The Cornell Ithaca campus was modeled as a single, lumped hydrologic unit. Despite the diverse land surfaces and complicated placement of pervious and impervious surfaces, variations in the landscape were considered suitably homogeneous in aggregate to justify forgoing more spatially refined modeling. We assumed the campus area total 560 hectares, the land area of the Ithaca campus excluding agricultural research facilities. Average annual runoff was estimated on a daily basis by applying the SCS Curve Number Equation (with CN = 87) to the 2001 to 2005 daily weather record for Ithaca. A TSS load was estimated by multiplying the runoff volume by an Event Mean Concentration (EMC) for TSS. Stormwater sampling of catch basins and outlet pipes on the Cornell campus from storm events on 9/27/05 and 9/29/05 suggest an average TSS EMC of 77 ppm, consistent with literature values of 72.8 ppm for high density residential (Lee & Bang 2000) and a combination of 110 ppm for parking areas to 33 ppm for landscaped areas (Pitt et al. 1995). The total annual TSS load generated by the campus is approximately 73 metric tons.

There is some possibility of retrofitting campus with localized detention ponds and other structural sediment detention measures to reduce this load. However, given that the campus is nearly fully built-out with little unoccupied space, there are few opportunities for constructing such structures. Figure 7 indicates major storm sewer lines and discharge points. The green, dashed arrows indicate areas where enough room may exist in which a stormwater management measure could be constructed, approximately 30% of the total campus drainage area. Assuming a properly sized urban sedimentation basin can remove 50% of TSS over the long-term (Stahre and Urbonos 1990) over 30% of the 560 ha drainage area, the sediment load could only be reduced by 15% to 62 mt.

Modeling of TSS Settling in Beebe Lake

Assuming quiescent settling, input well mixed across the water column, and steady state flow, we use the simple overflow rate approach to estimate the critical settling velocity (v_c) for particles:

$$v_c = \frac{q}{A} \tag{1}$$

where q is stream flow entering Beebe Lake and A is the lake surface area (5.4 ha). The critical settling velocity is the minimum settling velocity a particle must have for its entire mass fraction to settle out in the basin. Particle fractions with larger settling velocities will entirely settle out. Particle fractions with smaller settling velocities will settle out in the ratio of the respective settling velocity to the critical velocity.

Figure 7. Cornell campus map indicating major storm sewer lines and discharge points. Green, dashed arrows indicate discharge lines where it may be feasible to construct a detention basin or other stormwater management structure.

A v_c is calculated for the complete range of flows observed in Fall Creek (Table 1). For Eqn. 1, we assume A is only 2.7 ha to account for hydraulically "dead" space in which the bulk inflow has little interaction. During large flows (>1000 cfs), a higher velocity current can readily be seen north of the island tracking directly to Triphammer Dam, not circuitously passing around the island (Figure 2). In addition, using Stokes Law for settling, a v_c is calculated for a range of sediment sizes (Table 2). Comparing Tables 1 and 2, we find that the particle size removed only shifts moderately downward with decreasing flow. At a flow of 100 cfs, up to 20 micron diameter particles would settle out entirely but at a flow of 1000 cfs up to 100 micron sized particles would settle out entirely. While no analysis of the particle size distribution of TSS in Fall Creek has been conducted to date, qualitative observation of water samples during TSS analysis indicates most material is relatively small in size (less than 100 microns). This simple settling analysis indicates that Beebe Lake should be able to settle some fraction of particles in this 100 micron size range even at large flows – consistent with our observations.

While the overflow rate approach is generally independent of depth, it does assume that the depth is great enough so that lateral shear forces do not re-entrain settled particulate material. Assuming a 100 m width and 1 m depth cross-section for a 28 m^3/s flow (1000 cfs), the average velocity would be 0.28 m/s. For designing vegetated waterways, the critical threshold at which erosion occurs is typically considered to be near 1 m/s (Schwab et al. 1993 Table 7.2), relatively far above our presumed velocity currently. But, if the lake continues to fill in at a rate near 8 cm/yr, it would appear that it would begin to reach a threshold at which shear would play a role within the next five to ten years.

Table 1. Critical settling velocity in Beebe Lake for a range of stream flows.

Flow (cfs)	Critical Velocity (m/s)
10	1.05E-05
100	1.05E-04
250	2.62E-04
500	5.25E-04
1000	1.05E-03
2000	2.10E-03
3000	3.15E-03
4000	4.20E-03
5000	5.25E-03

Table 2. Critical settling velocity calculated via Stokes Law for a range of particle sizes.

American Soil Classification	Particle Diam. (microns)	Critical Veloc. (m/s)
Clay	1	5.44E-07
Fine Silt	4	8.71E-06
Med. Silt	13	9.20E-05
Coarse Silt	35	6.67E-04
Fine Sand	175	1.67E-02
Med. Sand	375	7.66E-02
Coarse Sand	750	3.06E-01

CONCLUSIONS

Partially due to the large sediment load originating from the large upstream contributing area, Beebe Lake annually captures a much greater mass of sediment than generated by the Cornell campus. Enhancing the trapping efficiency of Beebe Lake to offset sediment loads from Beebe Lake seems to be more feasible option than retrofitting the Cornell campus with localized detention basins. Specifically, a 5% decrease in hydraulic dead space in Beebe Lake results in 5% decrease in critical settling velocity resulting in a shift of minimum particle size settled from 45 microns to 42 microns (for 1000 cfs flow). For a representative particle distribution in which 80% of total sediment is assumed to be uniformly distributed below 63 microns (small sand) at higher flows (Slattery and Burt 1997, Walling et al. 2000), this would result in a shift from 43% [20% sand fraction plus (63-45)/63*0.8] to 47% [20% sand fraction plus (63-42)/63*0.8] of TSS available for settling. Normalizing by the actual measured capture rate of 30%, ~3% more of the particle distribution could be fully settled, upwards of 500 mt. While only a rough estimate, this calculation demonstrates the order of magnitude of the enhancement that could be expected. Alternatively, as discussed previously, localized sedimentation basins removing 50% of TSS over 30% of the 560 ha drainage area could reduce the load by only 11 mt.

Modifications to Beebe Lake would require diverting a greater a fraction flow to the southerly side of the existing island either by modifying the shape of the island or installing diversion vanes possibly similar to rock vanes routinely used in channel restoration projects. Additionally, more frequent dredging of the lake would need to occur, primarily to maintain a depth of at least a meter in order to minimize re-entrainment of sediment by shear.

While the paired sampling provided useful empirical information regarding Beebe Lake's trapping efficiency, additional data is necessary to more accurately model potential changes resulting from modifications to the lake. Most critically, the actual particle size distribution at different flow rate is needed. Using a similar calculation as above but with a known particle size distribution specific to Fall Creek would permit more accurate calculation of the benefits of enhancing Beebe Lake trapping efficiency.

NEW EXTERNAL PROPOSALS (these build substantially on this project)

Title: Characterizing Landscape-scale Transport Pathways of Pathogens using Innovative DNA-based, Nanotech-tracers
Agency: USDA NRI-GGP 26. Water and Watersheds
Duration: 9/1/2006-8/31/2009
Request: $393,614
PIs: Walter, M.T., J.M. Regan (Penn State Univ.), D. Luo

Title: Developing and Testing an Innovative Approach for Characterizing Particle Transport in Hydrological Systems
Agency: NSF-EAR Hydrology
Duration: 1/1/2007 - 8/31/10
Request: ~$500,000
PIs: Walter, M.T., D. Luo

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Nutrient balances -- involving farmers and their advisors in addressing nutrient excesses for improved water quality for Upper Susquehanna Watershed farms

Basic Information

Title:	Nutrient balances -- involving farmers and their advisors in addressing nutrient excesses for improved water quality for Upper Susquehanna Watershed farms
Project Number:	2005NY73B
Start Date:	3/1/2005
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	20-26, 29
Research Category:	Water Quality
Focus Category:	Nutrients, Sediments, None
Descriptors:	
Principal Investigators:	Quirine M. Ketterings

Publication

1. Czymmek, K.J.; Q.M. Ketterings; C. Ramussen; L. Chase, 2006, Striking the Right Balance, The Manager, Northeast Dairy Business 8(4), 21-22.
2. Rasmussen, C.N.; Q.M. Ketterings; J. Mekken; K.J. Czymmek, L.E. Chase, 2005, Statewide and Whole Farm Phosphorus Balances- Tools to Help with Long-term Nutrient Planning On Dairy and Livestock Farms, What's Cropping Up, 15(6), 7-9.
3. Ketterings, Q.M.; C. Rasmussen; J. Mekken, K. Czymmek, 2005, Statewide, County-based, and Whole Farm Nutrient Balances: Tools to Help With Long-term Nutrient Planning, in Field Crop Dealer Meetings, Department of Crop and Soil Sciences Extension Series No. E05-1, 19-21.
4. Rasmussen, C.N.; Q.M. Ketterings; G. Albrecht; L. Chase; K.J. Czymmek, 2006, Mass Nutrient Balances- a Managment Tool for New York Dairy and Livestock Farms, in Silage for Dairy Farms; Growing, Harvesting, Storing, and Feeding, NRAES Conference, Harrisburg, PA, 396-414.

Final Report
USDA Competitive Grant – EPA Region 2

Nutrient Balances – Involving Farmers and their Advisors in Addressing Nutrient Excesses for Improved Water Quality for Four Upper Susquehanna Watershed Farms

26 June 2005

Principal investigator(s) name(s) and university:

Quirine M. Ketterings[1], Nutrient Management Spear Program (NMSP), Dept. of Crop and Soil Sciences, Karl Czymmek, PRO-DAIRY, and Larry Chase, Department of Animal Science, Cornell University.

Collaborators:

Caroline Rasmussen (NMSP, ***project coordinator***), Jim Curatolo (Coordinator, Upper Susquehanna Coalition - UCS) and Soil and Water Conservation Districts (SWCD) in the New York Counties that fall within the boundaries of the Upper Susquehanna Watershed. 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 State (Allegany, Steuben, Schuyler, Chemung, Tompkins, Tioga, Broom, Cortland, Chenango, Madison, Onondaga, Otsego and Delaware) and three in Pennsylvania. Together the New York counties comprise 7 congressional districts (20, 21, 22, 24, 25, 26, and 29).

Justification and Scope:

At present, the Chesapeake Bay does not meet federal water quality standards. The Chesapeake Bay Program defines the water quality conditions necessary to protect aquatic living resources and assigns load reductions for nitrogen (N), phosphorus (P), and sediment needed from each tributary basin to achieve the necessary water quality. New York State is developing a Tributary Strategy to avoid additional environmental regulations in the Chesapeake Bay Watershed that will occur unless contributing states substantially reduce sediment and nutrient loads before 2011. The Susquehanna River contributes 50% of the fresh water to the Bay (http://www.u-s-c.org/html/CBP.htm). Typically more nutrients come onto farms as purchased feedstuffs and fertilizer than leave the farm as animal products and crops but an analysis of the nutrient flows onto and off of the farm, a mass nutrient balance (MNB), is essential to quantify current nutrient imbalances and identify farm practices which could be more efficient, thereby, increasing farm profitability and decreasing nutrient losses.

In January of 2005, a proposal submitted to the Water Resources Institute was awarded DEC funding to work with USC personnel to generate a 6-farm dataset of nutrient balances (N and P

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inputs and outputs). We proposed to expand the scope of this proposal by adding 4 additional farms and requested USDA funds to do so. This document is our final report on the 4 farms that were evaluated for their whole farm balance with USDA EPA Region 2 funds.

Approach:

Farm selection: Farms were identified by local Soil and Water Conservation District personnel working with the Upper Susquehanna Coalition. The 4 case study farms were located in four different counties within the Upper Susquehanna Watershed (Cortland, Chemung, Chenango, and Schuyler). The farms were dairy farms varying in size from 40 to 624 milking cows (Table 1). One of the four farms was a Jersey farm (Farm D) while the other three were Holstein farms.

Training: Three training sessions were held to raise awareness about the MNB project and provide instructions for data collection and analysis interpretation. These meetings were held on September 30, 2004 in Ithaca, on May 20, 2005 in Owego and on June 2, 2006 in Horseheads. The Ithaca and Owego sessions were directed towards training of Soil and Water Conservation District and Natural Resources Conservation Service personnel, and private sector service providers associated with the Upper Susquehanna Coalition. The training session in Horseheads was for producers in the Chemung River Watershed.

Data collection and mass nutrient balance calculations: The whole farm mass balance assessments included quantification of imports through feed, fertilizer, nitrogen fixation from legumes, animals purchased and bedding and exports in the form of milk, animals and crops sold, manure transported off the farm. These data were collected by interviewing the producer (and nutritionist, crops consultant or feed company where needed) using the survey forms shown in Appendix A. Data were collated from available farm records which included farm financial records, crop recordkeeping and animal nutrition records. Acres of legumes, percent legume in the stand, yield and crude protein content were used to estimate symbiotic N fixation. A description of the calculations used in the program can be found in Appendix B.

Animal nutrition consultants and feed mill operators commonly provided feed nutrient composition data. Changes in purchased and farm produced feed inventories were accounted for as well. The farm data were entered into the Excel spreadsheet during the farm visit and the producer was provided with a farm specific MNB Analysis Report (example shown in Appendix C) at the time of data collection.

Results:

General farm characteristics: The four farms varied in size from 40 to 640 milking cows representing animal densities of 0.42 to 1.13 animal units[2] per acre. Milk production per acre ranged from 3,911 to 12,090 lbs of milk per acre and from 13,688 (the Jersey farm) to 22,886 lbs of milk per cow per year. Farm purchased feeds as a percentage of all livestock feed (dry matter basis) ranged from 33% in farm D to 60% in farm A. The general farm characteristics for each of the 4 farms are shown in Table 1.

[2] One animal unit equals 1000 lbs.

Table 1: General farm characteristics for four case study dairy farms located in the Upper Susquehanna Watershed (2004 data).

		Farm A	Farm B	Farm C	Farm D
Animal density	animal units/acre	0.99	0.86	1.13	0.42
Milking cows	cows	471	110	624	40
Milk production	lbs/acre	10,024	8,943	13,090	3,911
	lbs/cow per year	20,490	16,259	22,886	13,688
Purchased feeds	% dry matter	60	40	36	33
Crop and tillable pasture	acres	963	200	1091	140
Legume crop	acres	200	140	350	41

Nitrogen balances: Nitrogen balances for the 4 farms are shown in Table 2. Three of the four farms were very similar in the percentage of N imported that did not leave the farm through exports of milk, animals, crops, and/or manure (73-76% “remaining” on the farm). The fourth farm showed a higher percentage, most notably because of lower milk sales. The total lbs of N per acre “remaining” ranged from 143 lbs N/acre for farm A to 240 lbs N/acre for farm C (the farm with the highest animal density).

Table 2: Mass nitrogen balance for four case study dairy farms located in the Upper Susquehanna Watershed (2004 data). General characteristics of the farms are given in Table 1.

		Farm A	Farm B	Farm C	Farm D
		-------------------------- *Nitrogen (N)*			--------------------------
Annual imports					
Feed	tons/year	71.59 (76%)	9.15 (39%)	129.43 (75%)	11.44 (93%)
Fertilizer	tons/year	14.02 (15%)	8.88 (38%)	24.56 (14%)	0.45 (4%)
N fixation	tons/year	3.80 (4%)	4.94 (21%)	16.80 (10%)	0.40 (3%)
Animals	tons/year	0.04 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Bedding	tons/year	5.17 (5%)	0.66 (3%)	1.19 (1%)	0.00 (0%)
Total	tons/year	94.62 (100%)	23.62 (100%)	171.97 (100%)	12.28 (100%)
Annual exports					
Milk	tons/year	24.23 (93%)	5.58 (87%)	37.06(90%)	1.52 (95%)
Animals	tons/year	1.72 (7%)	0.79 (87%)	3.97(10%)	0.08 (5%)
Crops	tons/year	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Manure	tons/year	0.00 (0%)	0.02 (0%)	0.00 (0%)	0.00 (0%)
Total	tons/year	25.95 (100%)	6.39 (100%)	41.03 (100%)	1.60 (100%)
Import-export	tons/year	68.67	17.23	130.94	10.68
“Remaining”	%	73	73	76	87
	lbs/acre per year	143	172	240	153

Purchased feed and fertilizer accounted for the bulk of N imported onto these farms. Together these major contributors accounted for 79% to 97% of all N imports. The distribution between purchased feed and fertilizer N imports varied between farms. Farm D imported 93% of their N as feed and only 4 % as fertilizer; Farm B imported 39% of imported N as feed and 38% as fertilizer (Table2). On all 4 farms the largest N export was in the form of milk sales. None of the farms exported crops and only one farm exported a small quantity of manure off the farm.

Nitrogen contribution from fixation by legumes was estimated from legume crop acreage, yield and crude protein content. Nitrogen fixation accounted for 3 to 21% of the total N imports on the farms. One farm (Farm A) used low cost shredded newspaper for bedding which resulted in higher nutrient imports for bedding than on the other farms.

Phosphorus balances: The 4 study farms imported 0.94 to 16.36 tons of more P than they exported annually (Table 3). As with nitrogen, milk was the major P export item while feed and fertilizer accounted for most of the P imports. On Farms A, B and D, 60 to 67% of the imported P was brought onto the farm in the form of feed while 31 to 33% of all P imports on these 3 farms were purchased fertilizer. Farm C had a higher proportion (88%) of imported P carried on as purchased feed.

Table 3: Mass phosphorus balances for four case study dairy farms located in the Upper Susquehanna Watershed (2004 data). General characteristics of the farms are given in Table 1.

		Farm A	Farm B	Farm C	Farm D
		Phosphorus (P)			
Annual imports					
Feed	tons/year	7.88 (62%)	1.24 (60%)	20.00 (88%)	0.78 (67%)
Fertilizer	tons/year	4.15 (33%)	0.65 (31%)	2.47 (11%)	0.39 (33%)
Animals	tons/year	0.01 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Bedding	tons/year	0.71 (6%)	0.18 (9%)	0.14 (1%)	0.00 (0%)
Total	tons/year	12.70 (100%)	2.07 (100%)	22.61 (100%)	1.17 (100%)
Annual exports					
Milk	tons/year	3.57 (89%)	0.66 (77%)	5.28 (85%)	0.20 (91%)
Animals	tons/year	0.42 (11%)	0.19 (22%)	0.96 (15%)	0.02 (9%)
Crops	tons/year	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Manure	tons/year	0.00 (0%)	0.00 (0%)	0.00 (0%)	0.00 (0%)
Total	tons/year	3.99 (100%)	0.86 (100%)	6.24 (100%)	0.22 (100%)
Import-export	tons/year	8.76	1.22	16.36	0.94
“Remaining”	%	69	59	72	81
	lbs/acre per year	18	12	30	13

Preliminary Discussion and Summary:

The methodology of using MNB as a tool to diagnose individual farm nutrient management practices was used by Klausner and others (Klausner, 1992, Klausner, 1993, Klausner et al., 1998). These assessments, done in the early 1990s, indicated that the percent of the N and P that remained [(inputs-exports/imports] on the selected New York State dairy farms each year ranged from 64-76% and 59-81%, respectively.

The results of the 4 Upper Susquehanna Watershed farms show a similar order of magnitude for nitrogen (73-87% in our study) and identical ranges for P (59-81%). The phosphorus balances by Klausner et al. (1998) included three farms which ranged in size from 45 to 120 milking cows. The four farms in our study ranged from 40 to 624 milking cows (2004 data). The 40 cow dairy had a P balance of 81% while the 624 cow dairy had a P balance of 72%. When the mass balance is measured in tons P “remaining” per year, the 40-cow dairy showed a balance of just under 1 ton of P remaining per year, while the larger dairy had a balance of more than 16 tons of P per year. This shows the importance of looking at these balances in several different ways.

Another important finding in the studies by Klausner and others was that purchased feed accounted for 45-87% of the imported nitrogen and phosphorous. The same trends were seen for the four Upper Susquehanna farms: 39-93% of the N and 60-88% of the P was brought onto the farm as purchased feed. Klausner et al. (1998) showed that these proportions could be decreased on case study farms when rations were reformulated to limit excess nutrients in the diets. Further analysis of the four farms is needed to see if similar options exist for these producers.

To date, nutrient management regulations in New York and most other states in the US have addressed the Clean Water Act through implementation of the NRCS 590 standard for nutrient management. The NRCS 590 standard focuses on reducing risk to water quality as the result of over-application of fertilizer and manure, and prevention of direct manure losses to our streams and lakes; this is accomplished through development of plans that include the use of the P runoff index, the nitrate leaching index, and land grant university crop nutrient guidelines. Unfortunately, current nutrient management practices may not sufficiently address importation and subsequent loading of nutrients onto farms and watersheds as shown, among others, by a steadily increasing number of acres testing high or very high in P in New York (Ketterings et al., 2005).

Losses could be significantly reduced if fewer nutrients were imported onto the farm in the first place (Wang et al., 1999). ***The key solution lies in finding ways to increase nutrient use efficiency on farms and, thereby, decrease nutrient imports and reduce loadings to watersheds such as the Upper Susquehanna Watershed.*** Results of this study will be combined with the 6 farms that are being assessed with WRI funds (final report due February 28, 2006) and 6 farms that are part of a pilot study funded by the Upper Susquehanna Coalition. We hope to secure additional funds to expand the scope of the project to include more farms, an economic assessment of the farms and an evaluation of practical management options that could improve mass balances over time.

Websites:

1. Chesapeake Bay Program: http://www.chesapeakebay.net/.
2. Upper Susquehanna Coalition: http://www.u-s-c.org/html/CBP.htm.

3. Nutrient Management Spear Program: http://nmsp.css.cornell.edu/.

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Appendix A: Farm survey forms.

Cornell Nutrient Management Spear Program
Mass Balance Nutrient Accumulation Calculator

Producer Name	
Farm Name	
Address	
City, State, Zip	
Phone	
E-Mail	

Balance Year	
Crop and Tillable Pasture Acres	

Average Number of Animals

Animal Group	#	Weight

Have you completed a Dairy Farm Business Summary for the balance year?

Have you completed a Farm Credit Business Summary for the balance year?

IMPORTS

Feeds (purchased)	**Tons/year**	**% DM**	**CP (% DM)**	**P (% DM)**	**K (% DM)**	**% Grain**
Grain						
Milk replacer						
Forages						

Purchased Feeds Inventory	**Beginning Year (tons)**	**Ending Year (tons)**
Grain		
Milk Replacer		
Forages		

Fertilizer	**Tons**	**% N**	**% P_2O_5**	**% K_2O**	**Comment**
Corn Starter					
Urea					

Animals (purchased)	**Number**	**Weight (lbs)**	**Comment**
Calves			
Heifers			
Cows			

Bedding & Miscelaneous	Tons/year	% DM	N (%DM)	P (%DM)	K (%DM)	Comment
N Fixation-Legume Crops, Pasture	**% Legume**	**Acres**	**Dry Matter**	**Yield (t/a)**	**CP (%DM)**	**Comment**

EXPORTS

Milk	lbs/year	Milk Protein (%)	Comments
Animals (sold)	**Number**	**Weight (lbs)**	**Comments**
Calves			
Heifers			
Cows			

Crops (sold)	Tons/year	% DM	CP (%DM)	P (%DM)	K (%DM)
Other (sold)	**Tons/year**	**% DM**	**N (%DM)**	**P (%DM)**	**K (%DM)**

FARM PRODUCED FEED - Enter the type of feed, tons (as fed), average dry matter, percent grain, beginning and ending inventory balances. This input is optional and is used to compute nutrient management diagnostics.					
Item	**Tons/year**	**% DM**	**% Grain**	**Beginning Inventory**	**End Inventory**

Appendix B: Mass Nutrient Balance Help File

WHOLE FARM NUTRIENT BALANCE SPREADSHEET INSTRUCTIONS

November 19, 2004

INTRODUCTION

This Microsoft Excel program is design to assist in developing a mass nutrient balance. This software can be used to develop a mass nutrient balance for any type of livestock operation (dairy, swine, poultry, etc), or for non-livestock farms. For non-livestock farms, ignore all questions concerning animals. If the title screen box is not centered in the screen, use the "zoom" control on the toolbar menu to center the title box. Adjust all other worksheets to the same size with the "zoom" control. The screen size will be saved when the file is saved.

CONCEPT

Nutrients have three basic fates: 1) they are imported to the farm in purchased products; 2) they are exported from the farm in products sold; and 3) they remain on the farm to be recycled and some nutrient loss is likely. The mass nutrient balance will improve the understanding of nutrient movement onto, within, and away from the farm. A well managed nutrient management plan may reduce purchased inputs, improve nutrient cycling, and reduce the potential for nutrient loss.

FARM CHARACTERISTICS

<u>Contact Information:</u>
Record the producer contact information, year, crop and tillable pasture acres, and the average total animals units on the farm during the year. An animal unit is equal to 1,000 lbs of live weight.

<u>Farm produced feeds:</u>
Record the type of feed, tons produced per year, the percentages of dry matter, percentage grain, and beginning and ending inventories. This information is optional and used in the diagnostic report.

NUTRIENT IMPORTS
(worksheet to determine N, P, K imports in feed, fertilizer, etc.)

<u>Purchased feeds</u>
Record the type of feed, tons purchased per year, and the percentages of dry matter, crude protein, P, and K. Entering the beginning and ending inventory will result in a more accurate annual mass balance. The "% grain" is used to determine the proportion of forage purchased. To convert percent N to crude protein multiply by 6.25. To convert percent crude protein to N divide by 6.25.

<u>Purchased fertilizer</u>
Record the fertilizer types, tons purchased per year, and the percentages of N, P_2O_5, and K_2O.

Purchased animals
Record the number of adults and young stock purchased, and the average weight for each group.

N fixation by legumes
Record the number of acres, dry matter yield, and crude protein for each crop. The nitrogen contribution of legume nitrogen fixation is calculated as 60% of the crude protein. Thirty-six (36) % of the N in mixed legume crops is considered to be contributed by N fixation.

NUTRIENT EXPORTS
(worksheet to estimate N, P, K exports in milk, meat, etc.)

Animal products
Enter the amount of milk sold, milk crude protein and the number of animals and their average weight.

Crop products
Enter the type of crop sold, its quantity, and the percentages of dry matter, crude protein, P and K. Refer to the section on purchased feed to convert crude protein to elemental N or visa versa.

Miscellaneous products
Record any other significant products that were sold or given away, such as manure, fertilizer, etc. Enter the quantity, and percentages of dry matter, crude protein, P, and K.

Mass Balance Calculations

NUTRIENT IMPORTS

Purchased Feed

- Nitrogen (Tons N/year) = Sum of ((tons as-fed purchased + beginning inventory - ending inventory)*%dry matter*crude protein concentration))/6.25 for each purchased feedstuff.
- Phosphorus (Tons P/year) = Sum of ((tons as-fed purchased + beginning inventory - ending inventory)*%dry matter * %P for each purchased feedstuff.
- Potassium (Tons K/year) = Sum of ((tons as-fed purchased + beginning inventory - ending inventory)*%dry matter*%K for each purchased feedstuff.

Fertilizer

- Nitrogen (Tons N/year) = Sum of (tons fertilizer purchased*%N) for each purchased fertilizer.
- Phosphorus (Tons P/year) = Sum of (tons fertilizer purchased*%P_2O_5*0.43) for each purchased fertilizer.
- Potassium (Tons K/year) = Sum of (tons fertilizer purchased*%K_2O*0.83) for each purchased fertilizer.

Nitrogen Fixation
Nitrogen (Tons N / year) = for each legume crop or pasture, sum of:
If legume % >90%: (0.6*acres produced*dry matter yield*crude protein content)/6.25
If legume % ≤90%: (0.36*acres produced*dry matter yield*crude protein content)/6.25

Animals Purchased
This version of the Mass Balance Calculator assumes that dairy livestock are the primary animals purchased and sold. If this is not the case, contact the authors for N, P and K coefficients for other livestock species. The N, P and K concentrations are from M. Van Amburgh (personal communication, 8/10/2004).

- Nitrogen (Tons N/year) = Sum of (number of animals*average weight in pounds*0.029)/2000
- Phosphorus (Tons P/year) = Sum of (number of animals*average weight in pounds*0.007)/2000
- Potassium (Tons K/year) = Sum of (number of animals*average weight in pounds*0.002)/2000

Miscellaneous Purchases
For each miscellaneous item imported:

- Nitrogen (Tons N/year) = Sum of (weight in tons*%dry matter*%N)
- Phosphorus (Tons P/year) = Sum of (weight in tons*%dry matter*%P)
- Potassium (Tons K/ year) = Sum of (weight in tons*%dry matter*%K)

NUTRIENT EXPORTS

Milk Sold
Phosphorus and Potassium coefficients are from the Fundamentals of Dairy Chemistry (Noble P. Wong, Editor, and Robert Jenness, Mark Keeney, Elmer H. Marth, Associate Editors, Gaithersburg, MD: Aspen Pub., 1999). Milk protein reported to the producer as true protein is converted to crude protein by multiplying by 1.075 (Cornell Animal Science Dept. Mimeo 213). The N content of milk crude protein is calculated by dividing by 6.25.

- Nitrogen (Tons N/year) = ((Pounds of milk sold*(milk true protein*1.075)/6.25)/2000
- Phosphorus (Tons P/year) = (Pounds of milk sold*0.00074)/2000
- Potassium (Tons K/year) = (Pounds of milk sold*0.0014)/2000

Animals Sold
This version of the Mass Balance Calculator assumes that dairy livestock are the primary animals purchased and sold. If this is not the case, contact the authors for N, P and K coefficients for other livestock species. Nitrogen, P and K concentrations are from M. Van Amburgh (personal communication, 8/10/2004).

- Nitrogen (Tons N/year) = Sum of (number of animals*average weight in pounds *0.029)/2000

- Phosphorus (Tons P/year) = Sum of (number of animals*average weight in pounds *0.007)/2000
- Potassium (Tons K/year) = Sum of (number of animals*average weight in pounds *0.002)/2000

Crops Sold
- Nitrogen (Tons N/year) =Sum of (tons sold*dry matter%*crude protein concentration)/6.25
- Phosphorus (Tons P/year) = Sum of (tons sold*dry matter%*% phosphorus)
- Potassium (Tons K/year) = Sum of (tons sold*dry matter%*% potassium)

Miscellaneous Sales
- Nitrogen (Tons N/year) = Sum of (weight in tons*dry matter%*%N)
- Phosphorus (Tons P/year) = Sum of (weight in tons*dry matter%*%P)
- Potassium (Tons K/year) = Sum of (weight in tons*dry matter%*%K)

Diagnostics
- Animal Density = Crop and tillable pasture acres/animal units
- Animal units = sum of (number of animals*average weight in pounds)/1000 for each animal group.
- Milk Production Land Efficiency = milk sales in pounds/crop and tillable pasture acres.
- Farm Produced Feed (% of total feed dry matter) = total farm produced feed dry matter (total farm produced feed dry matter + total purchased feed dry matter)
- Farm Produced Forage (% of total feed dry matter) = total farm produced forage dry matter/(total farm produced forage dry matter + total purchased forage dry matter)

Fertilizer Value
- Lbs phosphorus remaining per acre is converted to P_2O_5 equivalent by multiplying the remaining value by 2.325.
- Lbs potassium remaining per acre is converted to K_2O equivalent by multiplying the remaining value by 1.2048.

Appendix C: Example of a Mass Nutrient Balance Analysis Report

MASS NUTRIENT BALANCE v. 2 OUTPUT **Sample Farm 2004**
6/21/2005 13:45

Category	N	P	K	N	P	K
Imports	-------- tons per year --------			------ lbs per acre per year ------		
Feed	9.95	2.13	3.51	33	7	12
Fertilizer	4.08	0.17	0.66	14	1	2
N Fixation (legumes)	2.16			7	-	-
Animals	0.17	0.04	0.01	1	0	0
Miscellaneous	0.34			1	-	-
Total Imports	16.70	2.34	4.18	56	8	14
Exports	-------- tons per year --------			------ lbs per acre per year ------		
Milk	5.16	0.65	1.23	17	2	4
Animals	0.30	0.07	0.03	1	0	0
Crops	0.27	0.05	0.34	1	0	1
Miscellaneous	0	0.00	0.00	0	0	0
Total Exports	5.73	0.78	1.59	19	3	5
Tons Remaining	10.97	1.57	2.59			
Lbs Remaining/acre	37	5	9			
Lbs Remaining/AU	58	8	14			
% Remaining	66%	67%	62%			

DISTRIBUTION OF IMPORTED NUTRIENTS

	N	P	K
Source	------------------- % ---------------------		
Feed	60	91	84
Fertilizer	24	7	15
N Fixation	13		
Animals	1	1	0
Miscellaneous	2	1	1

DISTRIBUTION OF EXPORTED NUTRIENTS

	N	P	K
Source	------------------- % ---------------------		
Milk	90	83	77
Animals	5	9	1
Crops	5	7	21
Miscellaneous	0	0	0

DIAGNOSTICS

Animal Density (au/acre)	0.64
Milk Production (lbs/acre)	2,917
Purchased Feed (% of total feed dry matter)	19%
Farm Produced Forage (% of total forage dry matter)	80%
Fertilizer Value	5 lbs P remaining/acre = 12 lbs P_2O_5/acre 9 lbs K remaining/acre = 10 lbs K_2O/acre

Itemized N, P, K imports

Import % from purchased feed	% N	% P	% K
Canola Meal	13%	18%	16%
Custom Mix	20%	13%	14%
Cottonseed	15%	21%	24%
Mineral Mix	0%	34%	24%
Corn Silage	12%	5%	6%
Import % from purchased fertilizers	**% N**	**% P**	**% K**
20-20-0	13%	7%	
Potash			15%
Urea	11%		
Import % from legume fixation	**% N**	**% P**	**% K**
Alfalfa	13%		
Import % from purchased animals	**% N**	**% P**	**% K**
Heifers Purchased	1%	1%	
Import % from misc. imports	**% N**	**% P**	**% K**
Paper sludge	1%	1%	1%
Kiln dry saw dust	1%		
Total import %	100%	100%	100%

Distribution of exported N,P,K

Export % from milk sales	% N	% P	% K
	90%	83%	77%
Export % from crop sales	**% N**	**% P**	**% K**
Dry Hay Bales	5%	7%	21%
Export % from animal sales	**% N**	**% P**	**% K**
Calves	1%	1%	
Cows	4%	8%	1%
Export % from misc. exports	**% N**	**% P**	**% K**
Total Export %	100%	100%	100%

Innovative management of stormwater on under-utilized urban surfaces

Basic Information

Title:	Innovative management of stormwater on under-utilized urban surfaces
Project Number:	2004NY47B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	26
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Treatment, None
Descriptors:	Urban stormwater, Combined sewer systems, Impermeable surfaces, Storage
Principal Investigators:	Tammo Steenhuis, Jackie Brookner, Franco Montalo, Eric Rothstein, Michael Todd Walter

Publication

1. Jawlik, P, 2004, Suspended solid removal from urban stormwater runoff, NSF-REU project report, Department of Biological and Environmental Engineering, Cornell University, Ithaca, NY.

TITLE: Innovative Management of Stormwater on Underutilized Urban Surfaces

Problem and Research Objectives

The 1972 amendments to the Federal Water Pollution Control Act (also known as the Clean Water Act) prohibit the discharge of any pollutant to waters of the United States from a point source unless the discharge is authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Despite the progress made by these amendments, degraded water bodies still exist. According to the 1996 National Water Quality Inventory, a biennial summary of state surveys of water quality, approximately 40 percent of surveyed U.S. water bodies are still impaired by pollution and do not meet water quality standards. A leading source of this impairment is polluted non-point source pollution. In fact, according to the Inventory, 13 percent of impaired rivers, 21 percent of impaired lake acres, and 45 percent of impaired estuaries are affected by non-point source urban/suburban stormwater. In New York City wastewater, stormwater, and combined sewer overflows (CSO's) are considered the largest single source of pathogens in the New York Harbor region.

The management of stormwater runoff in densely urbanized areas with substantial impermeable surfaces presents a major design challenge. Large volumes of runoff are generated from extensive impermeable surfaces, yet few locations exist within the urban watershed for its storage and treatment using conventional stormwater best management practices (BMP's). A further limitation of these conventional BMP approaches is their mixed track record in treating the suite of contaminants (i.e., pathogens, metals, nutrients, DOC, etc.) found in urban stormwater. End of pipe solutions, on the other hand, are costly.

A more viable option for urban stormwater management may be a pollution prevention approach whereby runoff is intercepted high in the urban watershed in or on small, underutilized areas and surfaces before it reaches catch basins and sewers. These urban stormwater "resisters" can then be used to facilitate evapotranspiration and infiltration vis-à-vis vegetation. Our goal is to design these systems to aesthetically improve the urban experience. This is the biosculpture™ concept developed by the designer, Jackie Brookner. The challenge of using such systems in temperate urban climates is to develop a substrate that is both porous, yet has enough structural integrity to withstand disintegration from freeze/thaw cycles, corrosion, sunlight, pH and other chemical interactions. In addition, the substrate would preferably be made from abundant, locally available materials, and must be economical and sustainable in terms of total life cycle analysis from origin to future uses.

The overall goal of the project was to create prototype structures that function ecologically and hydrologically in a stormwater treatment context, but that also aesthetically enhance urban environments.

Methodology

Two studies have been carried out. The first study was carried out by Paul Jawlik with the objective to test numerous materials for suspended solid removal ability. These materials were: Sand 800-1000 µm Grains: Porex Porous Plastic (Fine) 10-20 µm Pores: Porex Porous Plastic (Medium) 20-30 µm Pores; Porex Porous Plastic (Coarse) 90-130 µm Pores; Grodan Rockwool Water Flow – Along Grain; Grodan Rockwool Water Flow – Against Grain; Mirafi Geotextile

1120S; Volcanic Rock Whole; Volcanic Rock 1000-1500 µm Grains; The materials were tested for clogging, particulate removal capacity, and hydraulic conductivity with 20 µm particles and where applicable 200 µm particles. The results of this study were given in the technical report submitted last year to WRI. We found that Grodam Rockwool performed best and this material was used for further testing in the second year by M. Ekrem Cakmak a graduate student in the Department of Biological and Environmental Engineering at Cornell University.

In the second study Biosculptures™ were tested for their ability to treat storm water. The biosculpture™ concept was developed by the designer Jackie Brookner. It is envisioned that the Biosculptures™ are placed in urban watersheds in or on small, underutilized areas and surfaces for treating the stormwater before it reaches catch basins and sewers. These urban stormwater "resisters" can then be used to facilitate evapotranspiration and infiltration vis-à-vis vegetation.

Biosculptures

Brookner constructed specifically for this project six Biosculptures™ utilizing rockwool in five of them. The properties of the Biosculptures and their pictures are given in Table-1 and Figures 1-2, respectively. Pictures were taken 3 months after the last experiment.

Table-1. Properties and Moss Coverage Percentages of Biosculptures

Sculpture	Properties	% Moss Coverage of Surface
S1	Made from stucco with fine holes, *rock wool inside*	0.0
S2	Made from *rock wool*	5.0
S3	Volcanic rock, porous concrete, *rock wool inside*	10.0
S4	Made from stucco with coarse holes, *rock wool inside*	10.0
S5	No hole, no rockwool inside, only surface flow	70.0
S6	Non porous volcanic rock, concrete, *rock wool inside*	20.0

S1	S2	S3
S4	S5	S6

Figure-1. Individual Pictures of the Biosculptures

S4 S1

S5 S2

S6 S3

Figure-2. Photos depicting the individual biosculptures from a different angle

The six sculptures, with different structures and amounts of moss (Table-1), were treated at two different pH levels of simulated storm water. The ability of the sculptures to remove metals and nutrients from simulated storm water runoff was tested in two separate experimental runs in which the storm water was applied through nozzles on the sculptures. The sculptures were kept moist between rainfall events by applying tap water for one minute each hour using the same nozzles.

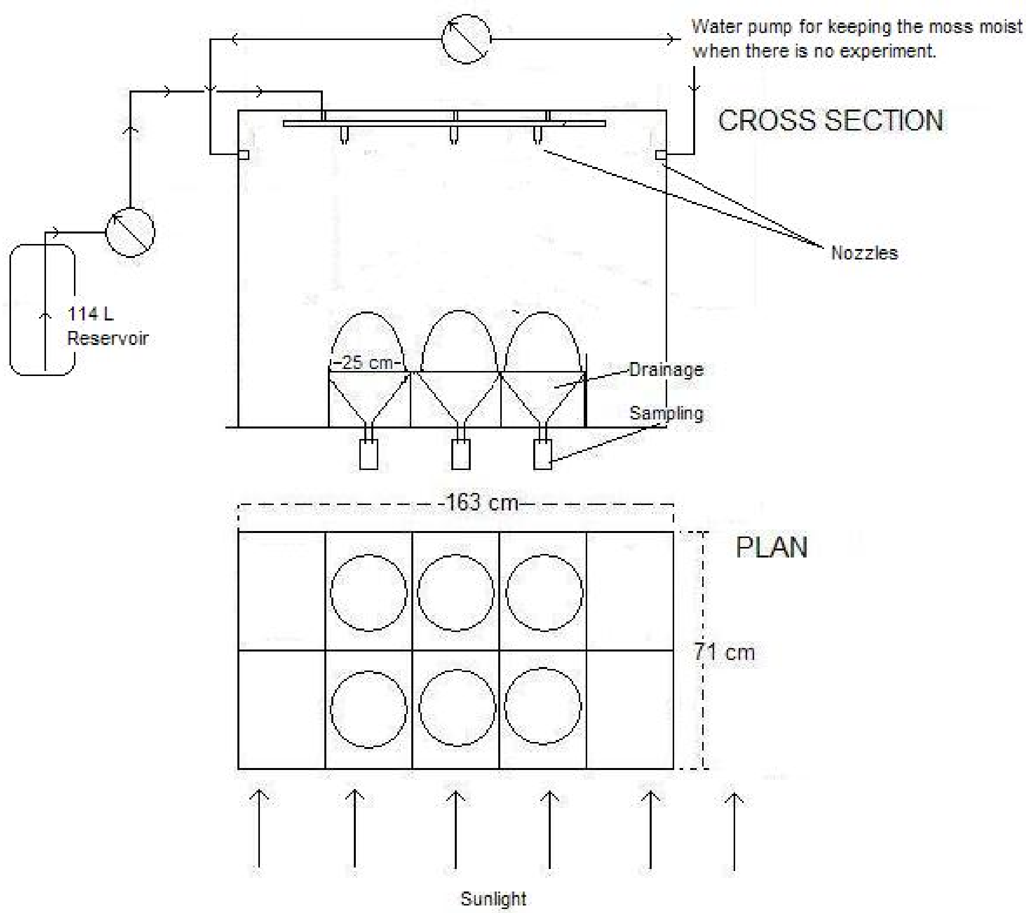

Figure-3. Experimental Set-up

During each experimental run sculptures were first flushed with tap water for 20 minutes. This was followed by the application of 114 L of simulated storm water for five hours at a rate of 3.3 cm/h. The experimental run was finished by flushing sculptures for 80 minutes with tap water at the same rate of 3.3 cm/h. The composition of the storm water is given in Table 2. Different amount of acid was added for each of the two experimental runs. In the first experimental run the sculptures were exposed to simulated storm water with a pH of 2.5 representing the first flush after snow melt and in the second run at 6.5 representing the summer months. Storm water was applied by using large rain-type nozzles (Figure-3).

Samples taken of the water draining from the sculptures were preserved by adding 0.1 ml HNO_3 to each 40 ml sample. This resulted in a pH of less than 2 (Standard Methods, 1998) (Section 1060C). The samples were analyzed for Pb, P, Cu, Cd and Zn with Inductively Coupled Argon Plasma (Thermo Jarrell Ash – ICAP61).

Table-2. Reagents Used and Initial Concentrations of Elements in Simulated Strom Water

Reagent	Element	Concentration (µg/L) (ppb)
$Pb(NO_3)_2$	Pb	469
KH_2PO_4	P	308
$CuSO_4.5H_2O$	Cu	98
$Cd(NO_3)_2.4H_2O$	Cd	337
$ZnSO_4.7H_2O$	Zn	410

Results: The amount of moss that covered each biosculpture was greatly different (Tables 1 and 3, and Figure 1 and 2). The surface of sculpture #5 was covered with 70 % moss initially, after the experiments at low pH the percentage of moss covering the sculpture decreased to 30-40 %, while the remaining ones had less than 10 % covered (Table 3) after the experiments at low pH. This was a direct result of the material used in the biosculpture and indirectly of the storm water application. Table 2 shows that the biosculpture #5 had no rockwool used in its construction. This sculpture retained significantly more moss than any of the biosculpture that had rockwool used as part of the design. The poor performance of the biosculptures with rockwool could be attributed to the rockwool providing a path for the water - applied between the experimental runs to keep the structures moist - to drain through the rockwool and as a consequence the moss was exposed to much dryer conditions than the biosculpture without rockwool in which all the water applied could be retained by the moss.

Table-3. Percentage of Moss Coverage of Biosculptures after Treating with Low pH Storm Water

Sculpture	Moss Coverage of Surface After Experiments At Low pH (%)
S1	0
S2	0
S3	2-5
S4	2-5
S5	30-40
S6	5-10

The overall removal rate of the metals and nutrient was the best for biosculpture #5 (Tables 4 and 5). For the pH of 6.5 it removed all of the Zn and Cu, most of the Pb and Ca and 75 % of the P (Table 4). Biosculpture #4 which was covered with approximately 10% (Table 1) had the generally the second highest removal rates (Table 4). The trends were the same for the treatment with the storm water with pH of 2.5 but the overall removal rate was lower with the exception of P of which the removal rate was as expected higher at lower pH (Table 5). Especially in the case of Zn, the effluent concentration was greater than the influent concentration. The main reason for this is low pH. Influent with low pH (2.5) dissolved the metals already attached to sculptures, which resulted in high metal concentrations in the effluent.

Table-4. Average Percentage Removal Capacity of Biosculptures (pH=6.5)

Element	S1	S2	S3	S4	S5	S6
Pb	65.8	86.1	76.8	**93.5**	**91.3**	87.6
P	36.3	44.4	26.6	**71.0**	**74.2**	64.8
Cu	65.0	84.4	71.6	**100.0**	**100.0**	**100.0**
Cd	62.9	91.9	90.8	**88.6**	**97.3**	80.8
Zn	55.0	80.6	86.1	**100.0**	**100.0**	96.9

Table-5. Average Percentage Removal Capacity of Biosculptures (pH=2.5)

Element	S1	S2	S3	S4	S5	S6
Pb	22.1	64.2	N/A*	41.1	95.8	76.1
P	61.7	99.1	N/A	81.4	100.0	97.5
Cu	N/A	N/A	66.6	100.0	100.0	100.0
Cd	N/A	N/A	N/A	20.6	89.8	43.0
Zn	N/A	N/A	N/A	N/A	N/A	N/A

*In the treatments labeled N/A there was more metals in the drainage water than in the original applied solution.

The loss of Pb (expressed a percentage removed from the influent) throughout the experimental period is shown in Figures 4 and 5 as an example for the other elements that behave. The removal capacity of biosculptures 4 and 5 is the best for lead at pH=6.5. At pH=2.5 the removal capacity of biosculpture 5 is the best. Not shown here, but significant is that the moss covering biosculpture 5 was able to bring the pH in the neutral range for the low pH storm water while this was not case for the other bio sculptures. The figures of the removal rates are available on request and soon at http://www.bee.cornell.edu/swlab/SoilWaterWeb/index.htm.

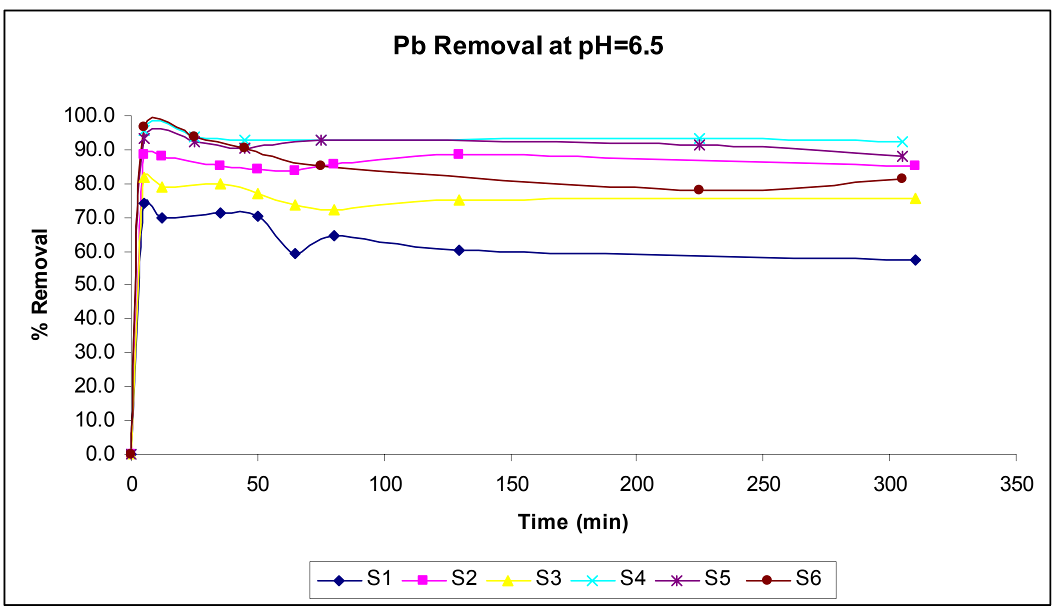

Figure-4. Percentage of Lead removal versus time. Initial concentrations were 469 ppb at pH=6.5.

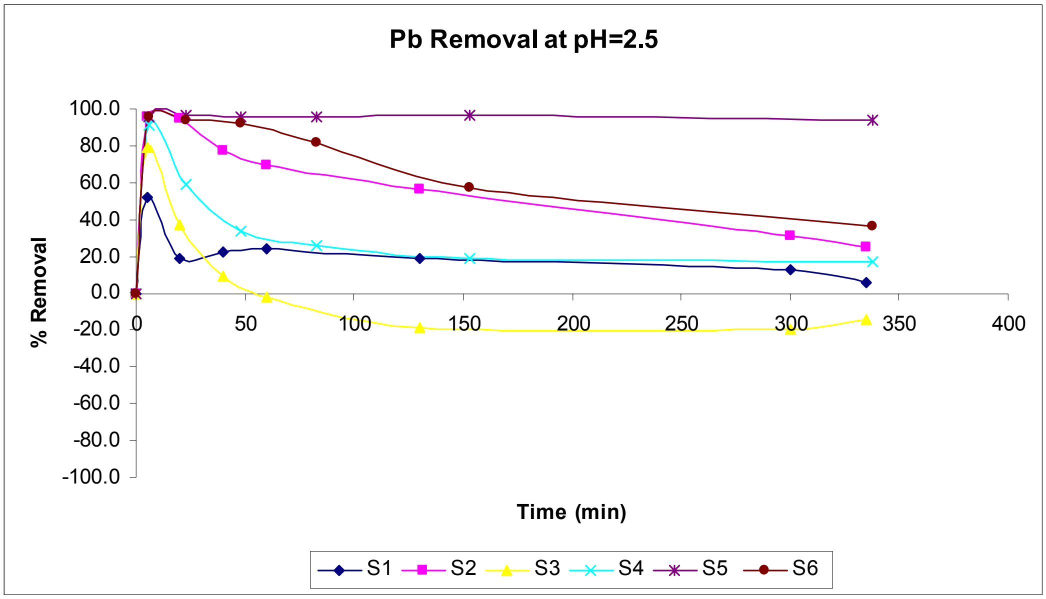

Figure-5. Percentage of Lead removal versus time. Initial concentrations were 469 ppb at pH=2.5.

Regional water quality tools for identifying high runoff risk areas in watersheds.

Basic Information

Title:	Regional water quality tools for identifying high runoff risk areas in watersheds.
Project Number:	2004NY48B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	22
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Agriculture, Nutrients
Descriptors:	Nonpoint pollution; Agriculture; Nutrients; Transport processes; GIS
Principal Investigators:	Todd Walter, Michael Todd Walter

Publication

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Annual Report for: NYS Water Resources Institute and U.S. Geological Survey

Regional Water Quality Tools for Identifying High Runoff Risk Areas in Watersheds

Project Duration: 3/1/2004 – 2/28/2005 (extended due to delayed funding)

Principle Investigators:
Drs. M.T. Walter and M.F. Walter, Biological & Environmental Engineering, Cornell University
Dr. A.J. Lembo, Crop and Soil Sciences, Cornell University

Introduction

Despite several decades of attention to the problem, nonpoint source (NPS) pollution from agricultural land continues to be an acute regional problem. The pollutant transport components of most water quality management strategies continue to lag several decades behind current scientific understanding of the relevant hydrological and transport processes. Runoff is perhaps the most substantial NPS pollutant transport mechanism. Recently the research group in Cornell University's Soil and Water Lab (SWL) has proposed water quality protection strategies based on saturation excess and variable source area (VSA) hydrology, hydrological concepts that have been well established since the in the 1960's but not been incorporated into the water quality dogma. SWL, a national leader in developing new NPS pollution control strategies based on the most current hydrological science, has developed the concept of hydrologically sensitive areas (HSAs), which are those areas in a watershed most prone to saturate and generate runoff (overland flow). The focus of this project is to develop user-friendly ways to identify where and when HSAs will occur in landscapes of the Northeastern U.S.

Project Description

The ultimate goal of this project was to develop tools to "increase the capability of county or municpal governments to… protect their water resources, especially… methods which provide quantified bases for decision-making (FY2004 RFP)." The primary specific goal of this project is to develop and evaluate new GIS-based, computational tools for identifying HSAs in Northeastern US landscapes, i.e., areas that are especially prone to generating runoff. This project has four distinct tasks: 1) determine monthly probabilities of generating runoff using a physically-based, fully distributed hydrological model applied to 6 to 12 twelve watersheds; 2) Overlay "proxy parameters" (based on topography or stream proximity) on maps of runoff probability developed task (1) and evaluate the statistical agreement between the runoff probability and the "proxy parameters;" 3) Evaluate the degree of similarity in the relationships among different watersheds to determine how regionally consistent proposed tools are 4) Determine which months are statistically different from each other in order to ascertain whether monthly, seasonal, or some other distribution of hydrological sensitivity is warranted. As part of this project we would also like to launch a usable Internet-based tool.

Principal findings and Notable achievements

The primary accomplishment of this project is the establishment of a simple relationship between landscape topography and risk of runoff generation. The relationships change throughout the year, but in a consistent and predictable way. As part of task (2) we also investigated relationship between runoff risk and proximity to stream and found that the relationships were substantially more inconsistent, although the relationships we found could be used if no reliable topographic data were available or if one needs a quick field-tool.

We determined runoff risks for eight basins from Connecticut, Pennsylvania, and New York (Task 1). In accordance with task (3), we found that the topography-runoff risk relationships are relatively similar among different watersheds and agreed well with our small duration (~ 8 months) of field measurements.

We are currently refining our point-and-click, interactive Internet-mapping tool for identifying HSAs in upstate New York. This activity has been unexpectedly difficult because Internet-mapping software is still rapidly developing and we have had to try several different platforms. We have decided on Manifold (GIS) and we will be launching tools for Delaware and Tompkins County this summer. We anticipated having our Internet tools fully operational by now. Even though they are still largely prototypes, we are using funds from other sources to finish this task. Due to the delay, we did spend last Fall developing a version of our HSA tool for Tompkins County's Environmental Planning Department (Kate Hacket) that they could implement in there office using their GIS data. Despite the delayed launch of our web-tools, the conceptual basis for this project has been successful enough that we are continuing to expand applications to a broader region and incorporating real-time measures for forecasting hydrological sensitivity.

Student support

Ben Liu (Spring 2005) - MS
Shannon Seifert (Summer 2005) - MPS

New External Proposals (these build substantially on this project)

Title: Integrating data and models from the Cannonsville, NY watershed to assess short- and long-term effects of phosphorus BMPs in the Northeast
Agency: USDA – CEAP
Request: $659,995 (funded)
Duration: 2005 to 2008 (3 yrs)
Cooperators/Affiliations: Steenhuis*, Shoemaker*, Walter*, Stedinger*, Richards, Geohring, (Cornell Univ.), Qui* (NJIT), Gburek, (USDA-ARS, Penn State University), Schneiderman, Thongs, Zion (NYC-DEP), McHale (USGS).
* Principal Investigators

Title: Improved Spatiotemporal Rainfall and Soil Saturation Distributions for Hydrometeorological Modeling
Agency: NASA-THP
Request: ~$500,000 (in review)
Duration: 9/1/2006-8/31/2008
Cooperators/Affiliations: Walter and Degaetano (Cornell)

Other related proposals are currently in development with primary cooperators from Cornell Univ. (M.T. Walter, Art Lembo, the Biological and Environmental Enginerering Soil and Water

Lab and other faculty), Pennsylvania State University (Dr. Gburek), the NYC-DEP (Drs. Schneiderman, Zion, Thongs), and environmental planners in Tompkins County (Kate Hacket and Crystal Buck). We anticipate that continued enthusiastic working relationships with the primary investigators noted above will continue for many years.

Assessing nitrate-nitrogen in surface and groundwater in eastern Wyoming County, NY

Basic Information

Title:	Assessing nitrate-nitrogen in surface and groundwater in eastern Wyoming County, NY
Project Number:	2004NY51B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	26
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Groundwater, Nitrate Contamination
Descriptors:	Nonpoint pollution; Groundwater; Drinking water; Nitrate-nitrogen;
Principal Investigators:	Larry D Geohring, Karl J. Czymmek

Publication

Assessing nitrate-nitrogen in surface and groundwater in eastern Wyoming County, NY

Problem & Research Objectives

High nitrate-nitrogen (NO_3-N) concentrations in groundwater used for drinking water are a concern to Wyoming County residents. A county-wide sampling of private drinking water supplies carried out in 1988-1989 found NO_3-N concentrations ranging from <0.1 to 40 mg/L, with 23 of 206 samples (11%) exceeding the 10 mg/L maximum contaminant level (MCL) established by the Safe Drinking Water Act. The majority of samples exceeding the MCL occurred at or near farm sites in eastern Wyoming County where agriculture is the major land use. Farmers and other rural residents in the area remain concerned about nitrates, and are interested in determining whether the implementation of nutrient management plans (NMP) are having an affect on reducing or curtailing nitrate levels. This information will also help in the development of a revised Nitrogen Leaching Index (NLI) for New York State.

The specific project objectives are: 1) to monitor surface and groundwater supplies for NO_3-N concentrations, 2) to collate and compare new sample data and trends with previous sampling results, 3) to conduct more detailed site evaluations using well pump tests, and 4) to develop, utilize, and disseminate the information in state/regional nutrient management/water quality education programs. The project was focused around locations where a significant number of samples had exceeded the MCL for NO_3-N during the previous testing in Wyoming County.

Methodology

In cooperation with Wyoming County collaborators, fifteen sites were selected for routine surface water sampling (small streams and drain tile outlets). Four sampling locations were chosen along each of two small perennial streams, and the rest were distributed around to other perennial streams in the area. These surface water locations were grab sampled at about 4-week intervals over a 1-year duration. The elevations and distances between surface water sampling locations were documented. Samples were also collected occasionally along other intermittent and perennial streams in the area.

Groundwater supplies used for drinking water (wells and springs) were also evaluated. Previous groundwater NO_3-N test results from 1988-1989 and from other private and Wyoming County DOH testing were obtained. Based on the earlier 1988-1989 study and landowner interest and cooperation, fifteen groundwater sites were selected for follow-up sampling and for comparative and trend analysis purposes. Eight of the groundwater sites were routinely grab sampled at about 4-week intervals, and the others were grab sampled at least once coinciding with the same time of year sampling had been done previously. Landowner cooperation and access was difficult to obtain for conducting well pumping tests or to collect other more intensive data. Consequently, a limited pumping test was done on only one shallow abandoned well.

The collected water samples were transported on ice in coolers to the Cornell Nutrient Analysis Laboratory for analysis. Water samples were routinely analyzed for NO_3+NO_2–

N, NH_4-N, and PO_4-P. Some of the surface and groundwater samples were also analyzed for other major cations and anions (Al, C, Ca, Cl, Fe, K, Mg, Mn, Na, and SO_4-S). Other available information was also collected such as ground elevations, well and equilibrium water-level depths, surface flows and well pumping rates, well driller notes, adjacent land use, and near-by on-site waste management systems.

Several meetings were organized and carried out with project collaborators and a local group of farmers and certified crop advisors. Two educational meetings were targeted specifically to farmers and advisors in the study area. Educational resource materials and presentations were prepared for these meetings and shared with project participants to illustrate the nature of the groundwater nitrate contamination problem in the area, how agricultural activities may be contributing to the problem, and to discuss potential courses of action.

Principal Findings & Significance

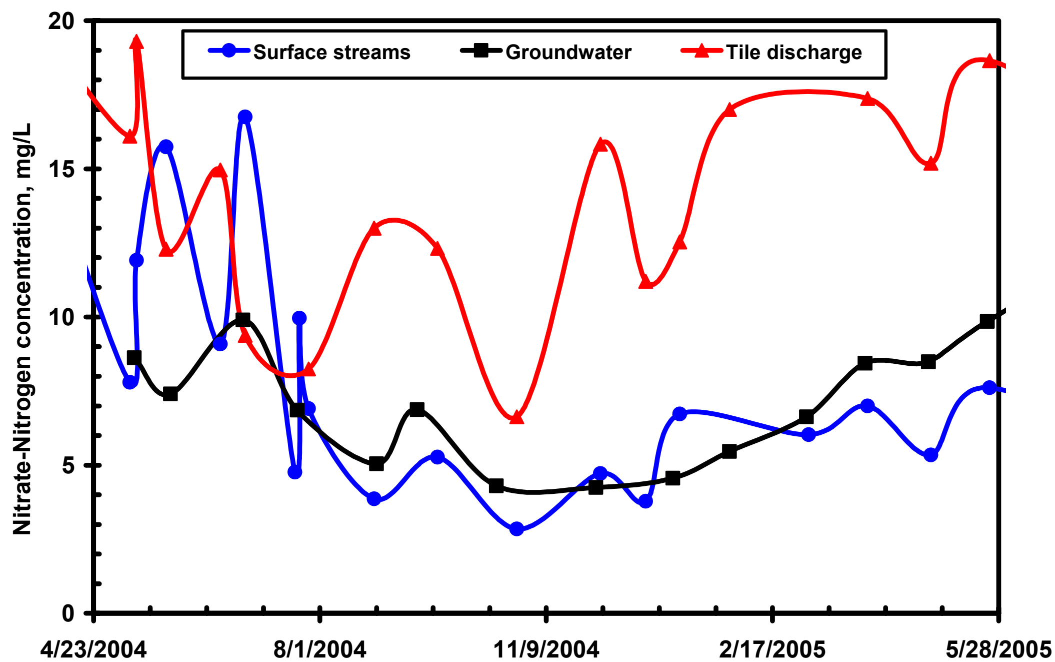
The surface and groundwater sampling was carried out in a rural area of Wyoming County within the Appalachian Basin. Although there are a few small sized towns distributed throughout the project sampling area, agriculture (mostly dairy farms) is the predominant land-use, and milk production is a major source of revenue for the local economy. The dairy farms in the area recycle manure to produce forage, corn, and other crops, and apply manure based on certified nutrient management plans.

Geologically, the region of study is located near the northern edge of the Alleghany Plateau. This area is just north of the southern limit of the extent covered by glaciers during the Pleistocene era. The unique valleys and gorges of this region are the result of the advancement and subsequent retreat of glaciers. The general structure of the region is composed of Paleozoic rocks overlying Precambrian crystalline basement rocks, with the rock strata dipping slightly to the south. The upper layers of Paleozoic bedrock are sedimentary, predominantly composed of heavily fractured Devonian sandstones, siltstones and shales. The extensive fractures in the bedrock cause a complex network of groundwater flow pattern(s), and appear to follow a more regional influence with increasing groundwater depth, rather than being associated specifically with the more identifiable topographic boundaries of the surface watersheds.

The overlying soils are poorly consolidated glacial sediments, deposited during the numerous glacial advances of the Pleistocene epoch. The most common soils in the study area are moderately- to well-drained, Bath and Mardin channery silt loams (Coarse-loamy, mixed, active, mesic *Typic Fragiudepts*). A fragipan layer can typically be found beginning at depths between 12 and 36 inches. Soil permeability is moderate above the fragipan, but slow to very slow within and below the fragipan. Other soils in the study area include somewhat poorly drained Churchville (Fine, illitic, mesic *Aeric Endoaqualfs*) and moderately well drained Collamer (Fine-silty, mixed, active, mesic *Glossaquic Hapludalfs*) silt loams, and the somewhat poorly drained Erie (Fine-loamy, mixed, active, mesic *Aeric Fragiaquepts*) and moderately well drained Langford (Fine-loamy, mixed, active, mesic *Typic Fragiudepts*) channery silt loams. The fractured shale bedrock is commonly within 40 to 100 inches of the soil surface over substantial areas from where water samples were taken. Perched water tables are common above the fragipan or bedrock of these soils, and thus both surface and subsurface drainage practices are frequently used to improve the soil's trafficability and productivity for agricultural purposes.

The climate in the area is broadly representative of the humid continental northeastern United States. Summers are warm and humid with high temperatures generally exceeding 75°F, whereas the winters are long and cold with temperatures dropping below -10°F in most years. Average annual precipitation is around 35 inches per year, of which about 15 inches falls between October and March when there is relatively little evapotranspiration. The precipitation is fairly uniformly distributed throughout the year with an average monthly low around 2 inches in February to a high of around 3.7 inches in June. During the winter months most precipitation falls in the form of snow, leading to substantial stream flow during periods of spring thaw. The higher monthly summer precipitation is often the result of thunderstorm activity. A total of 41 inches of annual precipitation occurred between May 2004-2005 when water samples were collected. Most of this excess above the long term norm occurred in May 2004 when 6.9 inches of precipitation fell, compared to the long term monthly average of 3.1 inches for May. During the rest of the study period, the precipitation was again more or less distributed to within one standard deviation of the monthly norms.

A total of 225 surface stream, 43 tile (drain) discharge, and 165 groundwater samples were collected from the various locations and analyzed during the period of study. The average NO_3-N concentrations for the three categories, as collected from the various locations at different times of the year are shown in the following figure.



The NO_3-N concentrations are highest from the tile drain discharges, which reflect the shallow groundwater collected from immediately below the crop rooting zone. In this study, the tile discharges generally reflect fields planted to corn. The range in concentration for all tile discharge samples was from 1.7 to 28 mg/L, and which occurred in July and December, respectively. Twenty-nine (67%) of the 43 samples were above the 10 mg/L drinking water MCL. Although there is considerable variability in the average monthly tile discharge concentrations, there appears to be a seasonal pattern. The lowest concentrations occur during the time of crop growth, and the highest during winter and early spring. The monthly variability is likely a result of numerous factors such as fewer sample locations, fewer total samples, and the timing of leaching events and various field operations.

The average NO_3-N concentrations in the surface streams are generally lower than those from the tile drain discharge, and also show a seasonal trend (Fig. 1). The concentrations were highest during June 2004, and were most likely influenced by the excessive precipitation that occurred during May 2004. The range in concentration for all stream samples was from 0.3 to 29 mg/L, and which occurred in December and May, respectively. Sixty-three (28%) of the 225 samples were above the 10 mg/L drinking water MCL. Several of the small streams that were sampled during this study receive direct inputs from tile drain discharges, and these inputs appeared to have a major influence on the streams NO_3-N concentrations. The highest measured stream concentration of 29 mg/L in May occurred in a stream receiving significant tile discharge, and at a point in the contributing watershed where nearly all the land-use was in agriculture. Seventy percent of the water samples at different points along this stream exceeded the MCL. On the other hand, the lowest measured concentration of 0.3 mg/L in December came from a much larger stream and contributing watershed with a mixed land use. None of the water samples from various points along this stream, including some near a small town, exceeded the MCL.

The average NO_3-N concentrations in groundwater were similar to those measured in the stream, and also had a similar seasonal trend (Fig. 1). The high amount of precipitation in May 2004 also appeared to cause a small increase in the concentration, although the peak occurs later compared to the tile and surface water concentrations. The trend in average NO_3-N concentrations in the groundwater is very similar to those of the tile discharge and the surface streams, suggesting that there is a high connectivity and relatively rapid recharge in the fractured shale bedrock. The range in concentration for all groundwater samples was from 0.01 to 25 mg/L, and which also occurred in December and May, respectively. Forty-eight (29%) of the 165 samples were above the 10 mg/L drinking water MCL.

Trends in the NO_3-N concentrations were compared over the 2004-2005 sampling period for the surface water data, and over the period from 1988-2005 for the groundwater data. Statistical analysis was carried out using STATA data analysis software. The trends in NO_3-N levels over time were determined using a simple Student's *t*-distribution test which controlled for the seasonal and monthly variation. The raw data was grouped and analyzed by month, year, surface tributary and elevation. For days when multiple samples were taken from the same source, average NO_3-N values for that location were used.

The average surface water NO_3-N concentration data collected between May 2004-2005 were found to change by -0.4 ± 1.69 mg/L (n = 185, 95% confidence interval), making it statistically impossible to determine whether or not the surface water NO_3-N levels were increasing or decreasing over this short time period. The large standard error in this data set can be attributed primarily to the substantial seasonal variation in NO_3-N levels, some of which probably resulted from the initial abnormal precipitation which occurred in May 2004. Unfortunately, no other earlier historical data for these surface waters were available.

The trend comparison of the 2004-2005 NO_3-N concentrations in the groundwater data to the previous groundwater sampling results from the 1988-1989 study or other privately collected data was done using the same 12 sites that were identified, and to which accessibility was granted. Unfortunately, broader participation could not be obtained for this part of the study to increase the number of sampling locations and sample size for this comparison. Nevertheless, a total of 151 groundwater samples, of which 46 were historic samples from the 1980s and 1990s, were used in this comparative analysis. The analysis showed that the groundwater NO_3-N concentrations at the 12 sites have been increasing annually by 0.228 ± 0.126 mg/L (n = 151, 95% confidence interval). The NO_3-N concentrations had increased substantially at 5 sites, with one site showing a significant increase of around 170% over earlier sampling results.

Sampling of the two small perennial streams at multiple locations provided some additional information regarding the relative contributions of the shallow (tile drain discharge) and deeper (bedrock) groundwater discharge to the stream flow. The most distal sampling locations for each stream were nearly two miles apart, and represented elevation differences of about 375 feet or slopes of around 5%. At the upper sampling locations, the two stream bottoms had a glacial till substrate, whereas at the lower locations, they were in the fractured shale bedrock. Both streams had very similar SO_4-S concentrations, but one stream had an annual average NO_3-N concentration of 5.6 mg/L and the other had a concentration of 13.2 mg/L. The contributing watershed of the latter stream included significantly more land area that was tile drained. For the stream with the higher NO_3-N concentrations, the NO_3-N concentration decreased about 16% and the SO_4-S concentration increased about 28% as it flowed downstream. The stream with the lower average NO_3-N concentration showed a decrease of 43% in NO_3-N and an increase of 52% in SO_4-S. These changes reflect differences in the chemical composition of the stream water as a result of increasing groundwater contributions from the shale bedrock.

The shallow (30 feet) abandoned well that was pump tested had a NO_3-N concentration of about 0.6 mg/L, which was much less then several adjacent (within 100 feet) deeper wells (80 to 170 feet) which had 3.5 mg/L of NO_3-N. Similar to the results obtained in the 1988-1989 study, no correlation of NO_3-N concentration with well depth could be determined for all the sampled groundwater wells. However, the wells and springs that had higher NO_3-N concentrations were also observed to have lower SO_4-S concentrations. This suggests that the wells having high NO_3-N concentrations were more subject to a (rapid) surface or shallow groundwater influence, reflecting the concentrations observed in the shallower tile drain discharge. The wells and springs with high NO_3-N concentrations must thus be connected to a network of fractures originating from areas where the bedrock is close to the soil surface. In order to determine where improved nitrogen management practices may be most beneficial, it will be necessary to determine the surface areal extent and source of an individual affected well's capture zone. In this type of geological setting, a rather intensive mapping and characterization of the extent and pattern of bedrock fracturing would be necessary, which would be a rather onerous and expensive task.

The significance of this surface and groundwater sampling study can be summarized from several important observations. These should be considered as further strategies are contemplated to maintain or reduce the NO_3-N levels in surface and groundwater sources in this area. The first important finding is that NO_3-N levels were highly seasonal. This seasonality means that in order to further determine long-term trends, it is therefore only valid to compare NO_3-N data from similar seasons. Since the study had no historical surface water data, and the 1-year duration was inadequate to detect any trend, additional monitoring of surface NO_3-N levels over a multi-year period may be beneficial for this area. For surface waters, the tile drain discharges and within season variability may be lquite important especially when precipitation norms are exceeded. This seasonal effect may perhaps be better correlated with the timing of nitrogen applications, which would be an important aspect related to the NMP recommendations. As a result of this seasonality, annual nitrogen balance plans may not accurately reflect the potential losses to the environment.

Secondly, the soils and underlying geology cannot be generalized when considering the impact of NO_3-N leaching losses. Although monitoring of tile drain discharges are often an effective method of evaluating and correlating in-field nitrogen management practices to leaching losses, it will be difficult to extrapolate those results on the impact to the surface and groundwater in this area with this type of geological setting. Furthermore, because of the complex nature and extent of bedrock fracturing, the actions on one field or even by one landowner may do little to reduce the NO_3-N level in a nearby well.

Third, because of the geology, the increasing NO_3-N concentration trend determined for the sampled wells cannot likely be extrapolated to all wells in the area, or to other wells in Wyoming County. The statistical significance applies only to the small number of wells sampled, several of which were already known to have high NO_3-N levels (and apparently sensitive to a surface water influence). A much larger number of wells, randomly selected, should be sampled to observe a general trend. As mentioned previously, the sampling would also need to be based on the seasonality.

Finally, the NO_3-N concentrations observed here were in a rural landscape dominated by intensive agricultural production, and which was the basis of the local economy. Most of the surface and groundwater sampling sites were in areas where almost all of the land use was in agriculture, and has been for the past 150 years. The soils and geological setting exasperate the NO_3-N leaching from below the crop root zone. These results are not likely to be typical of all agricultural settings where there is a more mixed land use and much deeper soils.

Student Support

One Ph.D. student, Brett Gleitsmann, studying water resources management was supported full time for the 2005 fall semester on this project.

Notable Achievements

The project effort has further enhanced local awareness regarding the potential off-site nitrate losses to surface and groundwater from dairy farms. The Wyoming County Soil and Water District has secured additional funds to implement BMP's on farms in the area (i.e., vegetated filter areas for treating runoff from barnyards and feed storage areas). Farm producers have a better understanding of nitrogen transformations from manure, are paying closer attention to nutrient management plans, making limited and more timely manure applications, and in integrating manure and other cover crops into crop rotations.

Measuring the effects of wetland and riparian zones on water quality in the urban Patroon Creek Watershed, Albany County, NY.

Basic Information

Title:	Measuring the effects of wetland and riparian zones on water quality in the urban Patroon Creek Watershed, Albany County, NY.
Project Number:	2004NY52B
Start Date:	3/1/2004
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	21
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Wetlands, Water Quality
Descriptors:	Nonpoint pollution; Stormwater; Wetlands; Urban and suburban land use;
Principal Investigators:	John G. Arnason, George Robinson

Publication

1. Arnason, J G, 2004, Conference on rising salt concentrations in tribuatries of the Hudson River Estuary, presentation and abstract, Hudson Eiver Environmental Society, Kingston, NY, December 6, 2004.
2. Robinson, G R, 2004, Environmental restoration within the Hudson River Basin, presentation and abstract, Hudson River Environmental Socienty, Hudson, NY, March 22, 2005.
3. Erickson, Elazabeth K, 2004, Road salt application ad its effects on sodium and chloride ion concentrations in an urban stream: Patroon Creek, Albany, NY, MS Thesis, Department of Earth and Atmospheric Sciences, University at Albany, State University of New York, Albany, NY.
4. Audette, L., 2004, Restoration Ecology of Riparian Zones on Patroon Creek, M.S. Thesis, University at Albany, Albany, NY, 105 pp.
5. Erickson, Elizabeth, 2004, Transport and Fate of Road De-icing Chemicals in the Patroon Creek Watershed, M.S. Thesis, University at Albany, Albany, NY, 83 pp.

Measuring the effects of wetland and riparian zones on water quality in the urban Patroon Creek Watershed, Albany County, NY

Final Technical Report

John G. Arnason, Department of Earth and Atmospheric Sciences

George R. Robinson, Department of Biological Sciences

University at Albany, State University of New York, Albany NY, 12222

June 19, 2006

Project Period: March 1, 2004 to February 28, 2006

Principal Findings

1. Significant spatial variations in major ion concentrations in surface waters of Patroon Creek and Rensselaer Lake indicate the presence of at least four principal source components: 1) calcium-bicarbonate type "uncontaminated" groundwater; 2) surface runoff; 3) surface runoff contaminated with road de-icing chemicals, principally sodium and chloride; and 4) groundwater contaminated by landfill leachate with elevated sodium, chloride, and ammonium, and low dissolved oxygen. The last component in observed only in the headwaters of the south branch of the Reservoir, closest to the City of Albany Sanitary Landfill.
2. Rensselaer Reservoir (14.3 ha) is a eutrophic waterbody that is an emergency water supply for the City of Albany. During summer stratification anoxic bottom waters become enriched in sodium and chloride with maximum concentrations exceeding 7 and 10 meq L^{-1}, respectively. Due to the long mean residence time (~1 year) and high sodium and chloride concentrations of the reservoir waters, it supplies saline waters to Patroon Creek year round.
3. The average summer chloride concentration of Rensselaer Reservoir has increased from ~ 6 to > 8.5 meq L^{-1}during the period 2002-2005. While some of this variation may be due to annual variations in climate and road salt application, it suggests that the reservoir may be becoming more saline over time due to application of road de-icing chemicals, as has been observed in other surface water bodies in the Northeast (e.g. Kaushal et al, 2005, e.g. Rosenberry et al., 1999). At current sodium and chloride concentrations, there could be detrimental effects on aquatic organisms and on potability; continued application of road salt will exacerbate this problem. More monitoring is needed to determine if this trend continues.
4. There is a positive linear correlation (r^2= 0.79) between sodium concentration in reservoir surface waters and exchangeable sodium in shallow sediments, whereas no correlation was observed between surface water and nearby soils along the shore. These observations are consistent with the hypothesis that sediments are a sink for sodium from de-icing chemicals and that the observed decoupling of sodium and chloride in surface waters is a result of cation exchange with sediments. An increase in the sodium fraction in interlayer sites of clay minerals

in sediments can cause changes in sediment properties, including porosity, permeability, and biological productivity.

5. In most cases runoff from roads and other impervious surfaces is channeled directly into the Reservoir and Creek through pipes and culverts that bypass riparian buffer zones, thereby reducing potential impacts of these zones on water quality. In contrast, reservoir and wetland sediments provide sinks for anthropogenic sodium through cation exchange between surface water and clay minerals in sediments but not for anthropogenic chloride which remains in surface water.

Study Area

The Patroon Creek watershed (37 km^2) includes portions of the City of Albany and the Towns of Guilderland and Colonie, New York (Figure 1). Land use is largely urban and suburban with some forested area. Impervious surface covers ~35% of the watershed area and includes interstate highways, roads, parking lots, and rooftops (Audette, 2004). Interstates 90 and 87 intersect at a large interchange in the western part of the watershed. I-90 and the CSX railroad line traverse the watershed following a course closely parallel to Patroon Creek. From west to east, there are three main natural areas: the Pine Bush Preserve, Tivoli Lakes Preserve, and the Corning Preserve. In addition there are small remnants of riparian natural area along the creek.

Patroon Creek flows westward from the Pine Bush natural Area (~ 100 m elevation) approximately 11 km to its mouth at the tidal Hudson River (0 m; Figure 1). It has two main tributaries, the unnamed north branch and Sand Creek, as well as several smaller ones. The creek channel has been significantly altered during the last 150 years, particularly during construction of impoundments during the 19th Century and the construction of I-90 in the mid 1960's. At present about 40 % of the channel length is in culverts or underground. There are three impoundments: 6-mile Reservoir or Rensselaer Lake (14.3 ha), 3-mile or Patroon Reservoir (1.3 ha), and Tivoli Lakes Reservoir (2 ha). The water level of Rensselaer Reservoir is manipulated, whereas the other reservoirs are not and are essentially "run of river." Most of the work in the present study is concerned with Rensselaer Reservoir.

There is a stream gage operated by the USGS near the mouth of the Creek (Figure 1). From fall of 2002 to the present, this gage has continuously recorded stage, temperature, and specific conductance at the site. In addition, there are some annual peak flow measurements from the late 1970's and early 1980's. In the fall of 2005, a ISCO automatic water sampler was installed that is maintained by the USGS and funded by the NYS DEC. In addition to the gage record, we have a continuous weekly-to-monthly record of major ion concentrations from 7 sites along the creek from June 2002 to the present (Erickson, 2004; this study).

Rensselaer Lake is a eutrophic reservoir with maximum depth of 6.5 m near the dam on its SE shore. Prior to this study, depth profile measurements were made in summer and fall in 2002 and 2003. These results showed that during summer stratification, a distinct thermocline develops with oxic epilimnion and anoxic hypolimnion. Fall turnover usually occurs in October. It is not known if winter stratification and spring turnover occur. At its western edge, the main body of Rensselaer Lake (south of the CSX railroad line) is fed by two inlet streams (Figs. 1 and 2). The northern fork begins W of Rapp Rd just south of the tracks and meanders through the Pine Bush Preserve. The source is primarily ground water, with some surface drainage. We have a three year record of water samples from the upstream part of this creek (Site 1, Figure 1), and a shorter record for several sites downstream and along the banks of the northern fork as it widens into the reservoir (this study, Fig. 2).

As part of this study, we have traced the southern fork of Rensselaer Reservoir to a culvert that passes under Rapp Rd., across from the entrance to the Albany Sanitary Landfill, adjacent to I-90 (NYS Thruway). This south fork begins to widen approx. 350 m (1100 ft) northeast of the culvert, eventually mixing with the north fork about 700 m further east. USGS maps do not show any inlet, with the south fork drawn as a backwater without any feeding streams. We first followed this southern fork inlet in June 2004, as part of a study of potential road salt accumulation in the Patroon Creek watershed.

Methods

Site selection, sampling, and field measurements

Evidence from studies of other urban and suburban streams suggests that deicing salts may accumulate in ground water in winter, and their release into streams in summer may explain elevated chloride levels in warm months. However, the Patroon Creek flow includes a mix of inputs, including unabated stormwater, outlet flows from two impoundments, and groundwater, including the headwater source, the unconfined aquifer formed by the deep sand deposits in the Albany Pine Bush. Therefore, we focused our most concentrated sampling in summer months, and our sites were chosen to capture potential signals from surface waters, deep waters, near-shore sediments, and shoreline soils (Tables 1 and 2).

Shoreline sample stations were deployed at intervals that would capture potential variation in water properties, and this included the two western arms of the reservoir, a narrows that passes beneath an Interstate (I 87) overpass, and a northern basin, separated by the CSX main rail line, which recently has had a new conduit to the main reservoir installed (Fig. 2). During early phases, we discovered anomalous conductivity readings and ion concentrations (provided in our previous WRI report) that led us to subdivide the sampling station ('K' in Fig. 2) into several points, and to extend our sampling period for this area.

Away from shore, in the western part of the reservoir, we tested for relatively-small-scale gradients in water chemistry as a function of distance from the Interstate overpass and from headwaters, as well as riparian buffer width. The eighteen locations were designed to sample at regular intervals, but with attention to potential unbuffered inputs (Fig 3). A GPS receiver was used to relocate sample locations for repeated measurements (Table 2). Temperature, DO, and Specific Conductance were measured from a boat with field instruments (YSI® model 85), taking readings at the surface and (when possible) at 2 m depth.

Field measurements and surface water samples were collected monthly to bimonthly at twelve sites (Figure 2; A-L) on the shores of Rensselaer Lake (A-N) and monthly at eight sites along Patroon Creek (Figure 1; 1-8) between June 2004 and December 2005. Depth profile samples and measurements were also collected from the deepest part of the Lake during summer and late fall 2004 and summer 2005. Field measurements include temperature, specific conductance (YSI® 30 and 35 meters), and dissolved oxygen concentration (YSI® 550 meter), as well as water depth (tape measure) and visibility (secchi) for profiles. Grab samples were collected in 125 and 250 mL Nalgene® bottles that were prewashed with Citranox® and rinsed with 18.3 MΩ de-ionized water. Samples were stored in a cooler in the field, filtered (0.45 μm) in the lab and refrigerated until analysis.

At each site around Rensselaer Lake (A-N; Fig. 2), a soil sample was collected within 1-2 m of shoreline, and a sediment sample was collected approximately 1 m from shore in < 0.3 m water depth. Samples were collected to approximately 0.05 m depth with a corer and placed in plastic bags.

Chemical Analysis

Major ion concentrations were determined by ion chromatography using Dionex ICS-90 and DX-120 ion chromatographs with AS-40 autosampler for cations and anions, respectively. Quality control measures included analysis of laboratory reagent blanks, laboratory fortified blanks, laboratory fortified matrix samples, and standards. pH was determined in the lab on unfiltered samples using an Thermo Orion 420 pH meter, calibrated with buffers of pH=4.0, 7.0, and 10.0. Alkalinity in a subset of samples was determined by titration of 1.6N H_2SO_4 into 100 mL of unfiltered sample to a pH=4.5 endpoint using a Hach micro-burette. Alkalinity measurements are reported at ppm $CaCO_3$. For samples in which alkalinity was measured, charge balance calculations were used to check the validity of the analyses. For most samples, the charge discrepancy was less than 2% of the total charge in meq/L.

Soil samples were dried at 60 º C, sieved (#10) to remove coarsest particles, and homogenized using a ceramic mortar and pestle. For cation exchange capacity measurements, a 5 ± 0.1 g (dw) sample aliquot was combined with 30 mL of 0.2 M NH_4Cl in a 50 mL centrifuge tube, shaken for five minutes using a wrist action shaker, centrifuged for 15 minutes, and the supernatant transferred to a 250 mL volumetric flask. This was repeated two more times. The combined supernatant was then diluted to volume with a solution of 0.2 M NH_4Cl and 1560 mg/L cesium (matrix modifier for AA) and filtered with 610 grade filter paper. Filtered solutions were analyzed Potassium (K), Magnesium (Mg), Calcium (Ca) and Sodium (Na) using a Perkin-Elmer 2380 Atomic Absorption Spectrophotometer, calibrated using 0.2 M NH_4Cl/ 1000 mg/L Cs solutions of containing known concentrations of each cation. Cation Exchange Capacity (CEC) in meq/Kg was calculated for each sample by summing the concentration of K, Mg, Ca, and Na (in meq/Kg) and assuming that no other exchangeable cations were present. The percentage of each cation was calculated by dividing the concentration by the total CEC.

For soil and sediment pH, a 10 g aliquot of each sample was placed in a centrifuge tube along with 10mL of 18.3 MΩ de-ionized water, shaken continuously for 10 minutes, allowed to settle for 10 minutes before measuring using a ThermoOrion 420 pH meter, calibrated as above. Special care was taken to make sure the electrode was not submerged into the soil or sediment, but only reading the water above the sample.

Data preparation and analyses

Stream gage data were obtained in raw form (15 min. interval recordings) from the USGS office in Troy, NY, and summarized (daily and monthly mean, minimum, maximum) using programs written in database software (Microsoft Visual Foxpro) for the period 6/1/04 to 10/31/05. Box plots (Sokal and Rohlf 1995) were used to portray monthly medians, quartiles, and extreme values. The stream gage is approx. 16 km downstream of the reservoir outlet, the flow passes through a second impoundment, and we have not calculated travel times for this distance at different discharge rates, so values are reported simply as indicators of seasonal variation in flow and conductivity.

Outlines of reservoir surface waters and data points were mapped on orthoimages (NYS GIS clearinghouse) using ESRI ArcGIS 8.0 software. Sample points were grouped by distance from identified locations and by proximity to suspected contamination sources (road drains and other culverts), and differences in major ions and physical properties were tested with ANOVA, grouping all sample months. Cation concentrations were compared among soil, sediment, and water samples per site with Pearson correlations. Surface water properties were compared to subsurface values using T-tests. Chloride ion was regressed on sodium and on sodium plus calcium and magnesium (least squares linear model) for evidence of chloride source, as well as evidence for potential cation exchange. Linear regression was also used to test for a relationship between specific conductance (field measure) and chloride concentration (lab measure) per sample. All statistical tests were run with SYSAT 9.0 software.

Results

Hydrology

A summary of hydrologic data collected at the gage site is given in Figure 4 for the study period. The record of mean and maximum daily discharge is too short to draw conclusions about seasonal discharge patterns. The Patroon Creek hydrograph is characterized by an extremely rapid rise in discharge at the onset of a storm event followed by a more gradual decrease, typical for an urban system (not shown). When road-de-icing chemicals are applied during storms, there is a significant increase in specific conductance recorded at the gage. In contrast, during storms when de-icing chemicals are not used, there is a significant decrease in conductance caused by dilution of baseflow by precipitation. Reservoir release events are characterized by a discharge plateau with both rapid increase and decrease in discharge marking the beginning and end of the event, but no significant change in conductance. Temperature patterns are typical for a temperate climate in the N. Hemisphere with minima and maxima occurring in winter and summer, respectively. Temperature variation is greatest in spring and fall.

Mean daily specific conductance remains above 1000 μS-cm all year with the highest values during the winter months when road de-icing chemicals are applied. High conductance during the other seasons is a result of high background chloride concentrations. It is probable, that elevated chloride concentrations during the entire year are a consequence of the large storage capacity of Rensselaer Lake that results in a ~1-year residence time of saline lake waters.

Surface water chemistry

Significant spatial variations in major ion concentrations in surface waters of Patroon Creek and Rensselaer Lake indicate the presence of at least four principal source components: 1) calcium-bicarbonate type "uncontaminated" groundwater; 2) surface runoff; 3) surface runoff contaminated with road de-icing chemicals, principally sodium and chloride; and 4) groundwater contaminated by landfill leachate with elevated sodium, chloride, and ammonium, and low dissolved oxygen (Table 3). The last component in observed only in the headwaters of the south branch of the Reservoir (site K-1; Figure 2), closest to the City of Albany Sanitary Landfill.

In Figure 5A, Cl concentration is plotted as a function of Na concentration in meq/L for all surface water samples from Rensselaer Lake collected during the study period. There is a strong linear correlation between Na and Cl (r^2= 0.97, $p<0.001$). If Na and Cl were present in equimolar amounts, the regression line would have a slope of unity. The observed slope (1.17) indicates that the concentration of Cl (in meq/L) typically exceeds that of Na. There are two likely explanations for this: 1) significant quantities of Mg and Ca chloride salts are applied to the roadways; 2) Na and Cl are de-coupled in groundwater or surface water by cation exchange reactions with sediments. It is difficult to obtain reliable information about quantities of Mg and Ca salts applied, but it is generally reported that only very small quantities are used due to the added expense. In general, NaCl is the dominant de-icing chemical. The second explanation seems more likely and is supported by sediment chemistry data below. Regardless of the cause of Na loss and Ca and Mg gain in surface waters, if chloride is plotted as a function of the Na+Mg+Ca, the slope of the regression (0.97) is much closer to the value expected from stoichiometry.

Spatial variations in surface water chloride concentrations are illustrated in Figure 6A. The North Fork and Main Body of the lake have statistically similar average chloride concentrations, whereas the I-87 Overpass area and the South Fork have significantly higher mean chloride concentrations. This is consistent with known sources of de-icing chemicals on I-87 that is a source to the Overpass area, and de-icing chemicals from the Exit 24 interchange and leachate from the sanitary landfill that are sources to the South Fork. In contrast, the North Fork has few direct sources of chloride. If the sites adjacent to the landfill are removed from the South Fork data, the South Fork is not significantly different from the overpass area.

Lake profiles

Water column measurements in Rensselaer Lake are plotted in Figure 7 for August 24 2005, illustrating typical conditions during summer stratification. The epilimnion contains warm, oxic waters with relatively low specific conductance and dissolved ion concentrations. In contrast the hypolimnion contains cooler, anoxic waters with higher specific conductance and dissolved ion concentrations, especially sodium, chloride, and ammonium. Sulfate is the only major ion whose concentration decreases with depth, likely a result of activity of sulfate reducing bactera.

Following fall turnover which usually occurs in October, there is no observed stratification in temperature, dissolved oxygen, conductance, or major ion concentrations (not shown). Winter stratification and spring turnover, if present, have not been observed due to dangerous ice conditions.

The mean chloride concentration (meq/L) in the water column is plotted as a function of time in Figure 8 for the period May 2002 to August 2005. While there is significant monthly and seasonal variation, there appears to be a trend toward increasing chloride concentrations from ~ 5 meq/L in summer 2002 to >9 meq/L in summer 2005. It is likely that much of the variation in chloride concentration is due to climate-related factors such as temperature, precipitation, and amount of road salt applied during the period. Further monitoring is necessary to determine if the apparent trend toward increasing mean chloride concentrations is significant.

Soils

The mean sediment pH (7.12) is significantly higher than that of the soil (6.42), likely due to buffering of sediment by reservoir water. At these pH values, the contribution of H^+ and Al^{3+} to the exchangeable cation pool would be negligible, so the assumption that the total CEC is the sum of Ca^{2+}, Mg^{2+}, K^+, and Na^+ is a reasonable one.

Results of cation exchange measurements from soils and sediments of Rensselaer Lake are presented in Figures 8 and 9. Field observations indicate that both soils and sediments are dominated by sand with very low fractions of silt, clay, and organic matter. Neither grain size analysis nor carbon analysis were performed. The CEC range in soil was from 12 to 416 with a mean value of 99.5 meq/kg, while sediment samples ranged from 22.9 to 669 with a mean of 175 meq/kg. The significantly higher CEC in the sediment is likely the result of higher clay content in the sediment from deposition in the tranquil reservoir waters. In both sediments and soils, the dominant exchangeable cations are Ca> Mg> K=Na. Cation fraction is dependent on CEC with higher fractions of K and Na occurring in soils and sediments with lower CEC (Figure 8). This trend may reflect differences in the type of the clay minerals found, the proportion of organic matter, or it may indicate a selectivity preference for large, low valence ions (K^+ and Na^+) over smaller, higher valence ions (Mg^{2+} and Ca^{2+}).

Pearson correlation among water, soil and sediment samples shows a strong correlation (r^2= 0.786) between the Na^+ concentration in surface water and the percentage of exchangeable Na^+ in sediment (Fig. 9). There is a weaker correlation between K in water and exchangeable K^+ in sediment. There are no significant correlations among Ca^{2+} and Mg^{2+} in water and exchangeable Ca^{2+} and Mg^{2+} in sediment, and there are no correlations among water and soil for any of the base cations. These data are consistent with the hypothesis that the exchangeable Na^+ in sediment is derived by exchange with surface water, and that Rensselaer Lake sediments provide a sink for Na

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Kaushal, Sujay *et. al.* (2005) “Increased Salinization of fresh water in the northeastern United States.” PNAS. Vol 102:38.

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Students supported:

Three graduate and two undergraduate students were partially supported during this project. Sean Madden (M.S. Biological Sciences, 2004) was supported during summer 2004. His duties included water sampling, soil and sediment sampling, and laboratory analysis. Chuck Begeal (M.S. Geology, in progress) was supported during summer 2005. His duties included water, soil and sediment sampling, laboratory analysis, and data analysis. Elizabeth Erickson (M.S. Geology, 2004) conducted research on a mass balance model for sodium chloride in the watershed. Tim Koch (B.S. Environmental Science, 2006) and Paul Goebbels (B.S. Biology, 2006) were supported during fall 2005 and Spring 2006, respectively. Their duties included water and soil sampling, laboratory analysis, and GIS mapping. Students in two undergraduate field courses (Bio 442, Restoration Ecology, and Bio) participated in sampling, and results were presented in lectures and class exercises. These studies are also the focus of an annual lecture on urban ecology to our 500-student introductory Biology course (Bio 110).

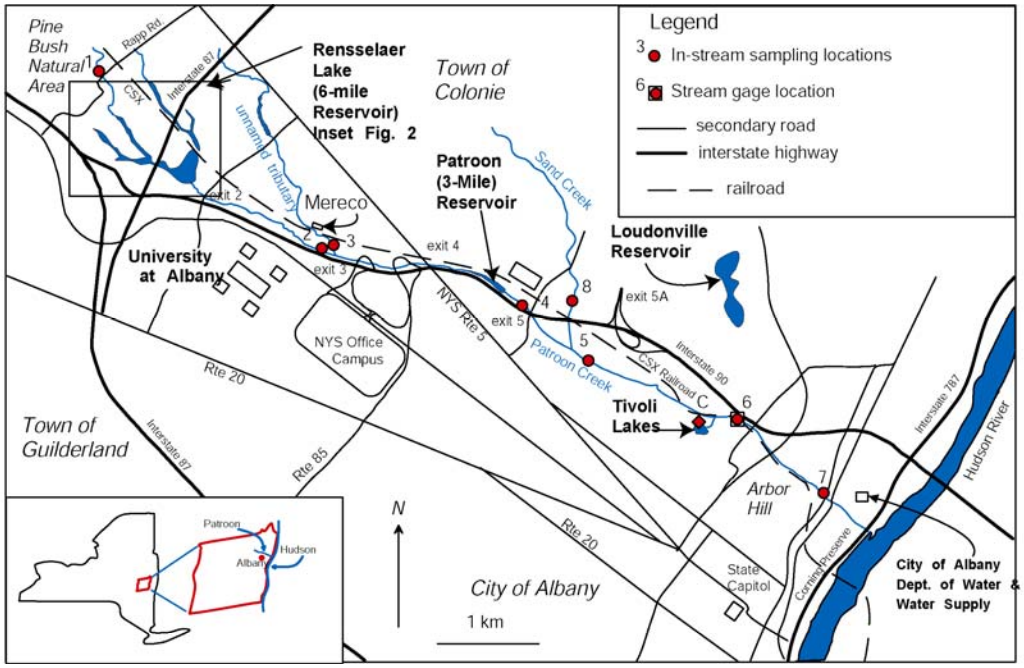


Figure 1. Map of Patroon Creek and Rensselaer Lake showing Creek sampling locations and major features

Figure 2. Aerial photograph of Rensselaer Lake showing soil, sediment, and water sampling locations (A-N), depth profile site, and major features. See text for explanation of site selection.

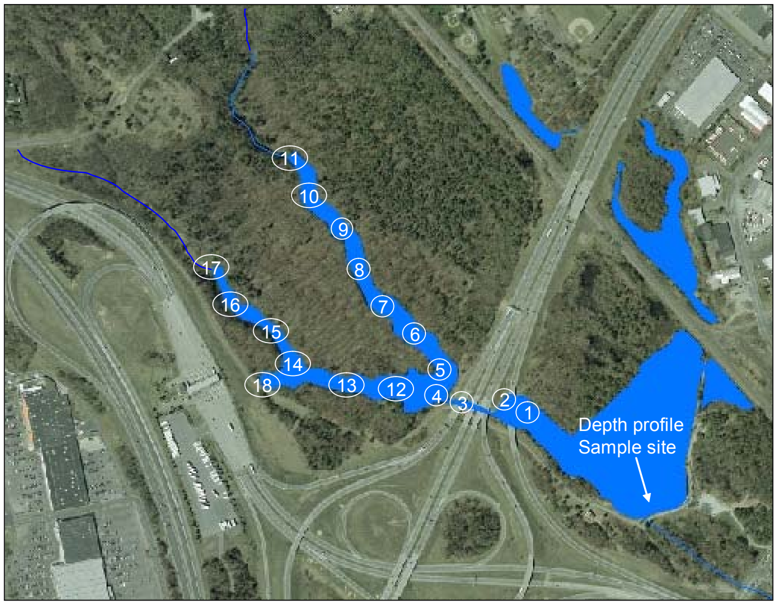
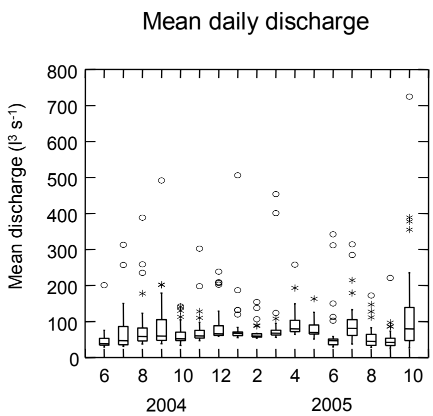
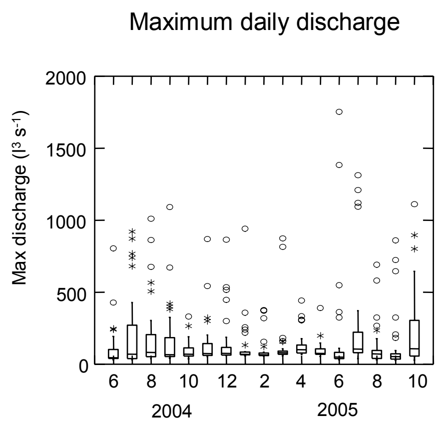


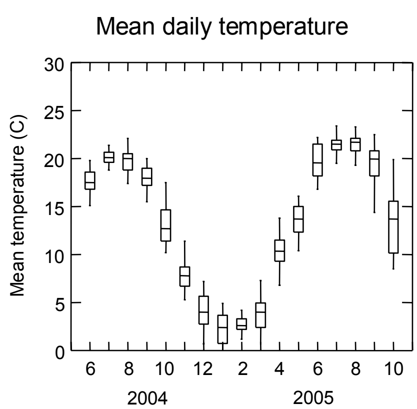
Figure 3. Aerial photograph of Rensselaer Lake showing field measurement locations. At each location, temperature, dissolved oxygen, and specific conductance measurements were made from a canoe at the surface and 2 m depth. See text for explanation of site selection.


Mean daily discharge
Mean discharge ($l^3\ s^{-1}$)
0
100
200
300
400
500
600
700
800
6
8
10
12
2
4
6
8
10
2004
2005

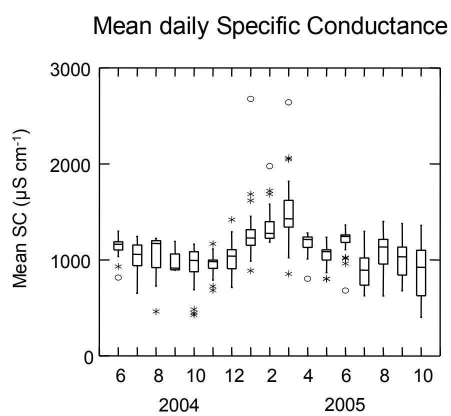
A.


Maximum daily discharge
Max discharge ($l^3\ s^{-1}$)
0
500
1000
1500
2000
6
8
10
12
2
4
6
8
10
2004
2005

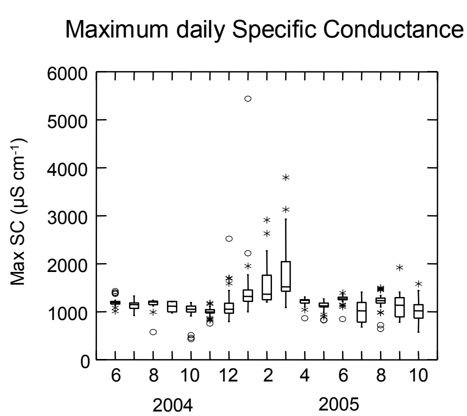
B.


Mean daily temperature
Mean temperature (C)
0
5
10
15
20
25
30
6
8
10
12
2
4
6
8
10
2004
2005

C.

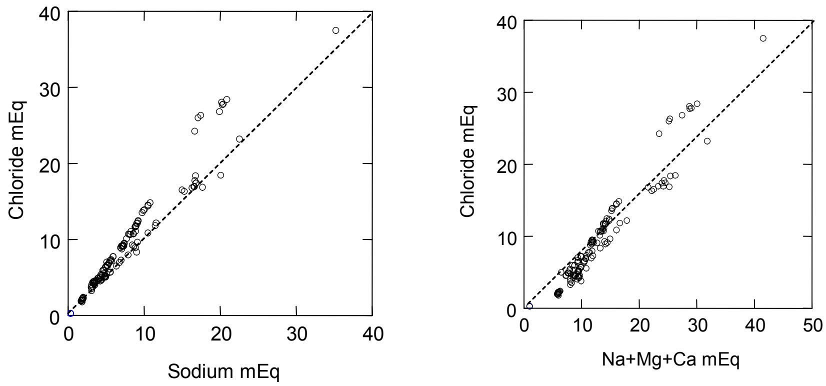

Mean daily Specific Conductance
Mean SC (µS cm^{-1})
0
1000
2000
3000
6
8
10
12
2
4
6
8
10
2004
2005

D.


Maximum daily Specific Conductance
Max SC (µS cm^{-1})
0
1000
2000
3000
4000
5000
6000
6
8
10
12
2
4
6
8
10
2004
2005

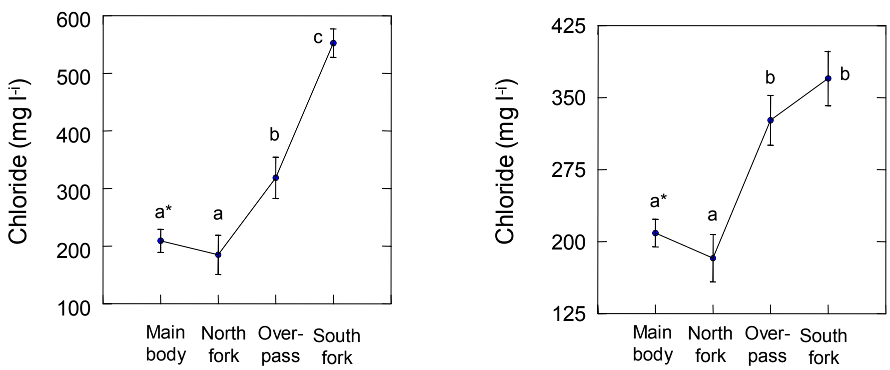
E.

Figure 4. Daily hydrologic data from Patroon Creek for the period June 2004 to October 2005 as box-and-whisker plots. Top, middle, and bottom of box represent 75th percentile, mean, and 25th percentile, respectively. Top and bottom whiskers are 90th and 10th percentile, respectively. A. Mean daily discharge. B. Maximum daily discharge. C. Mean daily temperature. D. Mean daily specific conductance. E. Maximum daily specific conductance.



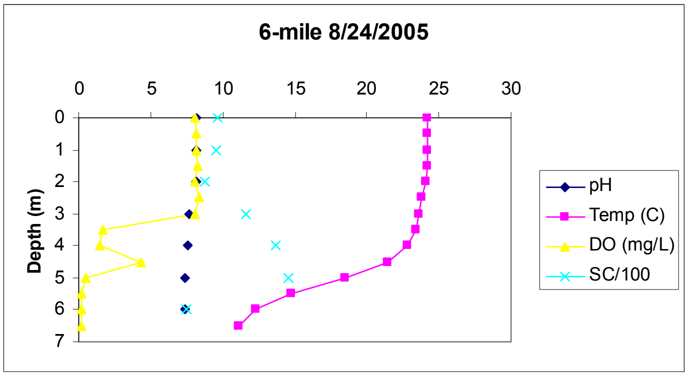
A. **B.**

Figure 5. **A** Chloride (meq) as a function of sodium (meq) for Rensselaer surface waters (sites A-N). $Cl = 1.172 * Na + .311$; $R^2 = .970$; $p < .001$.
B. Chloride (mEq) as a function of Na+Mg+Ca (mEq) for Rensselaer surface waters (sites A-N). $Cl = .975*(Na+Mg+Ca) -.3.248$; $R^2 = .938$; $p < .001$. In both graphs, dashed line has a slope=1.

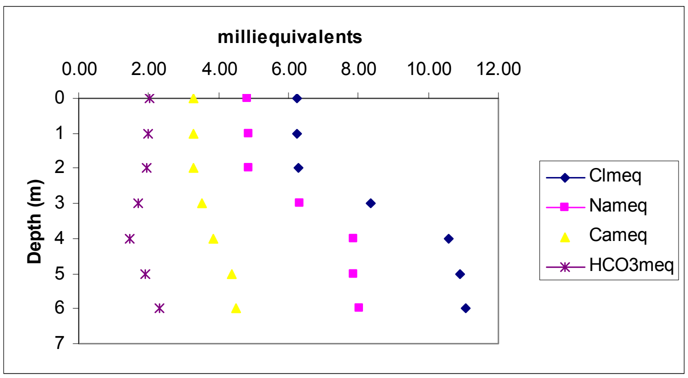


A. **B.**

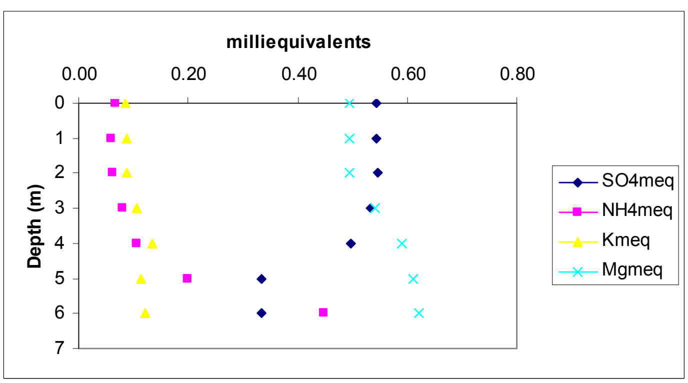
Figure 6. **A.** Chloride (mg/L) as a function of location for Rensselaer surface waters (sites A-N). (ANOVA $F_{3.134} = 45.02$; $p = .003$; * Dissimilar letters = Bonferroni post hoc $p < .05$). Main body = sites A,B,D,H,I,J; North fork = sites E,F,K5; Overpass = sites C,L; South fork = sites M,N,K,K1,K3. See Figure 2 for site locations.
B. Chloride (mg/L) as a function of location for Rensselaer surface waters (sites A-N) with suspected landfill leachate sites removed. (ANOVA $F3,107 = 13.96$; $p < .001$
* Dissimilar letters = Bonferroni post hoc $p < .05$).



A.



B.



C.

Figure 7. Profile of Rensselaer Lake collected on August 24, 2005 showing stratitification. **A**. Temperature, pH, dissolved oxygen (mg/L), and specific conductance (x 10^{-2}). **B.** Chloride, sodium, calcium, and bicarbonate (meq/L). **C.** Sulfate, ammonium, potassium, and magnesium (meq/L). Nitrate was not detected.

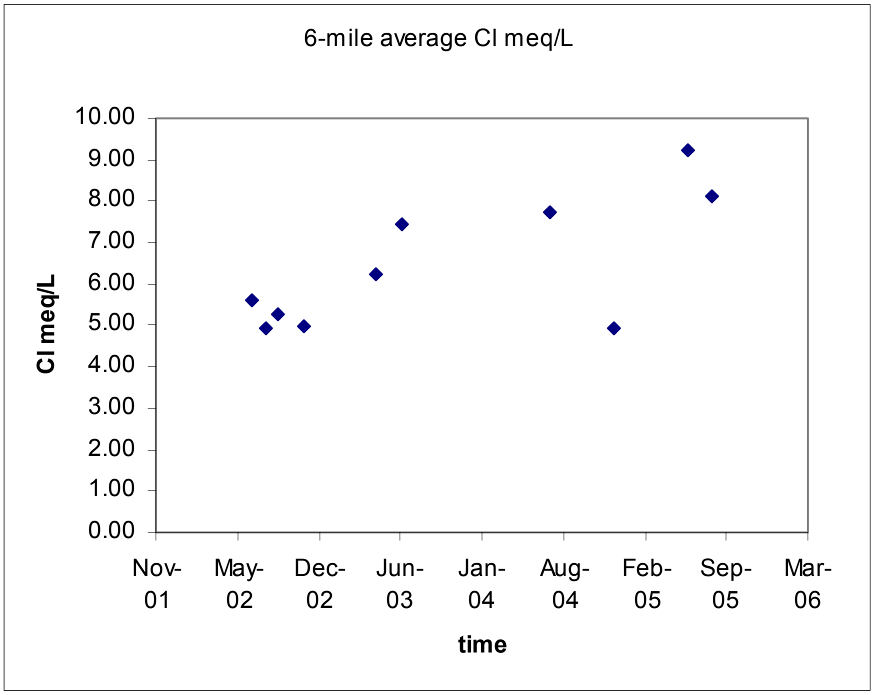


Figure 8. Average chloride concentration in Rensselaer Lake as a function of time for the period July 2002 to August 2005.

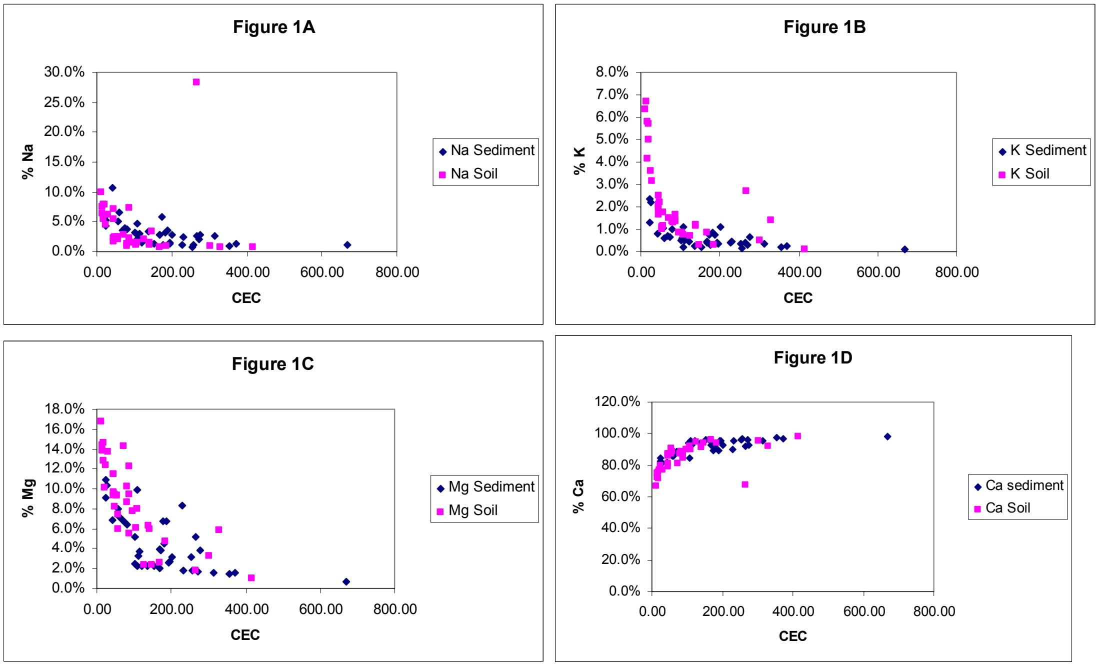


Figure 9. Scatter plots of cation percentage as a function of Cation Exchange Capacity (CEC). A: Sodium B: Potassium C: Magnesium D: Calcium

Cation correlations (conc. mg/l)
Water vs. sediment vs. soil

	NA	SEDNA	SOILNA
NA	1.000		
SEDNA	0.786	1.000	
SOILNA	0.116	0.137	1.000

	CA	SEDCA	SOILCA
CA	1.000		
SEDCA	0.056	1.000	
SOILCA	-0.187	0.093	1.000

	K	SEDK	SOILK
K	1.000		
SEDK	0.544	1.000	
SOILK	0.068	0.445	1.000

	MG	SEDMG	SOILMG
MG	1.000		
SEDMG	0.072	1.000	
SOILMG	0.308	0.221	1.000

Figure 10. Correlation matrix for Na, Ca, K, and Mg concentrations in water, sediment, and soil samples.

Table 1. Summary of measurements and water samples collected along Patroon Creek (sites in red, Figure 1) July 2004 to December 2005.

Date	*# Anion/Cation samples*	*# Bacteria Samples*	*# Temp, pH, & D.O. measurements*	*# Conductivity measurements*
7/13/04	7	7	7	0
8/10/04	7	7	7	0
10/12/04	7	7	7	0
11/3/04	7	0	7	7
11/9/04	7	7	7	7
12/14/04	7	7	7	7
1/11/05	7	7	7	7
1/26/05*	3	0	3	3
2/8/05	7	7	7	7
3/8/05*	1	0	1	1
3/11/05	7	7	7	7
3/21/05*	3	0	3	3
3/28/05*	5	0	5	5
4/12/05	8	7	8	8
5/10/05	8	7	8	8
6/14/05	8	7	8	8
7/12/05	8	7	8	8
8/9/05	8	7	8	8
9/13/05	8	7	8	8
10/11/05	8	7	8	8
11/8/05	8	7	8	8
12/13/05	8	7	8	8
Total	147	119	147	126

* Storm Events

Table 2. Summary of measurements and water samples collected at sites along Rensselaer Reservoir (sites in Figure 2 and 3), June 2004 to January 2006.

Date	*Surface water grab samples*	*Sediment and soil samples*	*Field Temp, D.O., and Conductivity measurements*
6/06	12	15	-
7/04	10	13	30
8//04	13	12	-
9/04	6	-	-
11/04	11	-	-
2/05	12	-	-
3/05	7	-	-
5/05	15	-	30
7/05	16	-	29
8/05	16	-	33
9/05	14	-	-
10/05	14	-	28
12/05	2	-	-
1/06	2	-	-
total	148	40	150

Table 3. Field readings from Feb. 20, 2005 field sampling. Air temp. was approx. -3 C (27 F). Site locations shown in Fig. 2.

Site	Possible sources	Water Temp	DO[1]	SC[2]
K-1 Culvert under Rapp Rd.	groundwater landfill leachate	10.2 C (50.4 F)	0.70	3508
K-1 Seepage around culvert.	groundwater landfill leachate	10.2 C (50.4 F)	3.8	3629
K-3 Culvert under I-90	road drainage groundwater	6.5 C (43.7 F)	10.6	2427
K-3 Corrugated pipe	road drainage groundwater	1.4 C (34.5 F)[3]	3.0	1193
K-5 N fork (APB Preserve)	groundwater	3.9 C (39.0 F)	10.4	570

[1]Dissolved oxygen in mg/l;
[2]specific conductance in µS-cm, adjusted for 25 C.
[3]Surface frozen, water not moving, pipe empty.

Information Transfer Program

Director's Office Information Transfer

Basic Information

Title:	Director's Office Information Transfer
Project Number:	2004NY56B
Start Date:	3/1/2002
End Date:	2/28/2006
Funding Source:	104B
Congressional District:	26
Research Category:	Not Applicable
Focus Category:	Management and Planning, Education, Law, Institutions, and Policy
Descriptors:	None
Principal Investigators:	Keith S. Porter

Publication

1. Porter, Keith S., 2005, The First Barrier: The Protection of Drinking Water at its Source. The Journal of Water Law. Vol 16, Issue 4, p 167-173.
2. Porter, Keith S., 2005, Fixing our Drinking Water: From Field and Forest to Faucet: An invited paper submitted to the Pace Environmental Law Review. (In Press).
3. Porter, Mary Jane and Keith S. Porter, 2005, Building Networks for a RELU Capacity Building Programme: Exploiting Options from the Eastern US and nearby European Continent. Workshop Summary, 10-11 May 2005. Withersdane Conference Center, Imperial College, Wye Campus, Wye Ashford, UK
4. Porter, Mary Jane, Keith S. Porter, and Dean Frazier, 2005, Linking Economic Vitality, Water Quality, and Sound Science. Delaware County Action Plan Report, draft version 4. Delaware County Department of Watershed Affairs, Delhi, NY 13753, 68 pages
5. Porter, Keith S., Mary Jane Porter, Patricia Bishop, Steven Pacenka and Siwing Ivy Tsoi, 2006, Scientific Work Based on a Farmed Drainage Basin and a Control Basin in the New York City Watersheds. Compendium report. NYS Water Resources Institute, Cornell University, Ithaca, NY 14853-5601, 56 pages.

NY WRI Information Transfer for FY2005

Over the past several years WRI has continued to promote the engagement of the wider academic community in water resource management issues in New York State. As in previous years, opportunities to pursue this aim were sought through federal, state, regional and local public and private partners. Most WRI activity with these groups in FY2005 related to the New York City Watershed Program (Delaware County phosphorus management projects), the Susquehanna River Basin in the Chesapeake Bay Watershed, and the Hudson River Watershed.

A new venture with Cornell's American Indian Program (AIP) on Native American water law began in September 2005. WRI engaged Cornell's AIP for their assistance in working with Tribal leaders and Cornell Law School Native American students to highlight prominent Native American water issues. As a result of the FY2005 meetings, a workshop is currently planned that will reach out to the Northeastern Indian Tribes. The Fall 2006 workshop will be sponsored by Cornell's Law School, AIP and WRI.

Continuing Outreach, Education and Information Transfer

Stormwater and Project WET
As part of the stormwater regulations imposed by the NYS DEC, WRI has been called on to assist in providing water education for municipalities through its NY Project WET (Water Education for Teachers) program. The NY Project WET developed regional stormwater training sessions with the NYS DEC for municipalities and other educators, such as the Soil and Water Conservation Districts, environmental groups and Cooperative Extension. Educational and stewardship activities continue as part of development of each municipality's stormwater management plans.

Susquehanna River Basin
A continuing focus for WRI's outreach is in the headwaters of the Chesapeake Bay. New York has entered into an interstate agreement with all other Chesapeake Bay watershed states to reduce nutrient and sediment loading to the bay. At the requests of the NYS DEC and the Upper Susquehanna Coalition (USC—a network of county agencies), WRI evaluated water quality monitoring and modeling activities carried out by the Chesapeake Bay program and considered how New York should marshal its own technical resources to evaluate its options and progress toward the very ambitious nutrient reduction targets assigned. Work continues through FY2005. A tributary strategy for New York is being prepared to prevent nutrients and sediments coming from nonpoint sources of pollution. In particular, WRI has assisted in fostering scientific support and the sharing of scientific understanding for the development of tributary strategies.

Hudson River Tributary Strategies
The Hudson River Estuary Program Action Agenda sets the official goals for the Hudson River Estuary Program. Among the twelve goals contained in the Action Agenda is one to protect and restore the streams, their corridors, and the watersheds that replenish the estuary and nourish its web of life. To assist in fulfilling that goal, WRI staff are working

with the Pace Land Use Law Center to create a model tributary strategy that will help other communities integrate natural resource protection principles into local land use plans. Pilot communities will be chosen under the FY2006 104B Competitive Grants Program to undertake the development of a pollution prevention strategy for their community that will ultimately contribute to a general tributary guidance document. Communities will be selected competitively.

International Outreach
Colleagues from Imperial College, the Westcountry Rivers Trust, and the University of East Anglia, United Kingdom, completed the Rural Economy and Land Use (RELU) Programme funded project in FY2005. The focus was building a network for a capacity building program for creating catchment strategies in the UK that exploit successful management options from the eastern US and European continent. Three US watershed programs that were highlighted as successful watershed programs and presented to UK stakeholders were the NYC Watershed Program, the Delaware County Action Plan (DCAP), and the upper Susquehanna River Basin. This project prompted a considerable dialog with watershed groups in the UK. Two workshops were convened of UK/US stakeholders, including representatives from agriculture, academia, local government statutory agencies, and the voluntary sector. A major outcome of this project was preparation of a catchment strategy for UK watersheds based on stakeholder inputs. A catchment strategy concept note was submitted to RELU for further consideration of funding in November 2005. UK and US principals were invited to submit a full proposal in the third funding round for capacity building under RELU.

Student Training in Water Law
The WRI Director's Course, *Water Law in Theory and Practice*, in the Cornell Law School, provided students practical opportunities to learn water law and to experience its multiple aspects through meaningful contributions. This was accomplished working directly with leading agencies and partners in the NYC Watersheds, Susquehanna River Basin and the Hudson River Estuary. Students selected a project topic, compiled relevant facts, critically researched the issues, and provided information and conclusions in presentations in the classroom, external seminars and public community meetings. Students also participated in a Water Law Colloquia jointly sponsored by the WRI, Pace University School of Law and the Albany Law School.

As part of the 2-semester course, *Water Law in Theory and Practice*, 11 students conducted community projects and were supported by WRI and it's staff. Project titles were:

- Seeing the Forest Through the Trees: A Critical Examination of the New York City. Watershed Land Acquisition and Easement Program.
- Development in the Watershed: Planning for Legitimate Reviews.
- Watershed Rules and Regulations.
- Comparative Study on the Use of Trusts for Watershed Management.
- Developing and Implementing Strategies to Protect Vernal Pools in New York.
- Groundwater Protection: Meeting the Challenge of a Failed Framework.

- CAFOs and the Changing Nature of Agriculture: Implications for farmland Preservation in the Hudson Valley.
- Water Allocation and Land Use Planning.
- The Legalities of Stream Interventions: Accretive Changes to New York State's Riparian Doctrine Ahead?
- Native Water Law Forum (prepared by 2 Native American students).

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	9	0	0	0	9
Masters	7	0	0	0	7
Ph.D.	7	0	1	0	8
Post-Doc.	0	0	0	0	0
Total	23	0	1	0	24

Notable Awards and Achievements

2003NY33G

Development of a GIS tool to automate the calculation of descriptive statistics from multiple raster datasets across watersheds in a region of interest. This tool was created to be of use with any polygon coverage, and thus can be employed with state, county, city, property, or any other boundaries of interest. Such flexibility makes this tool of wide interest to many researchers, not only hydrologists. The tool is freely available to the public and can be downloaded at www.esf.edu/erfeg/kroll. A tutorial has been created to aid users of this tool.

2003NY33G

This research has inspired the creation of an International Association of Hydrologic Sciences (IAHS) Prediction at Ungauged Basins (PUBs) low streamflow work group. This group is currently being formed as a joint venture with the Northern European Flow Regimes from International Experimental and Network Data (NE FRIEND), and will focus on international cooperation and information exchange with respect to low streamflow estimation. Through this group, a number of low streamflow study areas will be created throughout the world. These study areas will be the focus of long-term low streamflow research. Research from this group will help us better understand the performance of various estimators of low streamflow statistics at ungauged river sites in different hydrologic setting, as well as the uncertainty associated with these estimators.

Publications from Prior Projects

None