Vermont Water Resources and Lake Studies Center

The University of Vermont

Program Evaluation Report
Fiscal Years 2011 - 2015




Submitted by:

Breck Bowden, Director

To:

Office of External Research
Water Resources Discipline
U.S. Geological Survey

Preface

The Vermont Water Resources and Lake Studies Center receives an annual Federal matching grant as authorized by §104 of the Water Resources Research Act of 1984 (Public Law 98-242) as amended by Public Laws 101-397, 104-147, 106-374, and 109-471. §104 of the Act requires that the Secretary of the Interior "conduct a careful and detailed evaluation of each institute at least once every 3 years to determine that the quality and relevance of its water resources research and its effectiveness at producing measured results and applied water supply research as an institution for planning, conducting, and arranging for research warrants its continued support under this section." The U.S. Geological Survey (USGS), Department of the Interior, administers the provisions of the Act. This evaluation report describes, in the format prescribed by the USGS, the research, training, and information transfer activities supported by the §104 grants and required matching funds in fiscal years 2011 through 2015. Prior to 2008, the Act required an evaluation of the program at least once every 5 years. The last evaluation was conducted in 2013, covering fiscal years 2008 through 2010.

Vermont Water Resources and Lake Studies Center
EVALUATION REPORT
FY 2011 - FY 2015

Table of Contents

Introduction

The Water Resource Issues and Problems of Vermont

The state of Vermont is one of the most rural states in the nation, with 82.6% of its population living in towns with fewer than 50,000 people.[1]In total the population of Vermont was just under 625,000 in 2017.[2]Despite a low population and a rural character, Vermont has a productive, working landscape. Just over 20% of the land area is agricultural and 73% is identified as forest land.[3, 4]Of this forest land, 95% is identified as productive timberland that is also fragmented with rural homesteads on small parcels.[4]The remainder of Vermont's landscape (7%) is developed or urbanized. Thus, despite its relatively small size and rural character, the land resources of the state of Vermont are intensively used. In the past 25 years this intensive land use has resulted in a suite of water quality issues, including eutrophication of surface waters, contamination of groundwater, harmful algal blooms, beach closures from high-levels of enteric bacteria, and a proliferation of chemicals of concern including heavy metals, microplastics, pharmaceuticals, and personal care products. The degradation of major water bodies such as Lake Champlain on the western border of the state, the Connecticut River on the eastern border, and numerous streams, ponds, and lakes in between has raised alarm bells with communities, watershed groups, and state agencies. For example, the entire body of Lake Champlain, the largest body of freshwater in the northeast, is designated by the Environmental Protection Agency as impaired with elevated phosphorus levels and is under a negotiated TMDL plan. Recent research suggests that climate change will only exacerbate these problems and will challenge our abilities to improve conditions through currently available best management practices.

As a consequence, there are now several dozen non-governmental organizations, watershed groups, and state and federally funded programs that support or engage in research, education, and outreach to address the water resource challenges we now face in Vermont. Of these program the Vermont Water Resources Research Institute (locally known as the Vermont Water Resources and Lake Studies Center) is one of just a handful of programs that is viewed as an honest broker of knowledge about water resources and potential solutions to the challenges we face. In the remainder of this report we will refer to the Vermont Water Resources and Lake Studies Center as the "Water Center."

1. How Rural Are the States? (n.d.). Retrieved July 26, 2018 from http://www.dailyyonder.com/how-rural-are-states/2012/04/03/3847/

2. Vermont Population 2018. (n.d.). Retrieved July 26, 2018, from http://worldpopulationreview.com/states/vermont-population/

3. Farmland Information Center. (n.d.). Retrieved July 26, 2018, from https://www.farmlandinfo.org/statistics/vermont

4. Morin, R.S.; Widmann R.H. 2016. Forests of Vermont, 2015. Resource Update FS-80. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 4 p.

Institute Mission and Vision: An Overview

Our vision is that Lake Champlain is a healthy and functional ecosystem that supports a diverse and robust economy in the region. The mission of the Water Center during the review period has been to encourage, fund, execute, and communicate objective and competent research to assist in the solution of high priority water resources challenges in Vermont. The Water Center is directly integrated with the Lake Champlain Sea

Grant (LCSG) program, which shares a closely related mission. Both of these programs collaborate with key partners, including the Vermont Department of Environmental Conservation, the Lake Champlain Basin Program, and ECHO at the Leahy Center for Lake Champlain, among others.

Section 104 Objectives

The primary use of 104B funds by the Water Center has been to fund research aimed at quantifying sources of phosphorus and identifying best practices to reduce phosphorus loading. While phosphorus was the focus of many projects, proposals on any topic relevant to the mission of the Water Center were considered.

Allocation of Federal Grant and Matching Funds Among Program Activities: FY 2011 through FY 2015	
Activity	**Percent**
Research	60
Information Transfer	5
Education	30
Administration	5
Other (please specify)	0
Total	100

Administration and Coordination

Institute Directors during Evaluation Period

Name	Academic Discipline	Term
Dr. William "Breck" Bowden	Water Resources	2011-2015

Advisory Committees

Craig Heindel, Heindel & Noyes, 2011-2015

Crea Lintilhac, Lintilhac Foundation, 2011-2015

Eric Smeltzer, Vermont Agency of Natural Resources, 2011-2015

Mary Watzin, University of Vermont Rubenstein School of Environment and Natural Resources, 2011

Mike Winslow, Lake Champlain Committee, 2011-2015

The committee meets approximately twice per year, once to discuss the upcoming RFP announcement and once to review the proposals.

In 2014, the Water Center Advisory Committee merged with the Lake Champlain Sea Grant Program Advisory Committee to form a single board. This committee is composed of academic, governmental, and non-governmental experts who help us identify strategic directions and opportunities. A subcommittee meets to discuss, review, and recommend proposals for funding by the Water Center. The budgets of the Water Center and the LCSG remain independent. By creating a relationship between these two organizations, goals of each organization can be coordinated to more effectively utilize funds. During this reporting period, the Water Center tended to focus on support for new research while the LCSG was more focused on outreach and education. The joint effort of the two programs brings the strengths of the Water Center research program to the LCSG and the strength of LCSG outreach and education efforts to the Water Center.

Beginning in 2014, the Water Center initiated a new opportunity for graduate students to seek support directly for their research. This is an alternative that parallels our “general” grants program which supports project proposals from faculty. Each graduate student was required to have a faculty advisor included in the proposal and could request a maximum of $10,000 in federal funding for their own work. The goal of the graduate student research awards is to provide graduate students with a funding opportunity and to gain experience submitting proposals, while at the same time expanding the reach of the Water Center in the ability to fund diverse projects that fulfill our research priorities.

Research Proposal Review and Selection Process

Each proposal submitted to the Water Center for consideration, whether general or graduate student generated, is reviewed for technical merit and relevance to the state needs. External subject-expert reviewers were sought for each proposal. Each proposal typically received two external reviews. External reviewers did not always

have knowledge of Vermont-specific research problems but were able to review the technical and scientific merit of the proposal. The peer reviews were then considered by a subcommittee of the Advisory Committee for final discussion and selection. This panel provided guidance on research needs of Vermont as well as technical merit of the proposals. The Director received all comments from the reviewers and the Advisory Committee and worked with the Advisory Committee to come to a consensus decision about the suite of proposals to recommend for funding. Revisions of proposals based on external and internal comments were requested from PIs prior to submission of the consolidated Water Center proposal to the USGS.

Peer Review of Institute Publication

The Vermont Water Center encourages its principal investigators to publish their Section 104B research results in technical journals that receive peer review, primarily because these journals are typically trusted sources that have wide distribution. Though we require a final report for each project, we do so primarily to ensure there is full documentation of the activities and results from each project funded by the Center. These final project reports are retained and posted on our Center website. As PIs funded by the Water Center publish new, peer-reviewed reports, we collect those citations and post them on our website as well.

Number of Principal Investigators Supported, by Rank and Year

Principal Investigators on Research Projects Supported by §104 Grants and Matching Funds, by Academic Rank and Year: FY 2011 through FY 2015					
Academic Rank	**2011**	**2012**	**2013**	**2014**	**2015**
Assistant Professor and below	2	2	0	0	1
Associate Professor	3	3	2	3	4
Professor	1	1	0	1	1
unknown	1	0	0	0	0
Total	7	6	2	4	6

Significant Impact

Awards

Research, Information Transfer, and Education

· **Quantifying phosphorus transport from streambank erosion.** Dr. Ross led two projects which built on previous streambank erosion research and the study of phosphorus transport. The researchers quantified phosphorus from eroding streambanks and examined the relationship of phosphorus to soil texture. They found that smaller particles are more likely to erode from the streambank, are transported farther, and carry more total phosphorus than coarser particles. However, the phosphorus eroding from streambanks is not biologically available, meaning the phosphorus is not usable by algae and does not contribute to algae blooms. Phosphorus from agricultural fields that are near streams have more biologically available phosphorus. Overland runoff carries phosphorus from the fields to the streambanks, where it may be stored for the short-term, but as the streambanks continue to erode, they may become sources for biologically available phosphorus.

· **Using new technologies to measure water quality at high frequencies.** Two projects were funded that used high-frequency monitoring to improve water quality measurements. The first used data from an acoustic Doppler current profiler to quantify sediment and phosphorus transport that was installed by USGS at a stream gage. Samples were collected during storm events to compare to the continuous data and develop a rating curve relationship. A second project used a buoy located in Missisquoi Bay on Lake Champlain equipped with a sonde to measure physical and water chemistry parameters throughout the water column. Hourly data was used in conjunction with water samples collected three times/day. Each of these projects allowed for more frequent sampling to occur than can be done when water samples alone are collected, improving the ability to understand water chemistry and transport processes.

· **Research and assessment to improve state and local management practices.** Dr. Wemple analyzed several management practices used on gravel roads in Vermont that are designed to reduce sediment and phosphorus runoff. Types of installments include culverts, vegetated soil stabilization, and revetments. The installations were assessed for capacity to reduce erosion and life of the installment. Factors contributing to failure included topography and flood exposure, more than age of installation. This research was a part of the Better Back Roads program of Vermont and has contributed to the ability of state and municipal roads to be managed for local conditions.

· **Information transfer of research to practitioners.** In 2014, as part of the Vermont Water Center Information Transfer goals, a partnership among several Vermont-based research, academic, and governmental organizations was formed to create a portal to key findings from ecological research and monitoring being conducted across Vermont. The findings are sent in a quarterly email to subscribers and archived on the website. During the reporting period, 22 research digests were written, five emails were sent, and 224 subscribers joined the list. A graduate student is supported each year to develop content and manage social media accounts.

Budget Information

104 Program Federal and Required Matching Funds

Total Federal and Required Matching Funds Available to the Vermont Water Resources and Lake Studies Center under §104 of the Water Resources Research Act of 1984

	2011	2012	2013	2014	2015	Total Federal	Total Match	Total Funds
104(b) Total Federal	$92,335	$92,335	$55,525	$92,335	$92,335	$424,865	X	X
104(b) Total Match	$195,031	$204,217	$111,139	$184,674	$184,826	X	$879,887	X
104(b) Total Funds	$287,366	$296,552	$166,664	$277,009	$277,161	X	X	$1,304,752
104(g) Total Federal	$0	$0	$0	$0	$0	$0	X	X
104(g) Total Match	$0	$0	$0	$0	$0	X	$0	X
104(g) Total Funds	$0	$0	$0	$0	$0	X	X	$0
Total	$287,366	$296,552	$166,664	$277,009	$277,161	$424,865	$879,887	$1,304,752

Discretionary Base Funding

Appropriated or Other Discretionary Funds Available to the Institute: FY 2011 through FY 2015					
Source of Discretionary Funds	**2011**	**2012**	**2013**	**2014**	**2015**
Vermont Department of Environmental Conservation	$13,200	$8,160	$30,000		
Lintilhac Foundation			$9,500		

Other Water Resources Research Funding

Total and Average Value of Water Resources Grants, Contracts, and Cooperative Agreements in Which the Institute Had a Major Role During the Evaluation Period: FY 2011 through FY 2015	
Total Value of Awards, in dollars	$8,351,175
Number of Awards	10
Average Value of Awards	$835,118

Please list in the table below the 10 largest grants (other than section 104 grants), contracts, and cooperative agreements for which the Director or staff of the institute played a major role in assembling the proposal or otherwise obtaining the grant or contract. Include the dollar amount of the contract, grant, or cooperative agreement, the year that it was initiated, and the source of the funds. USGS-Water Resources Research Institute Internships and funds from other federal agencies passed through to your institute by the USGS should be included here.

The Ten Largest Water Resources Grants, Contracts, and Cooperative Agreements in Which the Institute Had a Major Role during the Period of the Evaluation: FY 2011 through FY 2015			
Title/Topic	**Source of Fundings**	**Year Initiated**	**Amount**
Lake Champlain Sea Grant	NOAA	2011	$3,149,961
Northeastern States Research Cooperative (annual awards)	USDA Forest Service	2011	$2,188,573
Vermont EPSCoR Project - NEWRNet	NSF	2013	$2,000,000
Arctic Long-Term Ecological Research (LTER)	NSF	2011	$807,023
Macrosystems Biology: SCALER project	NSF	2011	$205,615

Research

Summary of Research Projects

Number of Research Projects and Percentage of Research Funds, by Research Category: FY 2011 through FY 2015		
Research Category	**Number**	**Percent of Funds**
Biological Sciences	1	12.0
Climate and Hydrologic Processes	1	8.0
Ecological Processes	0	0.0
Engineering	1	10.0
Ground-water Flow and Transport	0	0.0
Social Sciences	0	0.0
Water Quality	9	70.0
Not Applicable	0	0.0

Research Projects

Project Number	Title	PI	Total budget
2011VT57B	Determining phosphorus release potential from eroding streambank sediments in the Lake Champlain Basin of Vermont	Donald Ross	$70,105
2011VT58B	Use of Acoustic Doppler Current Profiler data to estimate sediment and total phosphorus loads to Lake Champlain from the Rock River	Breck Bowden	$51,239
2011VT59B	Advanced and Integrative Model of Phosphorus loading from High Runoff Events	Arne Bomblies	$231,202
2012VT65B	Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff	Beverley Wemple	$259,968
2012VT69B	Development of monitoring buoy system for lake studies	Jason Stockwell	$74,463
2013VT72B	Automated Mapping of Effective Impervious Areas (EIA) to Assess the Impact of EIA on Stream Health	Leslie Morrissey	$93,940
2014VT75B	Organic phosphorus forms and transformations in Lake Champlain stream corridor soils	Donald Ross	$244,974
2014VT76B	An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish	J Marsden	$131,423
2015VT77B	System-wide quantification of streambank erosion	Mandar Dewoolkar	$117,215

Research Publications

Ishee, E.I. 2011. Characterizing phosphorus in eroding streambank soils in Chittenden County, Vermont. M.S. Thesis, Department of Plant & Soil Science, College of Agriculture and Life Sciences, University of Vermont, Burlington, VT, 90 pp.

Young, E. O., D.S. Ross, C. Alves, and T. Villars. 2012. Soil and landscape influences on native riparian phosphorus availability in three Lake Champlain Basin stream corridors. Journal of Soil and Water Conservation. 67:1 (1-7).

Young, E. O., D. S. Ross, B. J. Cade-Menun, and C. W. Liu. 2013. Phosphorus Speciation in Riparian Soils: A Phosphorus-31 Nuclear Magnetic Resonance Spectroscopy and Enzyme Hydrolysis Study. Soil Sci. Soc. Am. J. 77:1636-1647. doi:10.2136/sssaj2012.0313

Tyler, J. 2014. M.S. Thesis. Field scale topographical assessment of sediment transport and associated phosphorus using the WEPP and SWAT models. Department of Civil and Environmental Engineering. University of Vermont, Burlington, VT. 84 pp.

Garton, J. 2015. Evaluating the effectiveness of best management practices on rural backroads of Vermont: A retrospective assessment and cost analysis. Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, 98pp.

Ishee, E. R., D. S. Ross, K. M. Garvey, R. R. Bourgault, and C. R. Ford. 2015. Phosphorus Characterization and Contribution from Eroding Streambank Soils of Vermont's Lake Champlain Basin. J. Environ. Qual. 44:1745-1753. doi:10.2134/jeq2015.02.0108

Isles, P.D.F., C.D. Giles, T.A. Gearhart, Y. Xu, G.K. Druschel, and A.W. Schroth. 2015. Dynamic internal drivers of a historically severe cyanobacteria bloom in Lake Champlain revealed through comprehensive monitoring. Journal of Great Lakes Research 41:818-829.

Pinheiro, Victoria M., 2015, Lake trout spawning site use in Lake Champlain & the development of the binomial rolling residence test. M.S. Thesis. Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT. 59pp.

Bryce, T. 2016, Quantifying streambank erosion through Terrestrial LiDAR (TLS) and an Unmanned Aircraft System (UAS). M.S. Civil & Environmental Engineering, University of Vermont, Burlington, VT,

Isles, P.D.F., D.M. Rizzo, Y. Xu, and A.W. Schroth. 2017. Modeling drivers of interannual variability in cyanobacterial blooms severity using self-organizing maps and high-frequency data. Inland Waters 7:333-347.

Hamshaw, S.D. 2018, Ph.D. Dissertation, Fluvial processes in motion: Measuring bank erosion and suspended sediment flux using advanced geomatic methods and machine learning. Department of Civil and Environmental Engineering, University of Vermont, Burlington, VT, 306pp.

Wemple, B.C., J. Garton, A. Larson, and D.S. Ross. Evaluating the efficacy of adaptive interventions to reduce erosion and phosphorus inputs to waterways in a New England (USA) landscape: a multi-method approach. In preparation for Journal of the American Water Resources Association.

Hamshaw, S. D., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., Bryce, T., & Engel, T. Evaluation of unmanned aircraft system (UAS) photogrammetry for quantifying streambank erosion and comparison to terrestrial laser scanner (TLS). In preparation, to be submitted to Earth Surface Processes and Landforms, 2018

Information Transfer

Project Number	Title	PI	Total budget
2008VT39B	Information Transfer Activities	Breck Bowden	$34,220

Audio-Visual Productions

Newsletter

A newsletter specific to the Vermont Water Center has not been produced during the evaluation period. However, news of Water Center-funded research has been distributed to a wide audience via ecoNEWS VT quarterly emails and archived research summaries on the website. During the evaluation period, three of the research projects funded by the Water Center were summarized, among the 22 total research summaries. During the evaluation period, 224 subscribers joined the email list and the website had 9,000 unique visitors, including 250 visitors to the Water Center-funded research stories.

econewsvt.org

Conferences

Internet Services

The official Web site of the Vermont Water Resources and Lake Studies Center, hosted by The University of Vermont, appears at http://www.uvm.edu/rsenr/vtwater/.

Information Transfer Publications

IT Publication Type	IT Publication Citation

Education

Number of students supported by Base-level Grants

Educational Level	2011	2012	2013	2014	2015	Total
Undergraduate	4	7	0	6	0	17
Masters	1	1	1	2	2	7
Ph.D.	1	0	0	1	1	3
Post-Doc.	0	0	0	0	0	0
Total	6	8	1	9	3	27

Number of students supported by Competitive Grants

Educational Level	2011	2012	2013	2014	2015	Total
Undergraduate	0	0	0	0	0	0
Masters	0	0	0	0	0	0
Ph.D.	0	0	0	0	0	0
Post-Doc.	0	0	0	0	0	0
Total	0	0	0	0	0	0

Number of students supported by Internships

Educational Level	2011	2012	2013	2014	2015	Total
Undergraduate	0	0	0	0	0	0
Masters	0	0	0	0	0	0
Ph.D.	0	0	0	0	0	0
Post-Doc.	0	0	0	0	0	0
Total	0	0	0	0	0	0

Number of students supported by Supplemental Grants

Educational Level	2011	2012	2013	2014	2015	Total
Undergraduate	0	0	0	0	0	0
Masters	0	0	0	0	0	0
Ph.D.	0	0	0	0	0	0
Post-Doc.	0	0	0	0	0	0
Total	0	0	0	0	0	0

Theses and Dissertations

Number of Theses and Dissertations Resulting from Student Support: FY 2011 through FY 2015	
Master's Theses	5
Ph.D. Dissertations	2

Additional Information for the Evaluation Panel

During the evaluation period, the Water Center expanded its outreach and information transfer efforts to reach a wider audience. Support was provided to bring visiting scholars to campuses across Vermont to present research seminars, including a speaker at Norwich University and several to University of Vermont. The Vermont Water Center advertised and hosted "watch parties" for a variety of water resources-related webinars as a way to be engaged with water research being conducted across the country. In 2014, ecoNEWS VT (www.econewsvt.org) was created to highlight ecological research being conducted across Vermont. Several Vermont organizations, including the Vermont Water Center partnered to develop the website and contribute content for quarterly emails. An "umbrella" website for the New England Water Resources and Research Centers was developed in 2015 as a landing page for each of the regional offices (www.newrrc.org).

Additionally, researchers regularly gave presentations to technical, student, and public audiences. These efforts have broadened the reach of the Water Center. A listing of these presentations is below.

Presentations

Ishee, E.R. and D.S. Ross. 2011. Characterizing phosphorus in eroding streambank soils in Chittenden County, Vermont. H43F-1279, AGU Annual Meeting, San Francisco, CA, December.

Ishee, E. and D. Ross. 2011. Contribution of streambank erosion as a non-point source of phosphorus to Lake Champlain. Annual meeting of the Soil Science Society of America, San Antonio, TX, October.

*Isles, P., A. Schroth, Y. Xu, C. Giles, and J.D. Stockwell. 2014. Quantifying the effects of cyanobacterial buoyancy regulation on lake metabolism and bloom progression using high-frequency data. Joint Aquatic Sciences Meeting, Portland, Oregon.

*Isles, P., J.D. Stockwell, C. Giles, Y. Xu, and A. Schroth. 2014. Quantifying the effects of cyanobacterial buoyancy regulation on lake metabolism using high-frequency data. GLEON 16, Orford, Quebec.

Marsden, J. E. 2014. ROVs, AUVs, and Acoustic Telemetry - Studying Fish with Modern Technology. Public presentation at the ECHO, Leahy Center for Lake Champlain.

Marsden, J. E. 2014. Lake Champlain 2014: Familiar issues, emerging issues. Lake Champlain Committee.

Marsden, J. E. 2014. From CAT(o)S to fleas – updates from Lake Champlain and beyond. New York chapter, Trout Unlimited.

Ortiz, N., B. Roy, P. Isles*, and J.D. Stockwell. 2014. Monitoring cyanobacteria dynamics and water quality parameters in two productive systems – Shelburne Pond and Missisquoi Bay, Lake Champlain. Vermont Monitoring Cooperative Annual Meeting, Burlington, Vermont.

Ortiz, N., B. Roy, P. Isles*, and J.D. Stockwell. 2014. Monitoring cyanobacteria dynamics and water quality parameters in two productive systems – Shelburne Pond and Missisquoi Bay, Lake Champlain. University of Vermont Natural Areas – Celebrating 40 Years of Conservation and Stewardship, Burlington, Vermont.

Wemple, B. Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff. March 20, 2014. Vermont Agency of Natural Resources Brown Bag Seminar series, presentation to Agency of Natural Resources and Agency of Transportation staff). Montpelier, VT.

Wemple, B. Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff. March 31, 2014. Vermont ANR Municipal Day, presentation to town and local governance participants in day-–long workshop for municipalities at Vermont Agency of Natural Resources. Montpelier, VT

Marsden, J. E. 2015. Tracking lake trout with acoustic telemetry. Lake Champlain Fishing Forum.

Ortiz, N., B. Roy, P. Isles*, and J.D. Stockwell. 2015. Monitoring cyanobacteria dynamics and water quality parameters in two eutrophic water systems. Annual Conference of the Society of Freshwater Science, Milwaukee, Wisconsin.

Ortiz, N., B. Roy, P. Isles*, and J.D. Stockwell. 2015. Monitoring cyanobacteria dynamics and water quality parameters in two productive systems – Shelburne Pond and Missisquoi Bay. 7th Annual Vermont EPSCoR Student Research Conference, Burlington, Vermont.

Perillo, V.L., C. Balling, D.S. Ross and B.C. Wemple. 2015. Preliminary characterization of organic phosphorus species in soils along the Missisquoi River (Vermont, USA). Soil Science Society of America annual meetings, Minneapolis, MN, November.

Ross, D.S., E.R. Ishee, K.M. Garvey and R.R. Bourgault. 2015. Phosphorus contribution from eroding streambank soils of Vermont's Lake Champlain Basin. Soil Science Society of America annual meetings, Minneapolis, MN, November.

Sugla, M., P. Isles*, and J.D. Stockwell. 2015. A zooplankton respiration model to evaluate lake metabolism estimates from high-frequency data. GLEON 17, Chuncheon, South Korea.

Sugla, M., P. Isles*, and J.D. Stockwell. 2015. A zooplankton respiration model to evaluate lake metabolism estimates from high-frequency data. International Association of Great Lakes Research Annual Meeting, Burlington, Vermont. [Best Student Poster Award]

Xu, Y., P.D.F Isles*, A.W Schroth., D.M. Rizzo and J.D. Stockwell. 2015. Applying spectral analysis to quantify the drivers of cyanobacterial blooms. International Association of Great Lakes Research Annual Meeting, Burlington, Vermont.

Ross, D.S., B.C. Wemple and V.L. Perillo. 2016. Phosphorus in streambank soils in the Lake Champlain Basin. Lake Champlain Basin Program, Technical Advisory Committee, Grand Isle, VT, January.

Hamshaw, S. D., Bryce, T., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., & Engel, T. Site specific to system-level analysis of streambank erosion using unmanned aerial systems. Geocongress 2017 Conference, Orlando, Florida.

Other

Wemple, B. Assessing the Effects of Unpaved Roads on Lake Champlain Water Quality. May 28, 2014. Vermont EPSCoR Watershed Moments Video. Available at https://epscor.w3.uvm.edu/2/node/2202?URL=http://www.uvm.edu/~epscor/jwplayer.php?video=video/wm_BevWe

Dewoolkar, M. System-wide rapid quantification of streambank erosion. Class module on UAS and terrestrial-LiDAR technologies. UVM CE-1- Geomatics course. Fall 2015.

O’Neil-Dunne, J., and S.D. Hamshaw. System-wide rapid quantification of streambank erosion. August 3, 2016. Drones put to work to avoid natural disasters. WCAX news segment.

O’Neil-Dunne, J. System-wide rapid quantification of streambank erosion. May, 2015. Presented UAS technology and performed demonstration to Waitsfield Elementary School 5thgrade science class.

Dewoolkar, M. System-wide rapid quantification of streambank erosion. March 14, 2016. Presented research brief to staff from offices of Sen. Sheldon Whitehouse (RI) and Sen. Patrick Leahy (VT).

Attachments

Attachment A: Individual Project Descriptions

'Information Tran ...': 2008VT39B Information Transfer Description

Title	Information Transfer Activities
Project Number	2008VT39B
Start Date	3/1/2011
End Date	2/28/2012
Research Category	Water Quality
Focus Categories	Education; Management and Planning; Methods
Principal Investigators	Breck Bowden

The Vermont Water Resources and Lake Studies Center information transfer activities.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2011	$5,000	$12,110
FY2012	$5,543	$16,135

Degree Level	Number of Students	Number of Dissertations/Theses
Undergraduate		
Masters		
Ph.D.		
Post-Doctoral		

Title	Determining phosphorus release potential from eroding streambank sediments in the Lake Champlain Basin of Vermont
Project Number	2011VT57B
Start Date	3/1/2011
End Date	2/28/2012
Research Category	Water Quality
Focus Categories	Nutrients; Non Point Pollution; Water Quality
Principal Investigators	Donald Ross; Leslie Morrissey; Beverley Wemple

Streambank erosion is a significant contributor of sediment and sediment-bound phosphorus (P) into Champlain Valley riverways and Lake Champlain, lowering water quality. Sediment and P load studies usually measure only total P (TP) and occasionally readily available P, such as Modified Morgan P (MM-P), yet neither concentration reflects the amount of P that will be released from sediments over time. Available P tests reflect the fraction of P immediately bioavailable while TP includes occluded P that will likely never be released. Oxalate-extractable P (Pox) has been shown to be more representative of P that is released over time in aquatic systems, measuring immediately available P as well as P complexed with Al and Fe oxides. In reduced environments such as lake sediments, Fe oxides readily release P that can be cycled into the water column. Recent work in the Lake Champlain Basin has shown that Pox/TP ratios were strongly correlated with soil texture and therefore bioavailable P may be modeled throughout riparian landscapes using textural analysis only. The objectives of this project are to: 1) quantify the slow-cycling P contribution (Pox) from eroding streambank sediments into Lake Champlain; 2) further develop the relationships among Pox, total P and soil texture; and 3) model TP, MM-P and Pox variation in the riparian landscape. To meet these objectives, 400 archived soil samples representative of study extent, texture, and drainage (stratified random sample) will be analyzed for Pox. These samples were collected as part of two past studies and an ongoing study and will have been analyzed for MM-P, TP, and texture. Soils were collected in the Basin along the corridors of seven streams in three Vermont counties. A strong correlation between Pox/TP and texture would support previous research, allowing bioavailable P to be predicted by texture throughout riparian corridors in the region and to be modeled spatially. The proposed research would allow for calculation of potentially bioavailable P loading rates in addition to the total P load. This would in turn inform better riparian corridor and aquatic system management by more clearly identifying actual sources of bioavailable P to the Lake.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2011	$19,989	$50,116

Degree Level	**Number of Students**	**Number of Dissertations/Theses**
Undergraduate		
Masters	1	1
Ph.D.		
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**

Articles in Refereed Scientific Journals	Young, E.O., D.S. Ross, C. Alves, and T. Villars. 2012. Influence of soil series on phosphorus forms and availability at two riparian sites in the Lake Champlain Basin (Vermont). J. Soil Water Conserv. 67:1-7.
Dissertations	Ishee, E.I. 2011. Characterizing phosphorus in eroding streambank soils in Chittenden County, Vermont. M.S. Thesis, Dept. Plant & Soil Science, Univ. Vermont, 90 pp.
Articles in Refereed Scientific Journals	Determining phosphorus release potential from eroding streambank sediments in the Lake Champlain Basin of Vermont: Young, E. O., D. S. Ross, B. J. Cade-Menun, and C. W. Liu. 2013. Phosphorus Speciation in Riparian Soils: A Phosphorus-31 Nuclear Magnetic Resonance Spectroscopy and Enzyme Hydrolysis Study. Soil Sci. Soc. Am. J. 77:1636-1647. doi:10.2136/sssaj2012.0313

Title	Use of Acoustic Doppler Current Profiler data to estimate sediment and total phosphorus loads to Lake Champlain from the Rock River
Project Number	2011VT58B
Start Date	3/1/2011
End Date	2/28/2012
Research Category	Water Quality
Focus Categories	Hydrology; Methods; Sediments
Principal Investigators	Breck Bowden; James Shanley

Reduction of phosphorus loading to Lake Champlain is a major management objective for the state of Vermont, so monitoring phosphorus transport to the lake is an essential task. For nearly twenty years this task has been accomplished by standard methods to estimate solute loads, based on manual sampling at discrete and relatively infrequent intervals. Most of the phosphorus is transported on sediments and so suspended sediment concentrations (SSC) are an excellent surrogate of total phosphorus transport. SSC can be measured relatively easily and continuously with acoustic Doppler current profilers (ADCPs). This presents the opportunity to measure a surrogate of total phosphorus concentration at a finer scale of temporal resolution than has ever been practicable before. The objective of this project is to calibrate a new ADCP that has recently been installed on the Rock River near Highgate, Vermont to estimate SSC. The instrument was installed primarily to measure discharge, but the data can be used for the purposes of this project if calibrated against manual SSC measurements. Once calibrated, we can use the ADCP data to explore the dynamics of sediment and total phosphorus transport at scales ranging from individual events to seasonal and interannual. At the very least this project will provide data that will help the Vermont Department of Environmental Conservation (VTDEC) decide if the ADCP provides a viable alternative to the current manual sampling program for sediment and total phosphorus. More importantly, the continuous record provided by the ADCP will quantify whether the current intermittent sampling program significantly biases estimates of total phosphorus loading.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2011	$20,988	$30,251

Degree Level	Number of Students	Number of Dissertations/Theses
Undergraduate		
Masters		
Ph.D.		
Post-Doctoral		

Title	Advanced and Integrative Model of Phosphorus loading from High Runoff Events
Project Number	2011VT59B
Start Date	3/1/2011
End Date	2/28/2012
Research Category	Water Quality
Focus Categories	Models; Water Quality
Principal Investigators	Arne Bomblies; Jane Hill

Farmers in Vermont often apply manure fertilizer to their fields in the spring after April 1, when a ban on the practice expires annually. This seasonal ban is intended to reduce nonpoint phosphorus loading from the high runoff generated during spring flush events, when the ground is still frozen. However, phosphorus (P) loading to Lake Champlain remains a problem, and the practice of spreading manure on fields outside of the period of the ban (December 15th – April 1st) may still have adverse impacts on environmental quality, if hydrological conditions lead to impermeable soil due to saturation. Critical source areas of nonpoint phosphorus pollution within the Lake Champlain watershed contribute the most P to the watershed, however their identification remains a challenge. Land characteristics often vary at a sub-plot scale. Topographic variability can lead to preferential flow paths and accumulation of water, which can have a greater scouring and mobilization effect. The identification of critical source areas within the watershed remains elusive, because intra-field variability is usually ignored. We aim to investigate the role of the variability leading to plot runoff by systematically measuring the physical and chemical characteristics at a field site and then use them to populate a process-based model with distributed parameters. Mechanistic, process-based models are able to simulate the detailed causative pathways between perturbations and system response. This understanding of P mobilization under variable conditions during spring flush events can then be extended to other parts of the Lake Champlain watershed.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2011	$35,258	$80,343
FY2012	$24,750	$63,912

Degree Level	**Number of Students**	**Number of Dissertations/Theses**
Undergraduate	1	
Masters	1	1
Ph.D.		
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**
Dissertations	Advanced and Integrative Model of Phosphorus loading from High Runoff Events: Tyler, J. 2014. M.S. Thesis. Field scale topographical assessment of sediment transport and associated phosphorus using the WEPP and SWAT models. Department of Civil and Environmental Engineering. University of Vermont, Burlington, VT. 84 pp.

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
Research Category	Water Quality
Focus Categories	Non Point Pollution; Water Quality
Principal Investigators	Beverley Wemple; Donald Ross

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 for 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.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2012	$19,791	$66,865
FY2013	$16,206	$34,169
FY2014	$16,206	$34,169

Degree Level	**Number of Students**	**Number of Dissertations/Theses**
Undergraduate	3	
Masters	1	1
Ph.D.		
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**
Dissertations	Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff: Garton, J. 2015. Evaluating the effectiveness of best management practices on rural backroads of Vermont: A retrospective assessment and cost analysis. Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT, 98pp.
Articles in Refereed	Evaluating effectiveness of BMP implementation on gravel roads to reduce sediment and phosphorus runoff: Wemple, B.C., J. Garton, A. Larson, and D.S. Ross. Evaluating the

Scientific Journals	efficacy of adaptive interventions to reduce erosion and phosphorus inputs to waterways in a New England (USA) landscape: a multi-method approach. In preparation for Journal of the American Water Resources Association.

Title	Development of monitoring buoy system for lake studies
Project Number	2012VT69B
Start Date	3/1/2012
End Date	2/28/2013
Research Category	Water Quality
Focus Categories	Water Quality; Methods; Non Point Pollution
Principal Investigators	Jason Stockwell; Breck Bowden

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.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2012	$31,000	$43,463

Degree Level	Number of Students	Number of Dissertations/Theses
Undergraduate	3	
Masters		
Ph.D.		
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**
Articles in Refereed Scientific Journals	Development of monitoring buoy system for lake studies: Isles, P.D.F., C.D. Giles, T.A. Gearhart, Y. Xu, G.K. Druschel, and A.W. Schroth. 2015. Dynamic internal drivers of a historically severe cyanobacteria bloom in Lake Champlain revealed through comprehensive monitoring. Journal of Great Lakes Research 41:818-829.
Articles in Refereed Scientific Journals	Development of monitoring buoy system for lake studies: Isles, P.D.F., D.M. Rizzo, Y. Xu, and A.W. Schroth. 2017. Modeling drivers of interannual variability in cyanobacterial blooms severity using self-organizing maps and high-frequency data. Inland Waters

	7:333-347.

Title	Automated Mapping of Effective Impervious Areas (EIA) to Assess the Impact of EIA on Stream Health
Project Number	2013VT72B
Start Date	3/1/2013
End Date	2/28/2014
Research Category	Water Quality
Focus Categories	Methods; Water Quality; Management and Planning
Principal Investigators	Leslie Morrissey; Beverley Wemple

Although total impervious area (TIA) within a watershed has often been used as an indicator of development and its impact on stormwater runoff, recent studies have demonstrated that the effective impervious area (EIA) within a watershed, i.e. the impervious area that is hydrologically (directly) connected to the receiving stream network or stormwater system, may prove a far better predictor of the impacts of development on stream geomorphology and ecosystem health. The key issue raised by these results, therefore, is how best to protect stream systems in developing watersheds, i.e. by limiting total impervious area or the hydrologic connectivity linking impervious surfaces to receiving waters. Greater understanding of the impact of development on stream ecosystems is needed to address this issue. Unlike TIA, direct measurement of effective impervious areas has proven challenging and thus the number of watershed-scale studies remains extremely limited. We propose to take advantage of recent advances in geospatial technologies and available data to develop and evaluate a methodology to directly measure EIA and then apply that methodology to address how development impacts stream biological health at sub-reach to watershed spatial scales in a range of small watersheds in the Lake Champlain Basin. Our direct approach potentially marks a tremendous improvement over that of past efforts that have relied on coarser scale and less accurate methodologies, site-specific field surveys, or indirect estimates based on analysis of rainfall-runoff data and empirical relationships between TIA and EIA. The increasing availability of high spatial resolution digital imagery and LiDAR data in Vermont, cutting edge image classification techniques, and GIS-based hydrologic modeling, however, now offers the unprecedented opportunity to accurately, reliably, and cost effectively map EIA at sub-reach to watershed spatial scales. Our overall goal is to assess the relationship between EIA and stream biological health as determined by VT DEC within select watersheds in Chittenden County representing a wide range of development. To this end we will develop and evaluate a methodology to map EIA integrating high spatial resolution imagery, object oriented classification techniques, LiDAR-derived elevation data, and hydrologic flow modeling to identify hydrologic connectivity between impervious areas and nearby streams and stormwater conveyance systems. This effort will build on existing data, expertise, and our exploratory efforts to map EIA within an expert and automated classification system. Validation of resultant EIA maps will be made in comparison to independent image photointerpretation and VT DEC field survey data. Watershed-scale estimates of EIA, in addition, will be compared to estimates derived from rainfall-runoff data and USGS empirically defined TIA coefficients. We will then assess the relationship between our measures of EIA and VT DEC measures of biological stream health. Success in this effort will allow regulatory agencies to effectively target specific sub-watersheds where a reduction in hydrologic connectivity between impervious surfaces (i.e. EIA), rather than in TIA, might best minimize ecological and hydrological impacts to streams.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2013	$30,628	$63,312

Degree Level	Number of Students	Number of Dissertations/Theses

Undergraduate		
Masters		
Ph.D.		
Post-Doctoral		

Title	Organic phosphorus forms and transformations in Lake Champlain stream corridor soils
Project Number	2014VT75B
Start Date	3/1/2014
End Date	2/28/2016
Research Category	Water Quality
Focus Categories	Nutrients; Non Point Pollution; Water Quality
Principal Investigators	Donald Ross; Beverley Wemple

Understanding the mechanisms of bioavailable phosphorus (P) delivery from the landscape to fresh water bodies remains a key need. Recent work has shown that streambank erosion is responsible for a large portion of the sediment load entering Lake Champlain. The speciation and reactivity of the P in that sediment has not been adequately researched. Our recent work has shown that concentrations of soil test P (correlated with bioavailable P) are usually relatively low in near-stream soils and streambanks—even when high in adjacent land use. Additionally, we have shown that a large portion of the bioavailable P is in an organic form. Organic soil P is much less understood than inorganic phosphate, largely because of the difficulties involved in analysis. We propose to use a new microplate reader technique, developed by other researchers at UVM, to perform enzyme hydrolysis studies that reveal both the quantity and character of soil organic P. We will take advantage of past sampling funded by the Water Center and ongoing sampling that is supporting research on P transformations in the Missisquoi Bay. Soils adjacent to specific land uses will be analyzed for total organic P and the organic fraction then separated into reactive monoester P and nucleic (diester) P. This procedure will also be used to determine inorganic and organic P species classes in soil extractions designed to remove the bioavailable P fraction. A series of experiments will be performed to determine the release potential of both inorganic and organic P of the whole soil and the fine soil fraction that would be more likely to be transported to the lake. The soil sampling will be designed to also determine if narrower field buffer width leads to higher P in near-stream soils. This project will train a Ph.D. student and at least two undergraduate students. The results will increase our knowledge on the mechanisms and forms of bioavailable that move into the lake following the erosion of streambank soils.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2014	$40,000	$82,487
FY2015	$40,315	$79,496

Degree Level	**Number of Students**	**Number of Dissertations/Theses**
Undergraduate	2	
Masters		
Ph.D.	1	
Post-Doctoral		

Title	An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish
Project Number	2014VT76B
Start Date	3/1/2014
End Date	2/28/2015
Research Category	Biological Sciences
Focus Categories	Conservation; Ecology
Principal Investigators	J Marsden; Jason Stockwell

The effects of habitat fragmentation on individual movements and population structure have been widely studied in terrestrial habitats and riverine systems, but there are few examples of large-scale fragmentation of lake habitats. Lake Champlain is an unusual system in which separate basins were isolated from the main lake by the construction of several causeways in the 1800s. Openings in these causeways are narrow and shallow, limiting access for coldwater species between basins to the winter months when surface waters are cold. As a result, fish populations may be fragmented, and movement of sub-populations may be largely restricted to basins where food or seasonal habitat are sub-optimal. We propose to study year-round movements of fish between the four major basins of Lake Champlain - the Main Lake, Malletts Bay, Inland Sea, and Missisquoi Bay - using an acoustic telemetry array focused at the causeways separating the basins. Acoustic telemetry allows passive detection of tagged fish that move within the range (1.25 km radius) of receivers; tag life is up to three years so data will be collected from individual fish over multiple seasons and years. Our objectives are to (1) establish an acoustic receiver array in Lake Champlain and provide infrastructure to support multiple studies of fish movements, and (2) determine the range of individual lake whitefish movements in Lake Champlain with particular emphasis on movements in relation to barriers (causeways) that fragment the lake. In total, between this study and the non-federal matching funds, 24 receivers will be deployed and 72 fish will be tagged. In addition to this project, the receiver array will be useful for a wide array of future studies on fish movements.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2014	$40,000	$91,423

Degree Level	Number of Students	Number of Dissertations/Theses
Undergraduate	3	
Masters	1	1
Ph.D.		
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**
Dissertations	An acoustic telemetry array for Lake Champlain: investigating effects of aquatic habitat fragmentation on lake whitefish: Pinheiro, Victoria M., 2015, Lake trout spawning site use in Lake Champlain & the development of the binomial rolling residence test. M.S. Thesis. Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT. 59pp.

Title	System-wide quantification of streambank erosion
Project Number	2015VT77B
Start Date	3/1/2015
End Date	2/29/2016
Research Category	Engineering
Focus Categories	Sediments; Models; Geomorphological Processes
Principal Investigators	Mandar Dewoolkar; Jarlath ONeilDunne; Donna Rizzo; Jeff frolik

Streambank erosion is estimated to account for 30-80% of sediment loading into waterways. In many cases, this sediment is carrying important pollutants, such as phosphorus. Langendoen et al. (2012) recently completed a study involving extensive fieldwork and BSTEM (Bank Stability and Toe Erosion Model) modeling for the State of Vermont to estimate sediment loadings from streambank erosion in main stem reaches of Missisquoi River. Using the flow records between 1979 and 2010, they predicted that 36% of the total suspended-sediment load entering Missisquoi Bay (31,600 t/yr) was derived from streambank erosion. These estimates were based on "one-time", yet labor and resource intensive, field work conducted at 27 sites that were extrapolated to 110 km of stream length and across 30 years in time. Although this study demonstrated that the estimates of streambank erosion can be obtained at the watershed level, this approach requires tremendous resources. Recent approaches such as aerial LiDAR have proved effective for watershed level assessment, but airborne LiDAR data collection is costly. Terrestrial LiDAR is more affordable if the equipment is available, but the equipment is bulky (especially for reaching remote locations) and data collection is time consuming and limited to relatively small areas. Therefore, cost-effective approaches to reliably quantify streambank erosion at the watershed level have remained an elusive goal. Recent developments in Unmanned Aircraft Systems (UAS) provide opportunities for rapidly and economically determining streambank erosion and deposition at variable scales (from site specific to watershed scale). The objectives of the proposed study are to: (1) develop decision support tools to effectively acquire and process continuous streambank profiles using an affordable UAS; (2) compare the results at select sites from terrestrial and airborne LiDAR-based surveys; (3) develop and validate a methodology to reliably quantify annual system-level streambank erosion and deposition rates; and (4) develop and incorporate related educational modules for the University of Vermont (UVM) coursework and conduct professional development workshops for Vermont state and government personnel, and disseminate the results through publications. Considerable progress has been made in the first year of this project (March 1, 2015 to February 29, 2016). A total of 18 km of stream reaches within the Mad River watershed, 2 km along the Winooski River, and 1.5 km along the New Haven River were flown using the SenseFly eBee UAS during 2015. Seven streambank sites were simultaneously surveyed using terrestrial LiDAR and RTK-GPS. Data processing for all seven sites has been completed and shows good agreement between the UAS and terrestrial LiDAR data in areas not obscured by vegetation. Year 2 effort will include repeat flights and scans again in spring and fall, with additional flights in response to storm events. Analysis in Year 2 will also include similar comparison to the aerial LiDAR data expected to be released in spring 2016, and will allow assessment of the ability of UAS to reliably quantify annual streambank erosion and deposition rates at a watershed level. This work should have substantial impact on the understanding of bank stability and sediment input to Vermont streams. In particular, we will be able to provide a field-validated methodology that will allow reliable quantification of the contribution of streambanks to sediment loadings in waterways, using Vermont as the case study. The developed methodology will be cost-effective for measuring rate and quantity of streambank erosion and transferrable to other regions in and outside of Vermont.

Funding		
Funding Period	**Federal §104 Funds**	**Required §104 Matching Funds**
FY2015	$38,542	$78,673

Degree Level	Number of Students	Number of Dissertations/Theses
Undergraduate		
Masters	1	1
Ph.D.	1	1
Post-Doctoral		

Publications	
Publication Type	**Publication Citation**
Dissertations	Bryce, T. 2016. Quantifying streambank erosion through Terrestrial LiDAR (TLS) and an Unmanned Aircraft System (UAS). M.S. School of Engineering, University of Vermont, Burlington, VT.
Dissertations	System-wide quantification of streambank erosion: Bryce, T. 2016, Quantifying streambank erosion through Terrestrial LiDAR (TLS) and an Unmanned Aircraft System (UAS). M.S. Civil & Environmental Engineering, University of Vermont, Burlington, VT,
Dissertations	System-wide quantification of streambank erosion: Hamshaw, S.D. 2018, Ph.D. Dissertation, Fluvial processes in motion: Measuring bank erosion and suspended sediment flux using advanced geomatic methods and machine learning. Department of Civil and Environmental Engineering, University of Vermont, Burlington, VT, 306pp.
Articles in Refereed Scientific Journals	System-wide quantification of streambank erosion: Hamshaw, S. D., Dewoolkar, M., Rizzo, D. M., O'Neil-Dunne, J., Rizzo, D.M., Frolik, J., Bryce, T., & Engel, T. Evaluation of unmanned aircraft system (UAS) photogrammetry for quantifying streambank erosion and comparison to terrestrial laser scanner (TLS). In preparation, to be submitted to Earth Surface Processes and Landforms, 2018