Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2008

Introduction

The Annual Report for the Vermont Water Resources and Lake Studies Center for FY2007 is attached. The grant awarded under the State Water Resources Research Institute Program is 06HQGR0123.

Research Program Introduction

In the 2008-2009 project year the Vermont Water Resources and Lake Studies Center continued its productive collaboration with the River Management Program in the Department of Environmental Conservation (Vermont Agency of Natural Resources or VTANR). In recognition of substantial state matching support provided by the River Management Program, the Vermont Water Center RFP for 2008-2009 was again designed to specifically address several broad aspects of river management that are of direct interest to the Department of Environmental Conservation. While proposals on any topic relevant to the mission of the Water Center were considered, proposals that addressed some aspect of the research needs expressed by the River Management Program were given priority for funding. The general objectives of the Joint VTANR/Water Center RFP included:

1. to advance scientific understanding that helps quantify the contribution of sediment and nutrients derived from fluvial processes in Vermont's rivers;

2. to establish the socio-economic justifications, costs, and benefits associated with or represented by river corridor protection in Vermont; and

3. to contribute to Vermont's river corridor management, restoration, and protection infrastructure.

Several areas of particular interest were identified. Proposals were sought that to strengthen and help validate Vermont's draft fluvial geomorphic-based model for describing sediment regime departures from reference or equilibrium conditions, which may influence the magnitude of sediment and nutrient production, transport, and attenuation or storage on a watershed scale. Suggested research areas of particular interest included:

A. building on the existing VTANR stream geomorphic assessment protocol, develop techniques for systematically identifying critical in-stream source areas, meaning those segments of the river system that contribute a disproportionate amount of the total P/sediment load

B. quantify how sediment and nutrient reductions may be achieved by managing river systems toward equilibrium conditions, and alleviating constraints to sediment load attenuation at a watershed scale,

C. examine and quantify the P and sediments available to be mobilized by fluvial processes and represented in various legacy sediment accretions in the Northern Lake Champlain watershed,

D. quantify sediment and P production in selected meso/macro scale examples and relate to the extant of fluvial geomorphic evolution or adjustment processes and the driving forces and stressors for such adjustments,

E. collect new and/or use existing data to test fluvial-geomorphic-based models currently being applied by the River Management Program and generate innovative new map products, or

F. place fluvial adjustment processes and sediment/P production rates on a geologic time scale/continuum such that a comparison of rates of sediment/P delivery to receiving waters can be made.

Proposals were also solicited to address socio-economic analyses which would build upon the Vermont River Management Alternatives White Paper and other VTANR River Management Program fact sheets and papers published by the RMP and available at http://www.anr.state.vt.us/dec/waterq/rivers.htm. Suggested research areas included:

A. identify/test/validate innovative voluntary landowner and municipal incentives that could be created in Vermont to enhance participation in river corridor protection initiatives,

B. quantify the socio-economic costs and benefits of river corridor protection, or

C. identify economic factors that have driven river and river corridor management historically (nineteenth and twentieth centuries) as compared with current day economic drivers and develop ways to use this information in way to that might influence public perception/values..

In addition to funding from the VTANR the Vermont Water Resources and Lake Studies Center received important funding and in-kind support from the Lintilhac Foundation and from Shelburne Farm, a public outreach and education organization in Shelburne, Vermont that promotes better farming practices in the New England region.

A total four projects were supported by the combined USGS, VTANR, and foundation funding:

Project 2008VY34B: Tracing sources of eroded sediment with atmospherically produced 10-Be. Mandar M. Dewoolkar (Assistant Professor, School of Engineering, University of Vermont) and Paul Bierman (Professor, Department of Geology and The Rubenstein School of Environment and Natural Resources, University of Vermont)

Project 2008VT35B: Soil phosphorus landscape variability and soil mapping in a stream corridor of the Northern Lake Champlain watershed. Donald S. Ross, Department of Plant and Soil Science, UVM and Eric O. Young, Department of Plant and Soil Science, UVM

Project 2008VT36B: Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability. Jane Hill; School of Engineering (Civil and Environmental Engineering Program)

Project 2008VT32B: Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms. Sarah Lovell Department of Plant and Soil Science, UVM and Alan McIntosh, Rubenstein School of Environment and Natural Resources, UVM.

These projects are described in greater detail in the Information Transfer sections.

Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms

Basic Information

Title:	Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms
Project Number:	2008VT32B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, Non Point Pollution, Agriculture
Descriptors:	
Principal Investigators:	Sarah Lovell, Alan Mcintosh

Publication

1. Lovell, S. Taylor, Johnston, D.M. Creating multifunctional landscapes – How can the field of ecology inform the design of the landscape? Frontiers in Ecology and the Environment. In press. Online: http://www.esajournals.org/archive/1540-9295/preprint/2009/pdf/10.1890_070178.pdf
2. Taylor Lovell, S., Sullivan, W.C. 2006. Environmental benefits of conservation buffers in the United States: Evidence, promise, and open questions. Agriculture, Ecosystems & Environment 112(4):249-260.
3. Sullivan, W.C., Anderson, O.M., and Taylor Lovell, S., 2004. Agricultural buffers at the rural-urban fringe: an examination of approval by farmers, residents, and academics in the Midwestern United States. Landscape and Urban Planning 69:299-313.
4. Taylor-Lovell, S., Sims, G.K., and Wax, L.M. 2002. Effects of moisture, temperature, and biological activity on the degradation of isoxaflutole in soil. Journal of Agricultural and Food Chemistry 50:5626-5633.
5. Taylor-Lovell, S., Sims, G.K., Wax, L.M., and Hassett, J.J. 2000. Hydrolysis and soil adsorption of the labile herbicide isoxaflutole. Environmental Science and Technology 34:3186-3190.

Title: Treatment Solutions to Reduce Nutrient and Bacterial Inputs to Lake Champlain at Shelburne Farms

Rationale:

Agricultural runoff in the Lake Champlain basin has long been recognized as a major water quality problem that threatens the ecological health and human uses of the lake. Point and non-point source pollution from farms can carry excess nutrients and other pollutants to downstream aquatic ecosystems and can create a variety of problems including toxic algal blooms, fish kills, loss of biodiversity, beach closures, and increased human health risks. Shelburne Farms is a 1400-acre grass-based dairy, a national historic landmark, and a non-profit environmental education center situated on the eastern shores of Lake Champlain. With their proximity to the lake and strong commitment to agricultural and natural resource stewardship, Shelburne Farms is eager to ensure that their agricultural practices do not negatively impact water quality. However, water quality monitoring in recent years has shown that unacceptably high concentrations of nutrients and bacteria are present in agricultural runoff during summer storms. To minimize agricultural pollutants from entering the lake, Shelburne Farms has decided to install a vegetated treatment system designed to intercept and treat runoff from the dairy barnyard area. Our research at Shelburne Farms will focus on evaluating the performance of the vegetative treatment system in mitigating agricultural pollutants during the startup phase of the system. We will also investigate whether the use of this technology is appropriate on sixteen selected dairy farms in the Champlain Valley.

Goals:

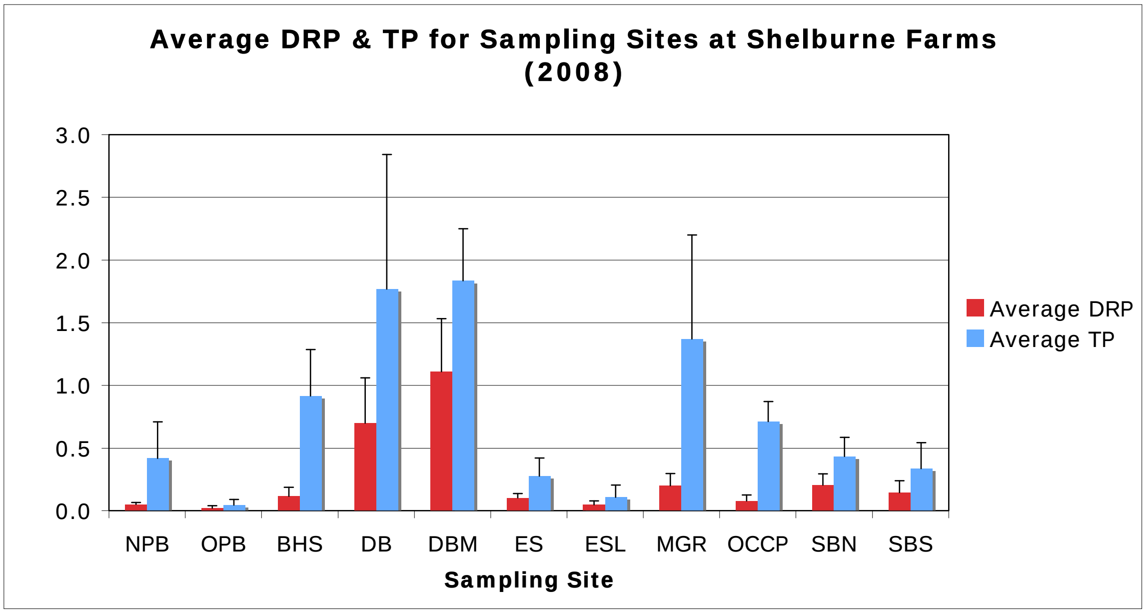
The goals of this project are to characterize the quality of surface water resources at Shelburne Farms, to design an innovative and cost-effective treatment system to improve water quality, and to monitor the performance of the treatment system once it has been installed. We will monitor influent and effluent water quality for Total Dissolved Phosphorus (TDP), Total Phosphorus (TP), Total Suspended Solids (TSS) and *E. coli*. We will also investigate whether the use of this technology is appropriate on sixteen selected dairy farms in the Champlain Valley.

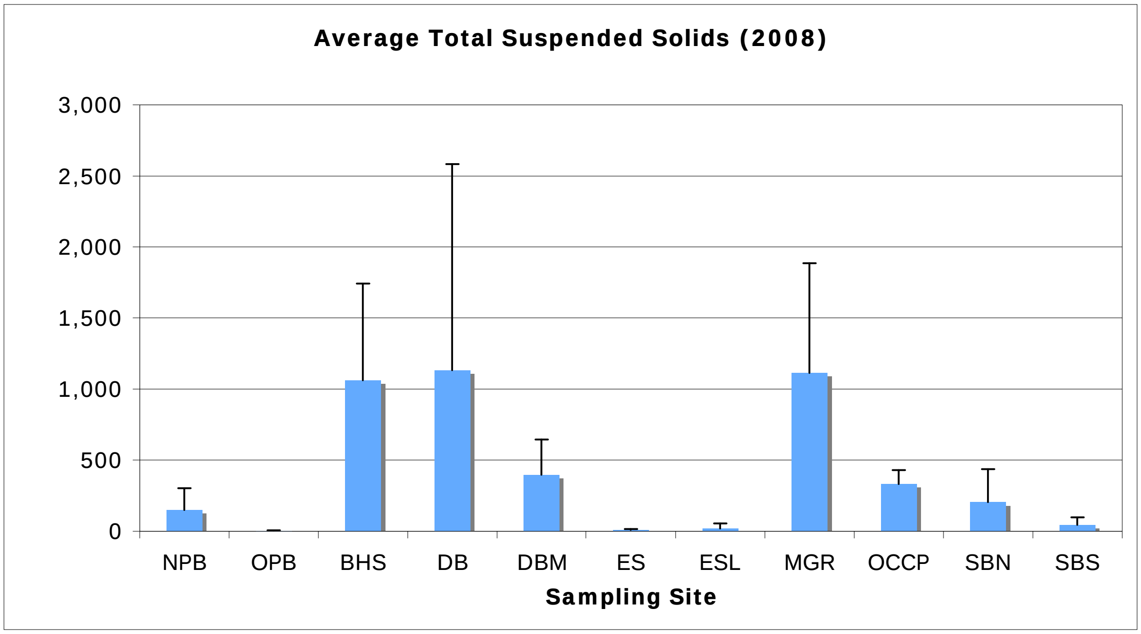
Progress to Date:

Hisashi Kominami, a M.S. student in the Plant & Soil Science Department, has been responsible for collecting data and performing the research for this project. Water quality was monitored during seven summer rain events in 2008 to characterize pollutant concentrations in agricultural stormwater. During each of the sampling events, replicate grab samples were collected for the eleven sampling sites (when applicable) and then tested for the following parameters: total phosphorus (TP), dissolved reactive phosphorus (DRP), total suspended solids (TSS), and E. coli. Monitored sites included two in-lake and nine in-stream sampling sites. A map showing sampling site locations and descriptions is found below as well as results obtained from monitoring in 2008.

2008 Sampling Sites at Shelburne Farms

Abbreviation	Sampling Site Name*	Site Sampling Description
NPB	North Pasture Beach	Stream outflow sampling
OPB	Orchard Point Beach	Lake sampling
BHS	Butternut Hill Stream	Stream sampling
DBM	Dairy Barn Manure	Drainage ditch sampling
DB	Dairy Barn	Drainage ditch sampling
ES	Elm Swamp	Wetland outflow sampling
ESL	Elm Swamp Lake	Lake sampling
MGR	Market Garden Road	Drainage ditch sampling
OCCP	Orchard Cove/Compost Pile	Outflow sampling
SBN	South Beach North	Outflow sampling
SBS	South Beach South	Outflow sampling



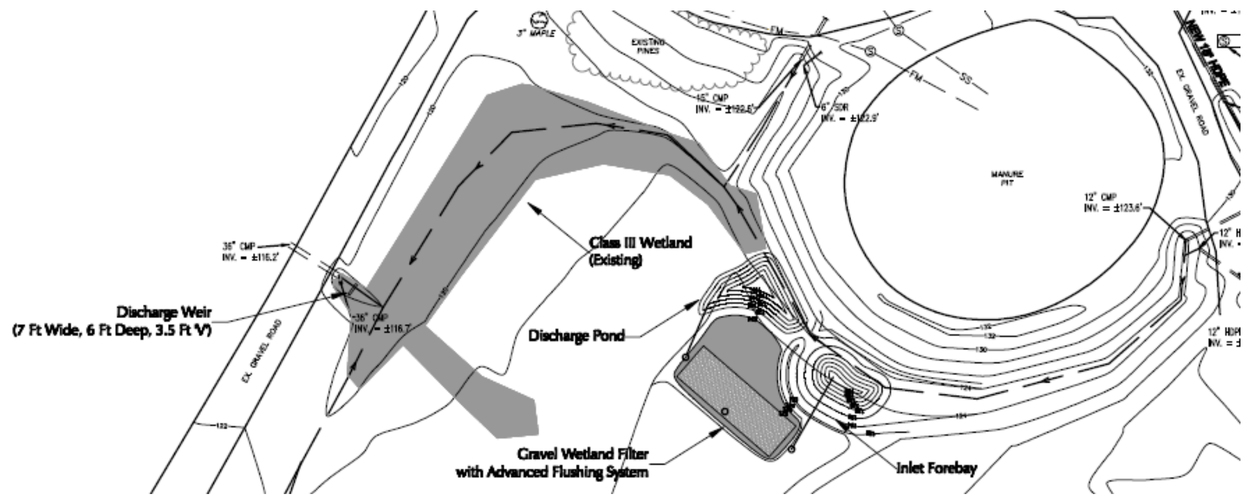


Monitored Swimming Beaches		
Sampling Date	Orchard Point Beach	Elm Swamp Lake
7/3/08	133	649
7/9/08	44	285
7/13/08	5	62
7/18/08	80	435
7/20/08	>2419	2419
7/24/08	10,462	9208
8/2/08	93	1986

Monitored Outflows & Drainages									
Sampling Date	NPB	BHS	DB	DBM	ES	MGR	OCCP	SBN	SBS
7/3/08	>2,419	1,414	22,210	98,040	1,553	71,700	68,670	>2,419	1,300
7/9/08	24,890	20,867	488,400	1203,300	10,462	NA	241,920	NA	6,131
7/13/08	384	2,909	48,840	209,800	1,986	NA	111,990	NA	291
7/18/08	413	15,531	27,230	173,290	3,873	92,080	36,540	NA	24,192
7/20/08	1,043	2,419	235,900	547,500	12,997	7,030	9,600	2,187	1,785
7/24/08	24,192	111,990	579,400	613,100	17,329	9,330	9,090	4,352	4,884
8/2/08	14,136	81,640	90,900	248,100	225	32,550	17,329	141,360	141,360

In addition to the monitoring effort, our research team consulted with an ecological engineer (David Whitney, EcoSolutions) and a watershed scientist (Evan Fitzgerald) to assess the hydrology of the dairy barnyard site and develop an ecological stormwater design. Subwatersheds were delineated and categorized based on the level of nutrient loading, in order to prioritize the treatment objectives. Initially, three systems were recommended to treat different areas of the site: a free water surface constructed wetland, a gravel wetland filter, and a bioretention system. Further analysis of the site, however, revealed the presence of a Class III wetland in the area where the free water surface constructed wetland was proposed. An alternative design was proposed, using a weir to control flow through a culvert, to take advantage of the treatment capacity of the existing Class III wetland (see figure next page). In addition, a vegetated gravel wetland was proposed for treating water prior to entering the Class III wetland. This design has been approved by the stakeholders and will be installed in early June. Once completed, Hisashi Kominami will assess the performance of the system in mitigating agricultural pollutants.

Proposed design for vegetated gravel wetland and discharge weir.



Water quality monitoring data collected at Shelburne Farms since 2004 was synthesized into a technical report and presented to Shelburne Farms stakeholders including the residents living near Shelburne Farms, the Shelburne Farms Water Quality Working Group, and the Shelburne Farms Board of Directors. A presentation of the 2008 summer sampling was also prepared for the Shelburne Farms board members.

This project received a second year of funding, so it will continue through February 28, 2010. As final tasks, we will complete research to assess performance of the agricultural stormwater treatment system and investigate the appropriateness of using this technology on sixteen dairy farms in the Champlain Valley. This research will comprise the bulk of Hisashi Kominami's MS thesis project. We will also coordinate outreach opportunities to educate the public about protecting water quality in Vermont's agricultural landscapes.

Tracing sources of eroded sediment with atmospherically produced 10-Be

Basic Information

Title:	Tracing sources of eroded sediment with atmospherically produced 10-Be
Project Number:	2008VT34B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Engineering
Focus Category:	Sediments, Geomorphological Processes, None
Descriptors:	None
Principal Investigators:	Mandar M. Dewoolkar, Paul Bierman

Publication

Tracing sources of eroded sediment with atmospherically – produced 10-Be

Progress Report May 12, 2009

Jaron Borg[1], Mandar Dewoolkar[1] and Paul Bierman[2]

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Project motivation and objectives

Surface water bodies are under constant threat of environmental degradation such as accelerated nutrient loading that has been linked to anthropocentric activities. Phosphorous, which binds tightly to soil sediments, has been noted as the largest pollutant of lakes and waterways. Although some land management practices focus on mitigating sediment removal from stream banks and agricultural fields, currently there are no analytical methods to provide sediment source information on a basin wide scale. Such a system may be economically beneficial in developing strategic land management plans specific to individual watersheds. Due to these difficulties this research is focused on the potential use of Cosmogenic beryllium-10 (10-Be) as a sediment fingerprinting tool in post glacial Vermont. Cosmogenic 10-Be is a radio-active isotope that occurs naturally by spallation of nitrogen and oxygen in the earth's upper atmosphere; with a constant global precipitation rate. After deposition of 10-Be to the earth's surface it binds tightly to soil sediments, and is subsequently transported with soil sediments. Due to the testing facilities necessary to measure 10-Be concentrations this research also focuses on correlating 10-Be concentrations to other compounds that require less specialized testing facilities. The work is in progress and expected to finish by October 2009.

Approach

In order to evaluate the use of 10-Be for tracing sediment entering the Lake Champlain basin, the research approach is to collect and process suspended sediment samples from a suite of geomorphic/human impact settings. Samples are taken from three different high flow events, including the spring snow-melt during which the bulk of sediment transport occurs. Our testable hypotheses are: (1) 10-Be concentration in river-transported, fine-grain sediment reflects the 10-Be concentration in sediment sources weighted by the proportion of sediment derived from each source; and (2) sediment from different sources has different average concentrations of 10-Be.

Figure 1. Image of Winooski river basin and section of Lamoille River basin showing suspended sediment sampling points.

Watersheds were selected in the Lake Champlain basin located in north western Vermont with five sampling sites located in the Winooski River basin, one sub-watershed located in the Lamoille River basin, and one that flows directly into Lake Champlain (Figure 1). Care was taken to have a variable selection of stream sources that include both upland and lowland streams that were located in forested and agricultural corridors: two in the main stem of the Winooski River, two upland streams, two lowland streams, and one impaired waterway located adjacent to Lake Champlain. Samples were also collected from agricultural fields and streambank material from several of the stream corridors. This distribution of samples was designed to allow us to estimate both the mean and spatial/temporal variability of 10-Be concentrations in fine grain sediment.

Progress

A custom sampling unit was developed to collect in-stream samples of sediments. This apparatus is composed of a compressed sieve stack with sieve increments of 53, 73, 125, 250, and 500 µm, allowing simultaneous collection of four grain size fractions. To date 21 sample sets have been collected from the selected stream points during high flow events. In order to test temporal variability of 10-Be, with minimal storm event influence, five sediment sample sets were collected at the mouth of the Winooski River during the spring melt. In addition to suspended sediment samples a series of samples have been collected from bank material and agricultural fields in the sample streams' corridors. All samples have been dehydrated and stored ready for the beryllium extraction process.

Future work

All sediment samples have now been collected and catalogued and are ready for beryllium extraction process prior to testing for 10-be concentration at Lawrence Livermore National Laboratory. Future efforts will include correlating other sediment bound compounds specifically aluminum and ferric oxides to 10-Be concentrations. For that purpose a standardized citrate-bicarbonate-dithionite extraction will be performed on the larger of sediment samples collected. Concentrations of iron and aluminum oxides will then be measured using ICP mass spectrometry and compared to 10-Be concentrations.

Values collected from testing will yield concentrations of 10-Be, iron, and aluminum oxide compounds of the various grain size fractions for both the suspended sediment and corridor material samples. Each individual concentration will then be analyzed looking at the concentrations specific to each suspended sediment and corridor material grain size fraction, noting variations in the concentrations based on the stream type sampled and the grain size analyzed. Temporal variation will be observed during the spring melt event at the main stem of the Winooski River. Variation between the spring, summer, and fall sample sets will be calculated using a paired t-test statistical analysis. Results from these analyses will suggest if 10-Be has potential use for fingerprinting suspended sediments, and if sediment sources change during different types of flow events.

Student Training

Jaron Borg has been working on this project and this research is a part of his M.S. thesis. The PIs, Mandar Dewoolkar and Paul Bierman, have been meeting with Jaron regularly. A journal paper is anticipated once the research is concluded. Jaron made a presentation on this topic in Civil and Environmental Engineering seminar series.

Soil phosphorus landscape variability and soil mapping in a stream

Basic Information

Title:	Soil phosphorus landscape variability and soil mapping in a stream
Project Number:	2008VT35B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Nutrients, Non Point Pollution, Water Quality
Descriptors:	
Principal Investigators:	Donald Ross, Eric Young

Publication

1. Young, E., O., D.S. Ross, C. Alves, and T. Villars. 2009. Influence of soil series on phosphorus forms and availability at two riparian sites in the Lake Champlain Basin (Vermont). In revision.

1. **Title: Soil phosphorus landscape variability and soil mapping in a stream corridor of the Northern Lake Champlain watershed: FINAL REPORT**

2. Project Type: Research

3. Focus Categories: Nutrients, Nonpoint source pollution, water quality

4. Research Category: Water Quality

5. Keywords: soil phosphorus, soil mapping, spatial variability, soil-landscape, P transport

6. Start date: March 6, 2008

7. End date: March 5, 2009

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9. Congressional District: Vermont-at-large

Abstract

Sediment and associated phosphorus (P) inputs from agriculture and stream bank erosion can be major contributors of P loading to Lake Champlain. Soil properties impose important physical and chemical constraints on P mobilization in riparian zones. Our previous research demonstrated that total and plant-available P can vary significantly among riparian soil series in northwestern Vermont. For this project, we remapped a 10 ha riparian site located along the Rock River in Franklin County Vermont in cooperation with USDA-NRCS soil scientists. The objective was to characterize the degree of spatial variation in soil P and determine the relationship to soil series. The research site was selected based on feedback from Julie Moore, Director of Vermont's of Clean and Clear program. For the soil P analysis, samples were collected from eight transects established roughly perpendicular to both the river and topographic contours. A minimum of four depth intervals (0-15, 15-30, 30-45, and 45-60 cm) were collected at seventy one locations and analyzed for total P, soil test extractable P (e.g., Modified Morgan's) and metal cations, pH, organic matter content, and soil texture.

Results showed that compared to the soil survey map (1:20000), the higher resolution mapping (approximately 1:4000) more accurately reflected the drainage class and soil series variability across the site. However, the delineation of stream bank soils did not change substantially. Both total and soil test P varied significantly across the site. The poorly drained soils (Limerick and Scantic) had greater total and soil test extractable P compared to the moderately well drained Buxton series. While there were significant P differences among the soils, there was also considerable spatial variation within series. For example, the Buxton series had greater total P at the lowest sampling depth (45-60 cm) and Limerick had significantly greater total P in the surface horizon (0-15 cm), while there were no total P differences among depths for the Scantic series. Soil texture showed only weak relationships with both total and soil test P concentrations. The best individual predictor of total P was the amount of total calcium (Ca), similar to our previous findings, indicating the importance of parent material and legacy sediments on total P content. Soil pH, total Ca content, total P, and clay content showed strong spatial autocorrelation at most depths, whereas soil test P and organic matter content had lower autocorrelation. Ordinary kriging revealed broadly similar spatial patterns for total P, total Ca, pH, and soil test P and reflected the transition in soil series characteristics across the landscape. Organic matter decreased significantly with depth, while clay content tended to increase. Average soil test P concentrations tended to be greater at the upper sampling depths (Ap and B horizons) compared to lower in the profile (B and B/C horizons). The quantity of soil test P measured depended on whether it was defined as that measured by molybdate colorimetry or ICP. On average, P measured in the Morgan extract by ICP was 70% greater than that measured by molybdate reaction. Soil organic matter content was highly correlated with the P difference between the methods, suggesting the importance of soluble organic P forms in the soils. Results show that soil series influenced the concentration and forms of soil P found in the floodplains. Results demonstrate that soil maps could be beneficial as an indicator of the expected range of soil P at this site and probably others in northwestern Vermont. The application of improved soil mapping tools (e.g., LIDAR and other geospatial tools) in combination with additional targeted sampling and more sophisticated modeling will lead to improved technology for prioritizing river management practices aimed at P mitigation.

Introduction

Nonpoint sediment and P sources are the largest contributors to surface water quality impairments in VT (VT DEC, 2002). Though research has identified various P sources within watersheds, there is still a need to identify P sources and landscape processes in the basin that affect P fate and transport. While some studies have investigated the effects of best management practices on P in agricultural settings, few have focused explicitly on P dynamics in riparian zones. Based on geomorphic assessment of more than 700 miles of VT stream reaches, it is estimated that 75% of the assessed reaches are eroding due to floodplain loss (VT DEC, 2007). There is a clear need for an improved understanding of the soil, sediment, and hydrologic dynamics of riparian zones to further water quality management efforts in VT.

Although streambank erosion can be an important P contributor in VT watersheds, it is currently poorly characterized. Since actual P fluxes from erosion depend on P source (e.g., amount and solubility of soil P) and transport factors (e.g., hydrodynamics and soil physical properties), estimating losses is difficult. DeWolfe et al. (2004) studied sediment and P contributions from stream bank erosion along ten reaches in the Lake Champlain Basin. There was little variation in eroded sediment total P concentration found, but the variation in erosion rates among sites was high. They found an average total P of 613 mg/kg in samples from 10 reaches, concluding that streambank erosion can be a significant source of sediment-bound P, and that it could be the largest P source for some river reaches.

Previous research by the current study's PI's (supported by the UVM Water Resources and Lake Studies Center) showed that both total and soil test P varied significantly among commonly mapped floodplain series in VT (Young et al., under revision). Results showed that total P tended to be greater in the more imperfectly drained, finer-textured soils. We also showed that soil mapping in floodplains can be subject to considerable error primarily due to: (i) the scale at which the mapping was originally performed, (ii) the inherent variability of floodplain soils, and (iii) the fact that there are now more soil series that closely match the soils in the field. Experiments conducted as part of this work also showed the importance of organic P in the soils. Much work remains to better understand source and transport aspects of watershed P management.

Methods

A 10 ha riparian site along the Rock River in Franklin County, Vermont was selected for remapping and soil sampling for P analysis based on consultation with Julie Moore, Director of Vermont's of Clean and Clear program. Soils at the sites are comprised of glacio-lacustrine sediments and alluvium in the floodplain (Flynn and Joslin, 1979). The site is located on a private dairy farm along a section of the Rock River (Fig. 1). The riparian buffer and floodplain are dominated by grasses and forbs in the floodplain and by forest to the north. Slopes are low to moderate.

The 10 ha area was surveyed and remapped by UVM and NRCS soil scientists in July 2008 (Fig. 1). The new map unit delineations were hand-drawn based on field profile sampling and interpretation of stereo imagery, and subsequently digitized. Soil samples were collected from eight transects established roughly perpendicular to both the river and topographic contours. Sampling points within transects were spaced from 20 to 30 m. A minimum of four depth intervals (0-15, 15-30, 30-45, and 45-60 cm) were collected from each of 71 transect points (Fig. 2). All samples were analyzed for total P, soil test extractable P (e.g., Modified Morgan's, an estimate of *soil solution* P) and metal cations, pH, organic matter content, and soil texture. Total P and metal cations were determined by nitric acid digestion in a microwave accelerated reaction system. Extracts were diluted and P and metals were measured by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP) using standard techniques. Soil test P and cations were determined by extraction (1:5) with ammonium acetate buffered at pH 4.8 (Modified Morgan's) (McIntosh, 1969). Phosphorus in the extract was measured by a spectrophotometer with the molybdate stannous chloride method and by ICP. Organic matter was determined by loss on ignition.

Statistical Methods

Soil P and other soil chemical and physical properties were evaluated for spatial autocorrelation using semivariogram analysis with the GS+ geostatistical package (Gamma Design Software, Plainwell, MI). Separation distances used for semivariogram models were between 200 and 240 m with the lag distance class set at 20 m. The general procedures outlined by Burrough (1991) were followed in modeling semivariance and variogram construction. Ordinary kriging was used to estimate total P, total Ca, soil test P, and pH at unsampled locations. The usefulness of the spatial models was evaluated by plotting measured versus predicted values. Analysis of variance was used to test soil P differences among the soil series (SAS, 1999). The general linear model procedure was used to test the effect of series and sampling depth on P concentrations. Least square means were separated by *a priori* linear contrasts. Correlation and regression were used to evaluate linear relationships among select variables.

Results and Discussion

Mapping

Results showed that compared to the soil survey map (1:20000), the high intensity soil map (approximately 1:4000) more accurately reflected the drainage class and soil series variability across the site (Fig. 1). The soil survey had the site mapped as Munson (somewhat poorly drained marine silt over clay), Scantic (poorly drained lacustrine silt loam), and Limerick (poorly drained alluvial silt loam). After the remapping, it was determined that the Munson characteristics in the field more closely matched Buxton (moderately well drained lacustrine lowland soil). Although one series changed by a drainage class and the delineations of Scantic and Limerick series was improved, the remapped floodplain delineation (Limerick) did not change substantially from the original soil survey.

Previous research also showed that soil mapping in floodplains can be subject to error due to: (i) the scale at which the mapping was originally performed, (ii) the inherent variability of floodplain soils, and (iii) the fact that there are now more soil series that may more closely match the soils in the field. Although discrepancies were found between the soil survey map and the high order remapping, this would not have influenced the use of soil maps for determining the type of stream bank/riparian soils at the site. However, we caution that these discrepancies may or may not be consistent throughout the Rock River corridor. A much larger mapping effort is required to evaluate the accuracy of the soil survey mapping in the Rock River watershed.

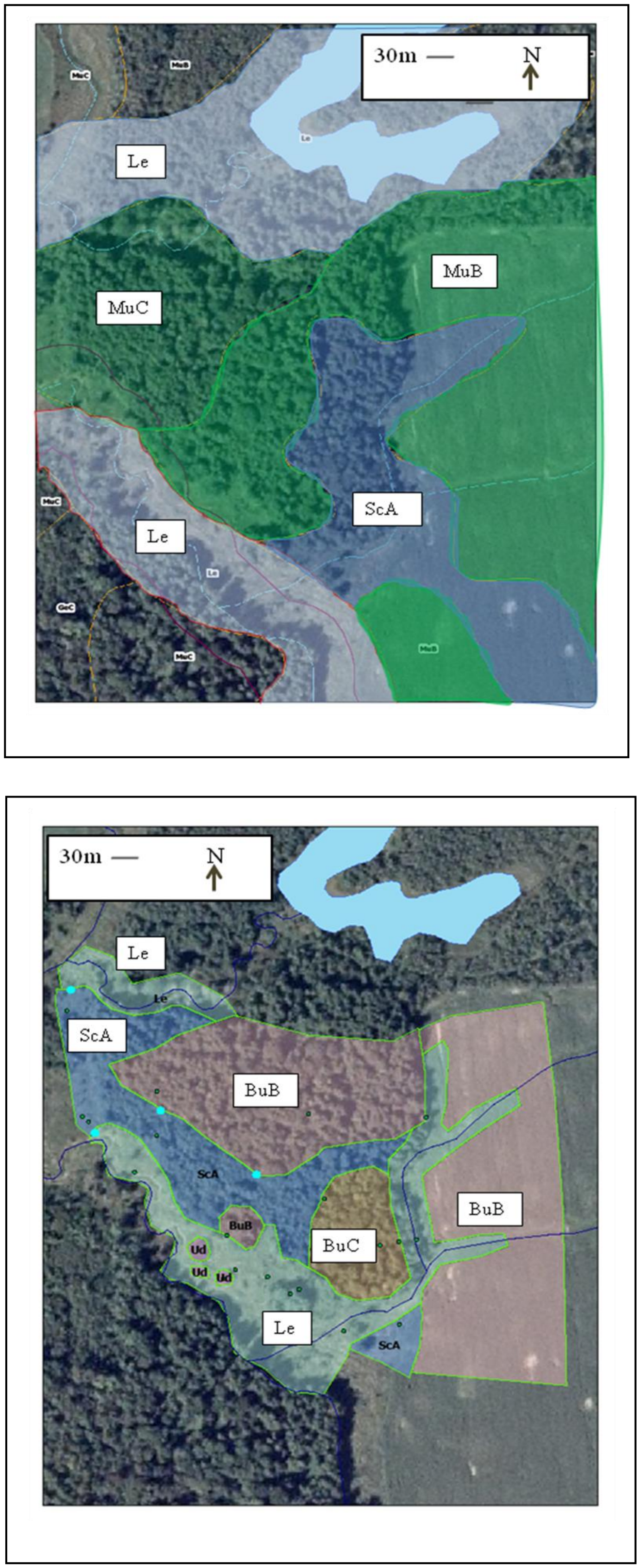


Figure 1. Soil survey map (mapped at 1:20000) (a) and the first order remapping (mapped at approximately 1:4000) (b) of the research site. Bu = Buxton, Le = Limerick, Sc = Scantic.

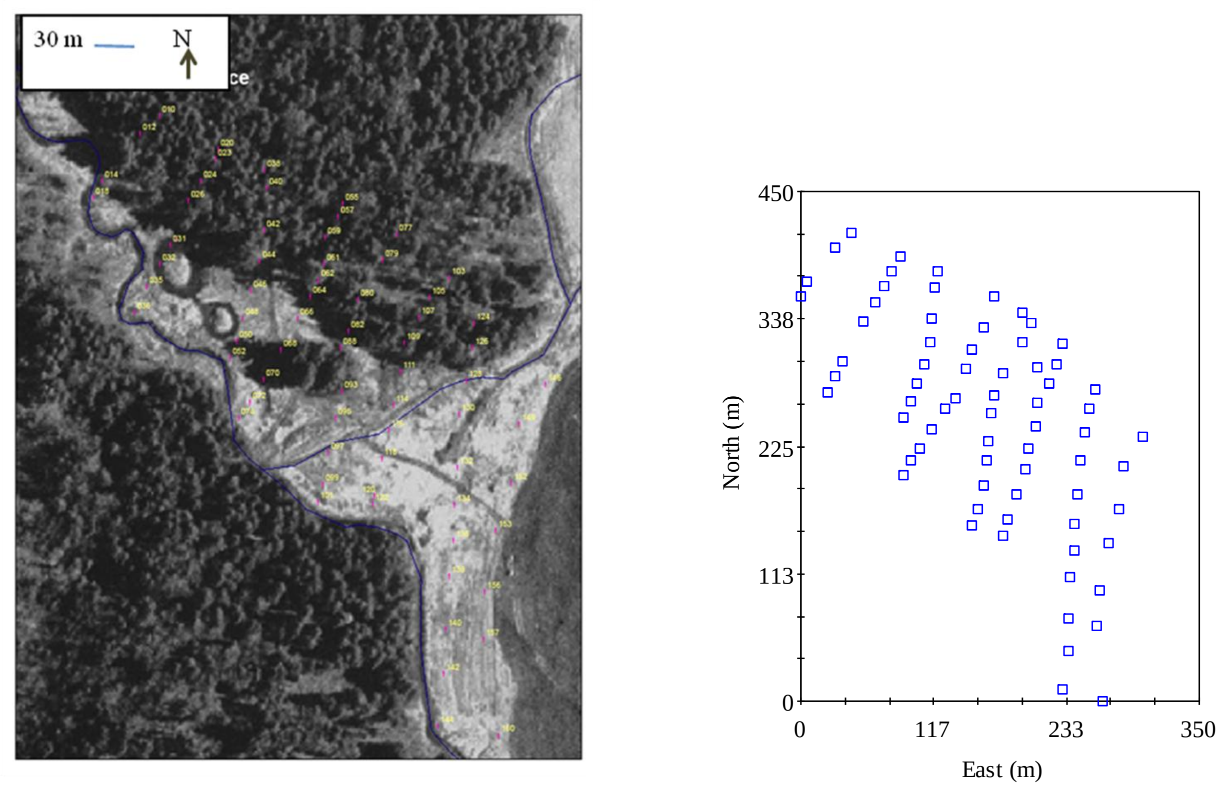


Figure 2. Location of transects and soil sampling locations at the Rock River site.

Soil Phosphorus Concentrations and Site Variability

Total P concentrations had a range of over 1300 mg/kg, while soil test P ranged from 1 to over 14 mg/kg. Analysis of variance showed that series and depth influenced total and soil test P concentrations. Of the three series described at the site, the Limerick had the greatest average total and soil test P concentrations (Tables 1 and 2). At the 0-15 cm depth, Limerick had a total P concentration of 792 mg/kg, which was significantly greater ($P \leq 0.01$) than all other depth by series combinations (Table 1). We found a similar average total P concentration for 0-15 cm and 15-30 cm Limerick samples (787 mg/kg and 695 mg/kg, respectively) that were collected at a riparian site along Rugg Brook in St. Albans. This suggests that the Limerick soil, an important soil due to its prevalence in VT floodplains, may have a predictable range of total P which could allow the use of soil maps to estimate total P for floodplains mapped as Limerick (assuming the maps are relatively accurate given riparian site).

Soil test P concentrations were also greatest for the Limerick series. At the lower three depths, mean soil test P concentrations in Limerick were greater than concentrations in the other two soils (Table 2). The Limerick and Scantic soils had significantly greater soil test P concentrations in their surface horizon compared to the lower profile depths (Table 2). The soil test P concentrations found at this Franklin County site were slightly greater than the average concentrations in the Limerick sampled at the Rugg Brook site (0.80 to 1.5 mg/kg).

Table 1. Mean total P concentration among the three soil series at the site.

Series	Depth interval	*n*	Mean total P	SEM*
	cm		mg/kg	
Buxton	0-15	12	329 a**	52
Buxton	15-30	14	301 a	32
Buxton	45-60	14	427 a	32
Buxton	60-75	14	578 b	38
Limerick	0-15	37	792 a	32
Limerick	15-30	37	689 b	39
Limerick	45-60	37	645 b	32
Limerick	60-75	34	657 b	34
Scantic	0-15	20	654	71
Scantic	15-30	20	588	44
Scantic	45-60	20	639	44
Scantic	60-75	20	623	45

*Standard error of the mean

** Means within a series with different letters are significantly different at $P \leq 0.05$

Table 2. Mean soil test total P concentration among the three soil series at the site.

Series	Depth interval	*n*	Mean soil test P	SEM*
	cm		mg/kg	
Buxton	0-15	12	1.3	0.4
Buxton	15-30	14	1.0	0.4
Buxton	45-60	14	1.0	0.4
Buxton	60-75	14	0.90	0.4
Limerick	0-15	37	2.9 a**	0.2
Limerick	15-30	37	1.7 b	0.2
Limerick	45-60	37	1.6 b	0.2
Limerick	60-75	34	1.9 b	0.2
Scantic	0-15	20	2.7 a	0.3
Scantic	15-30	20	1.3 b	0.3
Scantic	45-60	20	0.91 b	0.3
Scantic	60-75	20	0.94 b	0.3

*Standard error of the mean

** Mean depths within a series with different letters are significantly different at $P \leq 0.05$

Total soil P concentrations (for all locations and depths) were weakly correlated with pH (*r* =0.24, *P*<.01), soil test Ca (*r* =0.34, *P*<0.001), soil test P (*r* =0.37, *P*<0.001), and organic matter content (*r* =0.24, *P*<.01). Similar to previous findings in floodplain soils, there was a strong positive correlation between total P and total Ca (*r* =0.72, *P*<0.0001) (Fig. 3). This relationship suggests that Ca phosphate compounds (e.g., apatites, octacalcium phosphate, and/or organic Ca-P complexes) are probably contributing largely to the total P pool of the soils.

Soil pH was significantly correlated with both total and soil test Ca (Fig. 3). Clay, silt, and sand contents showed some degree of spatial autocorrelation (data not shown), but were weakly correlated with total P concentrations (*r* < 0.19). This suggests that factors affecting native soil Ca levels could be more important than factors such as organic carbon and texture in controlling native P fertility in lacustrine silt loams such as those found at this site, and underscore the important influence of parent material and legacy sediments on soil P contents.

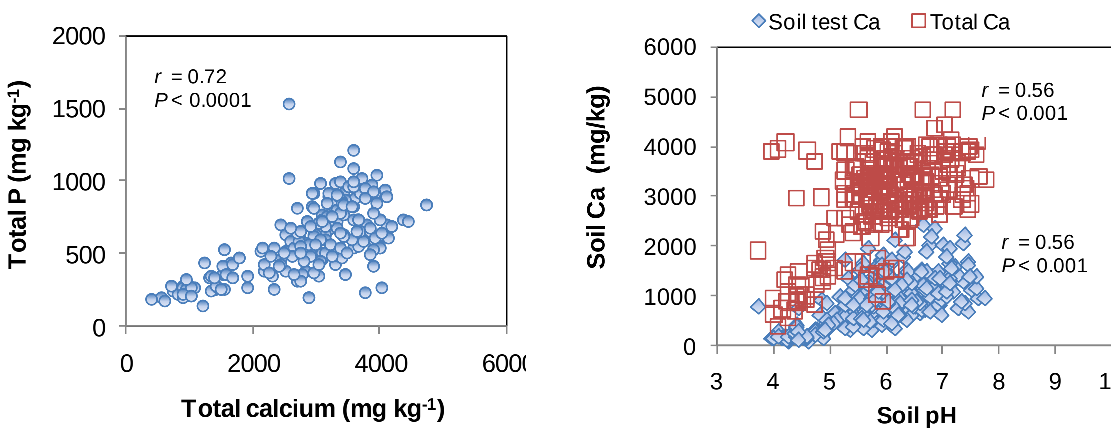


Figure 3. Relationship between total Ca and total P for all samples collected at the site.

Total P (log transformation) showed significant autocorrelation but krigged values related poorly to measured values (Fig. 4). Despite the poor agreement between measured and predicted total P values, the pattern suggested a similar distribution to that of Ca and pH (Figs. 4, 5, and 6). There was better agreement between measured and predicted values for pH and total Ca (square root log transformed) compared to total P. The relatively weak agreement between measured and estimated values in general conveys the high variability at the site, but krigged estimates for pH, total Ca and total P broadly reflected the transitions in soil series from the Buxton (upper landscape positions, lower pH, and moderately well drained), to the poorly drained Limerick and Scantic (higher pH and much greater native P fertility). In general, the deeper sampling depths showed broadly similar trends for pH and Ca (data not shown). Spatial variation in pH and total Ca reflect differences in parent material, and probably the native differences in calcium carbonate deposition from former marine waters. Historical erosion and deposition of legacy sediments along the floodplain have also likely contributed to variation in the total Ca and P pools of the soils. The eastern transect was on the edge of a cornfield, and the higher predicted Ca and pH in this area probably reflects some past lime inputs.

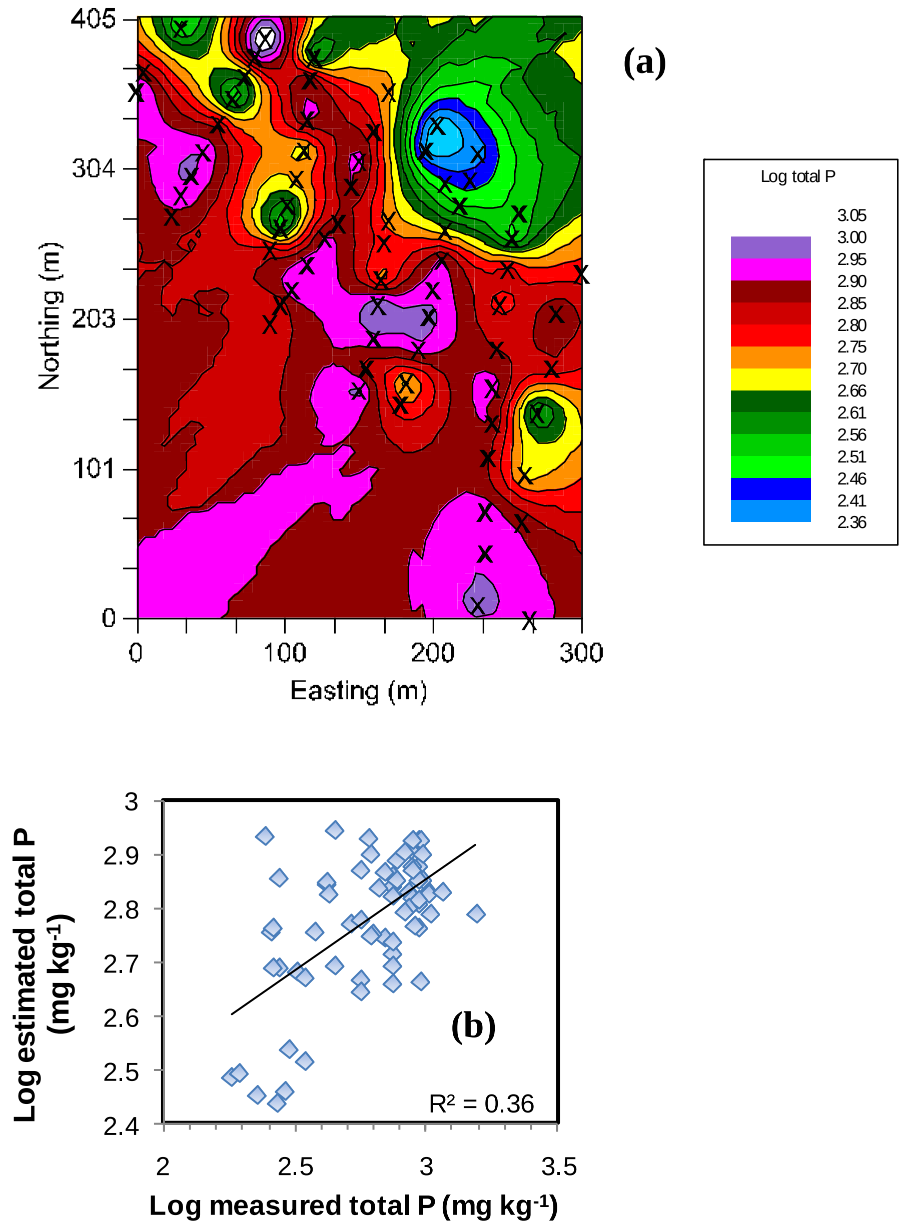


Figure 4. Estimated total Ca concentrations (square root transformed) at the site for the 0-6 cm sampling depth (a), and the linear relationship between measured and krigged total P values.

It is important to note that the stream location is not pictured on the krigged maps of total P, Ca, and pH. Each of the southernmost transect points was located within one m of the stream bank and thus defines the relative location of the stream. As can be seen by map of the estimated standard deviations for total Ca, the precision of the estimates drops fairly rapidly with distance from the transect. From a practical standpoint, krigged estimates for any of the variables beyond the stream bank to the south should not be considered realistic.

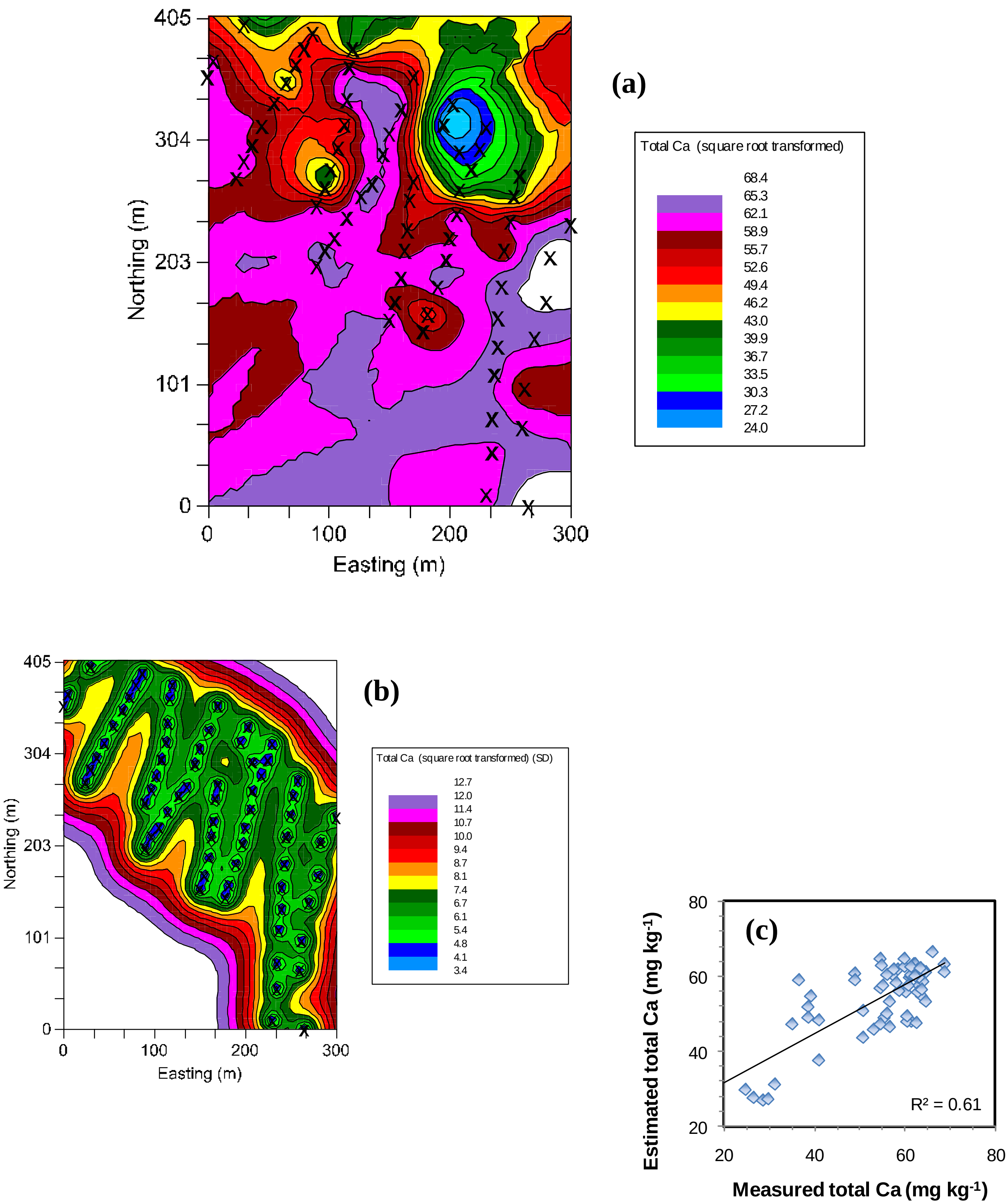
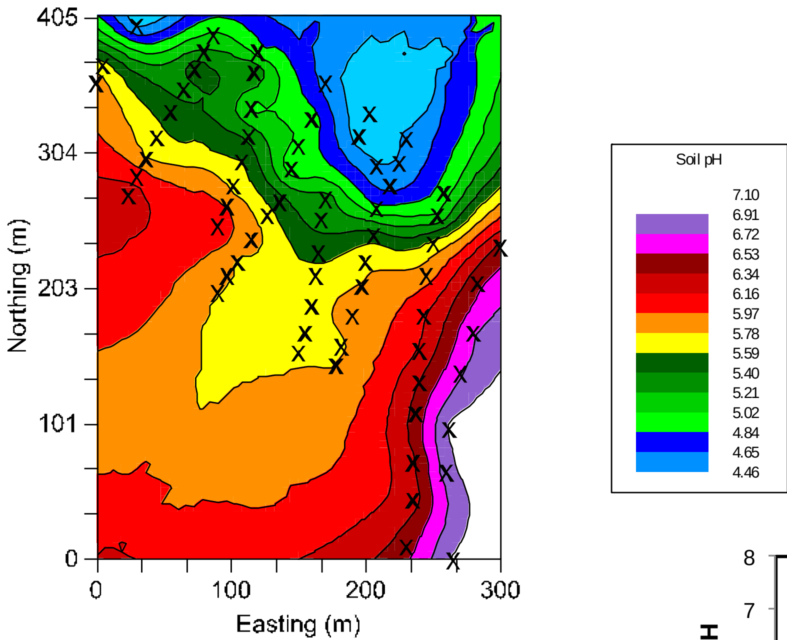


Figure 5. Krigged estimates (a) and standard deviations of the estimates (b) for total calcium and the relationship between measured and estimated total Ca values for 0-6 cm samples (c).



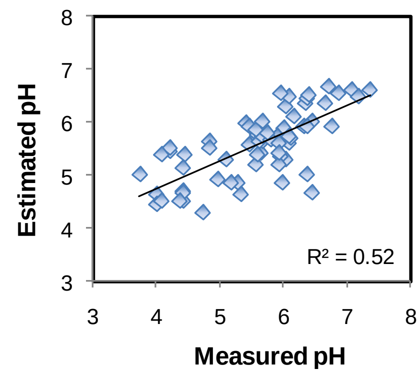


Figure 6. Krigged estimates for soil pH (a) and relationship between measured and krigged pH values for 0-6 cm samples (b).

The relationship between P fertility and soil Ca is not surprising. Calcium carbonate contains varying amounts of P and in some cases can be associated with apatite and other Ca-P compounds. Phosphorus also tends to be more readily available in the soil solution when pH values are closer to neutral, which is the case with the Limerick and Scantic series. Although the relationship between measured and krigged estimates of soil test P was weak ($R^2 = 0.17$), the broad spatial pattern of soil test P (0- 6 cm) was similar to that of total P, pH, and Ca (not shown). Other depths also showed strong spatial dependency between total Ca and total P (data not shown).

Soil Test P Differences Based on Measurement by ICP or Molybdate Colorimetry

The quantity of soil test P measured depended on whether it was defined as that measured by molybdate colorimetry or that measured by ICP. Several researchers have noted differences between soil test P values depending on whether extracts were measured by molybdate colorimetry (e.g., measured by absorbance on a spectrophotometer) or by ICP. While extracts measured by ICP should not be considered an estimate of total P, (Pierzynski et al., unpublished data), the high temperature plasma environment (10,000 K) can convert some organic P forms to inorganic P. Based on a linear regression ($R^2 = 0.70$), P measured in the Morgan extract by ICP was about 70% greater on average than that measured by molybdate reaction (data not shown). While organic matter content was a weak predictor of soil test P measured by colorimetry, it was a good predictor of soil test P measured by ICP (Fig. 7). In addition, soil organic matter content was linearly related to the difference in P between the ICP and colorimetric method (Fig, 7). This is an interesting finding and suggests the importance of organic P forms in these soils. Other research has shown that individual soil calibration studies may be required to account for the differences between soil test P measured by ICP and color methods (Mallarino, 2003). In our study, average soil test P measured by ICP was substantially greater than P measured by colorimetry. These differences have practical significance and would result in much different agronomic and environmental interpretations. We have also recently demonstrated that greater than 50% of the P extracted by NaOH-EDTA in 0-6 cm samples from the Lewis Creek and Rugg Rook riparian soils was organic as measured by ^{31}PNMR. In addition, about 70 % of the total water-extractable P in the same soils was unreactive P (organic and complex inorganic P), about half of which was hydrolyzed to orthophosphate by phosphatase enzymes (unpublished data). Collectively, these data illustrate the importance of organic P transformations in these soils and the need to develop better methods to estimate organic P release and bioavailability.

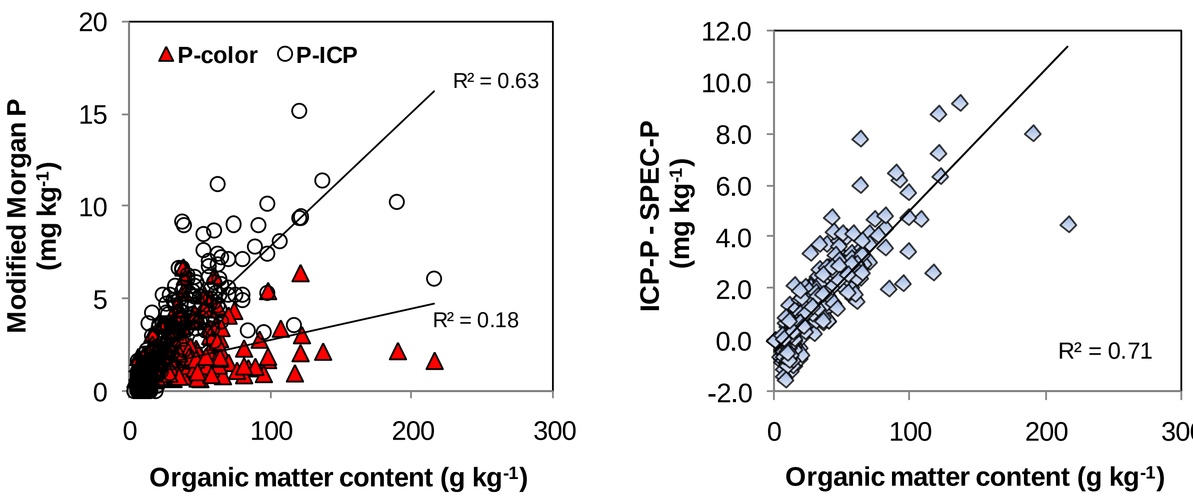


Figure 7. Relationship between soil organic matter content and soil test P as measured by either molybdate colorimetry or ICP for all samples (a), and the relationship between soil organic matter and the difference in soil test P between ICP and colorimetry (ICP-P – Color-P).

Conclusion

Results show that soil series variability significantly influenced the concentration and form of soil P found in the floodplain. The high order soil remapping of the riparian site provided a more exact depiction of soil variability at the site, but did not substantially change the mapping of the immediate floodplain. Soil P concentrations at this site were highly correlated with soil Ca content, confirming the importance of parent material and legacy sediments on the P content of floodplain soils. Results demonstrate that soil maps could be beneficial as an indicator of the expected range of soil P at this site. Additional soil map verification and sampling at multiple sites is needed to develop more robust estimates of soil P for a given series in the Northern Lake Champlain watershed. The application of improved soil mapping tools (e.g., LIDAR and other geospatial tools), in combination with additional targeted sampling and more sophisticated modeling techniques, should lead to improved technology for prioritizing river management practices aimed at minimizing P loading from bank erosion.

Other Soil and Phosphorus Data in the Rock River Watershed

In addition to the samples taken at this site for this study, additional soil samples were taken and series descriptions performed by USDA-NRCS and UVM scientists during the 2008 field season. Soil samples from ten sites were taken from different locations in the watershed and sent to the National Soil Survey Laboratory for detailed chemical and physical anlaysis. Several different types of extractable P tests will be also be performed and all the data will eventually be available on-line and free to the public. Contact Caroline Alves (USDA-NRCS) for further information.

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Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability

Basic Information

Title:	Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability
Project Number:	2008VT36B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Sediments, None, None
Descriptors:	None
Principal Investigators:	Jane Hill

Publication

1. Hill, Jane, 2009. Spatial and temporal timing of organic phosphorus transformation under till and no-till conditions for a poultry manure-applied Vermont soil. In Preparation.
2. Hill, Jane. 2008. Lake Champlain Watershed: from the Missisquoi Bay to the Lake (Poster; October 2008)
3. Hill, Jane. 2009. Oral presentation accepted for the American Chemical Society annual meeting August 16, 2009 in Washington D.C. (session: organic phosphorus transport, fate, and impact on the Chesapeake Bay).

VERMONT WATER CENTER ACTIVITY/ACCOMPLISHMENT DESCRIPTIONS

Project: Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability

PI(s): Jane Hill

Research Performance Metrics

R1. Faculty participation in water research projects

Title: Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability

Narrative:

Microorganisms alter the forms of phosphorus in soils and sediments over time. Some forms, such as orthophosphate, are more available to cyanobacteria and crop plants. We need to be able to measure phosphorus bioavailability in order to improve crop soil fertility as well as decrease the phosphorus in runoff from agricultural fields. Our present soil analysis methods for phosphorus forms are either very expensive or do not adequately reveal the amount of bioavailable phosphorus in the sample. This lack of knowledge hinders our ability to manage our agricultural soils and thus the watershed. In the past decade, scientists studying animal manures have developed a method for analyzing the bioavailable phosphorus in the manures using enzymes. The first objective of this study is to modify this enzymatic method so that it can be applied to characterize Vermont soil systems. The second objective of this study is to employ the new enzymatic method to a Vermont soil system within the Lake Champlain Watershed area, where we are most concerned about phosphorus pollution entering the Lake.

Number of faculty involved: 1

R2. Peer reviewed publications

(In preparation: spatial and temporal timing of organic phosphorus transformation under till and no-till conditions for a poultry manure-applied Vermont soil)

R3. Non-peer reviewed reports

None to report.

R4. Professional and scholarly conference presentations.

1. Lake Champlain Watershed: from the Missisquoi Bay to the Lake (Poster; October 2008)
2. Oral presentation accepted for the American Chemical Society annual meeting August 16, 2009 in Washington D.C. (session: organic phosphorus transport, fate, and impact on the Chesapeake Bay)

R5. Research conferences/symposia organized by the institute

None to report.

R6. External grants and contracts

None to report.

R7. Research awards and other recognitions

None to report.

R8. Patents and copyrights granted

None to report.

Educational Performance Metrics

E1. Water-related degrees awarded

None to report.

E2. Post-graduate placement in a water profession

None to report.

E3. Student support on water research grants

1. Nicholas Johnson, MS candidate (project title: Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability)
2. Joshua Tyler, BS candidate (project title: Improvement of Phosphorus Load Estimates through the use of Enzyme-Hydrolysis Measures of Phosphorus Bioavailability)

E4. Student awards for water research, teaching, or service

None to report.

E5. Water teaching assistants

None to report.

E6. Student attendance at professional water conferences

1. Lake Champlain: Our Lake, Our Future (Lake Champlain Research Consortium; 2 students, January 2008)
2. Lake Champlain Watershed: from the Missiquoi Bay to the Lake (Ad hoc research group; 2 students, October 2008)
3. Oral presentation accepted for the American Chemical Society annual meeting August 16, 2009 in Washington D.C. (1 student, session: organic phosphorus transport, fate, and impact on the Chesapeake Bay)

Outreach Performance Metrics

O1. Publications (e.g., fact sheets, newsletters, etc.)

Reflections on Water submission, Spring *2009*

O2. Training seminars and workshops

Fall 2008, Phosphorus in the Watershed. A 12 week, 3 credit class on how to assess the fate of phosphorus in a watershed from the macro (e.g., watershed) to micro (e.g., sediment water interface) contexts. 12 students were enrolled in the class.

O3. Technology and BMP demonstrations

None to report.

O4. Technology transfer activities

None to report.

O5. Water planning activities (field trips, water tours, etc.)

Canoe field trip with students of the Phosphorus in the Watershed class from Charcoal Creek to Campbell Bay (October 2008)

O6. Meetings with external advisory board

None to report.

O7. Website hits

Data not collected.

O8. Service on water committees and task forces

None to report.

Information Transfer Program Introduction

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center produces a web-based newsletter that highlights emerging research funded by the Center or relevant to water resources management in Vermont. The Director of the Water Center sits on the Lake Champlain Basin Program's Technical Advisory Committee (TAC) and regularly brings information from Center-funded projects to the attention of the TAC. The Center regularly supports seminars, workshops, and conferences relevant to water resources management issues in Vermont. Examples include specialty workshops designed to showcase emerging results from Center-funded projects. At other times the Center supports meetings that address topics that are directly relevant to the Center's mission. An example of this type of meeting is the 2008 conference entitled Our Lake, Our Future, which focused on current research that addresses key issues facing sustainable management of Lake Champlain and its basin. The Center has long advocated for this type of meeting and is actively involved in planning for the next meeting in 2010. In addition, during the summer 2009 the Center will co-host two technical workshops with the Consortium of Universities for the Advancement of Hydrological Sciences, Inc. (CUAHSI): one on serving hydrologic data over the web and another on innovative new optical sensors for use in biogeochemical studies of streams and lakes. Planning for these workshops has been ongoing in 2008 and 2009; we will report more fully on the outcomes of the workshops in the 2009 Annual Report next year. Over the next few years there will be a number of important opportunities for the Water Center to support other types of information transfer meetings. In particular, during 2009 the Lake Champlain Basin Program will seek guidance to update Opportunities for Action, a fundamentally important document that guides research and implementation projects focused on managing Lake Champlain and surrounding landscapes. The Water Center will help support meetings that are essential to gather expert and stakeholder input for this critical document.

Information Transfer Activities

Basic Information

Title:	Information Transfer Activities
Project Number:	2008VT39B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	First
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Breck Bowden

Publication

Information Transfer Section

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center produces a web-based newsletter that highlights emerging research funded by the Center or relevant to water resources management in Vermont.

The Director of the Water Center sits on the Lake Champlain Basin Program's Technical Advisory Committee (TAC) and regularly brings information from Center-funded projects to the attention of the TAC.

The Center regularly supports seminars, workshops, and conferences relevant to water resources management issues in Vermont. Examples include specialty workshops designed to showcase emerging results from Center-funded projects. At other times the Center supports meetings that address topics that are directly relevant to the Center's mission. An example of this type of meeting is the recently concluded conference entitled *Our Lake, Our Future*, which focused on current research that addresses key issues facing sustainable management of Lake Champlain and its basin. The Center has long advocated for this type of meeting and will promote and support meetings like it in the future.

Over the next few years there will be a number of important opportunities for the Water Center to support other types of information transfer meetings. In particular, during 2009 the Lake Champlain Basin Program will seek guidance to update *Opportunities for Action*, a fundamentally important document that guides research and implementation projects focused on managing Lake Champlain and surrounding landscapes. The Water Center will help support meetings that are essential to gather expert and stakeholder input for this critical document. Finally, 2009 will also mark the quadricentennial celebration of the discovery of Lake Champlain by Samuel de Champlain. Considerable planning is currently underway nationally and internationally (with the Province of Quebec) for this celebration. A substantial portion of this year-long focus on Lake Champlain will be devoted to an assessment of what we currently know and what we need to know to ensure the sustainable health of the lake and its environment for the next 400 years. The Water Center will actively participate in and support at least some of these activities.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	0	0	0	0	0
Masters	4	0	0	0	4
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	4	0	0	0	4

Notable Awards and Achievements

The Vermont Water Resources and Lake Studies Center partnered with the Lake Champlain Research Consortium and other state, regional and national partners to host a conference entitled “Lake Champlain: Our Lake, Our Future”. The conference drew nearly 200 researchers, managers, and policy makers from Vermont, New York and the province of Quebec, Canada, who have an interest in protecting the resources of Lake Champlain and its basin. Conferences sessions focused on nutrient loading, hydrodynamics, algal blooms, mercury deposition, invasive species, wildlife ecology, and watershed management. This conference was part of a continuing dialogue on research needs in support of management objectives that will support a strong economy, an enjoyable place to live, and a sustainable environment.

Dr. Donna Rizzo from the School of Engineering and Dr. Leslie Morrissey from the Rubenstein School of Environment and Natural Resources and their students at the University of Vermont have been working with the River Management Program in the Vermont Agency of Natural Resources on a project co-funded by the Vermont Water Resources and Lake Studies Center to identify improved methods to quantify geomorphic change in rivers using remote sensing tools. These new methods will be used to help identify flood hazards differs substantially from conventional approaches currently in use. The research tem is using advanced mathematical approaches patterned on the way the brain works – artificial neural networks – and high resolution satellite images to enhance GIS-based tools that are currently used by watershed managers in Vermont to characterize sensitivity of rivers to future flood threats, based on historic flood patterns and contemporary development and land use patterns.

Dr. Jane Hill and her students in the School of Engineering at the University of Vermont have been working with the Vermont Agency of Natural Resources on a project co-funded by the Vermont Water Resources and Lake Studies Center to develop more accurate methods to estimate the amounts of phosphorus in agricultural soils that might migrate to streams and lakes. Phosphorus is a byproduct of agricultural and urban activity that can lead to uncontrolled growth of undesirable algae in lakes. Unsightly and potentially dangerous algal “blooms” have been a problem in some parts of Lake Champlain in recent years and excess phosphorus is thought to be a critical factor supporting these uncontrolled outgrowths. The new methods under development are based on enzymes that may reveal the amounts of phosphorus in soil that are potentially biologically available to algae for growth.

Dr. Sarah Lovell Taylor in the Department of Plant and Soil Science and Dr. Alan McIntosh in the Rubenstein School of Environment and Natural Resources and there students at the University of Vermont have been working with the Lintilhac Foundation and Shelburne Farms to demonstrate innovative new ways to management of farm runoff. Shelburne Farms is a not-for-profit operational farm and educational organization whose mission is to serve as a model of environmental stewardship by demonstrating new ecological, practical, and cost-effective remediation strategies that will improve the water quality of runoff to Lake Champlain. With co-funding from the Vermont Water Resources and Lake Studies Center a bioretention system designed to treat runoff from the dairy barnyard source area is being installed. This project will be used to educate the public about opportunities to improve the health of Lake Champlain through innovative, yet practical solutions for stormwater management on farms.

Dr. Don Ross and his students in the Department of Plant and Soil Science at the University of Vermont are working with soil scientists from the US Department of Agriculture Natural Resources Conservation Service and the Vermont Agency of Natural Resources Clean and Clear Program with co-funding from the Vermont Water Resources and Lake Studies Center to develop high resolution mapping tools for floodplain soils. These new tools are expected to provide a more accurate representation of the variability in soil chemical characteristics and drainage compared to information provided in standard soil surveys. This information is critical to help design remediation projects that will reduce phosphorus and sediment inputs from streambank erosion that subsequently impair downstream water resources.

Dr. William “Breck” Bowden, project manager Meredith Curling, and a team of undergraduate students in the Rubenstein School of Environment and Natural Resources at the University of Vermont have been working with Vermont Agency of Natural Resources Stormwater Section to collect precipitation and discharge data for a set of previously ungauged streams, half of which are listed by the state as being impaired by stormwater and half of which currently attain the state’s existing biocriteria standards. This data will be used to document the degree to which the flow regime of stormwater-impaired streams differs from streams that are not impaired. It will also be used to monitor progress of the state’s stormwater discharge permit system toward flow reduction targets that have been designed to improve the health of the state’s stormwater-impaired streams.