Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2012

Introduction

The following sections describe the activities of the Vermont Water Resources and Lake Studies Center in the project year just concluded (2012-2013).

Research Program Introduction

In the 2012-2013 project year the Vermont Water Resources and Lake Studies Center continued its collaboration with the Vermont Agency of Natural Resources (VTANR) within the Vermont Department of Environmental Conservation (VTDEC). Vermont Water Center RFP for 2012 was designed to specifically address several broad aspects of water resources management in Vermont that are of direct interest to the VTDEC as well as other collaborating stakeholder groups. These groups include the Lake Champlain Basin Program, the Lake Champlain Research Consortium, municipalities, and NGOs.

In the Vermont Water Center RFP process for 2012-2013 proposals on any topic relevant to the mission of the Water Center were considered. As in previous years the Vermont Water Center solicited proposals that would:

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

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

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

During the 2012-2013 project year a total of 3 proposals were funded. Two of these three projects are concluding and so the reports here are final reports that may be updated briefly next year. The research projects summarized in the following sections are:

Bomblies, A. and J. Hill. Advanced and integrative model of phosphorus loading from high runoff events (final)

Stockwell, J. and W. B. Bowden. Development of monitoring buoy system for lake studies (final)

Wemple, B. and D. Ross. Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff (continuing)

These projects are described in detail in the sections that follow.

Advanced and Integrative Model of Phosphorus Loading from High Runoff Events

Basic Information

Title:	Advanced and Integrative Model of Phosphorus Loading from High Runoff Events
Project Number:	2011VT59B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	Vermont-at-Large
Research Category:	Climate and Hydrologic Processes
Focus Category:	Non Point Pollution, Hydrology, Nutrients
Descriptors:	Topography; sediment; nutrient; phosphorus
Principal Investigators:	Arne Bomblies, Jane Hill

Publications

There are no publications.

10. Abstract.

Lake Champlain Basin (LCB) non-point pollution control factors heavily into the environmental health of the lake, because excessive nutrient loading has resulted in a number of harmful algal blooms. Agricultural activity within the watershed is largely responsible for the phosphorus (P) and nitrogen (N) pollution, which originates in fields within the LCB. Critical source areas (CSAs) have been defined as nonpoint phosphorous sources that contribute disproportionally higher amounts of P to the watershed (Ghebremichael, 2010). The high P loss stemming from CSAs has been attributed to unusually high P concentration within a CSA resulting from soil types and management practices (Pote et al., 1996, 1999; Sharpley, 1995; Sharpley et al., 1996), and areas susceptible to high volumes of runoff and erosion (Pionke et al., 1997; Gburek and Sharpley, 1998). P source areas are locally controlled, but transport in the watershed depends on hydrological processes. In the LCB, studies have looked at P transport within the watershed using the curve-number based SWAT model (e.g. Gebremichael 2010), but process-based models have not been applied with much success. Since sediment-bound P transport plays a major role in nutrient transport, and because runoff generation processes are variable in time and space in a watershed, a process-based model representing sediment mobilization from individual fields may be better suited to simulate the changes expected from alterations of management of those fields that are small components of subwatersheds. Moreover, because much sediment transport occurs during discrete high precipitation events, a process-based model should be better suited to simulate the impacts of changes in the precipitation regime expected from climatic change on LCB nutrient loading, as well as anomalously high loading stemming from spring flush events and other extreme hydrological events. In synergy with the recent Vermont EPSCoR grant that aims to model regional adaptation to climate change within the LCB, *we propose to continue to build process-based models that can help determine CSAs, both present and future, from hydrological characteristics including intrafield topographic variability. This will allow the simulation of runoff and nutrient response to future precipitation regimes that differ from the previously-observed rainfall regime on which much watershed management is based.*

Item 11: Budget

Cost category	**Federal**	**Non-Federal**	**Total**
Salaries and wages			
- Principal Investigator	$ -	$ 23,530	$ 23,530
- Graduate Students	$ 20,000	$ -	$ 20,000
- Undergraduate Students	$ -	$ -	$ -
- Others: staff assistant	$ -	$ -	$ -
- Wages	$ -	$ -	
- Total Salaries and Wages	$ 20,000	$ 23,530	$ 43,530
Finge Benefits	$ -	$ 9,836	$ 9,836
Supplies	$ -	$ -	$ -
Equipment	$ -	$ -	$ -
Services or Consultants	$ 1,250	$ -	$ 1,250
Travel	$ 3,500	$ -	$ 3,500
Other Direct Costs	$ -	$ -	$ -
Total Direct Costs	$ 24,750	$ 33,366	$ 58,116
Indirect costs on federal share	XXXXXX	$ 12,994	$ 12,994
Indirect coss on non-federal share	XXXXXX	$ 17,517	$ 17,517

Total Estimated Costs	$ 24,750	$ 63,877	$ 88,627
Total costs at Center campus	$ 24,750	$ 63,877	$ 88,627
Total costs at other University	$ -	$ -	$ -

Item 12. BUDGET JUSTIFICATION

Salaries and wages: Funding is requested for one semester and one summer, for a fulltime graduate student ($20,000). Dr. Hill, through the School of Engineering, will be providing 0.5 month FTE cost-shared time to this project, and Dr. Bomblies will be providing 2 months FTE cost-shared time to this project.
Fringe Benefits: Fringe benefits are calculated at the standard University of Vermont rate. The undergraduate fringe is calculated based on the rate of 9%.
Travel: $3,500 is requested for travel domestically, to and from the study site, for 140 trips at $25/trip.
Water samples: $1000 is requested for the analysis of 250 water samples
Soil samples: $250 is requested for the analysis of 240 samples.

ITEM 13: TITLE:

Advanced and Integrative Model of Phosphorus loading from High Runoff Events

ITEM 14: STATEMENT OF REGIONAL OR STATE WATER PROBLEM

Lake Champlain Basin (LCB) non-point pollution control factors heavily into the environmental health of the lake, because excessive nutrient loading has resulted in a number of harmful algal blooms. Agricultural activity within the watershed is largely responsible for the phosphorus (P) and nitrogen (N) pollution, which originates in fields within the LCB. Critical source areas (CSAs) have been defined as nonpoint phosphorous sources that contribute disproportionally higher amounts of P to the watershed (Ghebremichael, 2010). The high P loss stemming from CSAs has been attributed to unusually high P concentration within a CSA resulting from soil types and management practices (Pote et al., 1996, 1999; Sharpley, 1995; Sharpley et al., 1996), and areas susceptible to high volumes of runoff and erosion (Pionke et al., 1997; Gburek and Sharpley, 1998). P source areas are locally controlled, but transport in the watershed depends on hydrological processes. In the LCB, studies have looked at P transport within the watershed using the curve-number based SWAT model (e.g. Gebremichael 2010), but process-based models have not been applied with much success. Since sediment-bound P transport plays a major role in nutrient transport, and because runoff generation processes are variable in time and space in a watershed, a process-based model representing sediment mobilization from individual fields may be better suited to simulate the changes expected from alterations of management of those fields that are small components of subwatersheds. Moreover, because much sediment transport occurs during discrete high precipitation events, a process-based model should be better suited to simulate the impacts of changes in the precipitation regime expected from climatic change on LCB nutrient loading, as well as anomalously high loading stemming from spring flush events and other extreme hydrological events. In synergy with the recent Vermont EPSCoR grant that aims to model regional adaptation to climate change within the LCB, *we propose to continue to build process-based models that can help determine CSAs, both present and future, from hydrological characteristics including intrafield topographic variability. This will allow the simulation of runoff and nutrient response to future precipitation regimes that differ from the previously-observed rainfall regime on which much watershed management is based.*

Multiple studies have focused on the importance of CSA identification and remediation to mitigate nonpoint P loss (e.g. Pionke et al., 1997; McDowell et al., 2001; Weld et al., 2001). Opportunities for

Action generated by the Lake Champlain Steering Committee, November 2010, addresses the importance of CSA identification through acknowledgment of current projects and future research:

- ID (4.6.1) - Continue the IJC* project, *Identification of Critical Source Areas of Phosphorus Pollution in the Missisquoi Bay Watershed* (Vermont, Québec, USDA-NRCS, LCMB)
- ID (4.6.7) - Seek funding sources to support analysis of Critical Source Areas in the New York portion of the South Lake watershed, similar to the Missisquoi Bay initiative funded by the IJC.
- ID (4.9.2) Explore management tools that can be used to identify critical source areas and effective interventions.

*International Joint Commission

Phosphorous sources and transport factors that drive disproportionate P contributions to the watershed lead CSA identification strategies to combine complex site specific variability of topography, hydrology, soil and management practices (Ghebremichael, 2010). Sediment transport from CSAs to the watershed can act as a conduit for P migration. Early approaches to estimating soil erodibility at concentrated flows were made using an erodibility factor generated from the Universal Soil Loss Equation (USLE) which describes the combined response to both sheet and rill erosion as an approximation (Knapen, 2007). The suitability of the USLE 'K' factor was rejected (Line and Meyer, 1989; Laflen et al., 1991; Zhu et al., 1995) due to the consideration that soil erosion is a process-specific concept and that intrinsically different processes are responsible for concentrated flow erosion compared to combined sheet and rill erosion and erodibility (Bryan, 2000; Sheridan et al., 2000a,b). Two major tools have been developed to address the need for watershed and subwatershed modeling: the Soil and Water Assessment Tool (SWAT) and the Water Erosion Prediction Project (WEPP). SWAT, generated by the U.S. Department of Agriculture's, Agricultural Research Service, was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods (Neitsch et al., 2005). WEPP, developed by the USDA-ARS National Soil Erosion Research laboratory, is a process-based continuous simulation program that predicts sediment yields and deposition from overland flow on hill slopes, sediment yield and deposition from concentrated flow in small channels, and sediment deposition in impoundments. WEPP computes spatial and temporal distributions of sediment yield and deposition, and provides explicit estimates of when and where in a watershed or on a hill slope erosion occurs so that conservation measures can be selected to most effectively control soil erosion (Flanagan and Nearing, 1995). Comparisons of SWAT and WEPP for watershed hydrology and erosion prediction have been performed (Shen et al., 2009; Boll et al., 2011). The outcomes have indicated that SWAT is useful for large scale watershed assessment due to the convention that areas with the same soil type and land use form a Hydrologic Response Unit (HRU), a basic computational unit assumed to be homogeneous in hydrologic response to land cover change, and that WEPP is an appropriate tool for medium to small watersheds. SWAT in not an appropriate tool for smaller watersheds and field specific use because of the soil module, Modified Universal Soil Loss Equation (MUSLE) which is an empirical equation and not appropriate to be used where detailed physical parameters are necessary to describe erosion and sediment yields mechanistically for determination of change impacts (Williams et al., 1985; Shen et al., 2009).

While generation of agricultural runoff, erosion and sediment yields are an important function of CSA identification, phosphorous generation from soil P and sediment transport need to be quantified at a field scale to validate modeling outputs. It is our intention to use the WEPP model to identify critical source areas generating disproportionate P inputs at an individual agricultural field scale and to quantify total P generation at a field scale. A study site, of 3 agricultural fields, has been acquired through the generous support of Tim Camisa, Vermont Organics Reclamation, located in Georgia, Vermont. A mass balance of the site water budget has been performed for the summer and fall through the installation of impoundments at the field drainages, 3 weirs and 1 flume. Phosphorous quantification will be performed at the weirs and flume to indicate total P leaving the site. Identification of potential CSAs will take place over a three-step process;

- The WEPP model will be parameterized specific to the site for management practices, soil classification, climate generation, and slope.
- Model output will indicate location of maximum sediment detachment and deposition specific to field slope inputs.
- At the point of maximum detachment specific to field slope, Gerlach sediment samplers will be installed to quantify sediment mass and P concentration.

Maximum detachment locations will be identified for multiple percent slope elevations and sediment samples will be collected for 24-hour rain event periods.

ITEM 15: STATEMENT OF RESULTS OR BENEFITS

Because phosphorus is often associated with suspended solids (Gray and Glysson, 2002), erosion in agricultural watersheds can be a source of non-point phosphorous pollution that can adversely impact receiving water bodies. Critical source areas of phosphorus will be associated with runoff generation in a field as well as the potential mobilization of P at that point. Runoff generation in turn is related to degree of saturation of the soil as well as the topography of the field. The seasonal legislative ban on manure application in Vermont during winter periods when the soil is frozen and impermeable has addressed the recognized problem of high P loading during winter periods of low soil permeability. However, high phosphorus loading continues to be a problem in the Lake Champlain watershed, despite regulatory efforts. This may be partially due to spring-like conditions during the summer or late spring (post April 1) when periodic high precipitation events saturate soils, runoff is high, and manure spreading is not prohibited.

Topography can influence the amount of runoff from a field in addition to soil moisture. Higher angled slopes will produce more runoff than lower-angled slopes, and the effects of topography can thus influence the distribution of critical source areas. Topographic variability within a field may play a significant role in determining the phosphorus mobilization from that field. Topographically lower areas where runoff water accumulates during spring-like conditions will contain deeper, faster flowing water whose greater scouring potential is expected to mobilize P more effectively.

We hypothesize that an understanding of the hydrological impacts of both topographic variability and the occurrence of soil saturation after the end of the manure spreading ban in Vermont (April 1) will help identify critical source areas of P pollution in the Lake Champlain Watershed. Consequently, a mechanistic model that simulates these potentially important processes, distributed in space, is of value as concerns about Lake Champlain water quality increase. Page et al. (2004) investigated at TOPMODEL-style distributed topographic index as a predictor for point P concentration, but the correlation was not good due to confounding factors such as uneven distribution of manure within the field. In this study, we will aim to understand the integrated impacts of topographic variability over an entire agricultural plot, during times when runoff is high. We will measure point P concentrations throughout the field to characterize the spatial variability within the field. Our modeling approach will allow spatially distributed estimates of mobilized P concentrations based on such measurements, which differs from the topographic index approach employed by Page et al. (2004). They assumed that topographically induced wetness can be used as a proxy for mobilized P. Our modeling results will explicitly simulate accumulated P at each location. These results will then be validated with field sampling of suspended P across the plot during precipitation events and at the outlet.

To simulate the non-linear response of agricultural watershed P mobilization to changes in land use, freezing patterns, climate patterns, or other perturbations, detailed process-based models are preferred over empirical models and lumped-parameter models, despite distributed process-based models' needs for many distributed parameters. Mechanistic, process-based models are able to simulate the detailed causative pathways between perturbations and system response. The effects of individual variables can be teased apart if all known processes are simulated, and so the potential impacts of changes in timing of rainfall vs. spring melting of the ground surface can be accurately modeled. This detailed representation of the nonlinearities within the physics-based modeling of processes and the mechanistic insight that it allows is a primary intellectual merit of this proposal. This understanding of P mobilization under variable conditions during spring flush events can then be extended to other parts of the Lake Champlain watershed.

B. Expected Results

The proposed research will yield a highly detailed, reliable, process-based model of field response to perturbations and spring-like conditions of soil saturation as well as the effects of intra-plot topographic variability. The proposed field-validated model will help understand the spatial distribution of critical source areas of nonpoint phosphorus pollution that may not be evident using lumped-parameter models. It will also help to understand the contribution of individual fields to watershed-scale P loading based on saturated conditions that occur outside of the seasonal ban on manure spreading. These conditions may result from extended high-precipitation events that render the saturated soil effectively impermeable.

The distributed parameter model that will result from the proposed research can potentially be very helpful in determining critical source areas for nonpoint P pollution. Although a distributed model representing sub-plot variability in topography, soil moisture, and overland flow characteristics is very data- and parameter- intensive, representation of this sub-plot variability can incorporate important processes that may be contributing to high nonpoint source pollution and that may be smoothed over in lumped-parameter models representing the entire plot. For example, overland flow from saturated or frozen soil may accumulate in topographically lower areas, causing deeper, faster flowing water. The higher velocity, deeper overland flow may be suspending sediment much more effectively than without topographic variability. Moreover, the ability to represent variable levels of freezing and thawing within a plot may prove to be important in distinguishing critical source areas from lower-impact agricultural land. Depending on aspect and antecedent moisture levels, sub-plot variability in saturation may affect the overland flow characteristics of the field, and resulting phosphorus transport. The resulting understanding of the hydrological impacts of a field's internal variability can shed light on the key characteristics of critical source areas, and may ultimately influence management practices.

It is expected that the simulated phosphorus during high flow events will closely match the observed P at the catchment outlet, for variable conditions of frozen ground, topography, or soil saturation. This model will be a research tool for the test catchment to help understand response to a variety of meteorological events and agricultural conditions. It will be highly parameterized based on field observations at the test plot, and as such will not be easily transferrable to other catchments, however the general understanding of nonlinear system response to spring flush events gained from this model development will be expected to apply to much of the Lake Champlain watershed. Certainly the impacts of topographic variability occurring throughout the Lake Champlain watershed can be better understood.

Prediction of total P (dissolved and suspended) efflux from frozen or saturated agricultural soils will inform the P release and organic P content components of total P loading to the Lake. Knowledge of these two index constituents will lead to an enhanced ability to manage agricultural soils in the regions of Vermont subject to manure spreading and high runoff events.

Bomblies has experience modeling overland flow and the development of highly detailed distributed hydrology models that are similar to the proposed model (Bomblies et al., 2008). These studies have involved much field data collection to parameterize a new numerical model (HYDREMATS, the PI's creation) which has been successfully applied to predict the hydrological details of distributed overland flow over an infiltrating surface.

Co-investigator Hill has experience field-sampling for phosphorus species and has specifically developed a technique to accurately quantify P species in a rapid and cost-effective manner (Johnson and Hill, 2010).

C. Benefits and Training
The project is very well suited for integrating research and education. The PI would continue to train the MS candidate Josh Tyler, who will become an expert in hydrology and environmental water quality. In addition, an undergraduate Environmental Engineering student at the University of Vermont will be supervised by Bomblies and Tyler to participate in the field investigations and modeling. This student will be trained in widely applicable modeling and field hydrology techniques. Bomblies is a hydrologist with experience in watershed modeling and Hill is an expert on environmental chemistry and specifically phosphorus in the environment.

Another benefit of the proposed work is that the resulting model is expected to be a component of the new Vermont EPSCoR project, linking best management practices in the Lake Champlain watershed to ecosystem services.

ITEM 16: PROJECT OBJECTIVES AND TIMELINE

The overall objective of the proposed study is to develop a new model to simulate the suspended phosphorus loading from non-point sources in frozen or saturated fields during the high runoff events.

Objective 1: Watershed modeling of P transport. We will develop a detailed, spatially explicit model to simulate the overland flow over the frozen, thawing or otherwise saturated field. This will entail simulations of snowmelt, precipitation and sediment transport to predict suspended P at the catchment outlet. One purpose of the model will be to study the role of intrafield topographic variability in determining sediment mobilization and potential role in CSA determination. We hypothesize that topographic variability can have a significant impact on runoff response to precipitation events. WEPP model output will be compared to SWAT model output to determine the efficacy of such a detailed process-based model for representing mechanisms of CSAs. Such a modeling approach will be very detailed and highly parameterized, but will also allow the detailed study of the mechanisms involved in sediment mobilization. The model will be capable of representing spring flush events, which result from rainfall and snowmelt on saturated, recently thawed bare soil and often mobilize large amounts of P from agricultural fields.

Objective 2: Field studies of P mobilization. To parameterize the model we will closely monitor a carefully chosen field site. As of December 2011, this field site has been in operation for eight months (Georgia, Vermont). We will set up automated monitoring at the catchment outlet and take repeated surveys of the catchment characteristics after April 1 and through the summer.

Progress to date: We (J. Tyler, M.S. student of J. Hill and A. Bomblies) have instrumented a field site near Georgia Center. Figures 1, 2 and 3 show the field site at various times of the year, with the variable topography across the site (an important determinant of P mobilization) accentuated in Figure 3. We have installed a meteorological station (Figure 4) and have monitored the site from May 2011 until the present. This period encompasses two field seasons, enough for Josh Tyler to complete his MS thesis. During this time, we have witnessed manure application (Figure 5), plowing (Figure 6), planting (Figure 7) and harvest of the crops (Figure 8). In short, we have taken note of the land management for an entire growing season using typical techniques, and have monitored the inflows and outflows of water at the site (to determine runoff generation). This was done using a 6" Parshall flume at the catchment outlet (Figure 9-11), which includes a pressure transducer with which the stage is continuously recorded. The flume was installed using sand bags instead of concrete, because we wanted the installation to be temporary, and also because it was installed while the ground was still frozen in March. The standard rating curve is used to convert stage to flow, and periodic pygmy meter measurements are used to verify accuracy of this measurement. In addition, the small amount of flow onto the site is gauged by three v-notch weirs (Figure 12), each instrumented with a pressure transducer to measure flow continuously. Together, these measurements allow a good estimate of runoff generation from the study site to be made.

We have also taken within-field samples of overland flow, and quantified the mobilized P and sediment. These measurements were done using Gerlach samplers (troughs). Gerlach troughs capture surface runoff and channel flow into a sealed bucket that is used to document sediment yields from unbounded plots (Gerlach, 1967). These have been used by the USGS in New Mexico and Puerto Rico with successful results (Gellis et al., 2004; Gellis et al., 2006). The trough is an aluminum channel 20" long with a 3/4" hose connection for collection in a 5 gallon utility bucket. The top of the trough has a galvanized sheet metal rain cover. Installation consists of digging an area the width and length of the trough, creating a slight slope in the direction of the runoff hole. Gerlach troughs were placed in the furrows to collect sediment yield. The sediment yield will be used in conjunction with the rainfall data from an onsite meteorological station to couple rainfall events with sediment transport. Once sampling was completed the collection buckets were brought back to the University of Vermont soils lab, weighted, and analyzed for sediment and phosphorous concentration. Some samples from the latter part of the 2011 growing season were collected and analyzed. These sample locations are shown in Figure 13. Several more samples were taken, but were not used because the Gerlach samplers repeatedly were flooded. Ultimately, we chose to abandon those samples and use only two sample locations of Figure 13. During 2012, four more Gerlach samplers will be installed and monitored in order to determine the role of topographic variability in mobilizing sediment. The measurements will constitute a model calibration target for 2011, and will be validated using 2012 data.

Similar measurements of sediment and P were taken from water sampled above the impoundments of the V-notch weirs to determine background P and sediment in the water entering the site, and the flume to determine total sediment and P at the catchment outlet. These measurements commenced in July 2011, and continued through summer 2012. Surprisingly little rain fell at the site during the Tropical Storm Irene event of August 28, 2011 (3.8 inches over 24 hours), and the fully-cropped conditions during the event prevented significant sediment mobilization from the study fields. Low flows were oberserved in the flow gauges, that were significantly less than flows in the spring. This is in contrast to observations of severe sediment transport in larger rivers post-Irene, but based on our observations the sediment may have originated elsewhere, such as bank erosion for example. The results of water measurements taken from impountments above flumes and weirs during the 2011 season are shown in Figure 14. During the 2012 summer field season, the site experienced low flow conditions due to a mild drought in Vermont. However, several significant rainfall events yielded flow and sediment measurements for use in Josh Tyler's analysis

Because topography is expected to be a key determinant of sediment and nutrient mobilization, and intrafield topographic variabilty may be very important for sediment mobilization, we have measured field topography at 5-meter resolution using a Topcon HiperLite Plus differential GPS system. This allows for distributed topography to be used as a model input and predicted sediment at the Gerlach trough locations to be simulated.

Objectives for 2013

Graduate student Josh Tyler has been working on building a process-based model using WEPP for the research site. This has involved gathering all of the necessary input and attempting calibration. He has collected all necessary field data for a WEPP model (and a SWAT model, for comparison), and is actively finalizing that work in his Master's thesis. He is expected to defend this work in August 2013, and will submit it for publication in a peer-reviewed journal: the Journal of the American Water Resources Association.

Timeline:

	2013	
Activity	***Feb - Apr***	***May - July***
MS student training	completed	
establishment of spring field sites	completed	
Objective 1 (model development)	completed	
Objective 1 (model calibration)	completed	
Objective 2 (field experiments)	completed	
Publishing preparation		In progress

ITEM 17: METHODS, PROCEDURES, STATISTICS AND FACILITIES

Objective 1: Model development.
We will develop a highly detailed model that can accurately predict the dissolved and suspended phosphorus from a field undergoing high runoff events either during frozen conditions or saturated conditions. Topographic variability will be explicitly represented to assess the role of topography as a determinant of critical source areas in the Lake Champlain Watershed. To this end, we will use the Water Erosion Prediction Project (WEPP) model (Laflen et al., 1991; NSERL, 1995, Flanagan and Nearing, 1995). The WEPP model is a physics-based model designed to operate at the field scale spatially, and daily scales temporally. It was written to simulate the essential processes governing water erosion at field scales, however watershed-scale processes are supported as well. WEPP also simulates other hydrologic processes such as redistribution of water in the soil profile (negligible in frozen soils), evaporation and transpiration, freezing and thawing, and agricultural manipulation of the soil surface and vegetation. Due to its distributed and physics-based nature, the model is often criticized for being overly data-intensive, and the mismatch between the scale of parameter measurements and the scale of simulation often restricts the model to intensively studied research applications (Merritt et al., 2003). However, it is an appropriate model for our research objectives, because of the planned spatial resolution of field measurements including P concentrations and elevation, as well as the desired functionality of the model. For the goal of

modeling suspended P attached to particulates, the use of WEPP is an improvement over the popular but empirical-based Universal Soil Loss Equation (USLE) for this site, because it allows continuous simulation of erosion and deposition along a hillslope to be simulated. This allows more accurate simulation of sediment load at the watershed outlet, provided the input data is sufficiently detailed. In addition, erosion and associated runoff are predicted for individual precipitation events. This capability allows detailed temporal analysis of individual hydrographs and sedigraphs.

Modeled precipitation is in the form of daily precipitation depth, duration and intensity, however field-measured meteorological data can also be used as model forcing. In this way, field-measured meteorological variables will be used to calibrate and validate the model for several events, and modeled climate variables can also be generated by WEPP to explore system response to various scenarios. Soil freezing and thawing is simulated on an hourly scale. Both sheet and rill flow are simulated, but gullies and channel erosion are not. In the subsurface, the model simulates infiltration, lateral flow, resurfacing and tile drainage, and at the surface both disturbances by tillage and natural processes are included (Fox et al., 2001).

Model meteorological input will come from local meteorological measurements. Bomblies has a Campbell Scientific meteorological station that will be installed on the site. This device will measure rainfall, temperature, solar radiation, soil moisture, soil temperature and wind data at high temporal resolution, and will store these variables in a datalogger for periodic download. For topography input, we will survey the site with survey-grade differential GPS equipment. Bomblies owns a Topcon Hiper Lite Plus system, with centimeter horizontal precision and 15-mm vertical precision. Bomblies also will provide associated data collectors and relevant software from Topcon. This is a state-of-the-art, highly accurate measurement system ideally suited for data collection for such a detailed study. Using this instrument, a highly detailed, hydrologically correct representation of watershed topography will be generated. This is necessary input for credible simulation using the WEPP model.

The application of WEPP will occur in conjunction with a Geographic Information System (GIS), to allow management of input datasets, and survey locations. A digital elevation model (DEM) generated from the topography data will form the basis for generating intra-field slope profiles and flow paths as needed in WEPP.

Facilities:
Modeling will be done using the Bomblies lab's computer. This is a Dell T7500 workstation with two 3.5 GHz quad-core processors and 4GB of RAM. ArcGIS and WEPP are installed on the computer. The School of Engineering owns a license for the ESRI ArcGIS software used in conjunction with WEPP.

Objective 2. Field measurements.
Many detailed field studies are needed to parameterize and validate the WEPP model. The primary field data need is total P at the watershed outlet, in response to precipitation and/or snowmelt events. For this, we will set up a flume at the catchment outlet, equipped with an automated depth gauge such as a pressure transducer. Bomblies has an automated pressure transducer available, and we will purchase a flume. The pressure transducer will likely be wired to the automated datalogger located at the meteorological station. Periodic visits with a flow meter during flow events will allow the rating curve to be developed, to allow continuous monitoring of the hydrograph.

During the high runoff events (high precipitation/saturation and snowmelt), detailed runoff samples will be taken to parameterize the model. Before, during and after storm events, graduate student Joshua Tyler will sample the catchment outflow at hourly intervals, and quantify the total, suspended, and dissolved phosphorus concentrations. Filtered and unfiltered samples will be measured for suspended and dissolved phosphorus as well as organic phosphorus composition using standard techniques such as molybdate-reactive phosphorus and total phosphorus from digestion and the high-throughput method developed by Hill, respectively.

In addition, regular surveys of the catchment surface will be made. These surveys will gather information on two key variables: the degree of snow cover or saturation throughout the test field and the spatial distribution of P-containing soil. These measurements will be repeated in order to characterize the response to flushing events. The spatial variability of phosphorus in the source area (manure-covered field) will be estimated with these samples. Each field sample at each location will be repeated in triplicate, and the locations chosen in order to generate a distributed field of available P as model input.

Soil Sampling methods:
Soil and sediment samples will be processed as follows. Total mass will be measured directly. Particulate mass will be quantified by drying at 55^{o}C. Total P and metals (Fe, Al, Mg, Ca, Mn) will be calculated from a digested sample (Parkinson and Allen, 1975) using inductively-coupled plasma-optical emission spectroscopy. Total C and total N will be determined on an Elemental Analyzer. Inorganic P will be calculated via a modified molybdate blue assay (Dick and Tabatabai, 1977; He et al, 2007). Organic P will be determined via the plate assay developed by Johnson and Hill (2010).

Runoff sampling methods:
Surface runoff samples will be collected during rainfall events. Liters of sample will be collected and analyzed as follows. The filtrate from 0.45 μm samples will be assayed for molybdate-reactive phosphorus (He et al, 2007) and total P will be measured directly using inductively-coupled plasma-optical emission spectroscopy. Unfiltered samples will be assayed for total P and metals after digestions as well as molybdate-reactive P and organic P in the same manner as soil samples.

ITEM 18: FINDINGS AND DISCUSSION

The goal of this research is to investigate the impacts of small-scale topographic and land use variability on non-point phosphorus pollution. The field component of this research was started in April 2011 by Josh Tyler (MS student, Civil and Environmental Engineering), and has been mostly completed. Samples are being analyzed in the Hill lab where total P, metals, and inorganic & organic P are being quantified by Tyler. We are noticing minor effects of topography on P from soil samples and are measuring overland flow directly using Gerlach samplers. So far, those samples have not yielded any major findings, but are carefully monitoring the actual, mobilized sediment and sediment-bound P in overland flow at various points in our study fields. This is important for our overall P and water budget that we are conducting and modeling.

The most promising result so far is a series of samples that indicate that pooled water in topographic depressions within the study fields has much higher dissolved P than typical runoff because it has been stagnant. Light rain adds more water to these depressions and seems to temporarily dilute the P but it returns to equilibrium after some time with relatively high P concentration and does not lose water to the watershed. However, when a large storm flushes out these depressions the dissolved P is washed downstream and enters the watershed in a significant pulse, greater than it would be from overland flow alone. This constitutes a mechanism by which P flushed from the fields depends nonlinearly on rainfall, and is dependent on microtopography that is smoothed over in many common models. Tyler and Bomblies are working on representing this effect using the WEPP model and will compare the results with the commonly-used SWAT. Field sampling and modeling are ongoing, and we are aiming to finish this research by the end of the summer.

Other research involves a careful water balance at the site, and an attempt at characterizing the groundwater contribution to both water and P into the stream draining the fields. It is thought that P in deeper soil from many years of past farming at the site can lead to a significant addition to the P budget when it is dissolved in moving groundwater. We are attempting to quantify this effect by sampling groundwater entering the streams using upside down buckets that sample only water from the flow lines entering the stream from below. A small amount of water may be due to hyporheic exchange from the channel flow as well.

ITEM 19 TRAINING POTENTIAL

This project is the MS degree research of Civil and Environmental Engineering graduate student Josh Tyler. He expects to finish his thesis in September 2012. This thesis will be published, and we are aiming for publication in the ASCE (American Society of Civil Engineers) journal "Journal of Hydrologic Engineering". Both the MS thesis and the research paper are in progress and will be completed by December 2013 at the latest.

Moreover, this project involves an undergraduate student in Civil and Environmental Engineering, Lindsay Taylor, who has won a summer grant from the Barrett Foundation at UVM. The travel money from this project is shared between Lindsay and Josh to travel repeatedly to the field site from Burlington, VT, to near St Albans, VT.

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THESES AND ARTICLES

This project is the MS degree research of Civil and Environmental Engineering graduate student Josh Tyler. He expects to finish his thesis in September 2012. This thesis will be published, and we are aiming for publication in the ASCE (American Society of Civil Engineers) journal "Journal of Hydrologic Engineering". Both the MS thesis and the research paper are in progress and will be completed by December 2012 at the latest.

Moreover, this project involves an undergraduate student in Civil and Environmental Engineering, Lindsay Taylor, who has won a summer grant from the Barrett Foundation at UVM. The travel money from this project is shared between Lindsay and Josh to travel repeatedly to the field site from Burlington, VT, to near St Albans, VT.

Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff

Basic Information

Title:	Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff
Project Number:	2012VT65B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	Vermont-at-Large
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Water Quality, None
Descriptors:	roads; best management practices; BMPs; water quality; sediment; phosphorus
Principal Investigators:	Beverley Wemple, Donald Ross

Publications

There are no publications.

10. Abstract:

Gravel roads in rural settings can adversely affect water quality through the contribution of excess runoff, sediment and sediment-bound nutrients to receiving waters. These contributions can occur through chronic wash off from the road surface and through catastrophic gullying and road bed failure during extreme storms. To mitigate the adverse effects of roads on water quality, a number of Best Management Practices (BMPs) have been developed and tested in diverse settings. Although these practices appear to reduce erosion and mass wasting from roads, evidence of the benefit of any single BMP on pollutant reduction is limited, and studies quantifying these reductions in rural Vermont do not exist. We will partner with the Vermont Better Backroads Program to identify candidate sites and install a suite of BMPs that are included in recent statewide directives for implementation on gravel roads. Using a paired-site design, we will leverage an existing dataset and monitor both treated (BMP sites) and untreated controls throughout the term of this project. Results from the project will provide guidance on pollutant reduction potential of these management practices, a key need of the Vermont Agency of Natural Resources. The proposed research will also provide a framework for developing a cost-benefit strategy for targeting future BMP implementation.

11. Budget Breakdown:

	PIs: Wemple, Ross		
	Evaluating Effectiveness of BMP implementation		
Cost category	**Federal**	**Non-Federal**	**Total**
Salaries and wages			
- Principal Investigator - Wemple	$ -	$ 14,347	$ 14,347
- Co-Investigator - Ross	$ -	$ 4,537	$ 4,537
- Graduate students	$ -	$ -	$ -
- Undergraduate Students	$ 2,880	$	$ 2,880
- Others: Technician	$ 10,080	$ -	$ 10,080
- Wages	$ -	$ -	$ -
- Total Salaries and Wages	$ 12,960	$ 18,884	$ 31,844
Fringe Benefits	$ 1,128	$ 7,988	$ 9,116
Supplies	$ 4,800	$	$ 4,800
Equipment	$ -	$ -	$ -
Services or Consultants	$ -	$ -	$ -
Travel	$ 3,680	$	$ 3,680
Other Direct Costs (lab fees)	$ 4,608	$ -	$ 4,608
Total Direct Costs	$ 27,176	$ 26,872	$ 54,048
Indirect costs on federal share	$ 14,267	n/a	$ 14,267
Indirect costs on non-federal share	n/a	$ 14,108	$ 14,108
Total Estimated Costs	$ 41,443	$ 40,980	$ 82,423
Total costs at Center campus	$ 41,443	$ 40,980	$ 82,423
Total costs at other University	$ -	$ -	$ -

12. Budget Justification:

Year 1 field activity began in July 2012, allowing us to extend Year 1 funds for technician and student support through June 2013. Funds for personnel in Year 2 are requested for a field season expected to extend through end of October 2013. We are requesting 4 months (July – October 2013) of funding to support a technician ($18/hour x 35 hours/week x 16 weeks) who will have primary responsibility for installing and maintaining field sampling equipment and weekly sample retrieval and processing. We also request support for 4 months (July – October 2013) of funding for an undergraduate student ($12/hour x 15 hours/week x 16 weeks) who will assist the technician two days per week with sample retrieval and processing. Wemple will manage communications with town administrators and road crews and supervise all field installations and sample retrieval. Ross will supervise all lab sample processing. Wemple and Ross will contribute their time during Year 2 to the project at the rate of 18% annual effort for Wemple and 5% for Ross.

Funds for supplies are requested in the amount of $4800 to cover materials for silt fences at 24 sites. These costs are estimated on a $200 per site basis as follows: $30 wooden stakes, landscaping nails and staples, $50 landscaping fabric, and $120 plastic sheeting to be replaced with each site visit. Travel funds are requested in the amount of $3680 to cover 2 trips/week x 16 weeks x $115 per trip (vehicle rental and gasoline) to field sites. Two round trips are needed weekly (12 sites serviced per day) to service and transport samples from field sites to Burlington. Funds for laboratory processing of samples to determine sediment dry mass and total phosphorus are requested for 24 sites x 1 sample/site/week x 16 weeks x $12/sample for a total of $4608.

13. Title: **Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff**

14. Statement of regional or State water problem

Transportation networks are a critical element of our society's infrastructure, linking communities and commerce, but with environmental effects that negatively impact a range of ecosystem processes (Formann and Alexander 1998; Gucinski, Furniss et al. 2001). The linear nature of roads and their tendency to cross topographic gradients influence watershed hydrologic processes on a scale far greater than one might expect from the small fraction of the land area they occupy (Luce and Wemple 2001). In rural settings of humid, temperate landscapes where soil infiltration capacity typically exceeds precipitation rates, roads represent relatively impervious surfaces that generate overland flow and efficiently route it to receiving waters (Luce and Cundy 1994; Ziegler and Giambelluca 1997; Croke and Mockler 2001). When roads are constructed on slopes in upland and mountainous terrain, subsurface flow can be intercepted along road cuts and ditches and redistributed as concentrated surface runoff (Megahan and Clayton 1983; Wemple and Jones 2003). Roads on steep slopes also pose a risk of shallow landslide initiation, producing sediment that can be delivered to downslope receiving waters (Montgomery 1994; Borga, Tonelli et al. 2005). Through these various mechanisms, roads generate water and sediment at levels significantly greater than the undisturbed or lightly disturbed terrain they occupy and effectively extend the natural channel network, providing a direct conduit for water and pollutants to enter receiving waters (Jones, Swanson et al. 2000; Bracken and Croke 2007).

To mitigate the effects of roads on pollutant production and water quality degradation, a number of best management practices (BMPs) have been developed and evaluated (Lynch, Corbett et al. 1985; Megahan, Potyondy et al. 1992; Kochenderfer, Edwards et al. 1997). These practices include guidelines for locating roads and stream crossings, installing drainage structures including culverts and water bars, spacing of structures by road grade, stabilizing road cuts and fillslopes through reseeding applications, use of vegetated buffer strips, and use of energy dissipating devices and sediment control structures at the outlets of culverts or drainage points (RC&Ds 2009). Studies of BMP implementation on forested lands in the northeastern U.S. have shown highly variable compliance with recommendations, pointing particularly to instances where the failure to use BMPs on roads resulted in significant hydrologic and erosion impacts (Brynn and Claussen 1991; Schuler and Briggs 2000).

Within Vermont, inventories are emerging to document the extent and form of road-drainage impairments to water quality (VBB 2008; Bartlett, Bowden et al. 2009).

Watershed planning efforts in the state call for attention to this issue (VCCAP 2009; VTANR 2010), however little guidance exists to assist managers with targeting management or restoration activities that would provide maximum benefit in reducing water quality impairments from roads. Recommendations for the mitigation of road impacts on water quality are available in the scientific literature (see for example Colbert 2003 and Buchannan et al., 2012), however previous assessments on forest roads in the region show very low levels of implementation and compliance with best management practices (BMPs) (Brynn and Claussen 1991; Schuler and Briggs 2000).

News reports (Remsen 2011; Schwartz 2011) of extensive road-related erosion and catastrophic road failures during record floods in Vermont in 2011 suggest that the transportation network is an important source and vector for pollutant contributions to Vermont's water ways. Recent events point to the need to stabilize roads and upgrade design elements through the application of BMPs that will reduce pollutant transfer to surface waters. This project seeks to improve our understanding of BMP efficacy on rural roads in Vermont and provide a framework for estimating pollutant reduction gains through variable BMP implementation strategies.

This project will quantify rates of sediment and phosphorus production on a set of gravel roads typical of rural upland settings in Vermont and identify the reduction in pollutant loadings associated with select BMPs. The project with result in the development of a decision support tool that can be used to target pollutant reduction and the costs associated with various reduction choices.

15. Statement of results or benefits

The proposed research will result in measurements that quantify pollutant production from gravel roads typical of those in rural settings throughout Vermont. Data collected through the proposed study will also allow the quantification of pollutant reduction associated with recommended BMPs for gravel roads. Findings from the proposed study should be directly applicable to the mandate under Vermont Act 110[1], passed by the Vermont legislature in 2010, to develop standards and best management practices to minimize water quality degradation from roads. The results of the proposed study will allow managers to target candidate road segments for future treatments and quantify pollution reduction associated with the implementation of BMPs.

16. Nature, scope and objectives of the project

This project aims to quantify the rate, magnitude and temporal dynamics of pollutant (sediment and phosphorus) production from gravel roads typical of rural upland settings in Vermont and to identify pollutant reductions associated with the application of select BMPs on roads. Specific objectives of the project are (1) to quantify the

[1] Town Road and Bridge Standards (January 4, 2011; Vermont Agency of Transportation). Section 17, paragraph 996 (a) and (b) of Vermont Act 110 directed the Vermont Agency of Transportation (VTRANS) to work with municipal representatives and the Agency of Natural Resources (ANR) to develop standards and best management practices for roads and bridges. These recommendations are now in the document titled Town Road and Bridge Standards (January 4, 2011) and were developed by a Task Force of staff members from VTRANS and ANR, along with town officials and staff of Better Backroads, a program of Northern Vermont Resource Conservation and Development Council.

reduction in sediment and phosphorus runoff from gravel roads associated with the implementation of selected BMPs, and (2) to develop a decision support tool that can be used to target the costs of pollutant reduction associated with various reduction choices. We will leverage results from an on-going study, sponsored by the Lake Champlain Basin Program, that monitored and quantified runoff, sediment, and phosphorus contributions on a suite of rural road segments within agricultural and forested settings.

Using a set of up to 12 road segment pairs (24 sites), we will measure storm characteristics (total precipitation depth, subhourly rainfall rates, storm duration) and pollutant (sediment, total phosphorus) production for storms that span the range of runoff-producing events in Vermont over a two-year field season (Table 1). In collaboration with the Vermont Better Backroads Program (http://www.nvtrcd.org/bbr.html), we will monitor changes in sediment and phosphorus loadings following the installation of BMPs on selected road segments. Our collaboration with the Better Backroads Program brings expertise in BMP design and installation to the project, along with their formal annual application program to identify sites in need of repairs to reduce erosion hazards. The findings from this work will be used to develop a decision support tool to evaluate pollutant reduction options and costs associated with BMP applications.

Table 1: Timeline of project activities

		Project Year 1*				Project Year 2			
Task/Activity	**Pre-Project**	**Spr (MAM) 2012**	**Sum (JJA) 2012**	**Fall (SON) 2012**	**Win (DJF) 2012/13**	**Spr (MAM) 2013**	**Sum (JJA) 2013**	**Fall (SON) 2013**	**Win (DJF) 2013/14**
meet with Better Backroads to identify candidate sites and application process	■								
select study sites in consultation with towns, Better Backroads staff		■			■				
install silt fences			■			■			
conduct pre-treatment monitoring of control and treatment sites			■			■			
install BMPs				■			■		
conduct post-treatment monitoring of control and treatment sites				■		■	■	■	
laboratory analysis of samples			■	■		■	■	■	
data analysis and development of decision support tool					■			■	■
report project findings									Jun-2014

* Project year 1 activities completed or in progress at time of submission.

Note: some overlap in installation, pre-treatment monitoring, and post-treatment monitoring shown in table. Silt fence and BMP installation require only 1-3 days during quarter. Pre-treatment monitoring will commence immediately after fence installation and continue up to the BMP installation. Post-treatment monitoring will commence immediately thereafter.

17. Methods, procedures and facilities

Our proposed methods for quantifying effectiveness of BMP implementation on rural, gravel roads involve bulk sample collection below road drainage outlets (cross-drain culverts) using a before-after treatment/control design. We will work in towns of the Mad River Valley, where we have conducted previous research on the effects of roads on water quality supported by the Lake Champlain Basin Program (LCBP). In collaboration with town staff (town administrator, road foreman) and in consultation with town select boards, we will select 12 study sites for BMP treatment identified by town road crews as in need of drainage improvement. For each treatment site, we will select a nearby untreated control site for paired monitoring, using our LCBP project sites, where possible, to extend the data record.

Bulk sediment samples will be collected at culvert outfalls in a silt fence, fabricated from plastic to retain coarse sediment and water, and landscaping fabric to allow drainage of effluent and reduce risk of failure (Figure 1). During the 2012 field season, we found the fence design to be robust to storms across the range of conditions monitored, with only three installation failures during very high precipitation rain events in mid-summer. This measurement technique misses the finest sediment fraction washed through the landscaping fabric during the storm event, a fraction we are attempting to estimate using grab sampling during storms.

The silt fences will be serviced between storm events, when the volume of sediment captured in the fence will be measured using manual excavation. A roughly 20 liter (5 gallon) subsample of the collected sediment will be retained and returned to the lab to dry and estimate dry mass. A subsample of the dried sediment will be analyzed for total phosphorus by microwave assisted digestion with concentrated nitric acid and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) using standard methods in the Agricultural and Environmental Testing Laboratory at UVM.

Figure 1: Plastic and filter fabric silt fence, installed out culvert outfall, with bulk sample collected after storm event in summer 2012

By project completion, we will monitor up to 24 sites, including 12 sites treated with BMPs and paired with an untreated control located within a 3 mile distance of the treated site. The control sites will be paired with the treated sites on the basis of similar grade, surfacing material and topographic and land cover (forested, agricultural) setting. For each road pair, we will collect baseline data for up to two months (estimated storm frequency of 3-6 frontal or convective storms per month in late spring and summer) during what we will define as a pre-treatment period. To evaluate BMP effectiveness in reducing total sediment and phosphorus runoff from roads, we will implement one of four BMP treatments (Table 2) on three road segments each, for a total of twelve treatments, with each treated site monitored concurrently with its untreated control (see Table 3). A shift in the relationship between the control and treated site in the post-treatment period, relative to the pre-treatment period, will be used to quantify BMP effectiveness across sites and under a range of storm conditions.

Table 2: Description of proposed BMP treatments to be installed on selected road sites (final treatment design to be refined in consultation with Better Backroads staff).

BMP treatment	Description
1. Rock-line ditch	Install up to 1 mile of rock in ditches lined with geotextile

	fabric
2. Stone check dams or compost socks and turnouts	Install stone check dams or compost socks and turnouts at spacing in compliance with BMP recommendations from Better Backroads staff to slow erosive ditch flow
3. Cutbank stabilization	Re-contour and stabilize eroding cutbanks above road; improve ditches with grass mix or stone
4. Outboard berm removal	Remove outboard berm from road contour to reduce concentration of flow

For all storms during the monitoring period, we will measure precipitation rates using tipping budget rain gages in order to quantify the magnitude and duration of precipitation events. For each site, we will map the area of the road surface and adjacent slopes contributing to each monitored culvert, in order to estimate water inputs to each site. Hydrographs available for the Mad River at Moretown, Vermont (USGS Station ID 04288000) will be used to estimate the size and recurrence frequency of all monitored storms.

We will attempt to explain variability in pollutant production between paired sites of the same treatment for a given storm by mapping contributing areas (road and ditch surfaces, hillslopes contributing subsurface flow) at each site. Although we cannot develop a full factorial design for the multiple factors likely to explain differences across sites (topographic position of the road, road surfacing material, road grade), we will control for road grade and surfacing material in the selection of sites and expect contributing area to be a first order control on site-to-site variability in pollutant production. We will quantify BMP effectiveness as a shift in the treatment vs. control regression relationship during the post-treatment period, relative to the pre-treatment period. We will also attempt to quantify the lag time between BMP installation (when heavy machine work can typically amplify sediment production at the site) and the reductions achieved in sediment and nutrient production by following the pollutant yields over time during our study period.

Using the results of our empirical work, we will develop a GIS-based approach to estimate pollutant reduction potential from BMP implementation and costs associated with various implementation scenarios. Costs of implementation will be directly extracted from project costs generated by our partners at the Better Backroads program, as they work with towns to purchase supplies and implement treatments. Using a set of simplified assumptions regarding sediment and phosphorus production per unit length of road, based on the results of this project and our previous LCBP grant, we will estimate pollutant production from the gravel road network and its contribution to streams via an estimate of connected (i.e. draining directly to streams) road length. Alternative treatment scenarios will be generated by identifying roads suitable for various treatments (i.e. roads > 5% grade to be treated with stone-lined ditch), and estimating sediment and phosphorus reductions from our field results. Within the GIS framework, we can then select one or more BMP options and apply them differentially across the road network to calculate pollutant yield and loading reductions associated with the application of BMPs. These calculations would also allow the user to trade off benefits of the BMP reductions with costs of their implementation.

18. Discussion of Progress (Year 1)

During the first year of the project we worked with staff in the towns of Fayston, Waitsfield, and Warren to select and instrument study sites (Table 3). This has involved collaboration with town road foremen to identify roads they wish to treat with BMPs to target existing erosion and road stability concerns. Each study "site" includes a road segment to be treated with a BMP and a paired nearby road segment to serve as an untreated control. By conclusion of our 2012 field season, we had selected six of these site pairs, giving us a total of 12 monitored road segments to date. We measured bulk sediment flux from the selected road segments during a series of six storm events between August and September 2012, covering a range of precipitation magnitudes (Table 4).

Table 3: Sites selected for study in Mad River Valley and proposed treatments

Town	Road	Proposed treatment
Fayston	Bragg Hill	Compost sock
Fayston	Kew Vasser	Rock-lined ditch
Fayston	Randell	Rock-lined ditch
Waitsfield	Rolston	Rock-lined ditch
Warren	Prickly Mtn/Fuller Hill/ Senor intersection	Compost sock
Warren	Prickly Mtn	Compost sock

Table 4: Storms monitored at paired treatment and control sites during Year 1 (pre-treatment period)

Storm date	Rainfall depth[1] (cm)	Mad River peak discharge[2] (cfs)
8/21/12	2.4	143
8/28/12	2.9	239
9/5/12	4.8	659
9/11/12	1.7	202
9/19/12	4.0	1360
9/23/12	2.5	165

[1] Rainfall depths measuring with Hobo tipping bucket rain gage located at the Randell Road site in Fayston.
[2] Data from USGS Station 04288000

Preliminary data (Figure 2) *for the pre-treatment period* during these 2012 summer storms at each site shows a range of sediment production rates. Among the six paired sites monitored, the average sediment flux at the control sites was 40 kg and, at the sites to be treated, 139 kg. Results from these 2012 storms also show that the paired treated-control sites are relatively well matched, in that sediment production increases across both sites as storm size increases. *We expect a downward shift in these trend lines with treatment, with the magnitude of that shift serving as a measure of effectiveness of the treatment on that road segment.* We also expect to see a range of phosphorus in the bulk samples collected over storm events, once laboratory analysis is complete.

six

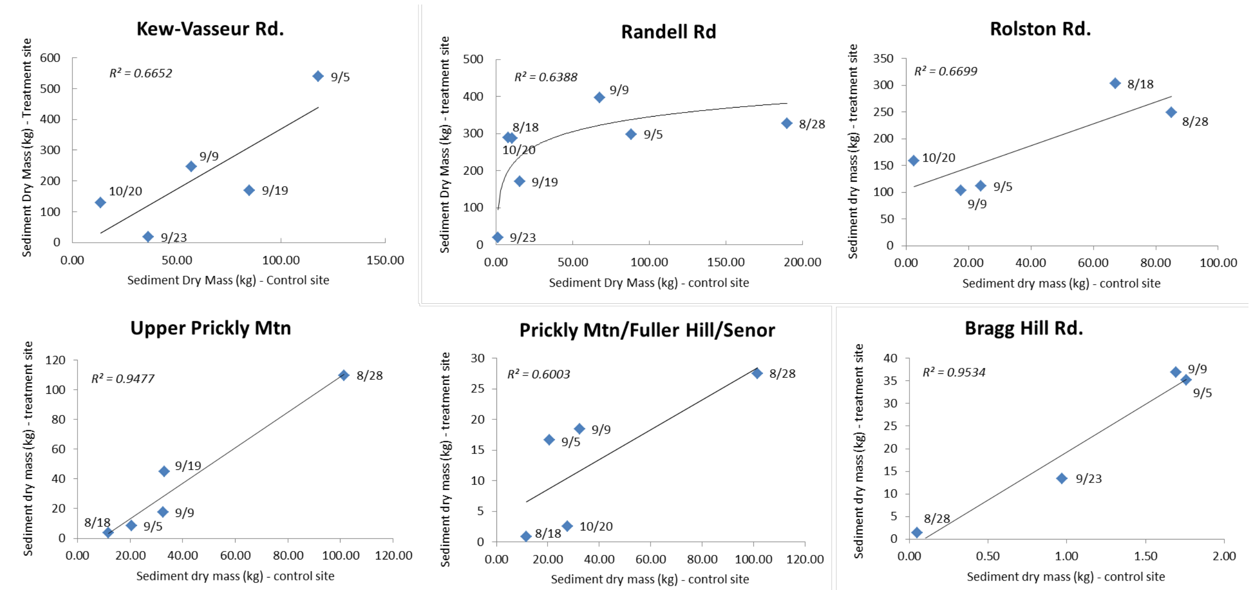

Figure 2: Preliminary dry sediment mass (kg) from six control sites and paired treatment sites monitored in 2012 field season. Each point represents a storm event (point labels are storm dates). All data are from the pre-treatment period.

19. Year 2 Planned Activities

During the second year of our project, we will select and monitor an additional six paired sites (control plus treated site) in consultation with participating towns and our partners at the Better Backroads program. We began discussion with town staff in early April 2013 and began installing monitoring devices on April 25, 2013. Installation of BMPs was completed at two of the field sites selected in 2012 in November of that year (Year 1 of project) and should be complete at the remaining four sites by May 2013. Pre-treatment monitoring at the second set of six sites will take place during May-July 2013, with installation of BMPs planned for late July and post-treatment monitoring for August-October 2013.

During Year 2 of the project, we will also work on materials to assist town officials and staff within our natural resources and transportation agencies with managing pollution production from unpaved roads. This work will involve the following elements: (1) assessment of prior Better Backroads projects for their long-term efficacy in reducing pollutant transfer to streams, (2)

20. Training potential

During year 1 of the project we have trained three UVM undergraduate students engaged in field and laboratory work associated with the project. We have also employed a 2012 UVM graduate as a technician on the project, providing valuable training as he transitions from student to professional. In summer 2013, we will engage and train a graduate student enrolled in UVM's Field Naturalist or Ecological Planning program. These project-based masters programs recruit students with keen interests in translating science into planning and policy guidance. Students (undergraduate and graduate) involved in the project will be mentored and co-advised by Wemple and Ross. Training in field, laboratory, and spatial analysis methods will be provided the co-investigators. Field safety training will be provided in collaboration with our colleagues in the Better Backroads program. Both Wemple and Ross teach undergraduate service-learning courses, and will integrate students from those courses into the proposed research to assist with mapping and grab sampling described in the proposal.

21. Presentations and Outreach

Presentation of our research to date has been limited to meetings with town officials participating in the project and Vermont Agency of Natural Resources staff involved in supporting the project. We anticipate completion of a masters student's research project by May 2014 and publication of our study results in a peer-reviewed scientific journal once the project is complete.

22. Investigator's qualifications (see attached resumes)

Wemple has extensive research experience with rural transportation networks and their hydrologic and geomorphic effects. She is PI of a New England Interstate Water Pollution Control Commission grant (awarded 2010) to quantify the contributions of rural roads to sediment and phosphorus pollution in the Lake Champlain Basin. Her faculty appointment at the University of Vermont is in Geography. She holds a secondary appointment in the Rubenstein School of Environment and Natural Resources, where she advises graduate students. Ross is a soil chemist with extensive research experience in soil nutrient and metals analysis. He manages the University of Vermont's Agricultural and Environmental Testing Laboratory, where samples for this project will be processed. His faculty appointment is in the Department of Plant and Soil Science, where he teaches and advises at the graduate and undergraduate level. He is also co-chair of the interdisciplinary undergraduate Environmental Sciences Program.

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Development of monitoring buoy system for lake studies

Basic Information

Title:	Development of monitoring buoy system for lake studies
Project Number:	2012VT69B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	Vermont-at-Large
Research Category:	Water Quality
Focus Category:	Water Quality, Methods, Non Point Pollution
Descriptors:	None
Principal Investigators:	Jason D. Stockwell, Breck Bowden

Publications

There are no publications.

Project Description – Stockwell/Bowden

10. Abstract:

Linking hydrology and biogeochemistry of rivers to water quality and ecosystem dynamics in lakes is a critical need for environmental management and regulation. Research programs that combine high frequency and spatially extensive measurements are particularly valuable in this context because they allow determination of spatial-temporal linkages that can be used to identify sources and controlling factors for biogeochemical processes that are difficult or impossible to observe by standard manual sampling techniques. In recent years rapid advances in sensor and communications technologies have created new opportunities to assemble sensor systems that can provide high frequency data (down to seconds if desired), often in near real time (by telemetry). The primary purpose of this project is to develop a lake monitoring buoy and sensor system that can enhance a river and lake monitoring effort that is based on a traditional, low-frequency (bi-weekly) sampling program. The lake monitoring buoy system will be used in part as a demonstration project to assess the utility of this approach for future monitoring in Lake Champlain. In addition, the lake monitoring buoy system will be used to examine short-term dynamics of key lake water quality characteristics as a complement to a companion study of river-to-lake and sediment-to-water column research (funded from other resources). The combined research will provide insight into lake responses to riverine inputs that is currently difficult to impossible to document by standard methods. It is expected that this research could provide insights that would be useful to help inform current management issues (for example, revision of a TMDL estimate for phosphorous inputs to Lake Champlain). It would also help inform future management decisions as development proceeds and the climate continues to change in the Lake Champlain basin.

11. Budget

Cost category	Federal	Non-Federal	Total
Salaries and wages			
- All PI Salaries		$ 2,167	$ 2,167
- All Graduate Students	$ 25,000	$ -	$ 25,000
- All Undergraduate Students (wages)		$ -	$ -
- All Others: staff assistant or PD		$ -	$ -
Total Salaries and Wages	$ 25,000	$ 2,167	$ 27,167
Finge Benefits	$ -	$ 908	$ 908
Supplies	$ 5,000	$ -	$ 5,000
Equipment		$ 22,500	$ 22,500
Services or Consultants		$ -	$ -
Travel	$ 1,000	$ -	$ 1,000
Other Direct Costs		$ 22,500	$ 22,500
Total Direct Costs	$ 31,000	$ 48,075	$ 79,074
Indirect costs on federal share	XXXX	$ 16,275	$ 16,275
Indirect costs on non-federal share	XXXX	$ 13,427	$ 13,427
Total Estimated Costs	$ 31,000	$ 77,777	$ 108,777
Total costs at Center campus	$ 31,000	$ 77,777	$ 108,777

12. Budget Justification

Salaries and Wages: The University of Vermont will costshare 1.1% of Stockwell's and Bowden's time to manage this project and mentor a graduate student. Funds are requested to support one, full-time (0.5 FTE) graduate student at $25,000/year.

Fringe benefits: Fringe benefits are calculated at the rate of 41.9% on the portion of Stockwell's and Bowden's salaries that is costshared. This cost will be supported by the University of Vermont as part of it's matching obligations. The University of Vermont does not assess fringe benefits on graduate students.

Supplies: We request $5000 in Federal funds for supplies that include materials to make the buoy system operational. We anticipate that this will include miscellaneous hardware and tools needed maintain and repair the buoy and it's components.

Travel: We request $1000 from Federal funds to support local travel between the University of Vermont in Burlington, VT and the field site in Missisquoi Bay to service the buoy and sonde system on an approximately weekly to bi-weekly basis. The funds may also be used by the project PIs and/or the graduate student to attend relevant local and regional meetings at which focus in on the long-term lake monitoring program and role this and future buoy systems might have. We have budget for a combination of approximately 15 such roundtrips at ~100 miles per trip. At the current mileage reimbursement rate at UVM ($0.50) this amounts to $750. These funds may also be used to pay registration and lodging expense for one person to attend a local or regional meeting to report the results of this project. We propose to limit these costs to $250.

Other direct costs: The Vertical Profiler Pontoon platform for this buoy/sonde system has been donated by Yellow Spring Instruments (YSI, Inc.). The unit is a used unit that has been refurbished using other funds. YSI has assessed the pre-refurbished value of the Vertical Profiler Pontoon at $45,000. A letter from YSI documenting this value has been submitted to UVM's office of Sponsored Projects

Administration. For the purposes of this budget we are only claiming 50% of the value of the unrefurbished pontoon system.

Indirect costs: Indirect costs are calculated on the basis of modified total direct cost which are the sum of all direct costs less participant support costs, equipment valued at more than $5,000 and subcontracts above $25,000. In this budget the claimed value of the YSI Vertical Profiler is counted as equipment and is not included in the computation of indirect costs. There are no subcontracts on this project. Indirect costs are then calculated at the rate of 52.5% of modified total direct costs. As per rule by the USGS these indirect costs are included as costshare by the University of Vermont.

13. **Title:** Development of monitoring buoy system for lake studies

14. **Statement of regional or State water problem**

Excessive sediment loading and the phosphorus loading associated with it is widely viewed as one of the key water resource management issues affecting Lake Champlain, which defines the entire western border of Vermont. Phosphorus loading generally contributes to eutrophication of the lake and specifically may be responsible for algal blooms, especially of cyanobacteria, that may at times create toxins that are of concern for human health. Excessive phosphorus loading from agricultural and urban land uses regularly tops the list of priority environmental concerns expressed by regional managers, policy makers, NGO's, researchers, and residents.

15. **Statement of results or benefits**

The long-term water quality monitoring program operated by the state of Vermont with support from the Lake Champlain Basin Program and in collaboration with the USGS bases its estimates of phosphorus loading on intermittent sampling followed by manual analysis of total phosphorus as described above. Under the best of circumstances it is difficult to deploy sampling personnel during rapidly developing events. It is especially difficult when these events occur at night and over weekends and holidays. Equally important, due to the low frequency of sampling it is not clear how non-linear dynamics such as hysteresis during events or season-specific sediment generation processes (e.g. ice floes, farming practices) affect the total loading of sediment, phosphorus, and other nutrients to the lake. Thus, it would be desirable to employ newer, off-the-shelf technologies to complement the manual sampling program that has been in existence for nearly 20 years. In part this proposed project is a demonstration project designed to appeal to stakeholders who have a responsibility to monitor water quality in Lake Champlain and in part it is a research project designed to test hypotheses that are of interests to the research community about links between river loading dynamics and algal bloom response dynamics in Lake Champlain.

During the current year (FY11) the USGS has supported a closely related project to employ an Acoustic Doppler Current Profiler (ADCP) to measure suspended sediment concentrations (as well as its intended purpose to measure discharge) in the Rock River in northwestern Vermont. The Rock River is a smaller analog for the Missisquoi River, which is the dominant source of water to Missisquoi Bay. While the upper reaches of these watersheds are largely forested, large areas of the valley bottoms are used for agricultural activities that have been identified as a major source of sediment and phosphorus that are suspected to support unsightly and potentially important cyanobacteria blooms in Missisquoi Bay. These blooms have occurred in late summer, nearly annually, over the last decade. There is a strong linear relationship between total suspended sediment concentrations and total phosphorus (TP) concentrations and so the expectation is that the ACDP will allow us to estimate TP loadings with greater assurance and accuracy. Initial results from this project are encouraging and will be reported to USGS later this year.

The dynamics recorded at the Rock River ADCP installation can be paired with the long-term monitoring results to infer TSS and sediment dynamics in the Missisquoi River and thus loading to Missisquoi Bay.

The purpose of this proposed work is to install a new monitoring buoy system in Missisquoi Bay, to monitor conditions in the lake at a much higher temporal frequency than can currently be achieved by the manual sampling program. The sampling frequency of the buoy system will be lower than can be achieved by the ADCP installation on the Rock River, but it will be much higher than can be achieved by manual sampling (hourly by the buoy system versus approximately bi-weekly for the manual sampling program). The higher sampling frequency will provide more robust correlations between river and lake conditions than would be possible with the manual sampling program alone. Furthermore, the buoy system will provide a continuous vertical profile of lake water quality conditions while the standard manual monitoring protocol only calls for sampling a few discrete depths (VTDEC 2011). Like the ADCP installation, the equipment on the lake buoy system will allow non-destructive, autonomous, continuous, and relatively robust sampling.

The results of this project will directly benefit the VTDEC's efforts to maintain a long-term monitoring program that can quantify the degree to which implementation of new management practices reduce the loading of total phosphorus to Lake Champlain. As a demonstration project this proposed installation will provide an alternative means to monitor lake conditions that may in the long-run require less effort and provide better information about the lake response to river loading events. At the moment, the single buoy installation will only be able address the benefits of increased temporal frequency of sampling. If successful, we would propose to install multiple buoy systems which would provide increased spatial coverage of high-frequency sampling.

In addition to the practical policy and management applications of the data produced by this project, it will also contribute to a major new initiative funded by the National Science Foundation through the Vermont Experimental Program to Stimulate Competitive Research (EPSCoR). This new initiative is focused on Regional Adaptation to Climate Change (RACC) with one sub-theme that focuses on "the relative importance of endogenous in-lake processes (e.g. internal loading, ice cover, hydrodynamics) versus exogenous to-lake processes (e.g. land use change, snow/rain timing, storm frequency and intensity, land management) to lake eutrophication and algal blooms." A substantial portion of this ESPCoR sub-theme will focus on sediment-water and river-lake interactions within Missisquoi Bay. The research is designed to rely heavily on the existing monitoring program to provide validation data for models that will derive from the in-lake experiments. Thus, the buoy system (and the ADCP installation) proposed here will directly benefit the new EPSCoR/RACC initiative by providing data at a much higher temporal frequency than can be achieved by the manual monitoring or field sampling programs.

16. Project Objectives

With the current intermittent, manual sampling protocol it is impossible to determine if there are important in-lake dynamics that occur as a consequence of specific river loading events. In particular, the timing of bloom development in response to loading events is unknown. Thus, we can only infer how phosphorus loading from rivers ultimately causes blooms in the lake. While it would be desirable to be able to measure all possible variables that could affect algal bloom dynamics in the lake, current sensor technologies are not up to this challenge. However, significant advances in sensor technologies in the last few years allow us to measure a number of parameters that could only be done manually before (e.g., algal pigments, chromophoric dissolved organic matter, dissolved oxygen, specific UV absorbance, pCO_2). When combined with existing sensors for important environmental drivers like temperature, light, and electrical conductivity (a measure of overall solute concentration) these combined sensor packages can provide useful insight into conditions that favor algal and cyanobacteria blooms.

The specific objectives of this project are to:

- Complete land tests and calibrations of a new buoy system that has been purchased with other funds, to be deployed in Missisquoi Bay.
- Deploy and operate the buoy system from May to November.
- Examine the fine-scale temporal responses of vertical profiles of key water quality parameters to individual storm events and to seasonal changes in the lake system.
- Identify the specific water quality conditions that prevail prior to, during, and after major algal blooms.
- Compare the costs and benefits of the automated buoy system to the manual sampling protocol. We do not expect the automated buoy system to be able to replace manual sampling. However, the automated buoy system could complement the manual sampling program in ways that could justify the cost of the automated buoy systems.

We propose a two year project. This proposal covers the first year of this project; a second proposal will be submitted next year to cover the second year of the project. The chart below shows the timeline of tasks and activities over the two year period.

		Project Year 1			
Task/Activity	**Pre-Project**	**Spr (MAM) 2012**	**Sum (JJA) 2012**	**Fall (SON) 2012**	**Win (DJF) 2012/13**
Acquire lake buoy system					
Test buoy system on land					
Deploy and operate buoy system					
Aquire data and preliminary analysis					
Final summary of data					
Report project findings					

17. Methods, procedures, and facilities

Moored buoys have been used for decades as a platform for environmental monitoring systems in oceanographic studies (e.g. Johnson 2003, Smyth et al. 2010). They are, however, less commonly used in studies of inland lakes (e.g. Effler et al. 2002, Consi et al. 2007). We acquired a Model 6591 Pontoon Vertical Profiling platform (Fig. 1). This system includes a submersible, watertight enclosure and a rugged non-corrosive mechanical winch and drive mechanism that allows for fully-automated data collection from a pontoon float. The system includes a depth sounder for automatic compensation of varying lake water levels, a meteorological package, wireless data transmission capabilities, and software (Profile Wizard®) to deploy and control the sensor package.

The buoy system was outfitted with a compatible data sonde that has turbidity, chlorophyll *a*, dissolved oxygen, blue-green algae, electrical conductivity, pH/ORP, temperature, and depth sensors.

Figure 1. Vertical Profiling Pontoon system from YSI. The winch housing is in the center of the deck. This unit has been completely refurbished for deployment in 2012.

The buoy and sonde system was deployed in Missisquoi Bay at one of the long-term monitoring stations that is nearest the mouths of the Missisquoi and Rock Rivers (Station 51). The system was deployed in mid-June and remained in place until early November. Each sensor was calibrated initially and through the season as per the manufacturer's recommendations. Data collected during routine visits to Station 51 for the Lake Champlain Long-Term Monitoring program will be used to compare to the data collected by the sensors.

The sampling schedule for the buoy/sonde system was to obtain vertical profiles on an hourly basis as well as while in the "parked" position at 2m. Collected data was downloaded and error-checked on a daily basis whenever possible with no more than 1 week between downloads at a maximum. Data was stored on a dedicated PC and was be backed up on servers at UVM and on an external hard drive within the Bowden Watershed Research Lab at the Rubenstein Ecosystem Science Laboratory.

In addition to the sonde, three ISCO autosamplers were deployed on the buoy collecting samples every eight hours from three different depths. Samples were analyzed for dissolved nutrients at Johnson State College as part of the EPSCoR portion of the project.

18. Findings - results

Summer 2012 was very warm and dry with few storm events. The buoy system worked well after a few initial startup difficulties, collecting hourly sonde data and eight-hourly water samples. Weekly visits to the buoy to collect water samples and recalibrate the sonde occurred throughout the season. The frequent sampling and long field season provides useful information for lake chemistry dynamics that was not previously available due to a more limited sampling regime. For example, water chemistry immediately prior to and following a fish kill that occurred in August in Missisquoi Bay can be seen in the data with a large drop in dissolved oxygen (Figure 2). A storm event that occurred on September 6, 2012 is apparent in the temperature and SRP data on September 6, is also captured in the acoustic Doppler current profiler and sediment samples from the Rock River, which is part of another Vermont Water Center funded project.

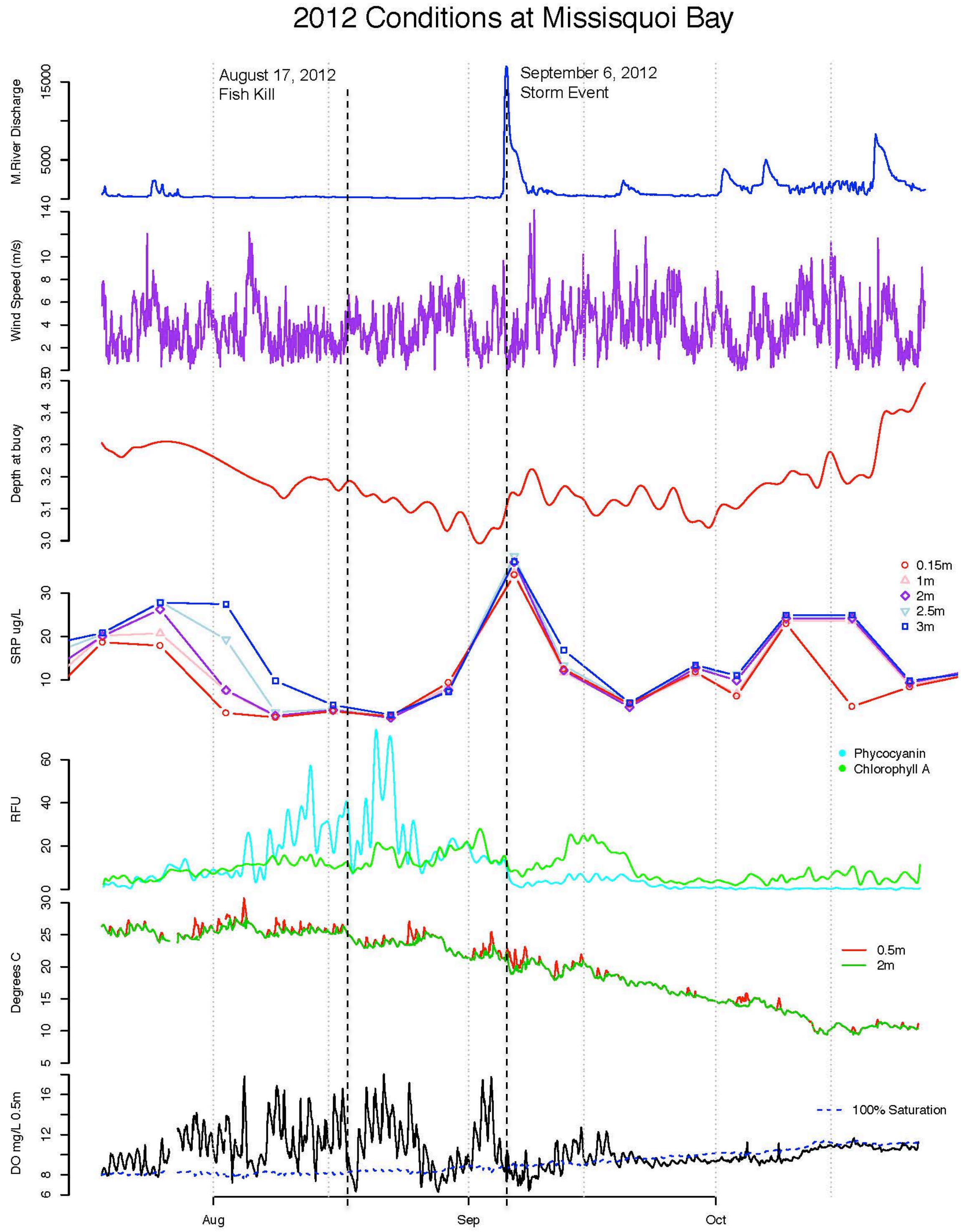

Figure 2. Data collected from the sonde and meteorological station measured hourly and water samples collected weekly for the following: Missisquoi River discharge (m^3/s), wind speed (m/s), depth (m), soluble reactive phosphorus (ug/L), phycocynanin and chlorophyll *a* (RFU), water temperature (^oC), and dissolved oxygen (mg/L)

19. Discussion

An important challenge in watershed research and management is to observe biogeochemical and hydrological dynamics at times and with sampling frequencies that match the times and frequencies over which important events (e.g., storms) occur. This is difficult to achieve by manual sampling for simple logistical reasons. For example, the current Lake Champlain Long-Term Monitoring Program (VTDEC 2011) adequately represents spatial patterns in the lake but employs a bi-weekly sampling frequency that does not adequately sample storm events that may unfold in a matter of hours or days. Finer temporal resolution of measurements would enable researchers to observe important signals associated with storm events or diurnal cycles that we now miss.

Recent research illustrates why it is important to measure key environmental variables at finer temporal resolutions. Many biogeochemical processes have distinct diurnal cycles that are largely undetected by most monitoring programs that rely on sampling infrequently (weekly or less often) and often at the same time of day (for consistency). The best example is use of recording sondes for measurement of dissolved oxygen concentrations at high frequencies (minutes). Use of these sondes has become routine and these measurements have allowed researchers to make and compare reach-scale measurements of stream metabolism and identify key hydrological and landscape-scale controlling factors (Young and Huryn 1996, 1999, Uehlinger and Naegeli 1998, Mulholland et al. 2001). The hourly data collected from the sonde provides a better understanding of the diurnal changes throughout the season (Figure 3). During July the diurnal pattern for dissolved oxygen was very regular and the percent saturation was relatively high (98-140%), however, in October the dissolved oxygen was more erratic diurnally, and much lower (88-102%). Without the frequent data these patterns would not be discernible.

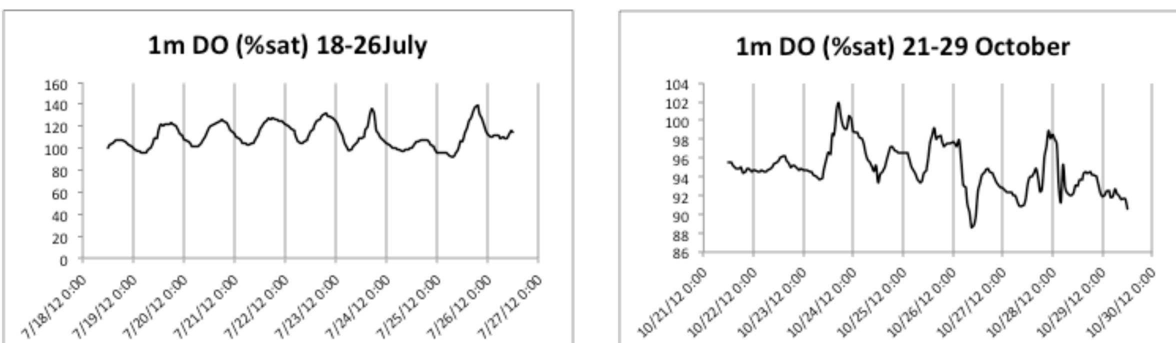

Figure 3. Dissolved oxygen percent saturation at 1m depth for two weeks during the field season, 18-26 July and 21-29 October, illustrating diurnal dynamics and seasonal differences.

Diurnal dynamics are complicated by changes in hydrological processes over short timeframes (e.g., variations in dominant flow paths, changes in water flux) during storm events and in response to different antecedent conditions (e.g., soil moisture) and season (e.g., Pearce et al. 1986, DeWalle et al. 1988, Mulholland 1993, Williard et al. 2001, Liu et al. 2004). These hydrological changes produce changes in chemical concentrations and fluxes which provide important information on the rates and spatial locations (i.e., hotspots) of biogeochemical processes in catchments (e.g., Kendall et al. 1995, Creed et al. 1996, Cirmo and McDonnell 1997, Schiff et al. 1997). Finally, we know that there are important in-lake dynamics that reprocess nutrients over short and long periods (e.g., Smeltzer and Quinn 1996, HydroQual 1999, Watzin et al. 2005). These sporadic dynamics combine with regular diurnal patterns to create complicated patterns that are difficult to decipher on the basis of data acquired from typical manual monitoring programs that employ infrequent sampling. Computer modeling can help to fill these gaps. But validation of computer models that have daily and even hourly time steps can be problematic when the validation data is only bi-weekly.

Use of automated sampling equipment (e.g., ISCO samplers) is one way to address this challenge and does allow higher frequency sampling (minutes to days) of storm events. However, these automated samplers have several limitations. Normally these samplers can collect only a small number of samples (up to 24) stored in the instrument before they must be manually reset. Preservation of non-conservative biogeochemical components stored within the instrument is frequently problematic; biological or physiochemical changes may compromise some types of analyses. Consequently it is rare that measurements are made across multiple successive storms or over long periods of time.

In recent years there have been considerable advances in sensor technologies, datalogger capabilities, and digital communication options that provide important new opportunities for high frequency data monitoring. Several of the most important advancements have been in optical sensors that allow improved analysis of oxygen and completely new means to measure components such as nitrate, chlorophyll a, chromophoric dissolved organic matter, and specific UV absorbance. These new optical sensors are important because they do not utilize reagents that have to be mixed and that can degrade over time and they do not produce wastes, which are often toxic and have to be carefully contained and disposed.

The sonde and ISCO autosamplers deployed on the buoy platform complement each other well to build upon the previous weekly monitoring program and fill in deficiencies. The data that was collected during the 2012 field season fills a gap that has previously existed for understanding in-lake dynamics in Missisquoi Bay. The monitoring will be continued by EPSCoR during the 2013 field season. Collaboration with EPSCoR as well as other projects previously funded by the Vermont Water Center builds a very strong data set connecting the watershed and contributing rivers to the lake.

20. Training potential

The funding from the Vermont Water Center supported three undergraduate students: Kelsey McAuliff, Ryan Sleeper, and Evelyn Boardman. Their involvement on this project gave them experience and training in lake processes and laboratory research as well as an understanding several types of field instruments. The project also supported a technician, Elissa Schuett, to be a part of the research team and attend Vermont EPSCoR events. Several graduate and undergraduate students that are a part of the EPSCoR/RACC program have benefited from the collaboration: Peter Isles, PhD student; Trevor Gearhart, PhD student; Courtney Giles, Postdoctoral researcher; and undergraduates Suzanne Ball, Frances Ianucci, Beth Mitchell, and Chelsea Mitchell.

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Williard K.W.J., D.R. DeWalle, P.J. Edwards, and W.E. Sharpe. 2001 ^{18}O isotopic separation of stream nitrate sources in mid-Appalachian forested watersheds. Journal of Hydrology 252:174-188

Young, R. G., and A. D. Huryn. 1996. Inter-annual variation in discharge controls ecosystem metabolism along a grassland river continuum. Canadian Journal of Fisheries and Aquatic Sciences 53: 2199-2211.

Young, R. G., and A. D. Huryn. 1999. Effects of land use on stream metabolism and organic matter turnover. Ecological Applications 9:1359-1376.

21. Investigators' Qualifications

JASON D. STOCKWELL

University of Vermont
Rubenstein Ecosystem Science Laboratory
3 College Street
Burlington, Vermont 05405

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Professional Preparation

B.S. 1991 (Biology, Mathematics) Northland College
Ph.D. 1996 (Zoology) University of Toronto
Postdoctoral Fellow 1996-1997 (Fishery Biology) Colorado State University
Postdoctoral Fellow 1997-1998 (Fisheries and Wildlife) Michigan State University
Fellow 2008 National Conservation Leadership Institute

Appointments

2011-present	Associate Professor of Aquatic Ecology, Rubenstein School of Environment and Natural Resources, University of Vermont
2011-present	Director, Rubenstein Ecosystem Science Laboratory, University of Vermont
2007-2011	Research Scientist, Gulf of Maine Research Institute, Portland, Maine
2003-2007	Field Station Supervisor/Research Fishery Biologist, Great Lakes Science Center, U.S. Geological Survey, Ann Arbor, Michigan
2001-2003	Senior Statistical Analyst, The Jackson Laboratory, Bar Harbor, Maine
1998-2000	Aquatic Biologist III, Massachusetts Division of Marine Fisheries, Gloucester, Massachusetts

Ten Selected Publications

Ahrenstorff, T.D., T.R. Hrabik, J.D. **Stockwell**, D.L. Yule, and G.G. Sass. 2011. Seasonally dynamic diel vertical migrations of Mysis (*Mysis relicta*), coregonines (*Coregonus* spp.), and siscowet lake trout (*Salvelinus namaycush*) in the pelagia of Western Lake Superior. Transactions of the American Fisheries Society 140:1504-1520.

Gamble, A. E., T. R. Hrabik, J. D. **Stockwell**, and D. L. Yule. 2011. Trophic connections in Lake Superior Part I: the offshore fish community. Journal of Great Lakes Research 37:541-549.

Kelly, J.R., P.M. Yurista, S.E. Miller, A.C. Cotter, T.C. Corry, J.S. Scharold, M.E. Siersen, E.J. Isaac, and J.D. **Stockwell**. 2011. Challenges to Lake Superior's condition, assessment, and management: A few observations across a generation of change. Aquatic Ecosystem Health and Management 14:332-344.

Stockwell, J.D., T.R. Hrabik, O.P. Jensen, D.L. Yule, and M. Balge. 2010. Empirical evaluation of predator-driven diel vertical migration in Lake Superior. Canadian Journal of Fisheries and Aquatic Sciences 67:473-485.

Stockwell, J.D., M.P. Ebener, J.A. Black, O.T. Gorman, T.R. Hrabik, R.E. Kinnunen, W.P. Mattes, J.K. Oyadomari, S.T. Schram, D.R. Schreiner, M.J. Seider, S.P. Sitar, and D.L. Yule. 2009. A synthesis of cisco recovery in Lake Superior: implications for native fish rehabilitation in the Laurentian Great Lakes. N. Am. J. Fish. Manage. 29:626-652.

Stockwell, J.D., D.L. Yule, O.T. Gorman, E.J. Isaac, and S.A. Moore. 2006. Evaluation of bottom trawls as compared to acoustics to assess adult lake herring (*Coregonus artedi*) abundance in Lake Superior. Journal of Great Lakes Research 32:280-292.

Johnson, B. M., P. J. Martinez, and J. D. **Stockwell**. 2002. Tracking trophic interactions in coldwater reservoirs using naturally occurring stable isotopes. Transactions of the American Fisheries Society 131:1-13.

Stockwell, J.D., and B.M. Johnson. 1999. Field evaluation of a bioenergetics-based foraging model for kokanee (*Oncorhynchus nerka*). *Canadian Journal of Fisheries and Aquatic Sciences* 56 (Suppl. 1):140-151.

Stockwell, J.D., K.L. Bonfantine, and B.M. Johnson. 1999. Kokanee salmon foraging: a *Daphnia* in the stomach is worth two in the lake. Transactions of the American Fisheries Society 128:169-174.

Stockwell, J.D., and O.E. Johannsson. 1997. Temperature-dependent allometric models to estimate zooplankton production in temperate freshwater lakes. Canadian Journal of Fisheries and Aquatic Sciences 54:2350-2360.

Five Synergistic Activities

- Reviewer for Aquatic Ecology, Canadian Journal of Fisheries and Aquatic Sciences, Ecological Applications, Ecology, Fisheries Research, North American Journal of Fish Management, ICES Journal of Marine Science, Journal of Great Lakes Research, Marine Ecology Progress Series, Oecologia, Transactions of the American Fisheries Society, Fisheries Oceanography, and Fisheries and Management Ecology. Grant proposal reviewer for Great Lakes Fishery Trust, Great Lakes Fishery Commission, North Pacific Research Board, Minnesota Sea Grant, National Fish and Wildlife Foundation, and UW-Milwaukee's Research Growth Initiative.
- Scientific Misconduct Formal Inquiry Review Panel, University of Vermont, 2011-2012.
- Undergraduate Research Advisory Committee, University of Vermont, 2011-2012.
- Lake Champlain Sea Grant Research Review Panel, Burlington, Vermont, 2011.
- Steering Committee, Cooperative Institute for the North Atlantic Region Workshop "Population connectivity and associated spatial and temporal scales in the east coast of the United States". 2010-2011.

Collaborators

M. Ebener (Chippewa-Ottawa Resource Authority); A. Gamble (UC-Davis); S. Hansson (Stockholm U.); T. Hrabik (U. Minnesota); M. Jech (NMFS); O. Jensen (Rutgers); M. Jones (Mich. State. Univ.); J. Kelly (EPA); C. Madenjian (USGS); J.E. Marsden (U. Vermont); D. Parrish (USGS/U. Vermont); A. Pershing (U. Maine); L. Rudstam (Cornell); J. Runge (U. Maine); G. Sherwood (GMRI); M. Sierszen (EPA); T. Weber (UNH); T. Willis (U. Southern Maine); K. Wilson (U. Southern Maine); D. Yule (USGS)

Graduate and Postdoctoral Advisors

Ph.D. Advisor: W. Gary Sprules (University of Toronto)
Postdoctoral Advisors: Brett M. Johnson (Colorado State University), Michael L. Jones (Michigan State University)

Thesis Advisor and Postgraduate-Scholar Sponsor

Dr. Carrie Byron, Post-Doc (University of Rhode Island), 2011
Edmund Isaac, University Minnesota Duluth, M.Sc. (2010) (co-advisor)
4 M.Sc. Committees, 5 Ph.D. committees

William ('Breck') Bowden
Rubenstein School of Environment and Natural Resources

(i) Professional Preparation

BS, 1973, Chemistry & Zoology, University of Georgia
MS, 1976, Zoology (Limnology), North Carolina State University
Ph.D., 1982, Zoology (Coastal Ecology), North Carolina State University

(ii) Appointments

2008 – present	*Lead PI*, Theme 1, Northeastern States Research Cooperative, University of Vermont
2004 – present	*Director*, Vermont Water Resources and Lake Studies Center, University of Vermont
2002 – present	*Patrick Professor of Watershed Science and Planning,* University of Vermont
1997-2002	*Programme and Team Leader, Integrated Catchment Management,* Landcare Research, Lincoln, New Zealand.
1987-1997	*Assistant/Associate Professor. Curriculum Coordinator,* Water Resources Management, Department of Natural Resources, University of New Hampshire

(iii) Publications

(a) 5 publications most closely related to the proposed project

Bowden, W.B., Fahey, B.D., Ekanayake, J., and Murray, D.L., (2001) Hillslope and wetland hydro-dynamics in a tussock grassland, South Island, New Zealand. Hydrological Processes 15: 1707-1730.

Edwardson, K.J., Bowden, W.B., Dahm, C., and Morrice, J., (2003) The hydraulic characteristics and geochemistry of hyporheic and parafluvial zones in Arctic tundra streams, North Slope, Alaska. Advances in Water Resources 26: 907-923.

Bowden, W.B., Fenemor, A., and Deans, N., (2004) Integrating water and catchment research for the public good: the Motueka River-Tasman Bay initiative, New Zealand. UNESCO/HELP special publication. Water Resources Development 20(3): 311-323.

Bernhardt, E.S., Likens, G.E., Hall, R.O., Buso, D.C., Fisher, S.G., Burton, T.M., Meyer, J.L., McDowell, W.H., Mayer, M.S., Bowden, W.B., Findlay, S.E.G., MacNeale, K.H., Stelzer, R.S., and Lowe, W.H., (2005). Can't see the forest for the stream? - In-stream processing and terrestrial nitrogen exports. BioScience 55(3): 219-230.

Bowden, W.B., M.N. Gooseff, A. Balser, A. Green, B.J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: Potential impacts on headwater streams ecosystems. Journal of Geophysical Research – Biogeosciences, Vol. 113, G02026, doi:10.1029/2007JG000470.

(b) 5 other significant publications

Bowden, W.B., and Bormann, F.H., (1986) Soil water transport and loss of nitrous oxide after forest clearcutting. Science 233: 867-869.

Peterson, B. J., Wollheim, W., Mulholland, P. J., Webster, J. R., Meyer, J. L., Tank, J.L., Grimm, N. B., Bowden, W. B., Valett, H. M., Hershey, A. E., McDowell, W. B., Dodds, W. K., Hamilton, S. K., Gregory, S.and D'Angelo, D. J., (2001) Stream processes alter the amount and form of nitrogen exported from small watersheds. Science 292: 86-90.

Slavik, K., Peterson, B.J., Deegan, L.A., Bowden, W.B., Hershey, A.E., Hobbie, J., (2004) Long-term responses of the Kuparuk River to phosphorus fertilization. Ecology 85(4):939-954.

Cao, W., Bowden, W.B., Davie, T., and Fenemor, A., (2006) Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability. Hydrological Processes 20: 1057–1073.

Mulder, K. and Bowden, W.B. (2007) Organismal stoichiometry and the adaptive advantage of variable nutrient use and production efficiency in Daphnia. Ecological Modeling 202: 427–440.

(iv) Synergistic Activities
Development of science infrastructure: Lead representative for University of Vermont, Consortium for Advancement of Hydrological Sciences, Inc. (CUAHSI, 2004-present). Co-PI, Hydrologic Measurement Facility sub-committee of the Consortium of University for the Advancement of Hydrologic Sciences, Inc. (CUAHSI, 2004-2009).
Improved mentoring in research: Established a new undergraduate major and later M.S. in Water Resources Management in the Department of Natural Resources, University of New Hampshire, Durham (1987-1997). Led an initiative to establish the Ph.D. program in Natural Resources Management. Department of Natural Resources, University of New Hampshire, Durham, NH (1989-1990). Developed a site-based Research Experiences for Undergraduates Program in forest ecology at Hubbard Brook Experimental Forest. Several participants are now NSF-funded scholars.
Programmatic research co-ordination: Coordinating-PI on the Arctic Long-Term Ecological Reseaarch Program, Stream Research component (2008-present). Lead scientist on research team for the National Park Service Inventory and Monitoring program to assess the health of aquatic ecosystems in the arctic parks (2005-present). Lead PI on the *Redesigning the American Neighborhood* program to evaluate and promote the use of low-impact designs for stormwater management in suburban areas (2003-present). Founded and lead the Cooperative Research Group for Integrated Catchment Management, an ad-hoc national coordinating group for interdisciplinary research on integrated environmental management in New Zealand (2000).

(v) Collaborators & Other Affiliations
(a) Collaborators and Co-Editors (48 months)
Baeseman, J. (University of Alaska-Fairbanks), Balser, A. (University of Alaska-Fairbanks), Bradford, J. (Boise State University), Burkhart, G. (National Park Service), Costanza, R. (University of Vermont, UVM), Crosby, B. (Idaho State University), Deegan, L., (MBL), Dodds, W.K. (Kansas State University), Dunn, T. (Univ. California - Santa Barbara), Eppstein, M. (UVM), Erickson, J. (UVM), Findlay, J.C. (USGS), Gens, R. (University of Alaska-Fairbanks), Giblin, A. (MBL), Gooseff, M. (Pennsylvania State University), Gotelli, N. (UVM), Grimm, N.B. (Arizona State University), Hamilton, S.K. (Michigan State University), Bret-Harte, S (University of Alaska – Fairbanks), Hershey, A. (University of North Carolina Greensboro), Hobbie, J. (MBL), Hooper, R. (CUAHSI), Huryn, A. (University of Alabama), Jones, J. (University of Alaska-Fairbanks), Jorgenson, T. (ABS-Alaska), Kling, G.W. (University of Michigan), Kofinas, G. (University of Alaska-Fairbanks), Likens, G.E.(Inst. of Ecosystems Studies), Lewkowicz, A. (University of Ottawa), Luecke, C. (Utah State University), Mack, M., (University of Florida), McDowell, W. (University of New Hampshire), McNamara (BSU), McIntosh, A. (UVM), Mitchell, B. (National Park Service), Mulholland, P.J. (Oak Ridge National Lab), Pellerin, B. (USGS – Sacramento), Peterson, B.J. (MBL), Rastetter, E. (Ecosystems Center/MBL), Rizzo, D. (UVM), Sanzone, D. (NPS now BP), Schimel, J. (UC-Santa Barbara), Schuur, T. (University of Florida), Shanley, J. (USGS – Vermont), Smith, T. (University of Toronto), Sparrow, E. (University of Alaska-Fairbanks), Tank, J. (Notre Dame University), Todd, J. (UVM), Troy, A. (UVM), Vallett, H.M. (Virginia Tech University), Vallino, J (MBL), Voinov, A. (US/ACOE), Watzin, M. (UVM), Webster, J.R., (Virginia Tech University), Wollheim, W. (University of New Hampshire), Young, S. (Sterling College).
(b) Graduate and Postdoctoral Advisors:
J.E. Hobbie, graduate advisor, North Carolina State University; B.J. Peterson, graduate advisor, North Carolina State University; F.H. Bormann, postdoctoral research advisor, Yale University
(iii) Thesis Advisor and Postgraduate-Scholar Sponsor (last 5 years):
W. Cao, Postdoctoral advisor, New Zealand; M. Flinn, Postdoctoral advisor, Univ. of Vermont; C. Cappelletti, MS advisor, J. Foley, MS advisor; E. Fitzgerald, MS advisor; M. Greenwald-Johnson, MS advisor; A. Hackman, MS advisor; A. Holland, MS advisor; P. Kanwar, Ph.D. advisor, J. Larouche, MS and Ph.D. advisor; K. Mulder, Ph.D. advisor, J. Nipper, Ph.D. advisor; L. Snyder, MS advisor. Since 1987: primary advisor to 23 graduate students; secondary advisor to 18 students.

Information Transfer Program Introduction

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center maintains a web site that highlights emerging research funded by the Center or relevant to water resources management in Vermont. During the current project year we did an overhaul of the Water Center website and keep it up to date with current research and local events.

The Director of the Water Center is also a member of the steering committee of Lake Champlain Basin Program (LCBP) and regularly brings information from Center-funded projects to the attention of the LCBP committees. His activities on this committee also helps to inform the directions of the Water Center and has led to a number of productive partnership. The Director of the Water Center also participated in discussions about creation of water quality advisory council.

From time to time the Center supports seminars, workshops, and conferences relevant to water resources management issues in Vermont. In the 2012-13 project year we provided funding to bring three scientists to present seminars and meet with faculty, staff, and graduate students. Dr. Doug Facey at St. Michael's College invited Dr. Gene Helfman, Professor Emeritus at University of Georgia, to speak at Norwich University and St. Michael's College, presenting talks on fisheries management and sport fishing. In April, 2013, Dr. Gillian Galford of the Gund Institute of the University of Vermont invited Dr. Michael Coe from the Woods Hole Research Center to give a lecture at the University of Vermont about deforestation, climate, and hydrology in the Amazon basin. Dr. Jason Stockwell of the Rubenstein Ecosystem Science Lab invited Dr. Paul Hershberger from the University of Washington in April 2013 to give a lecture at UVM about the ecological effects of fish parasites and diseases on wild fish populations.

We offered to provide support for a conference on flood hazards in Vermont and future flood mitigation that was proposed by the Governors of Vermont and New York and the Premier of Canada after the devastating spring flooding caused by rain on unusually deep snow and the fall flooding caused by Tropical Storm Irene that both occurred in 2011. The organizers were able to secure other funds.

Information Transfer Activities

Basic Information

Title:	Information Transfer Activities
Project Number:	2008VT39B
Start Date:	3/1/2012
End Date:	2/28/2013
Funding Source:	104B
Congressional District:	Vermont-at-Large
Research Category:	Not Applicable
Focus Category:	Education, Management and Planning, Methods
Descriptors:	
Principal Investigators:	Breck Bowden

Publication

1. There are no publications specific to this project. However, papers presented at the conference supported by the Vermont Water Center in 2010 will be published in a special issue of the Journal of Great Lakes Research, expected in late 2011.

Information Transfer – Vermont

The Vermont Water Resources and Lake Studies Center facilitates information transfer in a variety of ways. The Center maintains a web site that highlights emerging research funded by the Center or relevant to water resources management in Vermont. During the current project year we did an overhaul of the Water Center website and keep it up to date with current research and local events.

The Director of the Water Center is also a member of the steering committee of Lake Champlain Basin Program (LCBP) and regularly brings information from Center-funded projects to the attention of the LCBP committees. His activities on this committee also helps to inform the directions of the Water Center and has led to a number of productive partnership. The Director of the Water Center also participated in discussions about creation of water quality advisory council.

From time to time the Center supports seminars, workshops, and conferences relevant to water resources management issues in Vermont. In the 2012-13 project year we provided funding to bring three scientists to present seminars and meet with faculty, staff, and graduate students. Dr. Doug Facey at St. Michael's College invited Dr. Gene Helfman, Professor Emeritus at University of Georgia, to speak at Norwich University and St. Michael's College, presenting talks on fisheries management and sport fishing.
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We offered to provide support for a conference on flood hazards in Vermont and future flood mitigation that was proposed by the Governors of Vermont and New York and the Premier of Canada after the devastating spring flooding caused by rain on unusually deep snow and the fall flooding caused by Tropical Storm Irene that both occurred in 2011. The organizers were able to secure other funds.

USGS Summer Intern Program

None.

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

Notable Awards and Achievements

Publications from Prior Years

1. 2011VT57B ("Determining phosphorus release potential from eroding streambank sediments in the Lake Champlain Basin of Vermont") - Articles in Refereed Scientific Journals - Young, E. and D. Ross (2013). Phosphorus speciation in riparian soils: A phosphorus-31 nuclear magnetic resonance spectroscopy and enzyme hydrolysis study. Soil Science Society of America Journal. In Press.