Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2006

Introduction

The Annual Report for the Vermont Water Resources and Lake Studies Center for FY2006 is attached. The grant awarded under the State Water Resources Research Institute Program is 06HQGR0123.

Research Program

In the 2006-2007 project year the Vermont Water Resources and Lake Studies Center entered into an exciting new collaboration with the River Management Program in the Department of Environmental Conservation (Vermont Agency of Natural Resources). In recognition of substantial state matching support provided by the River Management Program, the Vermont Water Center RFP for 2006 was 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 ANR/Water Center RFP were:

1. to advance scientific understanding that helps describe and 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. We sought proposals that would 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. A draft description of this conceptual model is posted on the web site for the Vermont Water Resources and Lake Studies center at (http://www.uvm.edu/envnr/?Page=vtwater/default.html). Suggested research areas of particular interest included proposals to:

A. collect new and/or use existing data to test the draft fluvial-geomorphic-based model currently being developed by the River Management Program and generate innovative new map products,

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 available to be mobilized by fluvial processes and represented in various alluvial soil classifications,

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, or

E. 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 VT DEC 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 projects to:

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

B. 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, or

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

One continuing and three new projects were recommended for funding, as follows:

1. Trophic Status of Lake Champlain over 400 years of Changing Land Use: A Paleolimnological Study. Andrea Lini (UVM Geology) and Suzanne Levine (UVM Rubenstein School). Continuing. 2. Phosphorus Availability from the Soils along Two Streams of the Lake Champlain Basin: Mapping, Characterization and Seasonal Mobility. Donald Ross (UVM Plant and Soil Science), Joel Tilley (UVM Plant and Soil Science), Eric Young (UVM Plant and Soil Science), Kristen Underwood (South Mountain Research and Consulting). Cooperators: Steven Gourley (NRCS), Caroline Alves (NRCS). New.

3. An Adaptive Management System Using Hierarchical Artificial Neural Networks and Remote Sensing for Fluvial Hazard Mitigation. Donna Rizzo (UVM Civil and Environmental Engineering), Leslie Morrissey (UVM Rubenstein School). New.

4. Riverbank Stability Evaluations: Comparing Quantitative Assessments to Qualitative RGA Scores Mandar Dewoolkar (UVM Civil and Environmental Engineering) and Paul Bierman (UVM Geology). New.

These projects are described in detail in subsequent sections of this proposal.

In addition to oversight of these projects, the Water Center continued to play a leadership role in evolving strategies for watershed management in Vermont. In particular, the Director worked with state, regional, and national stakeholders to identify opportunities to link science knowledge with decision making in water resource management and policy development. For example, the Director is also a managing co-PI for the EPA-funded project entitled Redesigning the American Neighborhood' (RAN), which focuses on helping community members identify opportunities to manage stormwater runoff using low-impact, ecologically-based designs. In his capacity as the Director, Breck Bowden has been able to negotiate several important contracts with partners in the Vermont Agency of Natural Resources, which build on the efforts initiated in the RAN project. These efforts include a project to develop a new framework for stormwater management in Vermont, a project to revise evolving methods to assess geomorphic conditions in Vermont streams to better account for urban stormwater impacts, and a project to monitor the effects of development on discharge in a set of 27 watersheds across the entire state of Vermont.

In addition to oversight of these research projects the Water Center continued to publish its e-newsletter in collaboration with the University of Vermont Sea Grant Program. All of these projects are relevant to key policy and management needs identified by local stakeholders. The Vermont Water Resources and Lake Studies Center continues to be a visible and trusted source of data and knowledge about these issues.

Trophic status of Lake Champlain over 400 years of changing land use: A paleolomnological study

Basic Information

Title:	Trophic status of Lake Champlain over 400 years of changing land use: A paleolomnological study
Project Number:	2005VT22B
Start Date:	3/1/2005
End Date:	2/28/2007
Funding Source:	104B
Congressional District:	First
Research Category:	Water Quality
Focus Category:	Water Quality, Nutrients, Sediments
Descriptors:	
Principal Investigators:	Andrea Lini, Suzanne Levine

Publication

1. Burgess, Heather D. 2007. Geochemical Indicators of Productivity Change in Lake Champlain, USA-Canada. MS Thesis, The University of Vermont, Burlington, VT. 191 pages.

Trophic Status of Lake Champlain over 400 years of Changing Land Use: A Paleolimnological Study

Second Year Progress Report

Andrea Lini, Geology Dept., University of Vermont
Suzanne Levine, Rubenstein School of Environment and Natural Resources, University of Vermont Burlington, VT 05405

Project Objectives:

The purpose of this project is to use paleolimnological techniques to uncover the history of Lake Champlain's response to changing land use and eutrophication since European settlement. Our intent is to obtain and analyze sediment cores from several basins and bays in Lake Champlain that currently differ in trophic status, or have received waters from areas with different land uses in the past. Our hope is to provide managers with such important background information as the initial water quality and biological composition of the lake, and the lake's response to specific stressors, including the placement of causeways.
Our specific objectives are:

1) *To determine pre-settlement trophic conditions across the lake*

2) *To document changes in trophic state and algal assemblages over the period since settlement*

3) *To relate these changes to land use practices or other indicators of human activity*

The results of this study also will benefit public education. We plan to work with the staff of ECHO (Burlington's science museum) to create two linked displays. One will provide a time line comparing lake condition to activities in the Basin; the other will highlight the role of the paleolimnologist as a sort of environmental detective. Our goal is to have these displays in place by 2009, when Vermont will celebrate the 400th anniversary of Samuel Champlain's voyage of discovery into the lake.

Approach:

We analyzed four cores, two from regions of the lake where algal blooms are problematic (St. Albans and Missisquoi Bays) and two from open water areas that have been less stressed by excess nutrients and represent large expanses of water. For each location we assessed the following trophic state indicators over a 400 to 450 year period, with sediment age and accumulation rates determined by a combination of ^{210}Pb and ^{14}C dating:

- Sediment organic matter content (%C, %N, C/N)
- Stable carbon isotopes
- Nutrients (Phosphorous and biogenic Silica)
- Fossil pigment assemblages

- Diatom assemblages
- Soft algae

Records of forest cover, agricultural crops and livestock density, industrial and municipal discharges, human population density, and weather were gathered as well so that the relative impacts of these stressors can be evaluated. Our procedures are described in more detail in our original proposal (October 2004).

Analytical Methods:

Elemental Analyses (C and N content, C/N ratio)

Percent organic carbon (%C) and percent nitrogen (%N) in the sediment were determined at a resolution of 1 centimeter using a CE Instruments NC 2500 elemental analyzer (Environmental Stable Isotope facility, Geology Dept.) The carbon to nitrogen ratio (C/N) values was calculated from the %C and %N data.

Stable Isotope Analyses

Stable carbon isotopic analyses were performed with a CE Instruments NC 2500 elemental analyzer coupled to a VG SIRA II isotope ratio mass spectrometer (Environmental Stable Isotope facility, Geology Dept.) The analyses were conducted at 1-centimeter resolution and the results reported using the delta (δ) notation in units of per mil relative to the inorganic standard V-PDB. Analytical precision is ±0.05‰ (based on replicate standards).

Nutrient Analyses

Phosphorus: The phosphorus contained in lake sediments was analyzed by sequential extraction of functionally defined forms. Samples of known mass were sequentially extracted with 1M NH_4Cl, 0.1N NaOH, and 0.5N HCl, which remove loosely sorbed P, metal-bound P, and apatite P, respectively. After each extraction, the sample was centrifuged, and the supernatant analyzed for P using the molybdenum blue technique.

Biogenic Silica: Samples of known mass were incubated in hot (85°C) 0.1 M NaOH. Aliquots were withdrawn at hourly intervals and analyzed for silica using ion chromatography (IC available in the Geology Dept.) and wet chemistry (molybdosilicate method). The results were graphed against time, and the later, linear portion of the curve is extrapolated to the Y intercept to estimate biogenic (diatoms + sponge spicules) silica.

Total Nitrogen: Nitrogen content (% N) was determined with a CE Instruments NC 2500 elemental analyzer (Environmental Stable Isotope facility, Geology Dept.).

Fossil Pigment Analyses

Lipid-soluble (polar) pigments were extracted from the bulk sediments by soaking powdered sediments in a mixture of degassed acetone:methanol:water (80:15:5, by volume) for 24 h in the dark and under an inert N_2 atmosphere at 0° C. Pigment concentrations of the filtered and dried extracts were then determined in each sediment interval using a Hewlett Packard 1050 high performance liquid chromatography (HPLC) system calibrated with standards from the U.S. Environmental Protection Agency. Pigment concentrations are expressed as nmoles pigment g^{-1}

organic matter (the latter obtained from elemental analysis), an index that is linearly related to algal biomass in the water column.

Microfossils

Sediments for diatom analysis were digested with H_2O_2 (30%) and CH_3COOH (95%), and a standard solution of microspheres added to allow quantitative estimates of frustules concentration. Cleaned frustules were mounted on slides with Naphrax, and at least 500 valves or stomatocysts counted in each sample to determine % composition. For soft algae analysis, sediments were added to a 10% solution of KOH along with a standard solution of *Lycopodium* spores (to trace extraction efficiency) and boiled for 10 min. This process deflocculates sediment and removes humic acids. After sample settling, decanting, and washing with distilled water, the sample were stored in glycerol and slides made using Fuschin-B-glyceral as a mounting medium. Whole cells, resting propagules and identifiable fragments were counted.

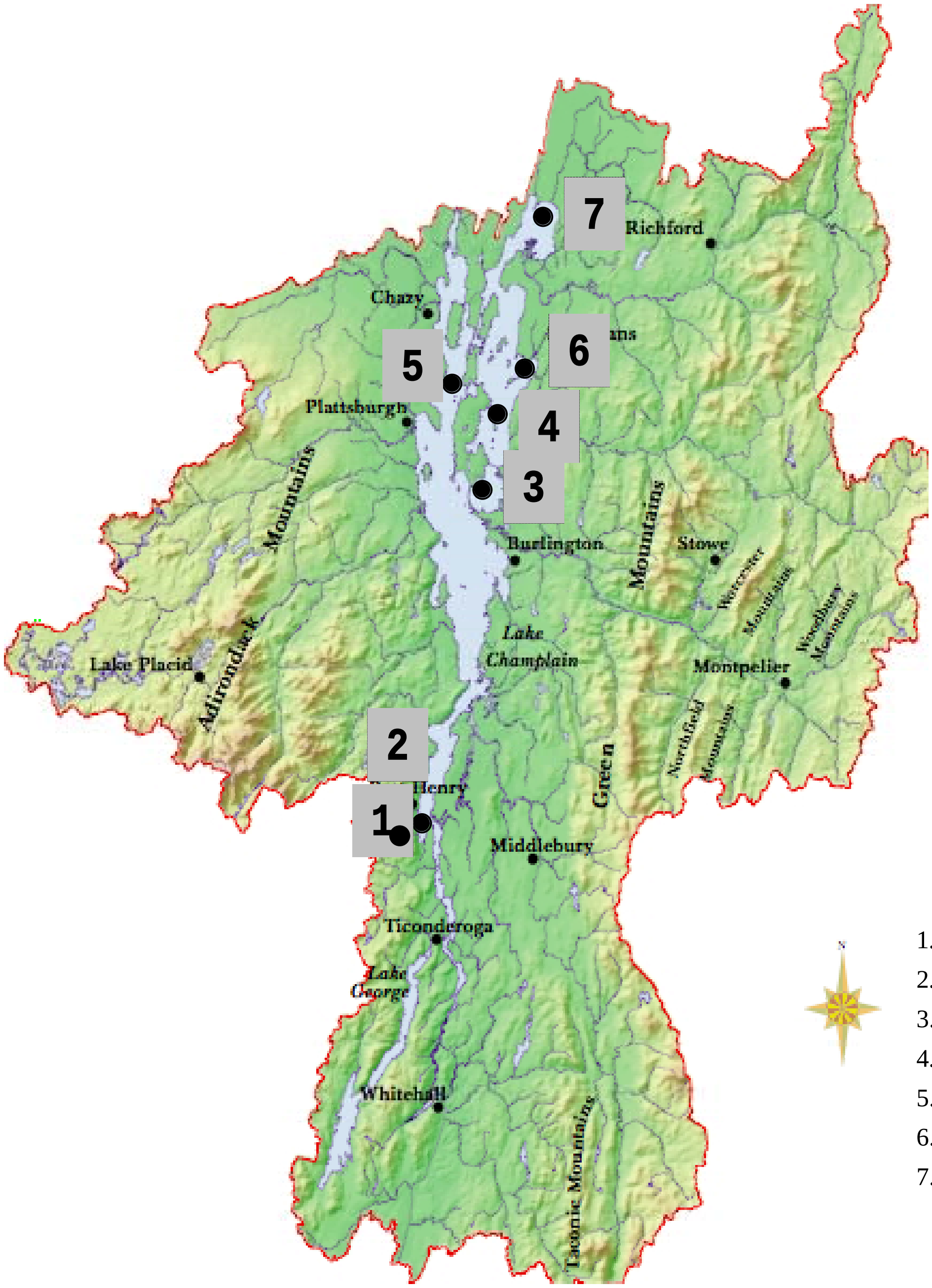
Sediment Chronology

Sediment chronologies are based on alpha spectrometric analysis of ^{210}Pb activities of recent sediments (1850–present), constant rate of supply calculations, and three accelerator mass spectrometric analyses of ^{14}C in macrofossils extracted from older sediments.

<u>Progress to date:</u>

This project began in March 2005 and has proceeded "on schedule" for its whole duration. We received funding to collect two cores in 2005 and two others in 2006. The 2005 cores were taken in summer from opposite ends of the lake, one near Port Henry and Crown Point, where settlement of the Lake Champlain Basin began (and thus where we expect to find the longest record of impacts) and one in the Northeast Arm (just north of Savage Island), a lake region settled late and thus likely to show pristine conditions until relatively recently. The two 2006 cores were obtained from regions of the lake that are currently strongly impacted by phosphorus inputs and cyanobacterial blooms, St. Albans and Missisquoi Bays. Because we knew from previous coring in these bays that sedimentation rates were high, we obtained 1.5-2 meter rather than 80 cm long cores. These were collected with a piston corer during the winter, using the ice cover as a coring platform. The VT DEC provided three additional cores that were also utilized for this study. The VT DEC cores were retrieved in Outer Mallets Bay, Cole Bay, and Point Au Roche Bay.

All cores were sectioned at 1 cm intervals and analyzed in our laboratory for %C, %N, C/N ratios, carbon stable isotopes, total and bioavailable P, and biogenic Silica (BSi). Paleopigment and soft algae analyses were performed at the University of Regina, Canada, and diatom assemblages were investigated at Paul Smith's College, NY.



1. Port Henry
2. Cole Bay
3. Malletts Bay
4. Savage Island
5. Point Au Roche
6. St. Albans Bay
7. Missisquoi Bay

Figure 1: Map of coring locations. Cores from locations 1-3 were provided by the VT DEC

Table 1: Summary of physical characteristics for coring sites

Core Name	Date Collected	Latitude	Longitude	Depth (meters)	Basin	Predominant Land-Use
Port Henry	Jul-05	44.0518	73.4346	9	Poultney-Mettawee	Agriculture, industry, forested
Cole Bay	Jul-03	44.1289	73.4094	50	Poultney-Mettawee	Agriculture, industry, forested
Malletts Bay	Jul-02	44.5225	73.2817	25	Lamoille	Forested
Savage Island	Aug-05	44.7197	73.2539	11	Grand Isle Lamoille	Forested, developed shoreline
Point Au Roche	Aug-03	44.7686	73.3403	30	Lamoille	Forested
St. Albans Bay	Mar-06	44.7833	73.1500	6	Saranac-Chazy Grand Isle	Forested, developed shoreline
Missisquoi Bay	Mar-06	45.0367	73.1300	4	Missisquoi-Pike	Agriculture

Summary of Results:

Prior to settlement, most cores exhibit stable geochemical and biological trends, however, in longer cores, such as Port Henry, St. Albans Bay and Missisquoi Bay, there is more variability in the older sediments, possibly related to climatic impacts. The Mallets Bay core is the shortest, with an extrapolated date of ca. 1700 at the bottom, and therefore it is difficult to determine background trends for this core, and what, if any effects Abenaki settlements may have had on the bay.

All cores display clear increases in %C upcore, as well as decreasing C/N and $\delta^{13}C$ values, interpreted as increased algal organic matter accumulation (Figs. 2, 4, 6, 8, 10, 12, 14). The C/N ratios exhibit an initial increase between the late 17th and early 19th century at all core locations but St. Albans Bay, followed by decreasing C/N to the top of the core. This is accompanied by a less negative $\delta^{13}C$ trend at each site, including St. Albans Bay. These trends are interpreted as the signal of initial land-clearing (leading to increased terrestrial inputs), followed by nearly total deforestation, which resulted in increased nutrient run-off, and hence increased algal contribution to the sediments. More rapid increases in %C occur after the mid-20th century in all cores, most likely in correlation to the advent of chemical fertilization of agricultural fields, mechanized agriculture, urban/suburban sprawl (and hence increased run-off) as well as increased sewage inputs.

Overall, the geochemical trends are supported by the BSi, P, sediment accumulation (Figs. 3, 5, 7, 9, 11, 13, 15), paleopigment, and diatom data, and can be construed as increasing algal dominance within Lake Champlain over time due to enhanced anthropogenic nutrient inputs from the surrounding watershed. Remarkably, the two cores collected in the shallow embayments of Lake Champlain (St. Albans and Missisquoi bays) do not appear to record the recent increase in macrophyte populations along the shorelines. This suggests that macrophyte-derived organic matter is not transported very far from shore, and that the geochemical trends documented in this study are reflective of changes in algal, rather that macrophyte productivity.

Conclusions:

The dataset indicates that productivity levels within Lake Champlain were low prior to settlement within the watershed. Since settlement, productivity has increased; this increase can be related to anthropogenic disturbances, such as deforestation, suburban settlement, artificial fertilization and P and sewage inputs. However, the margins of error, which occur with sediment dating, present difficulties in relating geochemical and biological trends to very short term or localized events, such as flooding. In conclusion, this study found that trends toward eutrophication continue in Lake Champlain, suggesting that the effects of remediation (e.g. phosphorous reduction efforts) are not yet evident.

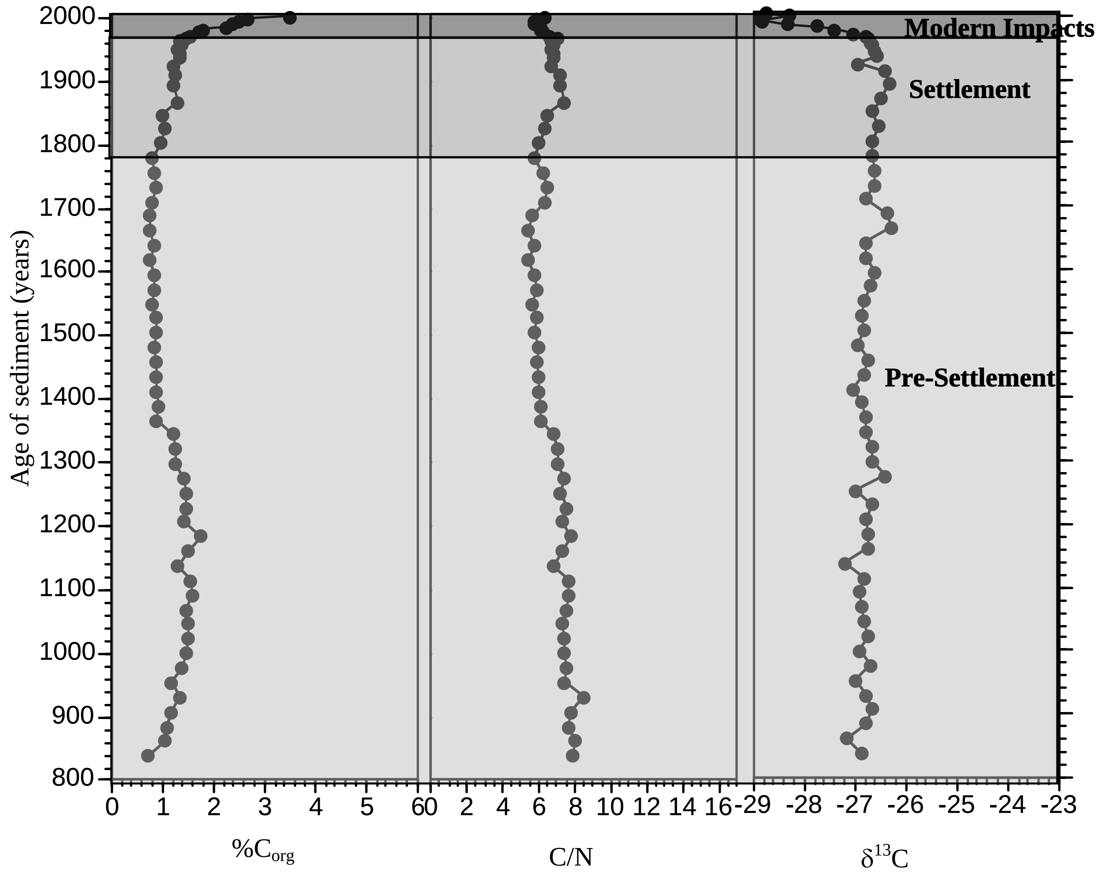


Figure 2: Port Henry $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

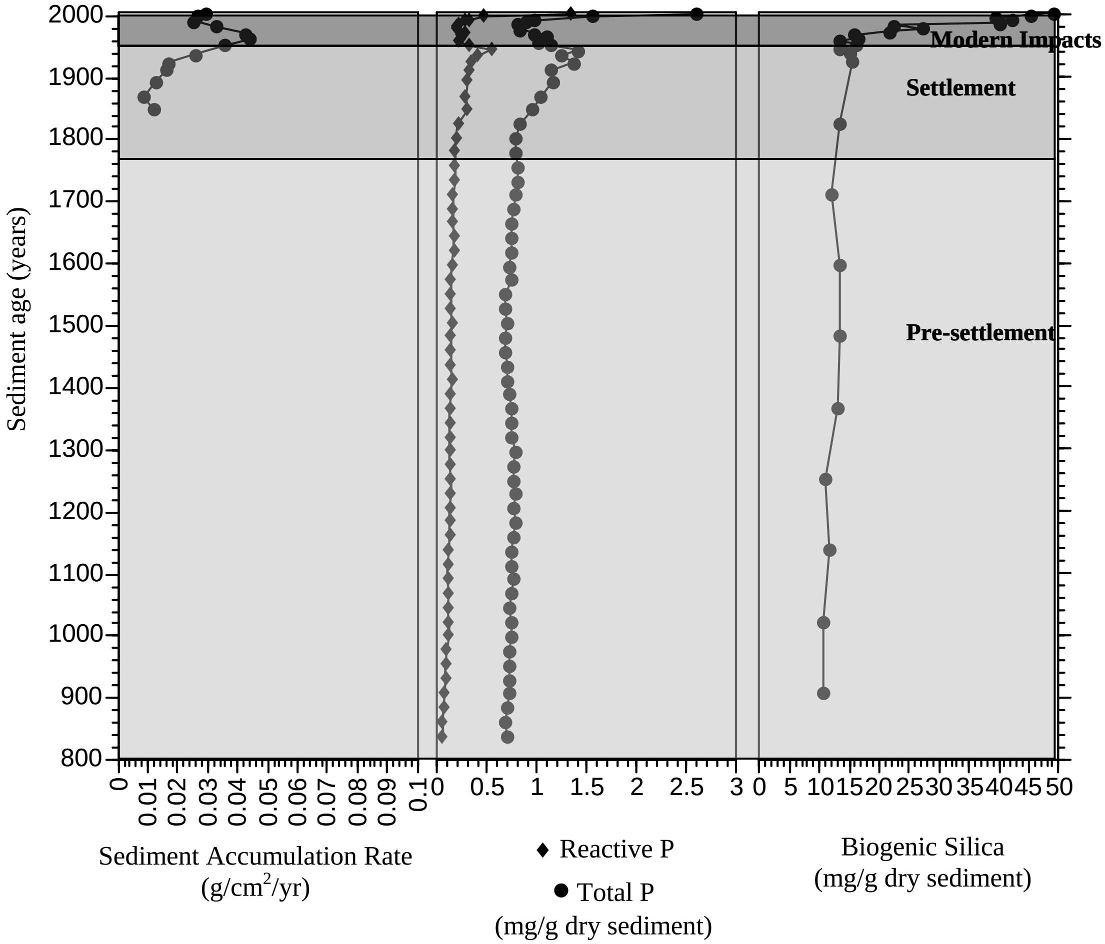


Figure 3: Port Henry sediment accumulation rates, phosphorus and biogenic silica vs. age.

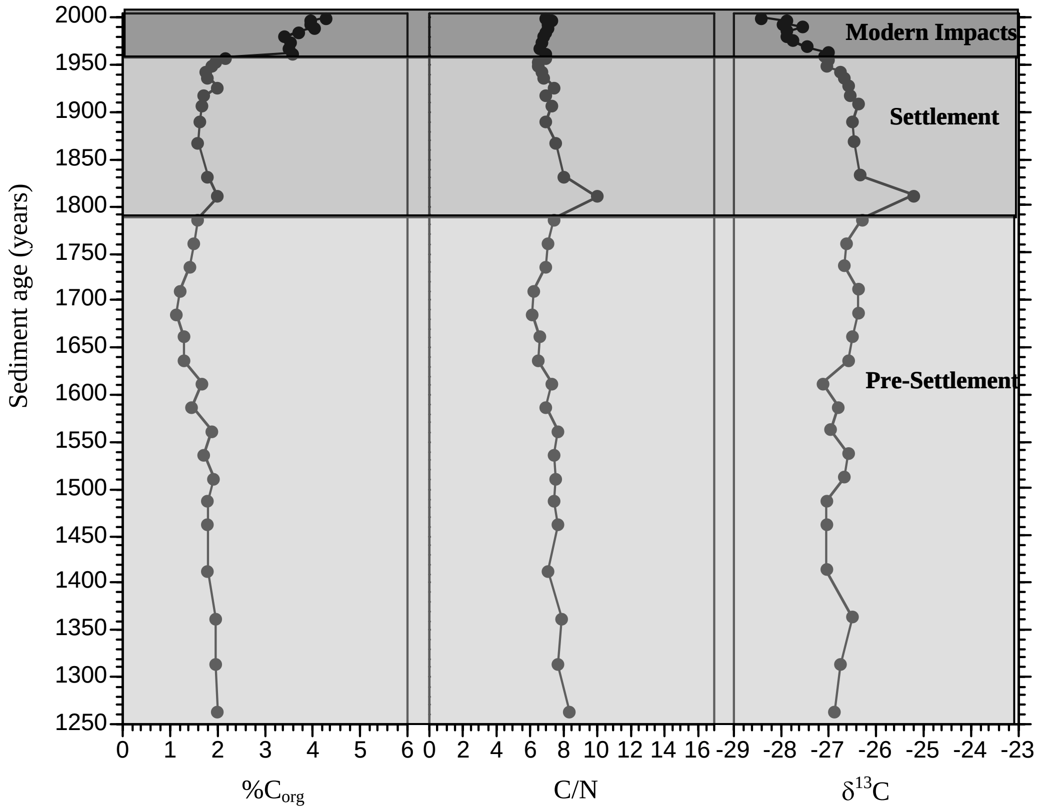


Figure 4: Cole Bay $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

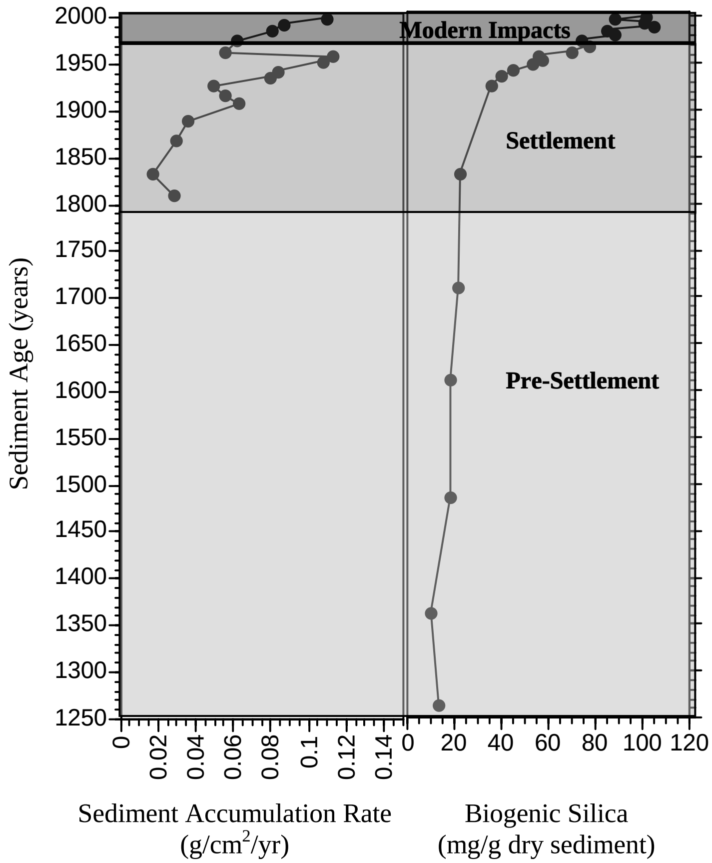


Figure 5: Cole Bay sediment accumulation rate and biogenic silica vs. age.

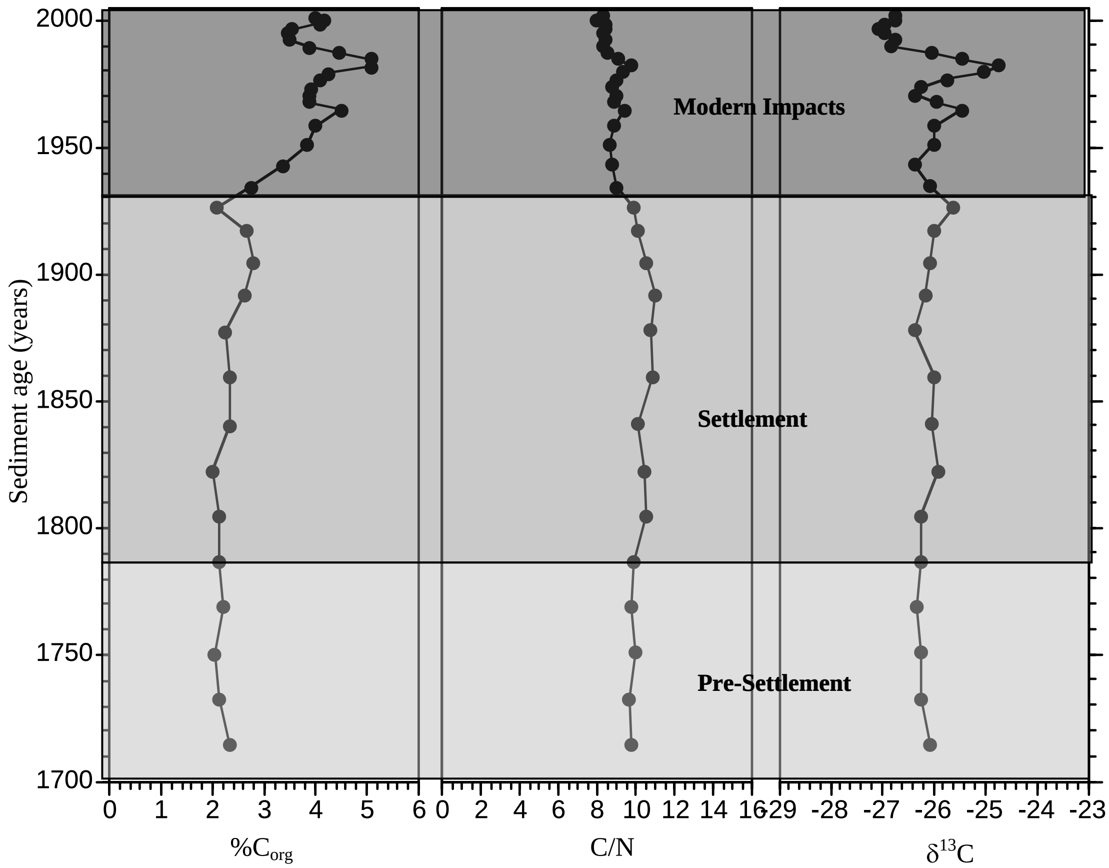


Figure 6: Malletts Bay $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

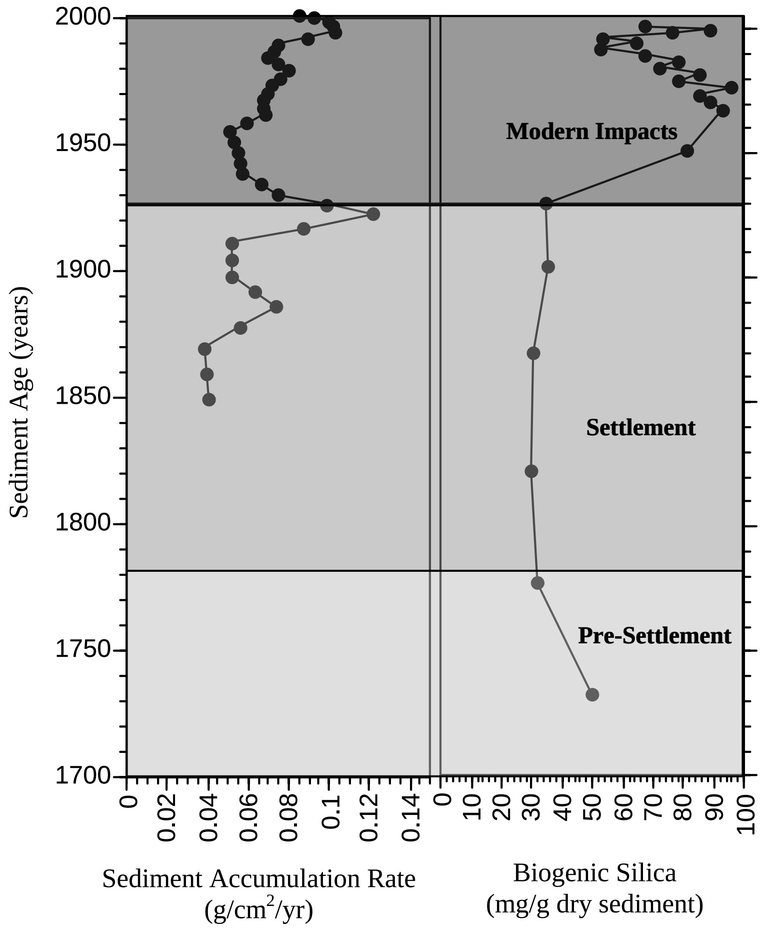


Figure 7: Malletts Bay sediment accumulation rate and biogenic silica vs. age

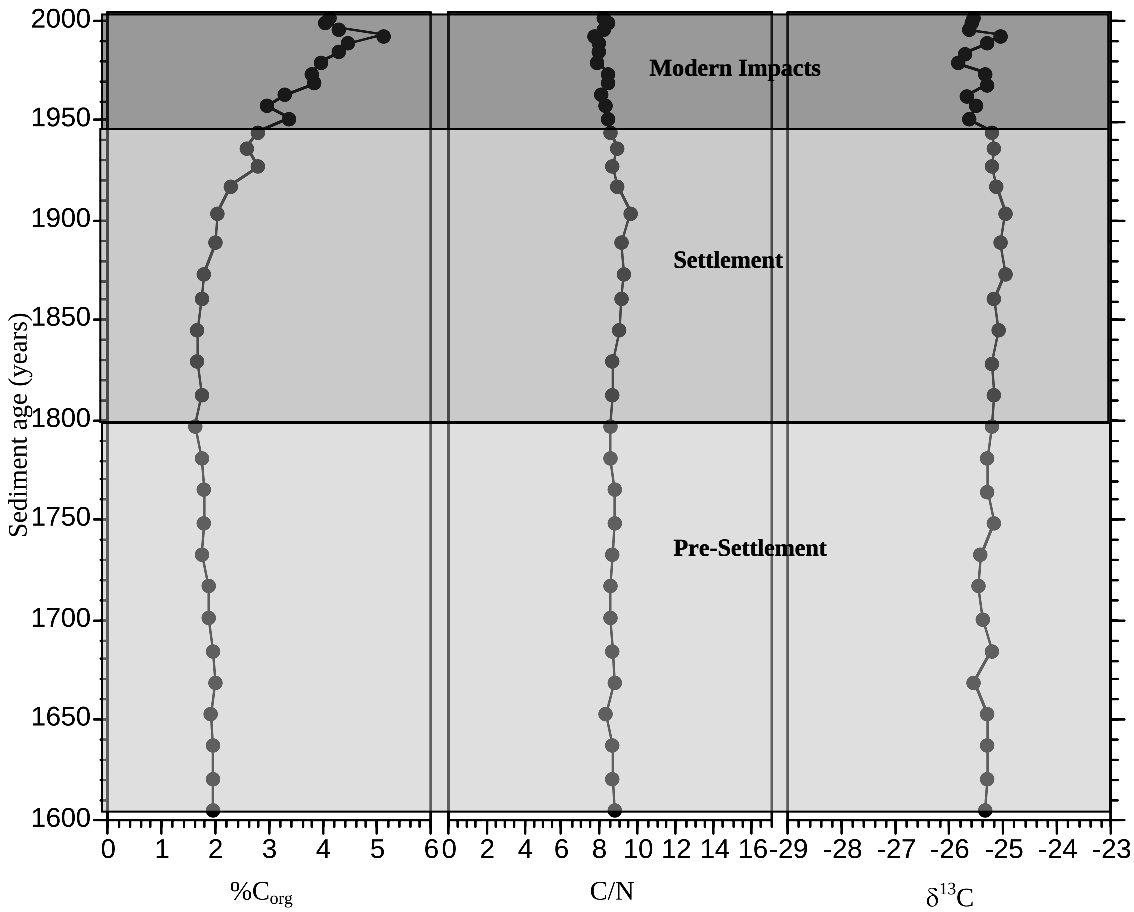


Figure 8: Point Au Roche %C_{org}, C/N and $\delta^{13}C$ vs. age.

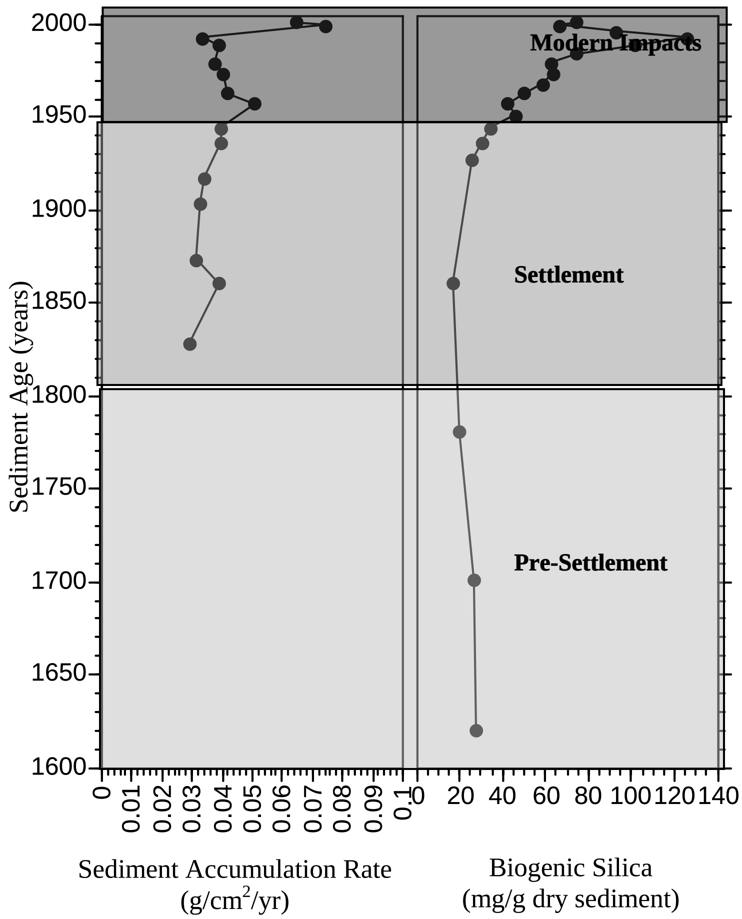


Figure 9: Point Au Roche sediment accumulation rate and biogenic silica vs. age.

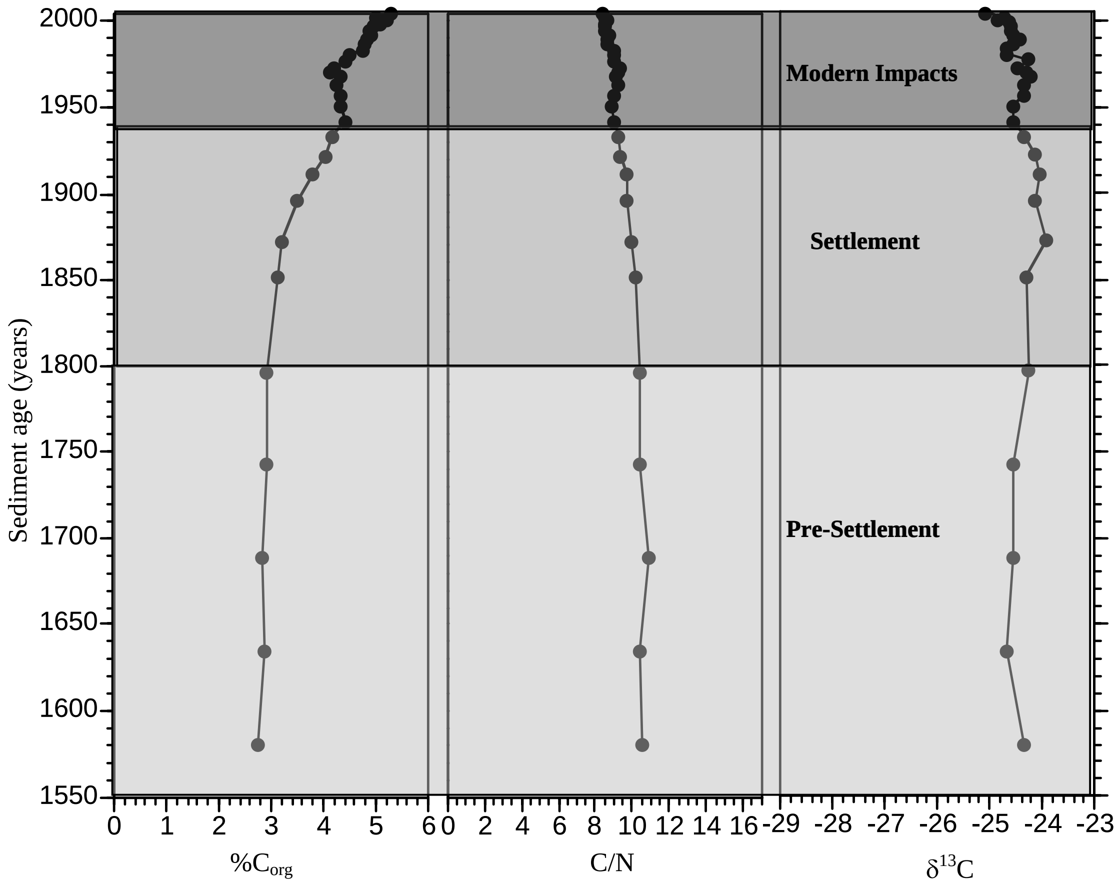


Figure 10: St. Albans $\%C_{org}$, C/N and $\delta^{13}C$ vs. age (recent sediment).

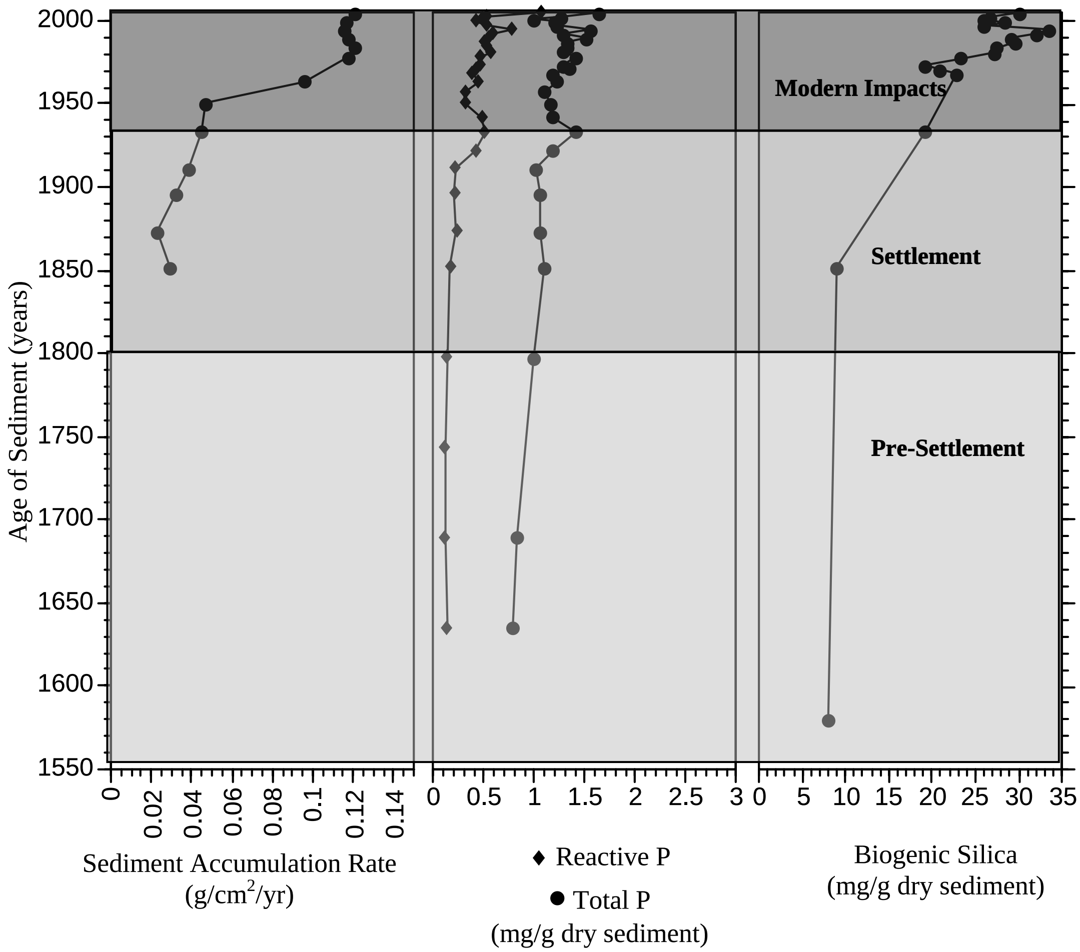


Figure 11: St. Albans Bay sediment accumulation rate, phosphorus and biogenic silica vs. age (recent sediment).

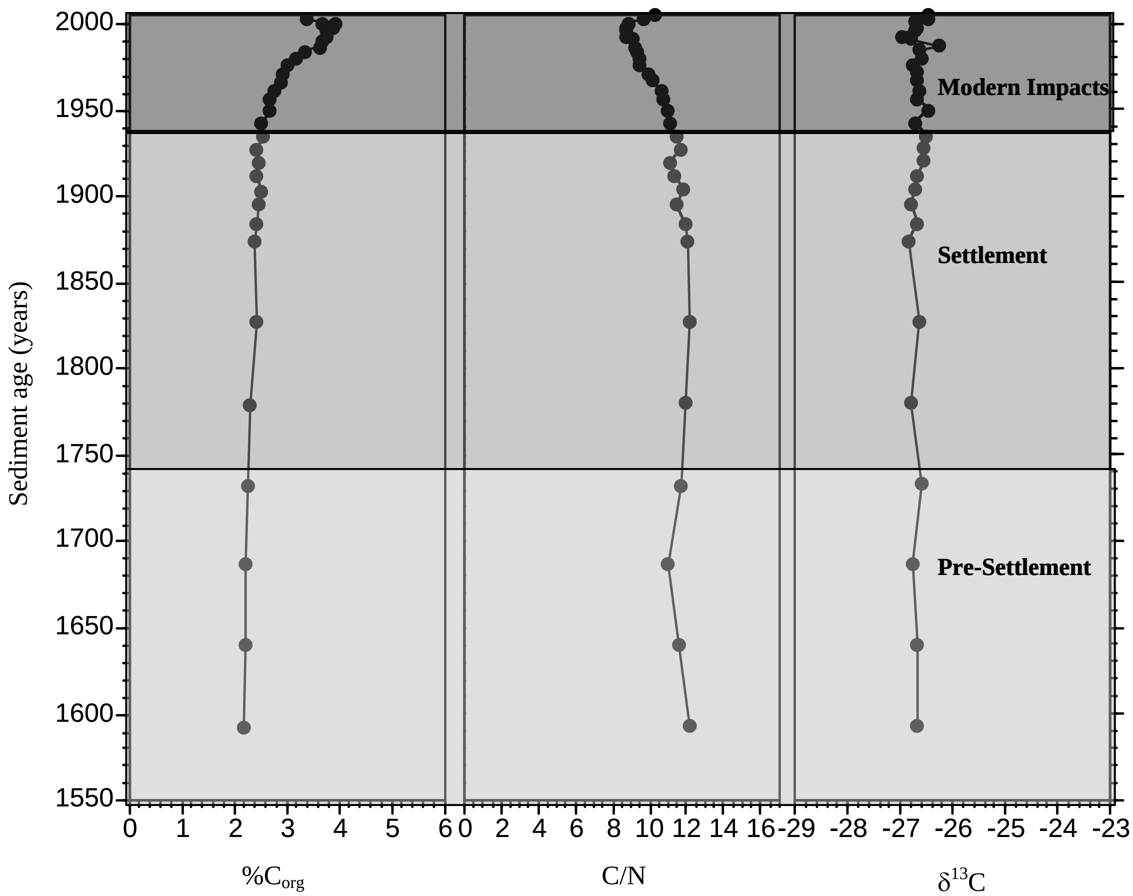


Figure 12: Missisquoi Bay %C_{org}, C/N and $\delta^{13}C$ vs. age (recent sediment).

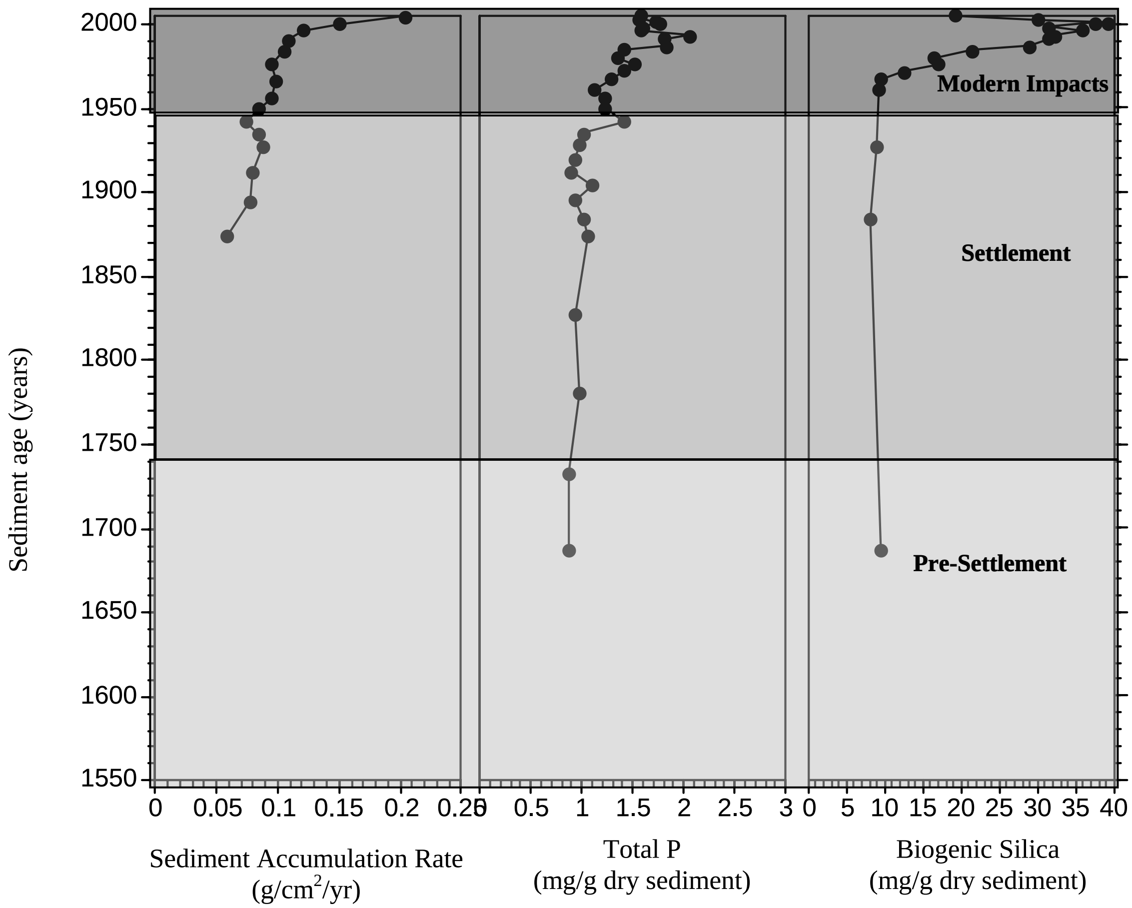


Figure 13: Missisquoi Bay sediment accumulation rate, phosphorus and biogenic silica vs. age (recent sediment).

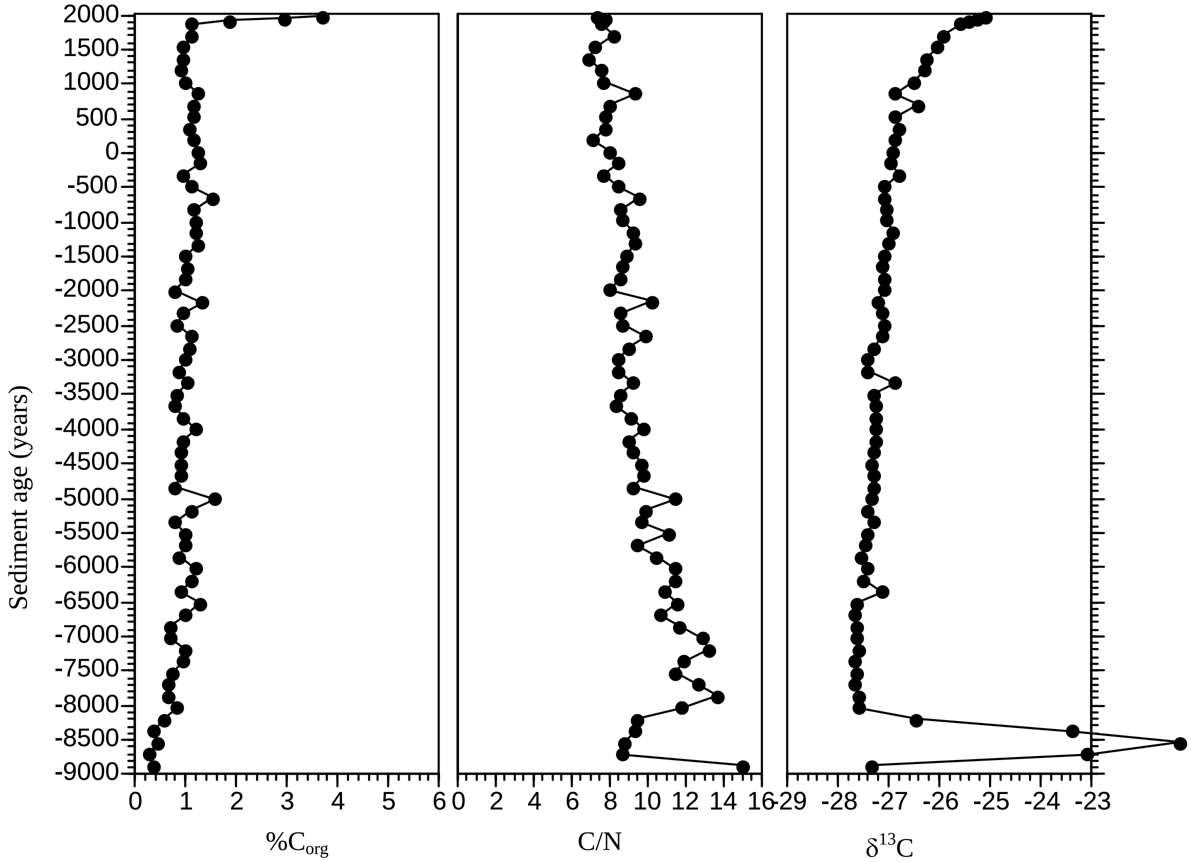


Figure 14: Savage Island $\%C_{org}$, C/N and $\delta^{13}C$ vs. age.

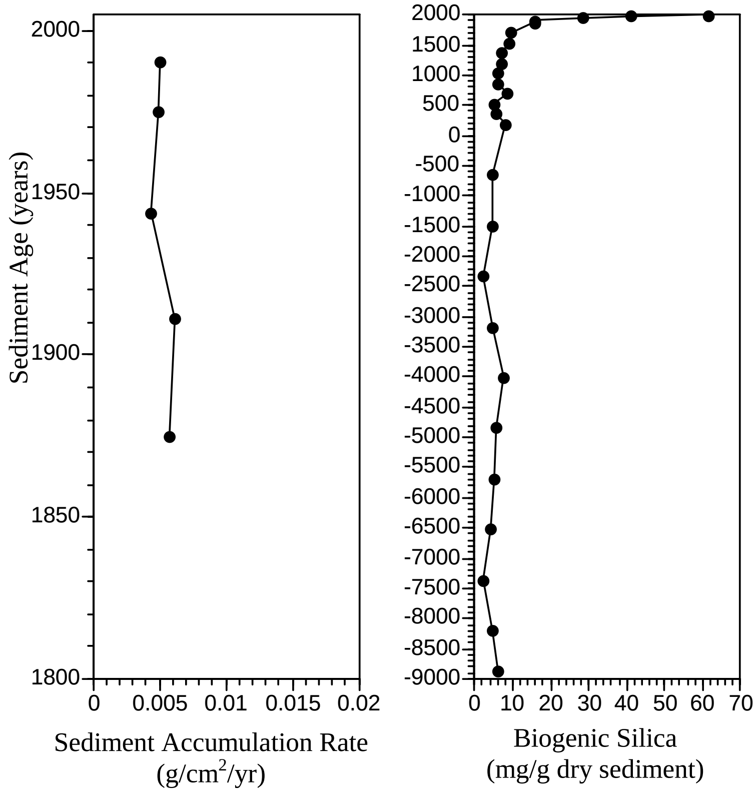


Figure 15: Savage Island sediment accumulation rate and biogenic silica vs. age. *Note different time scales.

A thesis with additional data about this report is on file with the Vermont Water Resources and Lake Studies Center at The University of Vermont. It can also be accessed at: www.uvm.edu/envnr/vtwater/pubs/yr2007.htm

Evaluating Quantitative Models of Riverbank Stability

Basic Information

Title:	Evaluating Quantitative Models of Riverbank Stability
Project Number:	2006VT25B
Start Date:	3/1/2006
End Date:	2/29/2008
Funding Source:	104B
Congressional District:	First
Research Category:	Engineering
Focus Category:	Sediments, Models, Geomorphological Processes
Descriptors:	
Principal Investigators:	Mandar M. Dewoolkar, Paul Bierman

Publication

Progress Report: Evaluating Quantitative Models of Riverbank Stability

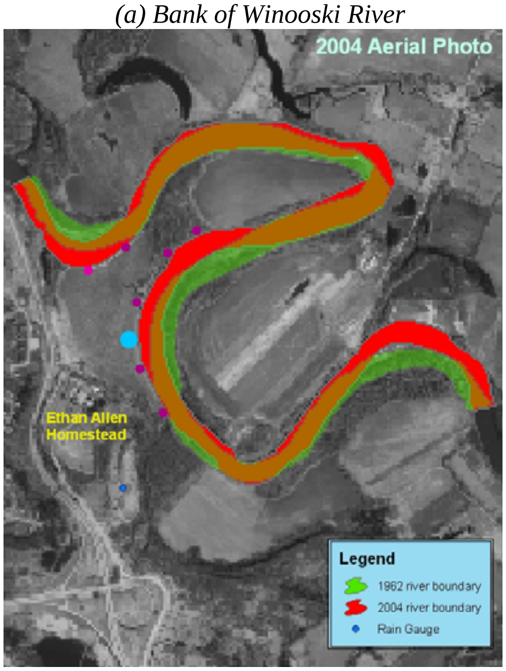
PIs: Mandar Dewoolkar and Paul Bierman

March 1, 2006 – February 29, 2008

Preliminaries

A kick-off meeting was held between the interested personnel from Vermont ANR and the project team, where ANR's relevant on-going projects and research priorities were discussed. We also reviewed relevant stream-related past and ongoing research projects on-campus so as to optimize research efforts. Based on these interactions, we decided that three types of streams/rivers will be studied, i.e. large low-gradient, smaller low-gradient, and smaller higher gradient. As described earlier, the research methods involve a variety of in-situ soil testing methods, laboratory experiments, multiple types of sensors, and analysis methods. We focused our effort during the 2006 field season on one river to ensure that all in-situ testing methods, sensors and laboratory methods would work satisfactorily and provide a consistent framework for analysis, before investing resources and efforts in instrumenting all sites at once. We chose a stretch of Winooski River (Figure 1) near Ethan Allen Homestead because of its vicinity to UVM. Here, the Winooski River is considered large low-gradient alluvial river. Eight sampling locations along the banks of the river were chosen (Figure 1b – larger blue circle indicates the instrumented site and purple circles indicate other seven sites). All locations were chosen along the outer bank of a meander bend in the river because this is where we expect bank failure is most likely to occur. Of these eight locations, four appeared to be unstable and four appeared to be marginally stable. Figure 1b shows how the banks of the river have changed between 1962 and 2004 from aerial photographs.

(a) Bank of Winooski River

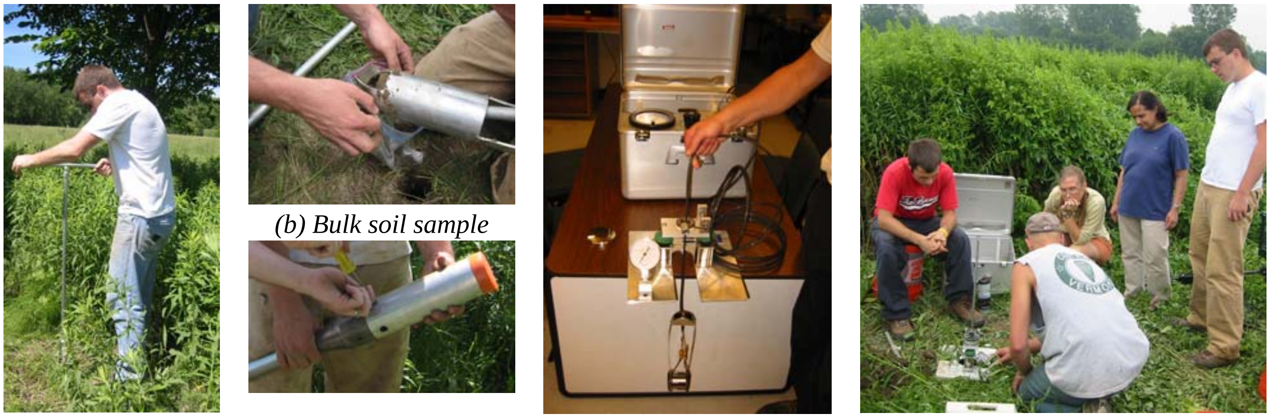


(b) Site locations

Figure 1 Selected site locations along Winooski River and analysis of aerial photos

Subsurface Investigations and In-situ Testing

At each of the selected locations, 3-inch diameter boreholes were advanced using a hand-operated auger (Figure 2a). Because of accessibility and safety issues, it was not possible to use a drill rig. We were able to auger to a depth of up to 16 feet using a hand operated auger above groundwater table. At each of the eight sites, multiple boreholes were augured and bulk soil samples were obtained in each soil layer (Figure 2b). In several locations, 10-inch long Shelby tubes (Figure 2c) were used to retrieve "undisturbed" soil samples. These "undisturbed" soil samples were needed for conducting the direct shear and triaxial tests in the laboratory for verifying in-situ shear strength parameters obtained using borehole shear tests (BST). The BST device (Figure 2d) was acquired for this project. Once the sample was removed from the hole, a BST was conducted to measure the shear strength of the same soil in-situ (Figure 2e).



(b) Bulk soil sample

(a) Hand auger *(c) Shelby tube sample* *(d) BST* *(e) Field operation of BST*

Figure 2: Subsurface investigations and in situ testing

The data collection for the four locations where the bank was on the verge of failure was fairly straight forward. At other four locations, hand auger and BST were a bit difficult to operate because of the presence of some gravel in soils. Soil samples were analyzed in the laboratory. Mechanical sieve and hydrometer analyses were used to determine grain size distributions of soil samples. Results were similar for the soil samples from multiple depths for the above sites. Atterberg limit tests were also conducted on these soil samples. The results from these tests in conjunction with the soil gradation indicate that soils retrieved from the sites can be classified as either silty sand or silt according to the Unified Soil Classification System (USCS).

The Shelby tube samples that were taken in the field were also used to obtain the angle of internal friction and cohesion in the laboratory and compare to those found in the field. The results from the laboratory direct shear tests provided on average higher angles of internal friction, 2 to 5 degrees, with greater variability than were determined using the BST. It is suspected that hand-operated sampling method caused significant compaction of the sample, and the laboratory strength values are not reliable. Presently we are exploring other methods of soil sampling for successful retrieval of soil samples with minimal disturbance. Another alternative is to verify the results of BST at very shallow locations where soil samples for laboratory testing can be retrieved with lesser disturbance.

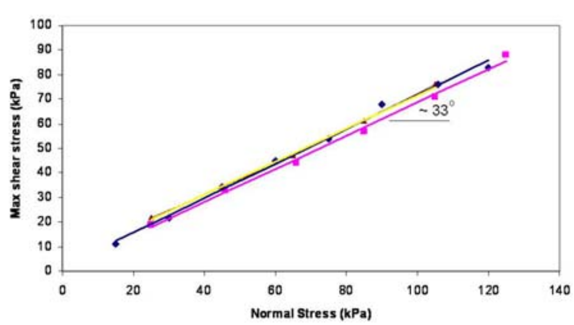
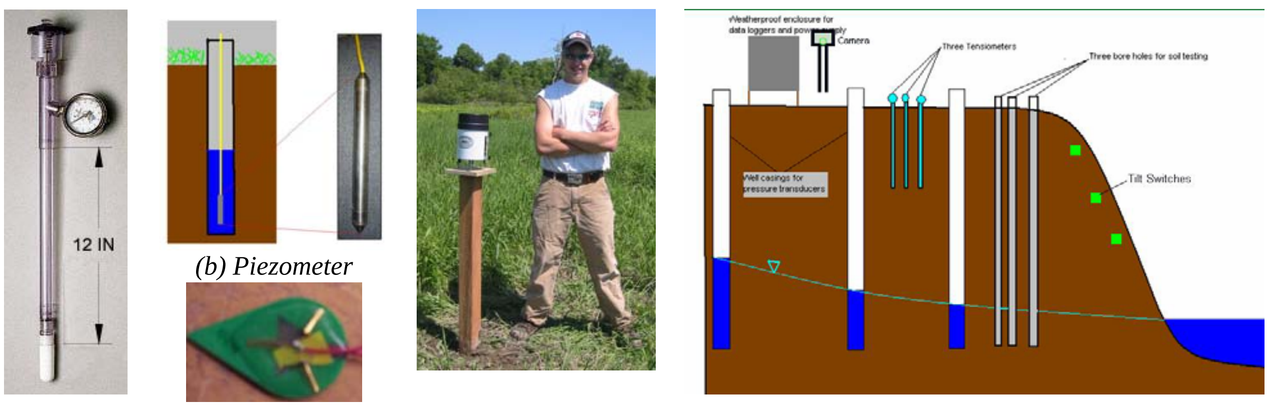


Figure 3: Shear stress versus normal stress data from BST tests conducted in silty sand at the selected sites

An example of BST shear stress versus normal stress data is shown in Figure 3. The data were taken in the silty sand layer at several locations. As seen, the results were repeatable. The data indicates soil cohesion to be close to zero (y-intercept) and effective friction angle of about 33 degrees, as expected for medium dense sand.

Instrumentation

At the locations of BST measurements, we attempted to obtain soil suction measurements using tensiometers (Figure 4a). Of the six tensiometers installed, three were installed with dial gages and three were installed with pressure transducers attached to a datalogger. These tensiometers worked quite well when tested dry to moist soils in our laboratory. However, they did not record suction in the field. We believe the reason for this is that the soil moisture content in the field was consistently high all summer long. This conclusion was also supported by measuring moisture content, which was generally high indicating that the soils were near full saturation. Continuous measurements of in-situ pore pressures are needed for analysis. This required installing electronic pore pressure transducers in groundwater wells. All summer near bank water table was too high to install wells by hand far enough below seasonal mean elevations. The monitoring wells and pore pressure transducers (Figure 4b) were therefore installed at the instrumented cross-section in September 2006, when the groundwater table was lower. There were also twelve tilt switches (Figure 4c) installed along this section of failing bank. A data logging rain gauge was also installed (Figure 4d) in the beginning of Summer 2006. General instrumentation plan at the site is depicted in Figure 4e.



(b) Piezometer

(a)Tensiometer *(c) Tilt switch* *(d) Rain gauge* *(e) Schematic of instrumentation plan*

Figure 4:Various Sensors installed at the instrumented site

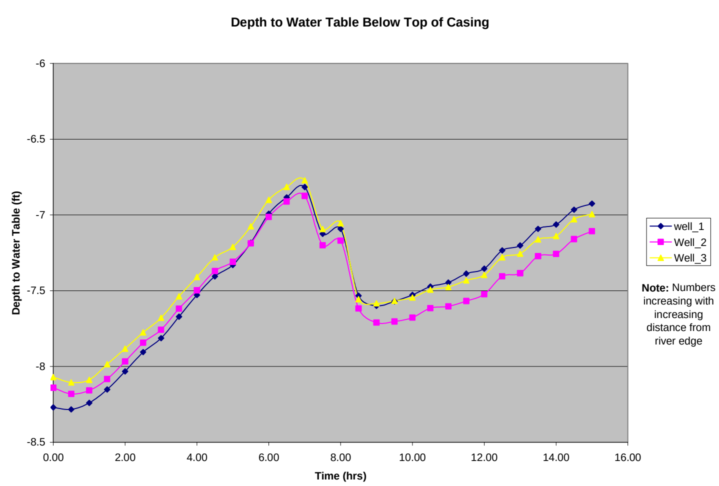


Figure 5: Example of groundwater table measurements

A snapshot of data from water pressure transducers for the on instrumented site is shown in Figure 5, which displays the ground water table during 16 hrs of a storm event.

Signals from the tilt switches are being recorded by an onsite data logger in a weatherproof box (Figure 6a), which is wirelessly connected to a computer in the Winooski Valley Park District Office, which is about 200 meters from the instrumented site. The initial plan was to embed accelerometers in the bank and obtain time history of movement using sophisticated hardware and software packages. However, the costs associated with such a system prohibited its use. Also, we realized that timing of bank failure is sufficient to relate the bank failure to precipitation (measured by the rain gage), river water level (inferred from USGS data), and pore pressures in soils (measured using piezometers installed in groundwater wells). The specifics of failure surface geometry were not needed through electronic measurements. They can be obtained by surveying the cross-section once the tilt switches indicate bank movement. A tilt switch creates a signal when its orientation changes by more than 10 degrees. In the field we noticed that large discrete blocks of soil fail from the bank rather than a progressive failure taking place over a number of days. Therefore, a sudden response from a tilt switch in the form of a binary signal will be sufficient to confirm that the soil around the tilt switch has failed.

(a) Weatherproof box *(b) Survey*

Figure 6: Weatherproof box with data loggers and surveying

These switches were embedded in custom designed caddies to be put into the edge of the bank. These switches were then connected to "CricketSats", which were developed specifically for this purpose. They can be disposable, but are expected to work reliably in the wireless node, and each assembly costs roughly $15 in hardware. Each CricketSat was given a specific tone to broadcast, all in the audible spectrum, to identify it. Since this is a planned network, the location of each node is known and by knowing which node is broadcasting its tone we know where the event occurred. CricketSat broadcasts its tone when the orientation of the tilt switch changes because of soil movement. The signal is received by a decoder board on a computer located in the Winooski Valley Park District office. We are presently evaluating the success of these tilt switches.

At each testing site, GPS coordinates were taken as well as several photographs. We also developed procedures for obtaining detailed surveys of bank cross-sections (Figure 6b), which will be required as input geometry for seepage and slope stability analyses.

Student Training

So far, two graduate (Andrea Pearce and Jaron Borg from Civil and Environmental Engineering) and four undergraduate students (Ryan Foster and Nathan Shaffer from Civil and Environmental Engineering, Christopher Palombini from Electrical Engineering and Jian Xin Yu from Environmental Sciences) worked on this project. Pearce, Foster and Borg are supported through this grant in addition to other sources. Shaffer and Palombini were supported through the Richard Barrett Scholarships. Yu is supported through an on-campus Math-Bio Scholarship supported by the National Science Foundations. Jaron Borg recently finished his B.S. and has decided to undertake this research as his thesis topic for his M.S.

The BST and some of the drilling and sampling equipment acquired through this project was used extensively in obtaining soil samples and conducting in-situ shear strength testing in "service-learning" term projects conducted in Dewoolkar's Geotechnical Design course and also a field course offered by Bierman in Summer 07 impacting a total of about 30 students.

An Adaptive Management System using Hierarchical Artificial Neural Networks and Remote Sensing for Fluvial Hazard Mitigation

Basic Information

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Descriptors:	
Principal Investigators:	Donna Rizzo, Leslie Morrissey

Publication

1.. ***Title:*** **An Adaptive Management System using Hierarchical Artificial Neural Networks and Remote Sensing for Fluvial Hazard Mitigation**

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3. ***Focus Categories:*** GEOMOR, HYDROL, MOD

4. ***Research Category:*** Hydrology

5. ***Keywords:*** artificial neural networks, fluvial geomorphology, remote sensing, eCognition, adaptive management, uncertainty assessment, stream assessment, hydrology

6. ***Start Date:*** March 1, 2006

7. ***End Date:*** February 28, 2008

8. ***Principal Investigator:*** Donna Rizzo, Assistant Professor, College of Engineering and Mathematical Sciences, University of Vermont, Donna.Rizzo@cems.uvm.edu, 802 656-1495

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9. ***Congressional District:*** 1st District, State of Vermont

1. INTRODUCTION

Adaptive management of hydrologic systems requires modeling of dynamic, nonlinear relationships and the assimilation of volumes of disparate data types over variable temporal and spatial scales. Artificial neural networks (ANNs) offer the capability to assimilate such complex data in real-time and are, therefore, promising tools for evaluating management alternatives. We propose to develop and test a hierarchical ANN system to more effectively integrate, model, and manage spatial and temporal hydrologic and fluvial geomorphic data. To demonstrate the efficient performance of ANN architectures in data assimilation, reduction, and classification at multiple scales, we will develop methods to enhance the GIS-based tools currently in use in Vermont watersheds to characterize the geomorphic condition and sensitivity of river reaches in response to historic and current watershed and corridor stressors. Input to the ANNs will include available GIS data layers, field data collected under (River Management Program's (RMP) geomorphic assessment protocol, and new data to be derived from high spatial resolution (0.16 – 2.4 m) remotely sensed aircraft and satellite data on stream sinuosity, and channel and valley slope. Recent advances in remote sensing technology make it possible to greatly improve the quantity and quality of input data in support of the proposed ANN. The proposed study will be conducted on five stormwater impaired watersheds in Chittenden County. These sites have been selected in cooperation with DEC RMP collaborators to take advantage of the availability of Phase I and Phase II geomorphic assessment data and multispectral remote sensing imagery (including LIDAR and QuickBird satellite data). Evaluation of the new data products will be conducted by ground surveys. Sensitivity analyses also will be conducted based on the results of the proposed ANN system to address the relative importance of the various ground and remote sensing data sources to meet and improve upon RMP's current fluvial modeling capabilities.

The proposed modeling system is directly applicable to the fluvial hazard mitigation mission of the River Management Program (ANR/DEC), but will differ sharply from conventional hydrologic models currently in use by the volume, variety, and types of spatial and temporal data assimilated. Moreover, the architecture of the proposed hierarchical ANN system is sufficiently flexible to allow for its continual update and refinement in light of advances in our understanding of fluvial geomorphology. This research will evaluate not only a new and innovative data assimilation and analysis methodology, but also data products derived from remote sensing imagery that we believe will substantially improve hydrological modeling in Vermont. In addition, it will compliment the existing RMP state program, taking advantage of existing data, protocols, and personnel – a modeling approach that could be adopted statewide. Our long-term goal is to build hydrologic information technology that provides watershed managers (regulators, regional planning organizations, municipalities, citizen groups, landowners, and other stakeholders) with an easy-to-use, graphical infrastructure for adaptive and effective decision-making at multiple spatial and temporal scales.

2. SUMMARY OF PROGRESS - YEAR 1

This research focuses the development and testing of a hierarchical ANN system to effectively integrate, model, and manage spatial and temporal hydrologic and fluvial geomorphic data.

RESULTS TO DATE: The specific objectives are:

Objective 1: Refine, test, and evaluate a set of simple classification ANNs for assessing the geomorphic condition and inherent vulnerability of stream reaches.

Objective 2: Derive and evaluate improved hydrologic information derived from remote sensing observations to be used as input parameters in the ANN hierarchy. These new data include: a) stream sinuosity, b) channel slope and valley slope, and c) other select yet critical variables identified as part of the ANN sensitivity analyses.

Task 1.1—Refine Geomorphic and Inherent Vulnerability ANNs (Modules B & C, Fig. 1) incorporating remote sensing data.

Research and development has been performed on a proof-of-concept prototype of the proposed counterpropagation ANN tool. A hierarchal system of ANNs has been developed to predict stream sensitivity using VTANR Phase II rapid stream assessment data (hereafter referred to as the Phase II dataset). The first of the two ANNs in series, Figure 1(a), utilizes inputs of channel geometry and bed form to predict a Rosgen channel classification (stream type). This ANN was tested using Phase II data collected on the five selected streams. Of the 89 reaches and segments, 72 (81%) were classified by the ANN correctly when compared to stream type classification reported in the Phase II assessment. The second of the two ANNs, Figure 1(b), is used to predict stream sensitivity (as described by VTANR) using inputs of stream type (output from first ANN) and stream condition (Phase II RGA score). The same 89 reaches were used to evaluate the performance of this ANN. Of the 89 reaches and segments, the stream sensitivity of 62 (70%) were classified by the ANN correctly compared with the Phase II assessment.

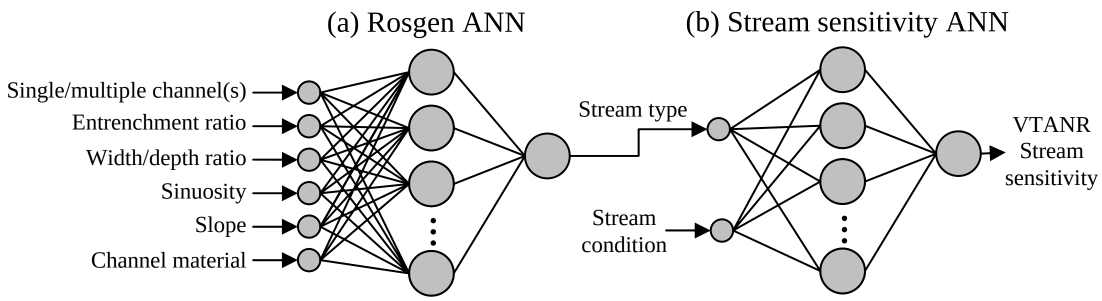

Figure 1. Graphical representation of (a) Rosgen ANN to determine stream type and (b) ANN for determining VTANR stream sensitivity using inputs of stream type and condition.

This first cut "Rosgen" ANN was implemented simply for development and testing purposes. This computational infrastructure can be modified easily and will provide the starting point for the proposed sensitivity ANN. These results are adequate (surprisingly good) for a first proof-of-concept. We believe they can be improved substantially by accounting for the ranges of values associated with stream geometry data (*i.e.* entrenchment can vary by ±0.2 units) and other subtle pieces of information provided by an expert. This will involve meetings with VT ANR.

ANN Task 1.2 – Identify "critical" geomorphic variables: A preliminary sensitivity analysis was performed to identify "critical" geomorphic variables needed for the proposed stream sensitivity ANN. First, we examined which of the available VTANR Phase I and Phase II geomorphic assessment data are most influential (statistically) for predicting stream sensitivity and geomorphic condition (using multivariate statistics). Stepwise discriminant and canonical analysis are multivariate statistical methods commonly used for classification prediction.

Table 1 displays the impact of each of the geomorphic variables ranked in decreasing order of importance when used as a predictor of classified stream sensitivity. Stream sensitivity provided in the Phase II database was classified into 6 categories using the geomorphic assessment (integer values ranging from very low = 1, low = 2, moderate = 3, high = 4, very high = 5 and extreme = 6). This rank ordered list was produced using discriminant analysis (*SAS Version 8.0*).

Table 1. Geomorphic variables rank ordered in importance for predicting stream sensitivity.

Rank	Variable	Number Class	Code Value
1	Substrate D50	Integer	1=sand, 2=gravel, 3=cobble, 4=boulder and 5=bedrock
2	Watershed size	Continuous	>=0
3	Width/depth ratio		>=1
4	Number of stormwater inputs	Integer	0, 1, 2, 3, etc
5	Change in valley slope	Continuous	+ to - infinity
6	Change in channel slope	Continuous	+ to - infinity
7	Upstream sinuosity	Continuous	>=1
8	Entrenchment		>=1
9	Cumulative urban watershed size (%)	Continuous	>=0 (summation of upstream conditions)
10	Urban watershed size (%)	Continuous	>=0
11	Number of grade controls	Integer	0, 1, 2, 3, etc
12	Confinement ratio	Continuous	>=1
13	Number of upstream stormwater inputs	Integer	0, 1, 2, 3, etc
14	Least forwarded buffer width	Integer	1=<5ft, 2=5-25ft, 3=26-50ft, 4=51-100ft, 5=>100ft
15	Channel slope	Continuous	>= 0
16	Valley slope	Continuous	>= 0
17	Sinuosity	Continuous	>=1
18	Straightening	Binary	1-yes, 0-no

Note that change in channel and valley slope over time and upstream sinuosity (ranked 5, 6 and7 respectively) are among the four most important variables specifically related to stream morphology. In contrast, measures of channel and valley slope at any point in time and sinuosity for a given reach are among the least important variables. This is due to the relative importance of variables 5 through 7 (Δ valley slope, Δ in channel slope and upstream sinuosity).

Table 2 summarizes the stream reach sensitivity classification results using the discriminant equations. For the 58 stream reaches that make up the study area, the stepwise discriminant equations were able to correctly classify the stream sensitivity for 41 of the 58 reaches. This results in 17 of the reaches being misclassified (with 12 reaches that should be classified as type 5 (very high) classified as type 4 (high); and another 9 that should have classified as type 6 (extreme) classified as type 5 (very high).

A similar analysis was performed on each of the four predictor variables (degradation, widening, aggradation and change in planform) that make up the total VTANR RGA score. The statistical results confirmed the four variables were equally important in predicting the geomorphic condition of the stream reach. Channel widening was less important than the other variables.

Table 2. Results of predicting stream sensitivity prediction using discriminant analysis.

		Classified by Discriminant Analysis					
	Class	**1**	**2***	**3**	**4**	**5**	**6**
Classified in Phase II Assessment	**1**	1	0	0	0	0	0
	2*	0	0	0	0	0	0
	3	0	0	3	0	0	0
	4	0	0	0	12	8	0
	5	1	0	0	9	24	0
	6	0	0	0	0	0	1

*Note: There were no classifications of 2 (low sensitivity) in the dataset.

The final ANN predictions/classifications may later be compared with the classifications produced from this statistical method. By ranking the importance of the Phase II variables using discriminant analysis, the ANN can be used to perform a sensitivity anslysis. Two ANNs in series were used to derive stream sensitivity based on Rosgen stream type and stream condition (Phase II protocols). As a result, a single ANN capable of incorporating channel geometry data and condition to predict stream sensitivity may be developed using kowledge gained from the stepwise discriminant analysis; therefore, consolidating the ANN portion of this project.

To study the influence of reach-scale channel geomorphic stability and physical habitat condition on benthic macroinvertabrate populations, Fitzgerald and Bowden [2006] performed preliminary statistics to test the following hypothesis: *Macroinvertabrate integrity declines as geomorphic stability and physical habitat conditions decline.*

For 26 stream reaches in a select set of stormwater impaired watersheds, they tested whether the stream reaches/segments (grouped by different channel evolution stage) had different mean values when compared against the VT ANR Biota Data (represented as EPT Richness). The results were very encouraging with a high average EPT richness scoring high (~ 25) for channels with an evolution stage of I, followed by a sharp decline (~8) for channels with an evolution stage of II and a gradual increase in average EPT richness for channel stages III, IV and V (~7, ~10, and ~13 respectively) [Fitzgerald and Bowden, 2006 and personal communication]

In an attempt to capture this temporal evolution for the streams examined in this work, we repeated this statistical analysis to further explore the existing correlations/links between the VT ANR habitat, geomorphic condition and the channel evolution stage of the stream reach data. We tested whether the stream reaches/segments (grouped by different channel evolution stage) have different mean values of habitat and geomorphic condition rating. The existing VT ANR Phase I and II dataset had channel evolution stages classified into five stages. Stage I represents the stable channels where sediment transport capacity is in equilibrium with sediment load. Stage II channels have lost access to their flood prone area via the process of bed degradation or floodplain buildup. In Stage III the channel is still entrenched and widening through bank erosion; and in Stage IV the channel dimension and planform adjustment continues. Stage V channels have reached a new stable or equilibrium condition.

Included are some results that suggest both habitat and geomorphic ratings have different means for the 5 stages but only the habitat ratings are statistically significant. Figure 3 displays evidence that the habitat rating scores are not statistically similar for streams at different stages of evolution. Streams in stage I have statistically higher habitat ratings than streams in stages II, III and IV. We only had one stream that classified as stage V within the study area data set.

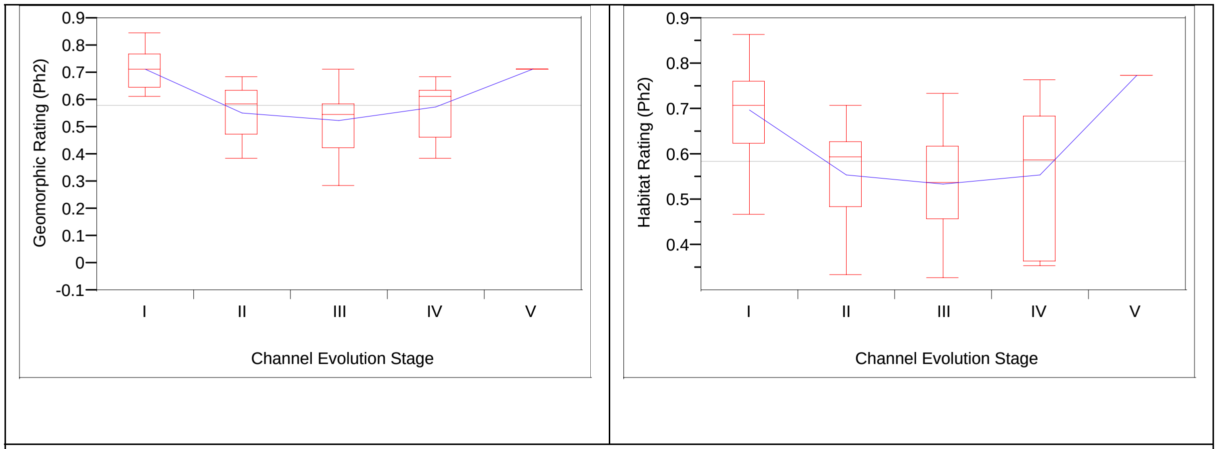

Figure 3. Stem and box plots comparing (a) geomorphic and (b) habitat rating scores grouped by channel evolution stage for Phase II data from selected streams with LIDAR data.

Similar results are observed in the mean geomorphic condition scores, when grouped by evolutionary stage. Stage I streams have higher geomorphic condition scores that the other stages. There is a slight increase in geomorphic condition in stream evolution stage IV compared to stage II and III. However these differences are not statistically separable for this dataset. These statistical findings provide reassurance that training the ANN using this existing dataset may be sufficient to capture the temporal component in the evolution of channel stage adjustment.

REMOTE SENSING Task 2.1 – Monitor stream sinuosity over time.

As part of our initial efforts to employ remote sensing and advanced digital image processing techniques to map and monitor stream sinuosity over time, recent aircraft (1:1250 CCMPO and 1:5000 Vermont digital orthophotography) and satellite (QuickBird) imagery were acquired for all stormwater impaired watersheds in Chittenden County and compiled within a GIS database. For the Allen Brook watershed, stream centerlines were digitized from the QuickBird and CCMPO imagery and sinuosity calculated for each stream reach using the Phase I valley length data. These preliminary analyses were limited to

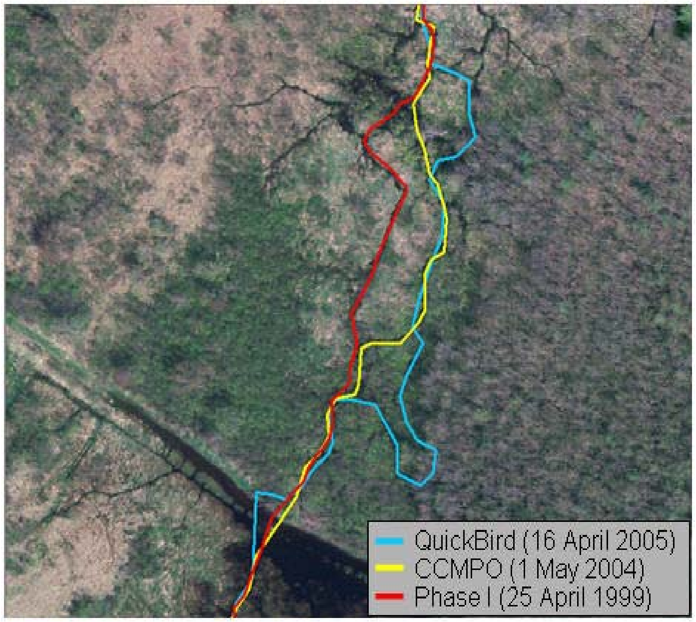

Figure 5. Stream centerlines derived from the QuickBird satellite data, Phase I (1:5000) data, and 1:1250 CCMPO imagery are shown for a section of reach M09 Allen Brook

the 9 reaches where QuickBird imagery was available. Sinuosity for each stream reach computed from the QuickBird imagery and as part of the Phase I stream geomorphic assessment (derived from the 1:5000 VT Hydrography dataset) was then compared with that computed from the higher spatial resolution CCMPO imagery.

Figure 5 documents areas of overlap as well as significant shifts in the Allen Brook channel between 1999 and 2004 and again between 2004 and 2005. More importantly the preliminary results demonstrate that over the range of sinuosity observed (1.01 to 4.1; n = 9) measures derived from the QuickBird imagery and Phase I data agreed well with those derived from the high spatial resolution CCMPO data (Figure 6).
The correlation between Phase I and CCMPO-derived measures of sinuosity was 0.984 (n = 7), whereas that between the QuickBird and CCMPO data was (0.998; n = 7), excluding the only reach with a sinuosity greater than 1.5 (M04, Phase I sinuosity = 3.98) and reach M09 which had undergone significant channel planform change. Note that although the stream channel for reach M09 changed course significantly from 1999-2004, sinuosity values changed little (1.18 to 1.21 as computed from Phase I CCMPO data respectively). The increase in sinuosity associated with the channel migration between 2004 and 2005, however, was much larger (1.21 to 1.38) as calculated from the CCMPO and QuickBird satellite data.

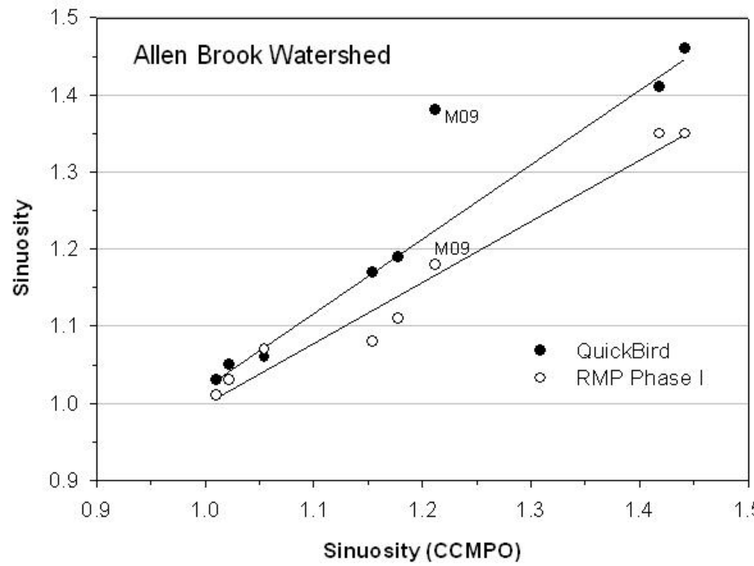

Figure 6. Channel sinuosity derived from QuickBird satellite imagery and Phase I (1:5,000) data compared to values calculated from photointerpretation of 1:1250 CCMPO imagery for the Allen Brook stream reaches. Data for reach M04 (sinuosity = 3.98) were not included in the correlation analyses nor were data for reach M09 because of the significant change in channel morphology between each of the image acquisition years (see Figure 5).

The channel migration between 2004 and 2005, however, resulted in a larger sinuosity value (1.38) as calculated from the QuickBird satellite data. These results support the value of remote sensing and QuickBird satellite imagery specifically as a tool for baseline mapping and monitoring of stream sinuosity and planform change over time.

Task 2.2 - Generate high spatial resolution elevation derivatives from LIDAR data, and quantify stream channel and valley slope at the reach scale.

We have initiated efforts to generate elevation data based on geostatistical kriging interpolation techniques. The computational requirements for kriging the immense LIDAR dataset for Allen Brook has resulted in processing the data using an ordinary Kriging algorithm written in MatLAB V8.0 rather than ArcGIS. Once the elevation data are derived, they will be evaluated against survey data that we have already acquired. Following QA/QC of the resultant data, we will derive channel and valley slopes for Allen Brook and at least one other watershed.

Phosphorus availability from the soils along two streams of the Lake Champlain Basin: mapping, characterization and seasonal mobility

Basic Information

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Descriptors:	
Principal Investigators:	Donald Ross, Joel P. Tilley

Publication

1. Young, E.O., D.S. Ross, J.P. Tilley, K. Underwood, C. Alves, and T. Villars. 2006. Phosphorus availability along two small streams in Vermont: Mapping, characterization and potential mobility. ASA-CSA-SSSA Annual Meeting. Indianapolis, IN. In Agronomy Abstracts.
2. Alves, C., E.O. Young, and D.S. Ross. 2007. Phosphorus availability in some Vermont floodplain soils. ASA-CSA-SSSA Annual Meeting. New Orleans, LA. In Agronomy Abstracts.

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3. Focus Categories: Nutrients, nonpoint pollution, water quality

4. Research Category: Water Quality

5. Keywords: phosphorus, soil, sediment, soil survey, soil test, P transport

6. Start Date: March 1, 2006

7. End Date: February 29, 2008

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9. Congressional District: Vermont-at-large

10. **Abstract**

Nonpoint source phosphorus (P) inputs into lakes and streams can be a major source of nutrient loading. A critical need is a better understanding of the relative importance of various P sources (e.g. sediment from streambank erosion, runoff from agricultural fields, or release from aquatic sediments). The use of the Vermont (VT) soil survey to help predict P losses may be limited by outdated mapping and a lack of information on P variability among soil series. We hypothesize that soil-landscape variability could be an important constraint on the amount of total and potentially mobile P along stream banks and in riparian areas. Our project will perform an extensive remapping, soil sampling and P analysis along areas of Lewis Creek and Rugg Brook in the Lake Champlain Basin. The objective is to determine the adequacy of the original map unit delineations and examine the relationship between soil series variability and profile P concentrations. Soils will be sampled at two riparian restoration sites, and at a number of other locations within the respective corridors. Results will include a new digital soils map of the two sites, and a data layer that includes total P concentration and a range of availability indices. Phosphorus availability will be evaluated by extraction with ammonium acetate (available P) and total P will be estimated by nitric acid digestion. A subset of soils representing the range of observed soil properties will be analyzed for additional availability indices (e.g., water-soluble, dilute electrolyte, ammonium acetate + fluoride, and soluble organic P). A subset of these soils will be used in laboratory microcosm experiments that will assess the potential for P release to solution under flooded conditions. Laboratory-based measures of P solubility will be compared to porewater P concentrations in the field at several locations. Phosphorus concentrations in stream channel sediments of differing physical properties will also be characterized. This project will be a collaborative effort between UVM and NRCS soil scientists. Results will contribute to a greater understanding of soil map unit variability and P levels in floodplains, and clarify relationships among fundamental soil properties, P availability, and the potential for P release to water.

Project Overview

Most soil surveys in VT were originally mapped at a scale of 1: 20000, with minimum mapping units of about 3 acres. Floodplain soils are often too small to be delineated at this scale. There is currently little information on the adequacy of map unit delineations and/or P levels for floodplain areas in VT. We hypothesize that subsoils of series with similar parent material will have comparable levels of total and available P. Though analysis of total P provides an estimate of the total quantity of P, P forms range from readily soluble to those occluded in crystalline soil minerals. Our project will characterize relations among total, available, and soluble P forms. The project is divided into three basic components: (i) a soil sampling and remapping for the Rugg Brook and Lewis Creek restoration sites, with additional soil sampling and series verification at selected locations within each stream corridor, (ii) an analysis of the total and available P concentration (and Fe, Al, Mn, Ca, Mg, and K), organic matter content, and pH, and (iii) laboratory and field-based experiments to determine the P release potential of soils.

Progress
The high-intensity mapping at the two study sites was completed in the fall of 2006. Available P concentrations, background soil test data (organic matter, pH, and available cations), and total P and cations (Fe, Al, Mn, Ca, Mg, K) have been determined for soil and sediment samples collected in 2006 (see Results). A subset of samples is currently being analyzed for additional extractable P forms. Eighteen porous cup lysimeters were installed in May 2007 between the two sites. Porewater samples are being collected and analyzed for dissolved reactive P concentrations (DRP). Additionally, floodwater from isolated areas and stream water are also being analyzed for DRP. Five additional soil sampling sites within the Lewis Creek corridor have been identified and are currently being sampled by UVM and NRCS. The soil series sampled at the additional sites will be verified (but not remapped) and profile samples will be analyzed for total and available P in 2007.

Results: Mapping
The Rugg Brook study area was mapped as one series by the 1979 Franklin County Soil Survey. Following the higher intensity mapping, five additional soil series were identified and mapped (Fig. 1a). At the Lewis Creek site, the 1971 survey mapped the area as three series; the remapping revealed three additional series that together accounted for about 90% of the site area (Fig. 2b). Results indicate that the SSURGO-level mapping differed significantly from the high-intensity remapping.

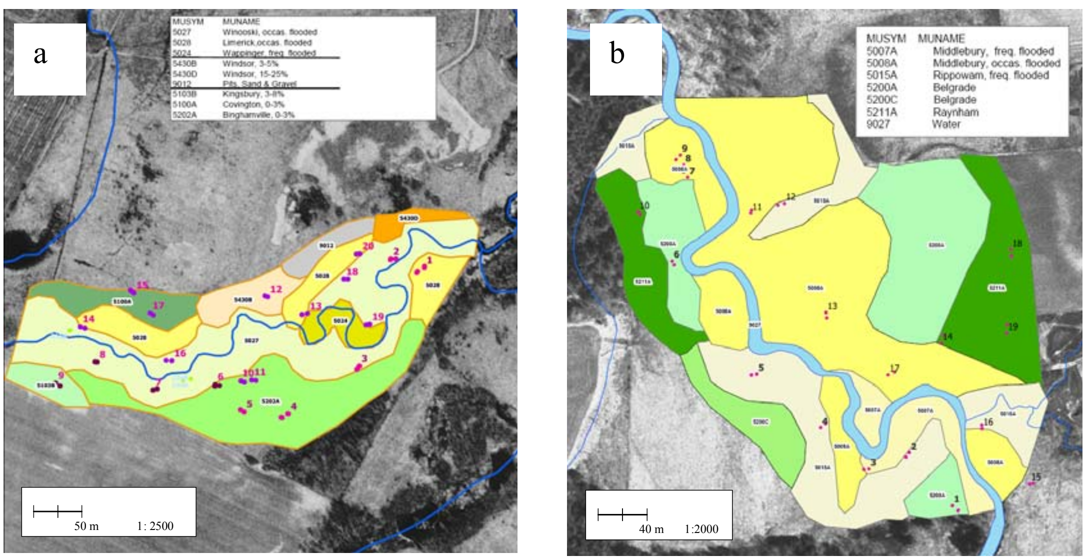

Figure 1. High intensity soil maps for the Rugg Brook (a) and Lewis Creek (b) sites. Map unit symbols correspond to the soil series listed at the top of the figure. Numbered points on the map are individual soil sampling locations taken for P analysis. Map unit delineations drawn by Thomas Villars, USDA-NRCS; maps prepared by Caroline Alves, USDA-NRCS.

Available and Total P Concentrations
Analysis of Variance revealed that available P did not vary significantly ($p = 0.64$) by depth (pooled across series). Total P concentrations varied significantly by depth ($p = 0.009$), but there were few meaningful differences among depths other than the notably

greater P at 0–15 cm (Table 1). Available and total P varied significantly ($p < 0.0001$) by series (pooled across depth) (Table 2). The Raynham and Rippowam series (both poorly

Table 1. Mean available and total P (mg kg^{-1}) by depth pooled across series.

Depth	n	Available P	SEM†	Total P	SEM
0–15	33	1.44	0.14	661a‡	36
15–30	33	1.35	0.20	568b	36
30–45	33	1.42	0.27	491b	35
45–60	36	1.46	0.21	522b	34
60–75	38	1.65	0.21	537b	26
75–90	37	1.74	0.22	534b	24
90–105	36	1.80	0.19	533b	24

† standard error of the mean
‡ total P means with different letters are significantly different at $p \leq 0.0024$

Table 2. Mean available and total P (mg kg^{-1}) for select soil series pooled across depth intervals.

Series	n	Available P	SEM	Total P	SEM
Belgrade	28	1.35b	0.17	459b†	38
Binghamville	28	1.17b	0.11	549b	26
Covington	14	0.71b	0.06	515b	72
Limerick	33	0.93b	0.07	577b	41
Middlebury	36	1.59b	0.08	557b	14
Raynham	28	3.27a	0.45	669a	23
Rippowam	23	2.50a	0.16	694a	32
Wappinger	14	0.59b	0.06	458b	24
Winooski	35	1.23b	0.08	506b	26

† means with different letters are significantly different at $p \leq 0.03$

drained) had greater ($p \leq 0.001$) average available P concentrations compared to other series (Table 2). Additionally, when all soils were grouped by drainage class, poorly drained soils had significantly ($0.0001 \leq p \leq 0.0024$) greater total P concentrations (605 mg kg^{-1}) compared to moderately well (512 mg kg^{-1}) and well drained (458 mg kg^{-1}).

The similarity in average available P concentrations across depths was relatively consistent *within* individual series. Only two series (Belgrade and Covington) showed significantly different available P concentrations with depth, and both had greater available and total P at the lowest two depths (Table 3). Total P levels varied widely within and among series and by depth, and the main effect of depth on average total P concentration was not significant ($p \geq 0.15$). However, there were some significant differences in mean total P concentrations among depths for some series (Table 3).

Since previous P applications influence soil P availability, landuse history can be an important factor affecting P levels. It should be noted that the samples were taken from pasture areas restored to permanent riparian buffers, and have not received any P applications in several decades. The fact that available P levels were not significantly greater in the upper horizons also suggests that previous landuse history had little impact on P availability as sampled at this point in time. Upper horizon samples in adjacent cornfields confirmed that P levels were much greater in actively cropped fields.

Table 3. Mean available and total P (mg kg^{-1}) for select soil series sampled in 2006.

Series/depth	*n*	Available P	SEM	Total P	SEM
Belgrade					
0–15	4	0.87a†	0.09	437ab	91
15–30	4	0.70a	0.07	305a	51
30–45	4	0.88a	0.17	283a	63
45–60	4	0.98a	0.21	510ab	201
60–75	4	1.65ab	0.45	519ab	42
75–90	4	2.18b	0.54	559b	18
90–105	4	2.18b	0.58	601b	53
Covington					
0–15	2	0.85ab	0.05	650	133
15–30	2	0.45a	0.05	455	168
30–45	2	0.60a	0.00	272	83
45–60	2	0.50a	0.00	206	95
60–75	2	0.65a	0.05	578	245
75–90	2	0.95b	0.15	721	216
90–105	2	1.00b	0.10	721	198
Limerick					
0–15	5	1.12	0.15	787b	140
15–30	5	1.00	0.18	695ab	141
30–45	5	0.94	0.33	570ab	144
45–60	4	0.74	0.07	476a	69
60–75	5	0.86	0.26	500a	50
75–90	4	0.82	0.10	480a	44
90–105	5	1.04	0.21	488a	32
Rippowam					
0–15	4	2.27	0.47	810b	51
15–30	4	2.23	0.55	793ab	59
30–45	4	2.37	0.93	740ab	42
45–60	4	2.40	0.33	737ab	32
60–75	4	2.90	0.26	662ab	57
75–90	4	2.73	0.23	538a	110
90–105	3	2.40	0.60	586ab	184
Winooski					
0–15	5	1.72	0.23	656b	50
15–30	5	1.14	0.15	585ab	59
30–45	5	1.08	0.22	469a	44
45–60	5	1.00	0.32	455a	83
60–75	5	1.06	0.18	460a	96
75–90	5	1.22	0.20	465a	58
90–105	5	1.36	0.14	455a	52

† means with different letters are significantly different at $p \leq 0.05$

Correlations between available P and ammonium acetate-extractable cations known to affect P sorption (e.g., Al, Fe, Mn, Ca) were weak across series, with some significant correlations within series. Across all samples and depths, total P was positively correlated ($0.0001 \leq p \leq 0.01$) with total Al, Fe, Mn, Ca, organic matter, and available P. In general, these correlations tended to be higher within individual series. These relationships will be explored more fully following collection and analysis of all samples in 2007. We will also select a subset of soils to determine the influence of soil textural variation on total and available P concentrations.

Information Transfer Program

Student Support

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	4	0	0	0	4
Ph.D.	1	0	0	0	1
Post-Doc.	1	0	0	0	1
Total	8	0	0	0	8

Notable Awards and Achievements

Publications from Prior Projects

None