Vermont Water Resources and Lake Studies Center
Annual Technical Report
FY 2013

Introduction

The following sections describe the activities of the Vermont Water Resources and Lake Studies Center in the project year just concluded (2013-2014).

The Vermont Water Center strives to work with faculty at Vermont colleges and universities to support water resources related research. Research priorities are identified each year, determined by the Water Center Advisory Board, as well as through collaboration with the State of Vermont Department of Environmental Conservation, Lake Champlain Basin Program, and other programs in the state. The Director works with state, regional, and national stakeholders to identify opportunities to link science knowledge with decision making in water resource management and policy development. 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 LCBP committees. His activity on these committees also helps to inform the directions of the Water Center and has led to a number of productive partnerships. The Director of the Water Center is also the Director of Lake Champlain Sea Grant, which allows further bridging of water research and outreach possibilities.

Research Program Introduction

In the 2013-2014 project year the Vermont Water Resources and Lake Studies Center continued to address several broad aspects of water resources management in Vermont that are of direct interest to the Vermont Department of Environmental Conservation (VTDEC) and other collaborating stakeholder groups. These groups include the Lake Champlain Basin Program, the Lake Champlain Research Consortium, Lake Champlain Sea Grant, municipalities, and NGOs who have an interest in water resources management in Vermont. In the Vermont Water Center RFP process for 2013-2014 proposals on any topic relevant to the mission of the Water Center were considered, including physical, biological, chemical, and social sciences plus engineering. As in previous years, we indicated a particular interest in 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. Identify means to reduce sediment and phosphorus delivery to receiving waters in the state of Vermont; and 3. Establish the socioeconomic justifications, costs, and benefits associated with or represented by water resources protection in Vermont.

The research projects supported by USGS 103b funds in the 2013-2014 project year were:

1. Automated mapping of effective impervious area (EIA) to assess stream health. Leslie A. Morrissey (Rubenstein School of Environment and Natural Resources, University of Vermont) and Beverly C. Wemple (Department of Geography, University of Vermont). New project. 2. Evaluating effectiveness of BMP implementations on gravel roads to reduce sediment and phosphorus runoff, Year 2. Beverly C. Wemple (Department of Geography, University of Vermont) and Donald S. Ross (Department of Plant and Soil Science, University of Vermont). Renewal project.

It should be noted that – as for all centers funded by the 104b program in 2014-15 – the Vermont Water Resources and Lake Studies Center operated on reduced funding (~56%) and so was not able to fund as many projects as in previous years.

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:	3/1/2013
End Date:	2/28/2015
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.

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

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.

Project Investment

Total Federal Investment: $16,206

Total Match: $34,168

Statement of regional or State water problem

Low-volume gravel roads in rural and upland settings are recognized as contributors to water quality impairment through contributions of overland flow, sediment, and nutrients to receiving water ways. These contributions can occur through chronic inputs of water and pollutants washed from the road surface during storm events or through episodic and often catastrophic road failure by mass wasting during extreme storms. Research studies in forested areas of the eastern U.S. (Swift 1984; Egan, Jenkins et al. 1996) and elsewhere (Ziegler and Giambelluca 1997; Wemple, Swanson et al. 2001; Borga, Tonelli et al. 2005; Lane, Hairsine et al. 2006) have documented rates of erosion and mass wasting from roads and impacts on water quality. A recent study on roads in an agricultural watershed in central New York documented a high level of road-stream connectivity and identified roads as an important vector for pollutant delivery to waterways (Buchanan, Falbo et al. 2012).

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), 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).

This project aimed to 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 will result in the development of information to support decision making and target pollutant reduction associated with various best management practices.

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. We will also evaluate past Vermont Better Backroads projects to determine long-term viability of BMP installations and evaluate factors that contribute to BMP success or failure. Findings from the 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.

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 reduction in sediment and phosphorus runoff from gravel roads associated with the implementation of selected BMPs, and (2) to develop information to support decision making that can be used to identify and optimize allocation of financial and technical resources to minimize erosion and pollutant production on Vermont's gravel roads. Our approach includes both an experimental component to evaluate BMP effectiveness at reducing pollutant runoff from roads and a retrospective analysis of past Better Backroads projects to evaluate longevity and factors associated with BMP success or failure.

Methods, procedures and facilities

Our methods for quantifying effectiveness of BMP implementation on rural, gravel roads involved an experimental field component and a retrospective analysis of past Vermont Better Backroads

[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.

projects. Site selection and monitoring for the experimental component of the study began in spring 2012 and continues through the summer of 2014. Retrospective analysis of Better Backroads projects began in summer 2013 and continues through summer 2014. Final results of the project will be available by December 2014.

Methodology for the experimental BMP installations involved bulk sample collection below road drainage outlets (cross-drain culverts) using a before-after treatment/control design. We worked in towns of the Mad River Valley, Vermont, in collaboration with town staff (town administrator, road foreman) and in consultation with town select boards. BMP treatments (Table 1) were selected in consultation with the lead technician of the Vermont Better Backroads Program. We selected and monitored 9 study sites, each of which includes a road segment to be held as an untreated control, along with a matched road segment that has been treated with a selected BMP. Each of the treated sites was identified by town road crews as in need of drainage improvement. Three additional sites were selected in summer 2012, but were subsequently abandoned by the town of Warren, Vermont due to excessive storm damage incurred during summer 2013.

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

Bulk sediment samples at each monitored road segment were 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). Silt fences were serviced between storm events. At each servicing interval, retained sediment was removed from the silt fence and measured as a bulk wet volume. A subsample of the collected material was retained and returned to the lab, where it was dried and weighed in order to determine dry mass. This dry mass fraction was then applied to the total volume collected to determine a dry bulk mass collected at each site for each servicing interval. A subsample of the dried sediment was 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.

Table 1: 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 and turnouts	Install stone check dams and turnouts at spacing in compliance with BMP recommendations from Better Backroads staff to slow erosive ditch flow
3. Compost socks	Install compost socks in ditches to trap sediment and slow flow
4. Grass seeding	Apply hydroseeding mix to ditch and adjacent roadside to initiate revegetation of ditches

To understand how Better Backroads erosion control projects have performed since their installation, we conducted a retrospective assessment of 45 historic Vermont Better Backroads (VBB) projects, or 12% of the total number of completed VBB projects. Sites were chosen based on two criteria: first, the availability of paper project files that outlined precise project locations and the work completed during the construction phase and second, geographic proximity to other project sites and within north central Vermont, in order to minimize travel time and expense. Project sites were selected regardless of BMP type or age. The geographic and age distribution of assessed sites is shown in comparison to all Better Backroads project sites in Figure 2 and Figure 3.

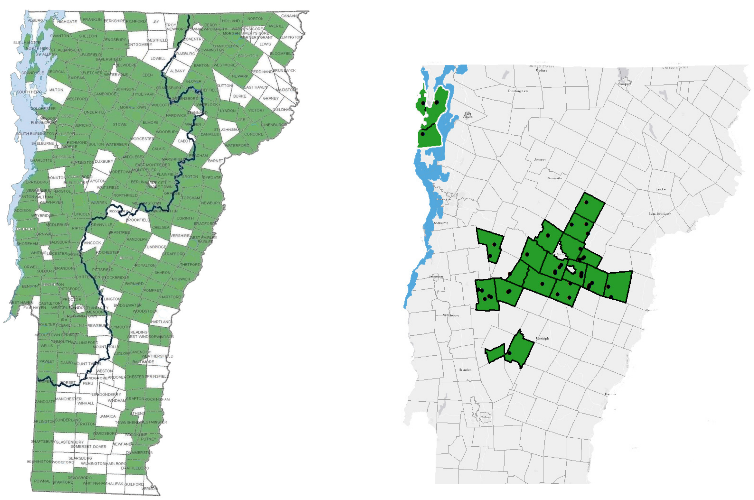

Figure 2: Left panel: map of Vermont towns (in green) participating in the Vermont Better Backroads program. Right panel: North-central Vermont towns (in green) with project sites assessed for this study and locations of those sites (black dots).

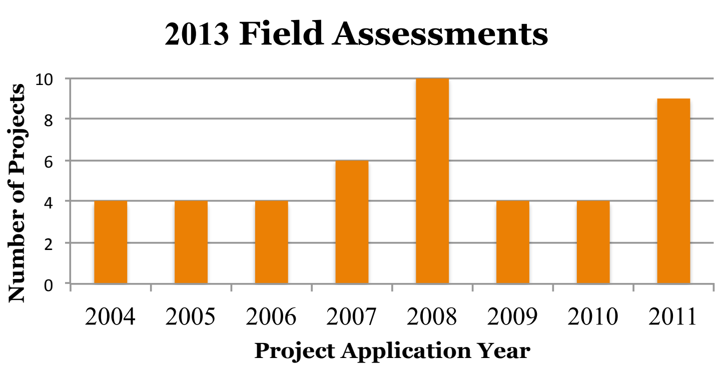

Figure 3: Distribution years of assessed projects.

For this study, Best Management Practices were ultimately grouped into four categories based on construction techniques, materials, purpose and behavior over time (RC&D, 2009).

- **Stonework** includes the following BMPs: stone lined ditches, check dams, turnouts, settling pools, plunge pools, rock aprons, stone dikes and stone water bars.
- **Culvert** work included the installation or replacement of stream and ditch culverts, and any associated headwalls, whether log, stone or concrete.
- **Revetments**, although constructed with stone, were grouped separately from Stonework due to their placement on the landscape with respect to water flow and their behavior over time.

Revetments observed in this study were entirely riprap systems placed on the banks of streams or lakes, or above or below roads cutting across steep slopes. Also included in this category, but not observed in the field, were gabion walls, log or timber cribs, and rock walls.

- **Vegetated Soil Stabilization** comprised primarily of grass lined ditching, seeding and mulching, and one log water bar. Included in the category, but not observed in the field, were live wattle/stake placement, sprig or plug planting, and terracing.

We used a review of historical Better Backroads project files to guide our selection of project sites and BMPs to review. A tally of the BMPs described in Better Backroads project folders was collected from the paper files of the 2007, 2009 and 2011 application years. The distribution of the BMPs, grouped by BMP types described above, is displayed in Figure 4. This review showed that the program typically funds over half its applications for stonework projects, roughly one quarter of the applications for culvert work, and almost equal proportions of the remaining quarter of projects address revetment construction and vegetated soil stabilization. During the field season of 2013, 106 BMPs were assessed in 45 project locations (any VBB "project" could have one or more BMPs installed). The BMP types assessed during the 2013 field season was approximately representative of the total BMP distribution funded by Better Backroads since 2004 (Figure 5).

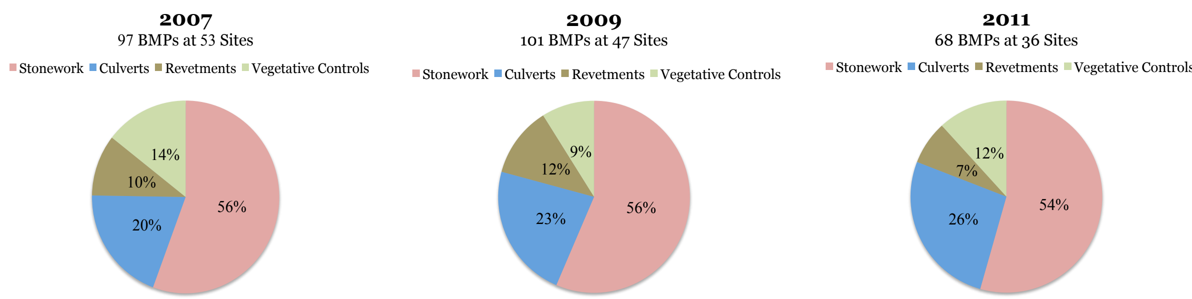

Figure 4: Distribution of BMP types funded over three application years.

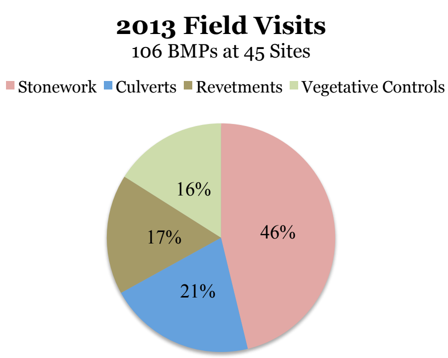

Figure 5: Distribution of BMP types assessed for this study.

At each project site selected for our assessment, each BMP constructed as part of a Better Backroads project was assigned a condition of ***intact*** if the BMP appeared to be functioning to improve drainage and reduce on site erosion, ***compromised*** if some evidence of reduced performance to drain water and reduce erosion was evident, and ***failed*** if the BMP as recorded on the project file archive has been undermined or destroyed Figure 6. The evaluation criteria were established by comparing the BMPs to other BMPs informally assessed earlier in the field season, by comparing the BMP to date with photos taken immediately after implementation, and through visual evidence of BMPs reducing the volume of sediment traveling to receiving waterways. We note that although each BMP was assessed individually using the coding described above, for the purposes of site-level statistical analysis, each BMP project *site* was later recoded as described below.

Figure 6: Examples of assessed Better Backroads sites and condition of BMPs -- left: *intact* stone lined ditch; middle: culvert *compromised* by debris partly plugging inlet; right: *failed* BMP installation showing evidence that stone and stabilization fabric have been undermined.

At each assessed project site, additional observations were made to evaluate site conditions leading to success or failure of installed BMPs. These observations included (1) road grade, (2) placement of road as cross-slope or slope-parallel, (3) road profile (crowned, insloped, outsloped), (4) presence or absence of vegetation between the BMP and the road, and (5) age of the BMP (i.e. years since BMP installation). In addition, we used mapped extents of flood impact zones published in the report by Castle et al., 2013[2] to code each assessed site with a binary variable for exposure to an extreme flood since BMP installation.

For the purposes of statistical analysis, overall project condition of either “All Intact” (i.e. complete project success) or “Some BMPs compromised or failed” (i.e. partial or complete project failure). Reclassifying project condition as a binary variable enabled use of a logistic regression of the field data to examine the likelihood that measured variables could explain project condition. This analysis neglects the type of, or specific, BMP used at the site. Logistic regressions were performed using the SPSS statistical software package.

Results

This section provides preliminary results of the experimental component of the study for one BMP type installed at the earliest stage of our study and final results of the retrospective assessment of

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[2] Castle, Stephanie S., Eric A. Howe, Emily L. Bird and William G. Howland (2013). Flood Resilience in the Lake Champlain Basin and Upper Richelieu River. Lake Champlain Basin Program. Retrieved March 27, 2014, from http://www.lcbp.org/wp-content/uploads/2013/04/FloodReport2013_en.pdf

past Better Backroads projects. Full project results will be given in next year's report when the experimental component of the study is complete.

Experimental manipulations

Preliminary post-treatment results for sites where rock was installed in ditches show that the reduction in sediment production is pronounced and that this treatment is highly effective at reducing sediment runoff from gravel roads, as evidenced by the downward shift in the treatment vs. control regression line in the post-treatment period (Figure 7). Because other treatments were not installed until late in the 2013 field season, post-treatment results will be forthcoming.

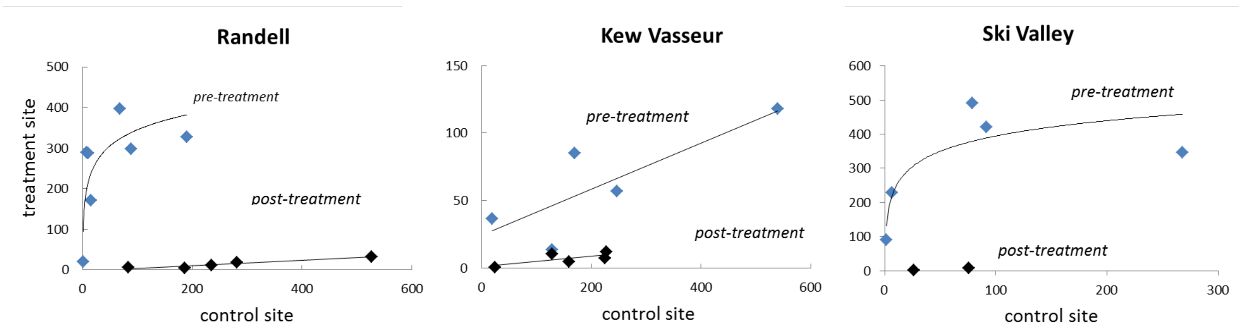

Figure 7: Plots of paired treated-control sites for three installations of stone-lined ditch in Fayston and Waitsfield, Vermont. Each point represents a storm or sequence of storm events monitored between silt fence servicing intervals. Data are sediment dry mass (in kg) collected at each measurement interval. A downward shift in the relationship post-treatment is a measure of BMP effectiveness.

Laboratory samples processed to date show that bulk sediment collected at the silt fences range from 70 to nearly 100% fines with total phosphorus concentrations that range from 350 to 600 mg P per kg soil (Figure 8). Highest total P concentrations were measured at sites with highly eroding ditches where town road foremen selected stone-lined ditches as the preferred treatment. The lowest total P concentrations were measured in soils at Bragg Hill Rd in Fayston, Vermont. Measured P concentrations will be applied to bulk soil mass to derive estimates of total P flux from roads monitored in this study and the magnitude of flux reduction associated with installation of BMPs.

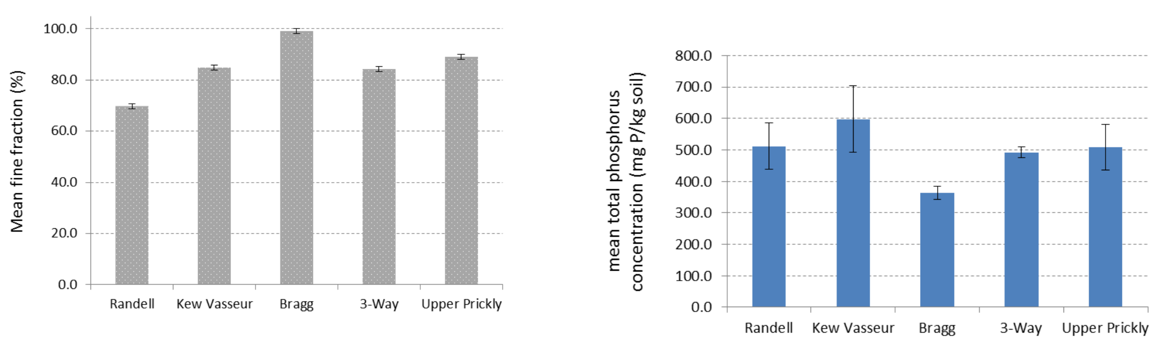

Figure 8: Mean values for samples collected of percent of bulk sample in less than 2mm size class (left panel) and total phosphorus concentration in the fine fraction (right panel). Results are presented by site for sites processed to date. Error bars are standard deviation.

Retrospective assessment

Among the BMPs we assessed, 59% were intact and functioning to provide water quality protection. Thirty-one of the BMPs assessed showed some evidence of compromised performance and only 10% had failed. This performance differed slightly with road orientation, with 65% of all inspected BMPs intact on cross slope roads and only 54% intact on typically steeper, slope-parallel roads (**Error! Reference source not found.**).

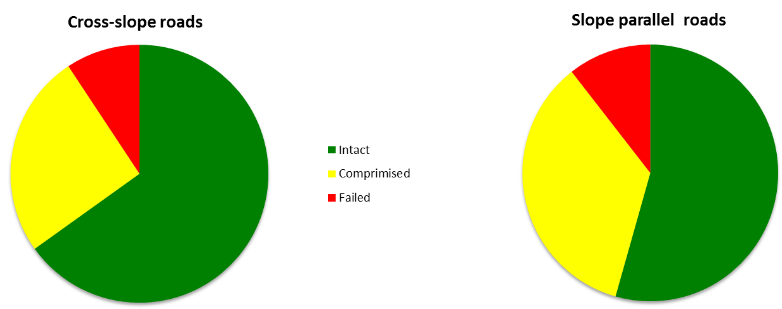

Figure 9: Condition of assessed BMPs by road position.

Within the first two years of installation, virtually all inspected BMPs remained intact (**Error! Reference source not found.**). In the set of BMPs assessed 3-4 years post-treatment, stonework was the most common treatment type to show evidence of compromised performance. Stonework, like other practices, remained intact at assessed sites aged 5-8 years. In sum, nearly two-thirds of the BMPs we assessed remained intact, provided water quality protection and demonstrated viability for up to nearly a decade.

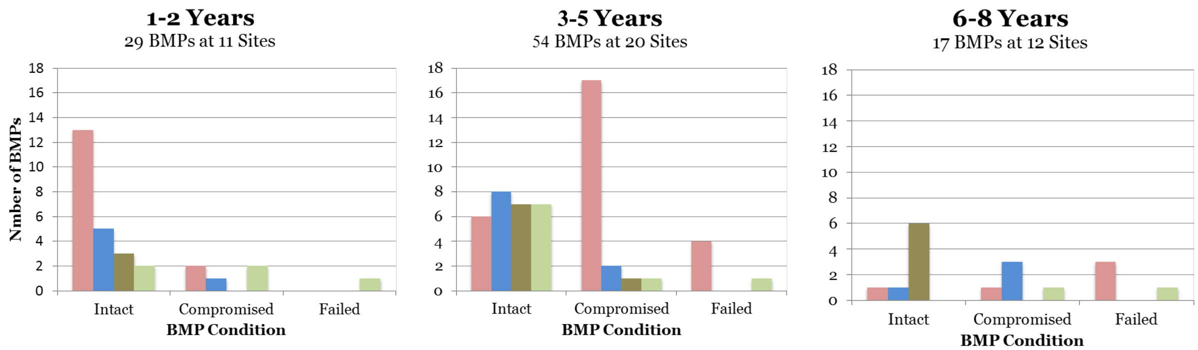

Figure 10: Condition of BMPs assessed grouped by age of project. Bar colors are as in figures 4 and 5 (pink = stonework, blue = culverts, dark green = revetments, and light green = vegetative controls).

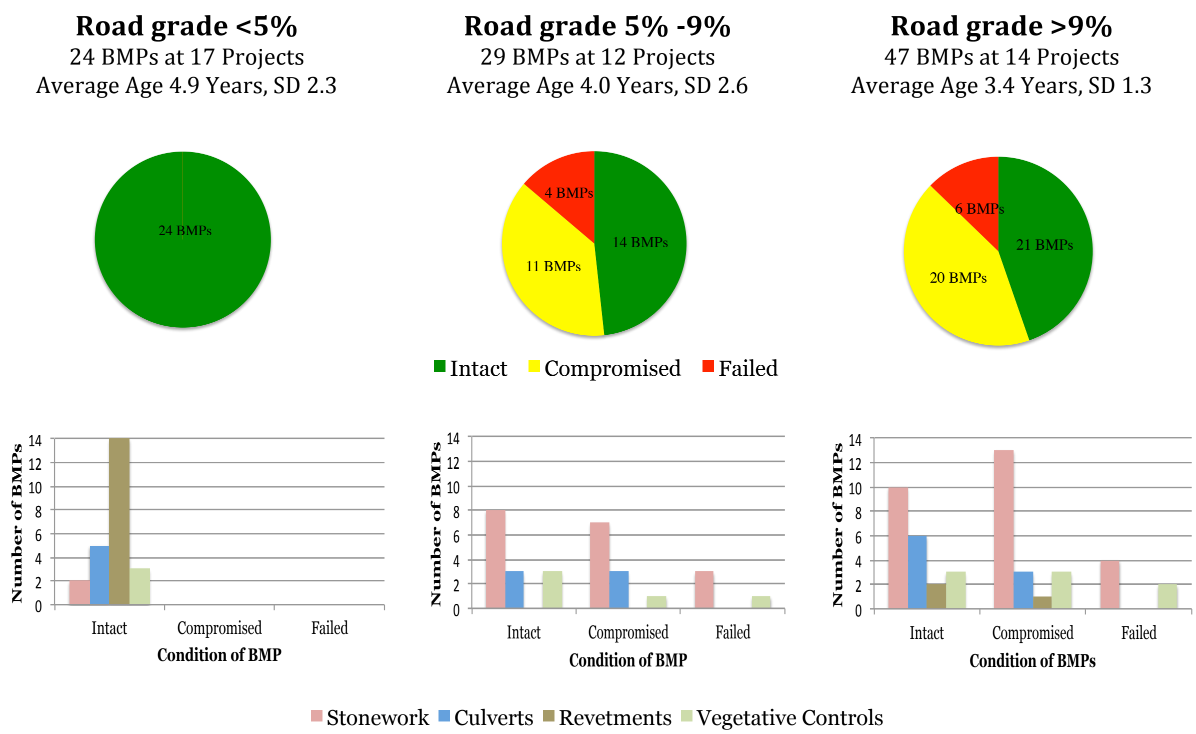

Figure 11: Condition of all assessed BMPs grouped by road grade. Upper panel shows all BMPs and percentages in each outcome category; lower panel shows BMPs color coded by type.

Statistical analysis of data by project site, using binary logistic regression, showed that grade, exposure to floods, the presence and extent of a vegetated border and the orientation of the road were factors that, individually, had a likelihood of predicting project condition (Table 1). Compromised or failed BMPs became more likely as grade increased, if the road slope was parallel to the slope of the hill instead of across the slope, if no vegetated border existed between the BMP and the road, or if a site was exposed to one or more floods. The probability that either the age of the BMP installation or road profile could predict failure on a site was negligible.

Table 2: Table of variables tested using binary logistic regression for prediction of the likelihood that a project will exhibit compromised or failed BMPs. Probability values (p) for statistically significant predictors of project condition are shown in bold.

Variable tested	Units or classes	Number of projects	p
Project age	years	43	0.970
Grade	percent	43	**<0.001**

Road profile	crowned , not crowned	42	0.268
Road orientation	cross-slope, parallel-to-slope	42	**0.019**
Vegetated border	none, some, extensive	37	**0.013***
Flood exposure	Exposed, not exposed **	43	**0.002**

* The overall statistical significance of the presence and extent of a vegetated border was 0.013. The significance of no vegetated border compared to extensive vegetated border was 0.003; the significance of some vegetated border compared to extensive vegetated border was 0.019.

** Flood exposure expressed as a binary variable with "exposed" including any site exposed to one or more historical flood events since installation.

Discussion

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.

Our results to date show that certain BMP applications on gravel roads can provide substantial reductions in erosion and on-site generation of pollutants (sediment, phosphorus) to waterways in Vermont. Retrospective analysis of BMP installations shows that BMPs persist over time with low failure rates that are typically associated with steep gradients of slope parallel roads. The presence of vegetation in ditches and as a buffer along roadsides significantly reduces BMP failure and minimizes on site-erosion. As designed, our retrospective assessment shows that BMPs provide viable long-term road drainage and pollutant reduction strategies, but that the significant flood events experienced in Vermont in recent years pose an important threat to these investments.

Training and outreach

<u>Students trained:</u>
Joanne Garton, masters degree candidate (expected completion, spring 2015), Rubenstein School, Ecological Planning program

<u>Outreach:</u>
Vermont Agency of Natural Resources Brown Bag Seminar series, presentation to Agency of Natural Resources and Agency of Transportation staff). March 20, 2014, Montpelier, VT.

Vermont ANR Municipal Day, presentation to town and local governance participants in day-long workshop for municipalities at Vermont Agency of Natural Resources. March 31, 2014. Montpelier, VT.

Project featured in Vermont EPSCoR ***Watershed Moments*** series, available at http://www.uvm.edu/~epscor/new02/?q=node/54&URL=http://www.uvm.edu/~epscor/jwplayer.php?video=video/wm_policy_social_master.mp4

Publications:
One planned for Journal of Environmental Management. Expected submission May 2015.

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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Beverley C. Wemple, Associate Professor

Department of Geography, 215 Old Mill, University of Vermont, Burlington, VT 05405-0082
(802) 656-2074, FAX: (802) 656-3042, e-mail: bwemple@uvm.edu

EDUCATION:

Ph.D., 1998. Department of Forest Science, Oregon State University, Corvallis, OR.
Major: Forest Ecology; Minor: Bioresource Engineering.
Dissertation title: *Investigations of runoff production and sedimentation on forest roads*.

M.S., 1994. Department of Geosciences, Oregon State University, Corvallis, OR.
Major: Physical Geography; Minor: Geographic Techniques.
Thesis title: *Hydrologic integration of forest roads with stream networks in two basins, Western Cascades, Oregon*.

B. A., *cum laude*, 1986. University of Richmond, Richmond, VA.
Major: Economics and German.

ACADEMIC APPOINTMENTS:

Associate Professor, Department of Geography. Secondary faculty appointments in the Department of Geology and Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT. 2005-present.

Assistant Professor. Department of Geography, University of Vermont, Burlington, VT. 1999-2005.

Postdoctoral Research Associate. U.S.D.A. Forest Service, PNW Research Station, Corvallis, OR. 1999.

Graduate Research Assistant. Department of Forest Science, Oregon State University, Corvallis, OR. 1993-1998.

Graduate Teaching Assistant. Department of Geosciences, Oregon State University, Corvallis, OR. 1991-1993

PUBLICATIONS:

<u>LAST FIVE YEARS</u>

Ross, D. S. and B. C. Wemple, 2011. Soil nitrification in a large forested watershed, Ranch Brook (Vermont) mirrors patterns in smaller northeastern USA catchments. Forest Ecology and Management, 262: 1084-1093.

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Donald S. Ross, Research Associate Professor

Department of Plant & Soil Science, Hills Building, University of Vermont, Burlington, VT 05405-0082
(802) 656-0138, FAX: (802) 656-0285, e-mail: dross@uvm.edu

ACADEMIC HISTORY

1990 Ph.D. UVM, Soil chemistry
thesis: Some aspects of the soil and water chemistry of two small watersheds in Vermont's Green Mountains

1980 M.S. UVM, Dept. of Plant and Soil Science
thesis: Toxicity of chromium to soil microorganisms and oxidation of manganese in soil.

1977 B.S. UVM, Dept. of Plant and Soil Science

1968-1971 Middlebury College
English major

EMPLOYMENT HISTORY

2007 to present Coordinator of UVM Agricultural and Environmental Testing Laboratory (Director, 1988 to 2005)

2005 to present Research Associate Professor, UVM Dept. of Plant & Soil Science

2003 to 2004 Research Program Coordinator (Interim) UVM Dept. of Plant & Soil Science

1996 to 2005 Research Assistant Professor, UVM Dept. of Plant & Soil Science

1996 to present Faculty and CALS Director, Environmental Sciences Program

1991 to present Lecturer, UVM Dept. of Plant & Soil Science

Awards

UVM College of Agriculture and Life Sciences H. W. Vogelmann Award for Excellence in Research and Scholarship, 2004.

Christine Negra (advisee) was the 2004 recipient of the Doctoral Student Scholar Award at the University of Vermont in biomedical, life, physical and applied sciences.

Membership

Soil Science Society of America
American Geophysical Union
Northeast Ecosystem Research Cooperative
Northeast Soil Monitoring Cooperative
Northeast Coordinating Committee on Soil Testing (USDA NEC-1007)

Publications in past five years (peer reviewed)

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Automated Mapping of Effective Impervious Areas (EIA) to Assess the Impact of EIA on Stream Health

Basic Information

Title:	Automated Mapping of Effective Impervious Areas (EIA) to Assess the Impact of EIA on Stream Health
Project Number:	2013VT72B
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Research Category:	Water Quality
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Descriptors:	stream health, impervious areas, stormwater, remote sensing, GIS, LiDAR
Principal Investigators:	Leslie Morrissey, Beverley Wemple

Publications

There are no publications.

Automated Mapping of Effective Impervious Area (EIA) to Assess Stream Health

Abstract

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 was to develop a methodology for mapping effective impervious area for a set of urban and suburban watersheds in northwestern Vermont. To this end we developed and evaluated 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 builds on existing data, expertise, and our exploratory efforts to map EIA within an expert and automated classification system. Validation of resultant EIA maps were made using measured flow data for a portion of an urban watershed in Burlington, Vermont.

Project Investment

Total Federal Investment: $30,628

Total Match: $63,312

Statement of regional or State water problem

Impervious surfaces associated with development can dramatically alter the hydrologic response of a watershed, impacting both stormwater runoff and base flow, water quality, fluvial geomorphology, and aquatic habitat [*Booth et al.*, 2002; *Zhou et al.*, 2010]. These impacts, in turn, can significantly affect aquatic animal and plant populations leading to a reduction in stream biodiversity [*Cuffney et al.*, 2010; *Fitzgerald et al.*, 2012; *May et al.*, 1997; *Moore and Palmer*, 2005; *Schiff and Benoit*, 2007; *Walsh et al.*, 2005].

Towards the goal of limiting the impact of development on stream geomorphology and ecosystem health, the Center for Watershed Protection [2003] recommends thresholds to limit the total impervious area (TIA) within watersheds. Although TIA has been linked to volume and rates of stormwater runoff [*Alley et al.*, 1980; *Beard and Chang*, 1979; *Cherkaver*, 1975; *Driver and Troutman*, 1989], more recent studies demonstrate that the impervious area that is hydrologically directly connected to the receiving stream network or stormwater system, i.e. the effective impervious area (EIA), is more closely linked to a broad range of geomorphological and ecological indicators of stream health (e.g., algal biomass and composition, indices of macroinvertebrate communities, and concentrations of contaminants) [*Roy and Shuster*, 2009; *Walsh et al.*, 2009; *Walsh et al.*, 2005]. Direct measurement of EIA, however, has proven challenging and thus how best to protect stream geomorphology and ecosystem health (e.g. by limiting the total impervious area or the hydrologic connectivity between impervious surfaces and receiving waters) remains a critical issue.

Greater understanding of the impact of development (as measured by EIA) on stream ecosystems is therefore needed to improve management of urban stream ecosystems [*Fitzgerald et al.*, 2012]. To this end, we propose to take advantage of recent advances in geospatial technologies to develop and evaluate a methodology to directly measure EIA and then apply that methodology to address how development impacts stream biological health in select Lake Champlain Basin watersheds.

Statement of results or benefits

This research directly supports on-going water quality efforts by the VT Department of Environmental Conservation (VT DEC) to manage stormwater runoff and associated pollutants, and prioritize mitigation efforts in stormwater impaired watersheds. While taking advantage of available data, this effort was intended to yield and evaluate an innovative methodology to accurately map EIA at sub-reach to watershed spatial scales, generate new data products (high spatial resolution, directly mapped EIA, enhanced DEMs), and contribute to improved understanding of how development impacts stream health in the Lake Champlain Basin. Methodology to accurately and cost effectively map EIA at sub-reach to watershed scales would benefit a wide range of local, state, and federal organizations involved in water quality monitoring, flood hazard management, urban planning, or the design and management of stormwater systems. The EIA map products and analyses resulting from this effort also could be used to cost-effectively target specific areas or sub-watersheds where a reduction in hydrologic connectivity might best minimize ecological and hydrological impacts to nearby streams and stormwater systems (in contrast to policies that attempt to limit more easily mapped TIA). This effort marks a significant step towards improving understanding of EIA and hydrologic connectivity at sub-reach to watershed spatial scales, and opens the way to extend the methodologies and understanding developed here to other watersheds throughout Vermont and the nation.

The proposed approach differs markedly from traditional approaches in its use of advanced geospatial technologies and *watershed-scale synoptic observations*. The use of very high spatial resolution imagery, LiDAR-derived elevation data and hydrologic modeling functions within a GIS framework offers the unique potential to yield accurate and cost-effective watershed-wide measures of EIA to aid oversight agencies and planning organizations in efforts to reduce stormwater impacts on receiving waters, complement established stream geomorphic and biological assessments, and aid community planning and development efforts. More specifically, our proposed research will complement and aid stream corridor and water quality management, restoration and planning efforts by VT ANR, Lake Champlain Basin Program, Regional Planning Commissions, and local towns.

Watershed-scale EIA mapping offers many advantages over past field survey or indirect watershed-scale measures based on rainfall-runoff analyses or empirical coefficients, including substantially greater accuracy in the resultant estimates and map products detailing the location and spatial context of each EIA feature throughout the watershed.

Nature, Scope, and Objectives of the project

Although it has been well established that stream ecological integrity typically declines in response to increased impervious cover within a watershed, considerable uncertainty remains on whether limiting TIA or the hydrological connectivity between impervious surfaces (EIA) and receiving waters would most effectively protect stream health [*Walsh et al.*, 2009]. Towards addressing this issue, our overall goal is to examine the relationship between EIA and stream biological integrity across a range of small watersheds in the Lake Champlain Basin in Chittenden County, VT. A key component of our effort will be to identify those impervious surfaces and catchments that are hydrologically directly connected to stream or stormwater networks (i.e. EIA), thus imposing a far greater impact on stream integrity than impervious surfaces that drain to pervious areas [*M. J. Boyd et al.*, 1993; *Walsh et al.*, 2005]. Our specific objectives are to:

1) Develop, evaluate, and automate a new methodology to directly map effective impervious areas at sub-reach to watershed spatial scales, and
2) Evaluate the relationship between effective impervious areas and stream biological health.[1]

Timeline (see footnote for revision to project timeline and scope)

Task Description	***Lead Investigator***	***YEAR 1***				***YEAR 2***			
		Q1	***Q2***	***Q3***	***Q4***	***Q1***	***Q2***	***Q3***	***Q4***
Task 1 Study Site Selection	All	X							

[1] Note: second objective and associated task 4 were eliminated from project in September 2014 and scope revised to one year project aimed at meeting objective 1 with tasks 1-3, following medical leave of project PI L. Morrissey. Co-PI Wemple assumed project leadership and responsibility for Morrissey tasks.

Task 2 Database Compilation		X							
GIS data layers	Morrissey	X							
TIA map products	Morrissey	X							
LiDAR data	Morrissey	X							
VT DEC Biomonitoring data	Pease	X	X						
VT ANR RGA data (stream)	Morrissey	X	X						
Hydrologic gaging station data	Wemple	X	X						
	All	X							
Task 3 EIA Mapping			X	X	X				
Generation of enhanced DEMs	Morrissey		X	X					
ArcGIS Hydro modeling	Morrissey			X	X	X			
EIA Metrics	Morrissey			X	X	X			
Validation	Morrissey				X	X	X		
- Fieldwork	Pease		X	X	X	X			
- *Boyd* EIA estimates	Wemple			X					
Task 4 Biological Health (EIA)					X	X	X		
Statistical analysis	All				X	X	X		
Thesis preparation and journal publication	All						X	X	X
Reporting to Water Center	Morrissey				X				X

Methods, Procedures, and Facilities

We developed an approach to map effective impervious areas (EIA) that traces terrain-driven hydrologic flow along contiguous impervious cells that drain directly to streams or enter streams via a stormwater system. EIA was mapped for 14 watersheds in the Lake Champlain Basin (Chittenden County). EIA map products were generated using total impervious area (TIA) data available through the Lake Champlain Basin Program (LCBP) Project (O'Neil-Dunne, UVM) and LiDAR-derived elevation data in combination with ArcGIS hydrologic flow modeling functions used to trace the flow path of runoff from impervious surfaces to nearby surface waters or stormwater conveyance systems. The methodology was automated using ArcGIS ModelBuilder to facilitate application to other watersheds.

Study Areas

Study watersheds representing a wide range of areas (0.5 – 26.7 km^2), TIA (2-35%), and stream length (0.04-45 km) are listed in Table 1 and shown in Figure 1. All are located in the Lake Champlain Basin, Chittenden County, VT and represent both streams listed on the state of Vermont's 303d list of stormwater impaired streams and attainment streams that meet VTDEC water quality standards (Foley and Bowden, 2005; Bowden and Curling, 2007). Study watersheds also have varying numbers of stormwater outfalls classified as connected (stormwater at any volume is conveyed directly to outfalls with no retention), semi-connected (stormwater at certain volumes is conveyed to outfalls, but some is retained under certain conditions), or disconnected (no stormwater is released from outfall; all stormwater is retained or infiltrated). One of the study watersheds, the catchment draining to the O8 detention pond within the Englesby Brook watershed, was selected because of the availability of hydrologic records for valdation of mapping as described below in section 17.6.

Data Layers

The LCBP total impervious area (TIA) data served as a foundation of our EIA mapping effort. The classification was based on an analysis of USDA NAIP (1m) digital orthophotography acquired in the visible and near infrared bands and derived using advanced object based image analysis (OBIA) classification methods. The nominal product accuracy is 99% (O'Neil-Dunne, 2013). The high accuracy of the TIA data was paramount to the success of the EIA mapping.

We also utilized airborne LiDAR elevation data to generate digital surface models (DSMs), which depict object heights (i.e. buildings and trees) and enhanced digital elevation models (DEMs) showing the ground surface. These data were used to support both hydrologic flow modeling and building footprint classification. High resolution LiDAR elevation data were acquired in May 2004 over much of Chittenden County by the Chittenden County Metropolitan Planning Organization and delivered as two point datasets: reflective surface (RS), an irregular point grid representing the height of features above the Earth's surface, and bare earth (BE), a systematic grid with a 3.2m post spacing representing the Earth's surface. Nominal vertical resolution of the elevation data is approximately 16-18 cm (Green Mountain GeoGraphics, 2005).

The first step in the hydrologic flow modeling task was to generate enhanced digital elevation models (DEMs) following methodology developed previously (Pelletier et al., 2007; Pelletier, 2011). Specifically, the LiDAR bare earth (BE) systematic grid of last return points (3.2 m spacing) was enhanced with nearby, low lying reflective surface (RS) first return points (<1 m irregular grid) depicting object heights to yield a spatially enhanced ground elevation data layer. These data were used to generate a high spatial resolution DEMs. Mean point spacing was reduced from 3.2 m to 1.2 ± 1.0 m (Figure 2).

We also utilized stormwater infrastructure information that was generated on a town by town basis by staff of the Ecosystem Restoration Section, Watershed Management Division of the Vermont Department of Environmental Conservation.[2] This data consisted of point information representing inlets (areas where water enters the system) and outfalls, as well as line information showing the underground connections between these inlets and outfalls. These data were manually edited to reflect the hydrologically connected, semi-connected, or disconnected status of the stormwater system.

Additional vector datasets that were utilized consisted of stream centerlines, extracted from the Vermont hydrography dataset, E911 building points, and E911 road centerlines. All of this data was available from the Vermont Center for Geographic Information (VCGI).

Hydrologic Modeling

In order to model the flow of stormwater, DEM grid cells that overlap mapped impervious surfaces were extracted. Additionally, 2.3m bordering each road was also extracted and modeled to account for roadside ditches. These ditches were included because they convey stormwater directly to receiving waterbodies or stormwater infrastructure without allowing for infiltration.

Areas potentially receiving surface flow were selected by defining the slope surrounding stream centerlines from the Vermont hydrography dataset. In order to model the delivery of stormwater from impervious grid cells into the stream channel (represented in GIS as a linear feature), cells surrounding the stream centerlines with a change in slope of ≤1% were selected to represent the stream channel (Figure 3).

The direction of surface flow based on a D-infinity flow method over the impervious areas in each watershed was then modeled, such that each grid cell was assigned a direction that water would flow from it using the steepest slope of a triangular facet (Figure 4; Tarboton, 1997). The D-infinity contributing area function was then used to map the hydrologically connected impervious area (Figure 4). To do this, the stream channel area was rasterized and used as pour points for the D-infinity contributing area function. Only flow direction cells classified as impervious and draining directly to their receiving waters (as opposed to a pervious cell) were identified as EIA (Figure 4). The D-infinity model is superior to the standard D8

[2] Stormwater infrastructure data were attributed and provided by Jim Pease, VT Department of Environmental Conservation (Jim.Pease@state.vt.us). Data are provided in digital format, along with mapped EIA for study watersheds, as a deliverable of this project.

model, where one of eight possible output directions is determined for each cell (Jenson and Domingue, 1988), in that flow can be proportioned between two cells when the angle of flow falls between the 8 directions found in the D8 model. This allows for converging and diverging flows, which identified an EIA that was more representative of real world conditions (Tarboton, 1997).

Stormwater Infrastructure

Stormwater infrastructure systems can have a major impact on stormwater flow, and as such the next step in the EIA classification process was to account for these systems. First, the outfalls for each stormwater system were labelled as "connected", "semi-connected", or "disconnected" to indicate the stormwater system's level of hydrologic connection. The outfall type determined whether a stormwater system was ***connected*** (stormwater at any volume is conveyed directly to outfalls with no retention), ***semi-connected*** (stormwater at certain volumes is conveyed to outfalls, but some is retained under certain conditions), or ***disconnected*** (no stormwater is released from outfall; all stormwater is retained or infiltrated).

For each stormwater system, inlets associated with the system were assigned the same connectivity type as their corresponding outfall. These inlets were then combined with the existing pour points associated with the stream channel, and the D-infinity contributing area was again calculated for all TIA (Figure 5). When the stormwater system is classified as disconnected, any TIA pixels that flow into that system are removed from the EIA classification. When the stormwater system is classified as connected, the area draining to that system is added to the EIA classification. Similarly, if a stormwater system is classified as semi-connected, the pour points for these systems are used in conjunction with the connected stormwater points (Figure 5B).

This resulted in three EIA map products. First, all EIA was mapped with no regard for stormwater infrastructure (hereafter referred to as "no stormwater EIA"; Figure 4). Second, we classified EIA while adding the contributing area from the connected stormwater systems and the removed the contributing area from the disconnected stormwater systems (hereafter referred to as "connected EIA"; Figure 5). Finally, we classified EIA while adding the contributing area from the connected and semi-connected stormwater systems and the removed the contributing area from the disconnected stormwater systems (hereafter referred to as "semi-connected EIA").

Rooftop Connectivity

The final alteration to the EIA classifications was to account for the fact that rooftops are often not fully hydrologically connected to impervious areas due to gutters, rain barrels, or other stormwater treatment methods. However, we did not have specific data on the numbers of connected, semi-connected, or disconnected rooftops and the connectivity of each rooftop in our study area could not be individually mapped due to the prohibitive time and effort involved. Despite these limitations, it was important to account for this limited connectivity as it could be potentially significant to our EIA assessment. As such, we corrected the EIA classifications of rooftops to account for this limited connectivity by assuming that 28% of rooftops classified as EIA are directly or indirectly connected to impervious surfaces. This assumption was based on a field survey of 1,514 rooftops in South Burlington, of which 925 were located in our study watersheds (Bartlett Brook, Centennial Brook, Englesby Brook, and Munroe Brook; Blue, 2009).

Building footprints were mapped by first creating a normalized digital surface model (nDSM) to show object heights (i.e. buildings and trees). This classification was then extracted by the TIA to exclude as much tree cover as possible and converted to a polygon feature class. Only polygons that were within 5 meters of E911 building points were selected. These classifications were then smoothed, removing sharp angles that were a byproduct of the conversion from raster to polygon data, and any polygons smaller than $20m^2$ were removed. These small polygons were most often small clusters of trees within close proximity to buildings. The classifications were then manually assessed and corrected as needed (Figure 6).

Once the building footprints were mapped, they were overlain on EIA classifications, and the EIA area was extracted for areas that overlapped. The area of the EIA located within these building footprints was altered to account for this limited connectivity by multiplying each area by 0.72. The corrected EIA classification was then recombined with the remainder of the mapped EIA and summarized.

Validation

For independent validation of effective impervious areas, we used the method of Boyd et al., 1993 to examine the rainfall-runoff relationship for storm events measured at the O8 stormwater detention pond in the Englesby Brook watershed, located in Burlington, Vermont. The O8 pond was propsed under the Englesby watershed plan and built by the city in 2006 (J. Pease, personal communication). The catchment draining to the pond is highly urbanized (35% TIA) and has a network of stormwater infrastructure that collects nearly all runoff from connected impervious areas. Hydrologic records for inflows to the pond are available through a joint University of Vermont – U.S. Geological Survey collaboration (J. Nipper and B. Bowden, unpublished data).

We selected storm events less than 0.5 inch (1.27 cm) precipitation, reasoning that “small” events of this magnitude would convey rainfall over connected impervious areas to the stormwater pond. Runoff associated with each precipitation event was selected from the record and matched to the associated rainfall event. Simple linear regression was used to model the relationship of the form

$$R = \beta_0 + \beta_1 P \tag{1}$$

where R is the event runoff, expressed in cubic meters, and P is the event rainfall, expressed in meters. β_0 and β_1 are regression coefficients. The form of the relationship yields a β_1 regression coefficient theoretically equivalent to the area producing runoff from the rainfall event.

Findings

EIA estimates for our 14 study watersheds ranged from 0.02% (Upper Allen Brook) to 6.6% by watershed (Middle Indian Brook; Figure 7). Our most robust metric, semi-connected EIA (includes both connected and semi-connected stormwater infrastructure), averaged 2.4 ±2.3% by watershed. Upper Allen Brook had almost no notable EIA (0.02%) for any of our three EIA estimates, largely due to the lack of development (2.7% TIA) especially in close proximity to the stream. Another factor was the complete lack of connected or semi-connected stormwater infrastructure in the watershed. Conversely, Middle Indian Brook is fairly heavily developed (26.5% TIA) with the highest number of connected or semi-connected outfalls per watershed area (22 outfalls / km^2). The remaining 13 watersheds averaged just 6 ±6 outfalls/ km^2.

No stormwater EIA

Our estimates for no stormwater EIA, our most conservative estimate, (Figure 10A) were predictably the lowest in each watershed. Estimates averaged 0.9 ±1% (Figure 8), ranging from 0.02% in Upper Allen Brook to 3.8% in Middle Indian Brook. As such, no stormwater EIA made up the smallest percent of the initial TIA estimate by watershed, which was 2-31%. The EIA accounted for an average of 7 ±5% of TIA (Figure 9). Middle Indian Brook, in addition to having the highest EIA estimate, had the highest portion of TIA classified as EIA (14.5%) due to the high development surrounding the stream.

Connected EIA

When hydrologically connected stormwater infrastructure was added to the model (Figure 10B), the EIA classification increased from an average of 0.9 ±1% for the no stormwater EIA to an average of 1.9 ±2%. Upper Allen Brook remained the watershed with the lowest EIA due to the lack of hydrologically connected stormwater infrastructure. Sand Hill Brook and Upper Indian Brook, both watersheds with low development (6.6 and 2% TIA, respectively), also had very low connected EIA estimates (0.2%). However, the estimate for Middle Indian Brook increased to 5.9% from 3.8% (no stormwater EIA estimate). The amount TIA classified as EIA rose to an average of 12 ±7% of the TIA from a mean of 7 ±5% for the no stormwater EIA (Figure 9). Both Middle Indian Brook and Bartlett Brook had the highest portion of their TIA classified as EIA (22%). Of the 54 outfalls in Bartlett Brook, 24 were classified as hydrologically connected over a small watershed area (3 km^2) resulting in this high classification.

Semi-connected EIA

When both connected and semi-connected stormwater infrastructure were added to the model (Figure 10C), EIA estimates increased to an average of 2.4 ±2.3% by watershed. EIA in Upper Allen Brook again did not increase from 0.02% as no semi-connected stormwater infrastructure was present. Middle Indian Brook EIA increased from 3.8% (no stormwater EIA) to 6.6% (semi-connected EIA). Semi-connected EIA estimates averaged 16 ±8% of initial mapped TIA, more than double the amount of TIA classified as EIA for the no stormwater EIA estimate (Figure 9). Bartlett Brook, which had 85% of stormwater outfalls classified as connected or semi-connected, had the highest amount (30.4%) of TIA classified as EIA.

Stormwater Impaired vs. Attainment Watersheds

We noted significant differences between our connected EIA and semi-connected EIA estimates in attainment vs. stormwater impaired watersheds. The connected EIA was significantly higher in impaired watersheds (2.8%) than attainment, where estimates averaged 0.7% (*Student's t-test*; p=0.03; Figure 8). Likewise, semi-connected EIA was significantly higher in impaired watersheds (3.5%) than attainment, which had an average of 1% EIA (*Student's t-test*; p=0.03; Figure 8). EIA estimates for the no stormwater EIA were not significantly different based on impairment status (*Student's t-test*; p=0.17). This is likely due to the significant amount of EIA omitted in this estimate due to the omission of stormwater infrastructure information.

Semi-connected EIA makes up a significantly higher percentage of the TIA in stormwater impaired watersheds than in attainment watersheds (*Student's t-test*; p=0.02; Figure 9). Semi-connected EIA in attainment watersheds averaged 10.2 ±6% of TIA (range: 0.7 – 16.5%) while the percent of TIA mapped as semi-connected EIA in stormwater impaired watersheds ranged from 9.6 to 30.4% (mean: 19.4 ±6.8%). No significant differences were found between attainment and impaired watersheds for either the amount of TIA that was classified as connected EIA (*Student's t-test*; p=0.06) or no stormwater EIA (*Student's t-test*; p=0.8).

Evaluation of mapping results using storm data

Storm events evaluated for the O8 Englesby Brook stormwater catchment provide an independent test and validation of mapped estimates of EIA. The O8 catchment has a catchment area of 475,210 m^2 with an estimated EIA of 14.3% or 67,955 m^2. Regression analysis of storms less than 0.5 inch (1.27 cm) produced a regression coefficient of 69,654 or only 2.6% less than the mapped estimate of EIA (Figure 11).

Discussion

Availability of a LiDAR elevation product and detailed stormwater infrastructure data were used in the development of a new approach to mapping effective impervious areas for 15 urban and suburban watersheds in northwestern Vermont. The approach made use of flowpath modeling to map areas contributing to semi-connected and connected stormwater infrastructure that discharges to streams. The mapping results were validated using an independent data set of rainfall and runoff for a small stormwater catchment in the Englesby Brook watershed, located in Burlington, Vermont. This independent validation produced an estimate of contributing area that closely matched our mapped EIA estimate.

Important factors will limit the application of this approach to other areas. Foremost is the availability of high-resolution elevation data that adequately represent topographic gradients in the area of interest. We suspect that adequate modeling of flow paths would be compromised in low relief terrain, where topographic gradients that drive the routing of storm water runoff are small. Along roadways, the presence of curbs and ditches will determine flow routing and estimates of EIA. Improved attributing of road ways to include these features will improve the representation of effective impervious areas along roads, which represent an important component of impervious areas. Finally, our approach relies on a robust dataset of storm water infrastructure, attributed according to inlet and outfall connectivity, and using a simple rule set to attribute outfalls as connected, semi-connected or disconnected from streams and rivers as described above. In this project, considerable effort was devoted to manual attribution of storm water outfalls and their connectivity to storm water inlets. Application of this approach in other areas will be limited by the availability and reliability of adequately attributed storm water infrastructure data.

Impervious area is widely used as a measure of human impact on streams and targeted as a metric for improving water quality in impaired urban and suburban watersheds. The approach described here can be automated and applied in any area with high-resolution topographic data and robust representations of storm water infrastructure. Our results show very clear differences between simple, remotely-sensed estimates of total impervious area for the watersheds we studied and effective impervious area estimated through this mapping method. Field verification of mapped areas using tracer studies (e.g. dye or salt), along with additional validation using rainfall-runoff data, could improve confidence in the automated measures of EIA derived here. Application of these results to the prediction of biologic metrics in streams, using data sets such as those collected as part of the Vermont water quality monitoring program, could be used to evaluate the usefulness of this approach in predicting water quality of urban and suburban streams.

Training and Outreach

Training

The project described here provided post-graduate training for Kerrie Garvey, a 2012 MS graduate of the University of Vermont.

Outreach

The project was developed in collaboration with Jim Pease of the Vermont Department of Environmental Conservation (DEC), Agency of Natural Resources. Regular meetings were held approximately once every three months, with a final project meeting held on March 17, 2014, including Pease and Kari Garvey, head of the Vermont DEC Ecosystem Restoration Program.

Table 1. Descriptive information for each study watershed.

Stream	***Class[1]***	***Drainage Area (km^2)***	***Stream Length (km)***	***TIA (%)[2]***	***Stormwater Outfalls - Connected (#)***	***Stormwater Outfalls - Semi-connected (#)***	***Stormwater Outfalls - Disconnected (#)***	***Disconnected Outfalls (%)***
Alder Brook	A	26.7	45.0	5.2	64	26	91	50.3
Allen Brook (Upper)	A	9.4	9.7	2.7	0	0	1	100.0
Indian Brook (Upper)	A	9.0	14.7	2.0	6	5	9	45.0
Munroe Brook (Upper)	A	5.4	10.8	4.7	0	0	4	100.0
Sand Hill Brook	A	2.8	4.2	6.6	1	3	21	84.0
Sunnyside Brook	A	1.4	3.3	30.3	5	11	20	55.6
Allen Brook (Lower)	I	16.0	24.9	8.7	29	37	27	29.0
Bartlett Brook	I	3.0	6.2	18.5	24	22	8	14.8
Centennial Brook	I	3.6	7.5	31.0	35	18	23	30.3
Indian Brook (Lower)	I	6.2	11.3	9.7	31	13	10	18.5
Indian Brook (Middle)	I	3.4	5.8	26.5	55	18	24	24.7
Munroe Brook (Lower)	I	6.2	10.4	10.7	12	6	16	47.1
Munroe Brook (North Tributary)	I	2.4	6.5	7.7	4	2	3	33.3
Sunderland Brook	I	5.7	17.2	21.9	56	17	68	48.2
Englesby 08 stormwater catchment	I	0.5	0.04	35.0	1	0	0	0

[1] Class: Attainment (A) vs. Stormwater Impaired (I), based on VT ANR's 303d list of impaired waters
[2] Total impervious area derived from LCBP 2011 impervious surface data layer

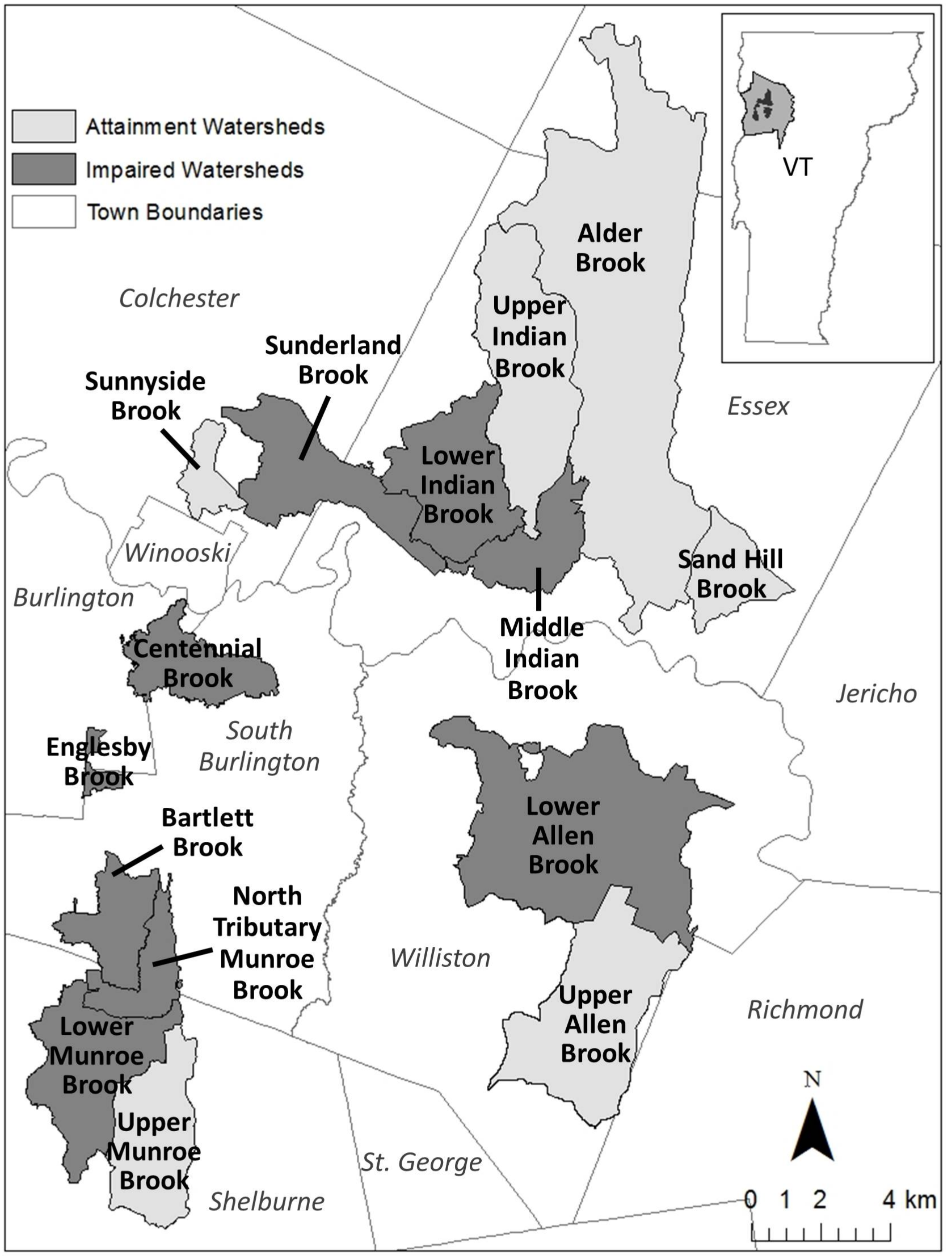

Figure 1. Study sites located in Chittenden County, VT include both attainment (light gray) and impaired (dark gray) watersheds. Town boundaries are also displayed (gray). Site locations within Chittenden County and the state of VT are shown in inset.

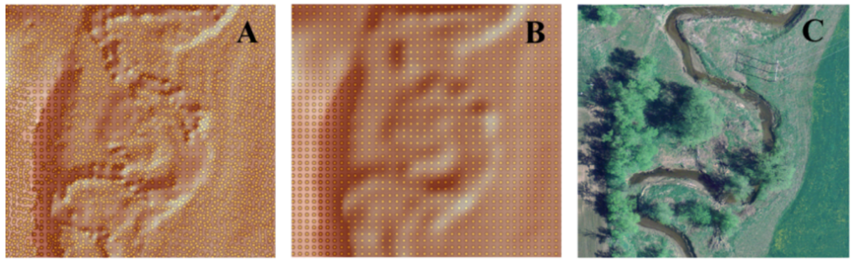

Figure 2. Improved terrain definition of the enhanced resolution DEM (A) is shown in comparison to the traditional DEM derived from bare earth (3.2m posting) systematic grid points (B) within Allen Brook. Natural color 1:1250 imagery (C) is shown for comparison.

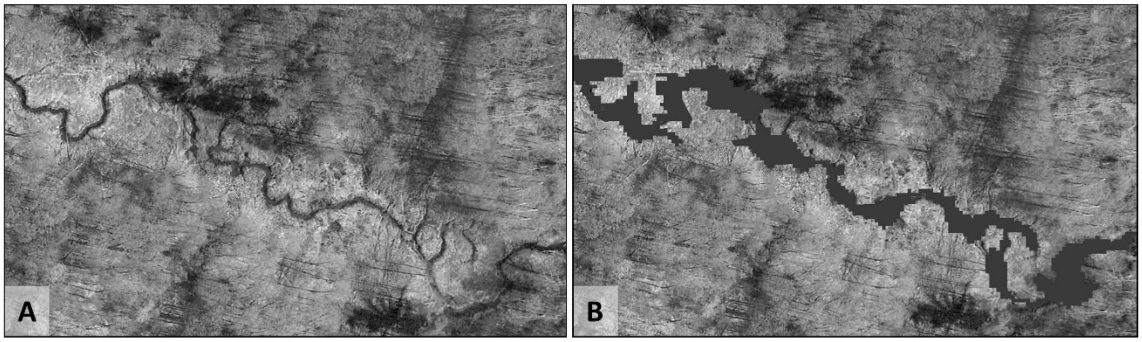

Figure 3. A section of Sunderland Brook is shown with digital orthophotography (A) and the stream channel defined by change in slope used in the EIA analysis shown in dark gray (B).

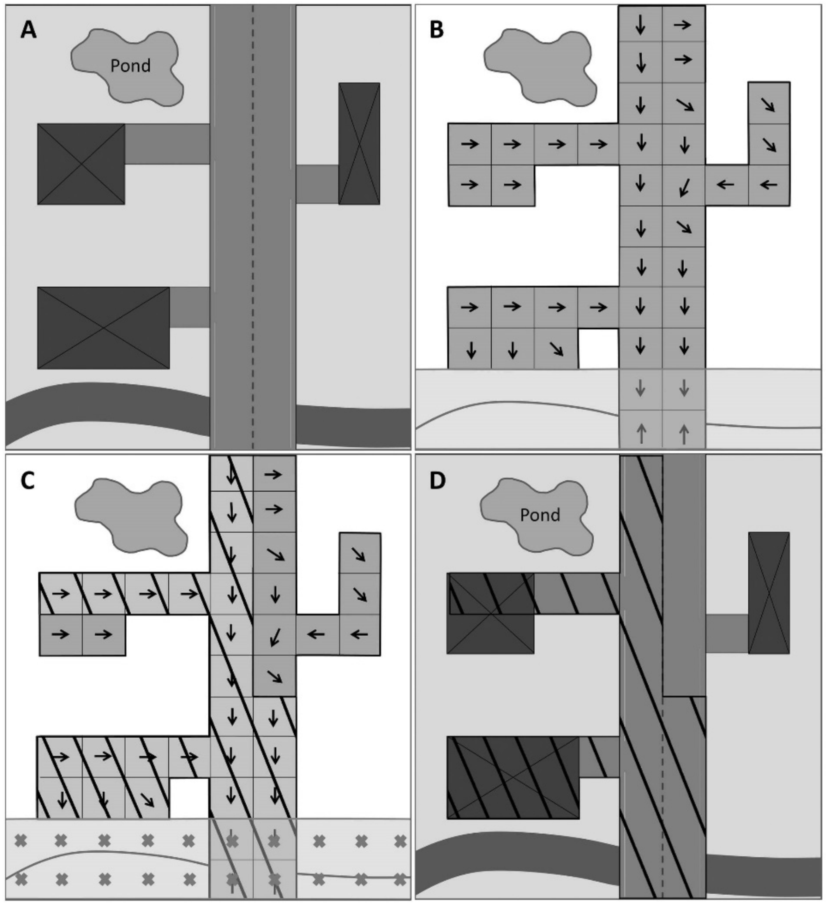

Figure 4. Impervious surface maps and hydrologic flow modeling were used to map effective impervious area (EIA). In this example landscape (A), total impervious surfaces were mapped by pixel and the hydrologic flow direction was extracted for each impervious surface grid cell (B) that drains directly to nearby stream channels (light gray areas) or to pervious areas (white areas). The EIA was mapped as the contributing area to each pixel in the stream channel (✖), and resultant EIA, depicted with diagonal black lines, is shown overlain on the flow direction model (C) and example landscape (D).

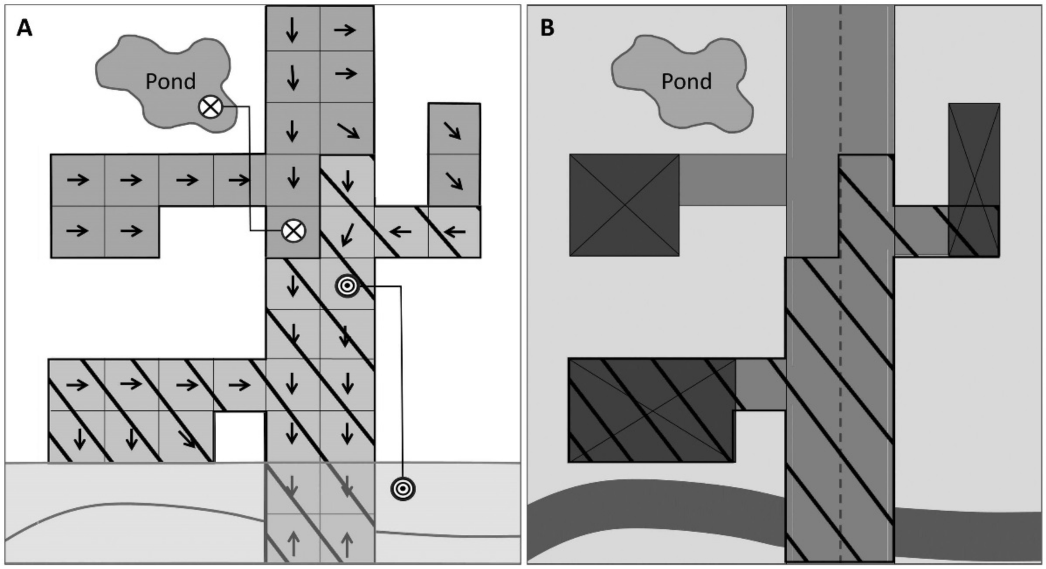

Figure 5. Effective impervious surface classification, depicted with diagonal black lines, was altered to account for stormwater infrastructure information. In this example, the impact of hydrologically connected (◎) and disconnected (⊗) stormwater infrastructure are shown overlaid on flow direction model (A) and example landscape (B).

Figure 6. Building footprints were mapped for each watershed. Here, digital orthophotography is shown (A) in comparison to building footprints, displayed in crosshatching (B).

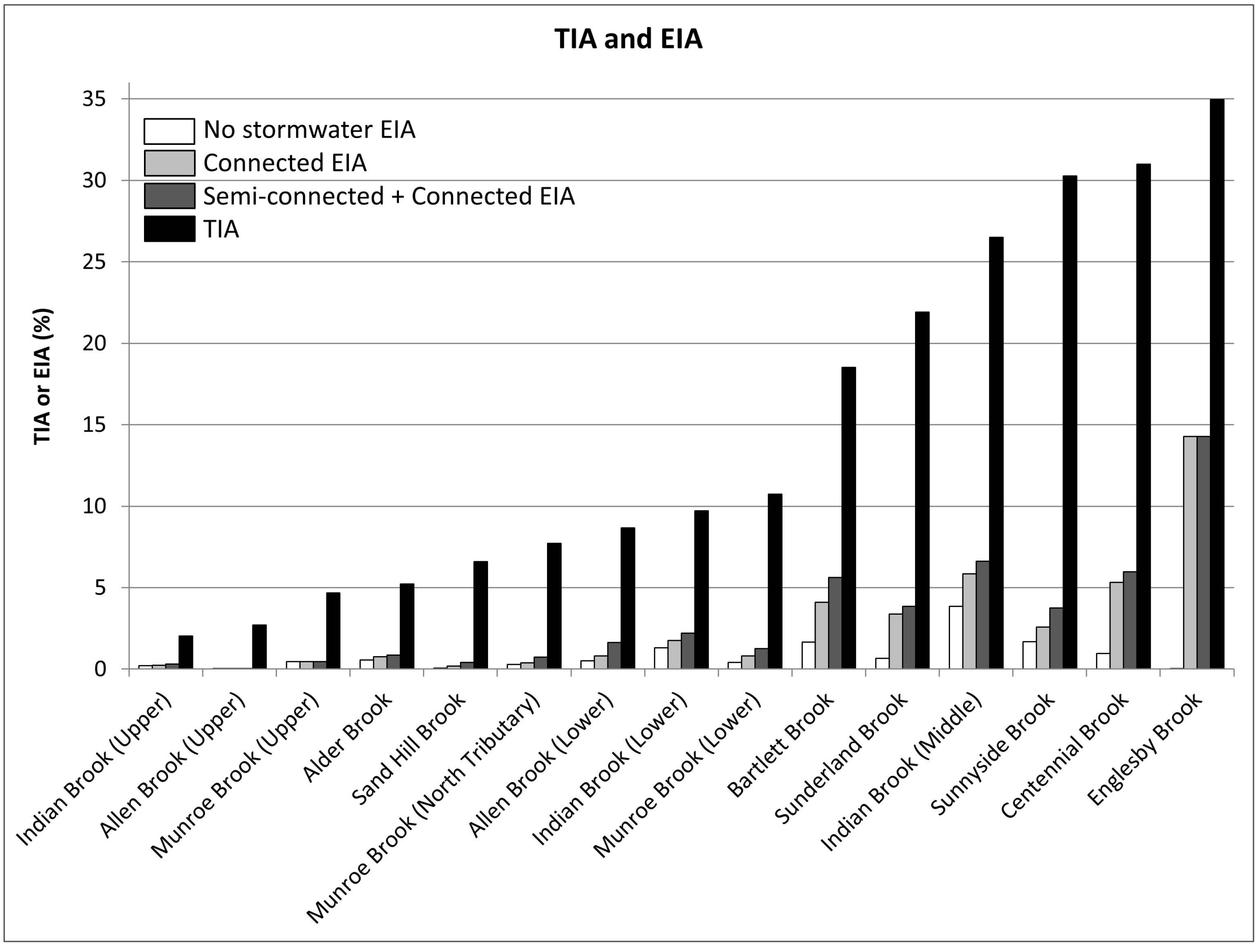

Figure 7. EIA results are shown for no stormwater EIA (white), connected EIA (light gray), and semi-connected EIA (dark gray). Watersheds are displayed in order of lowest to highest TIA (black).

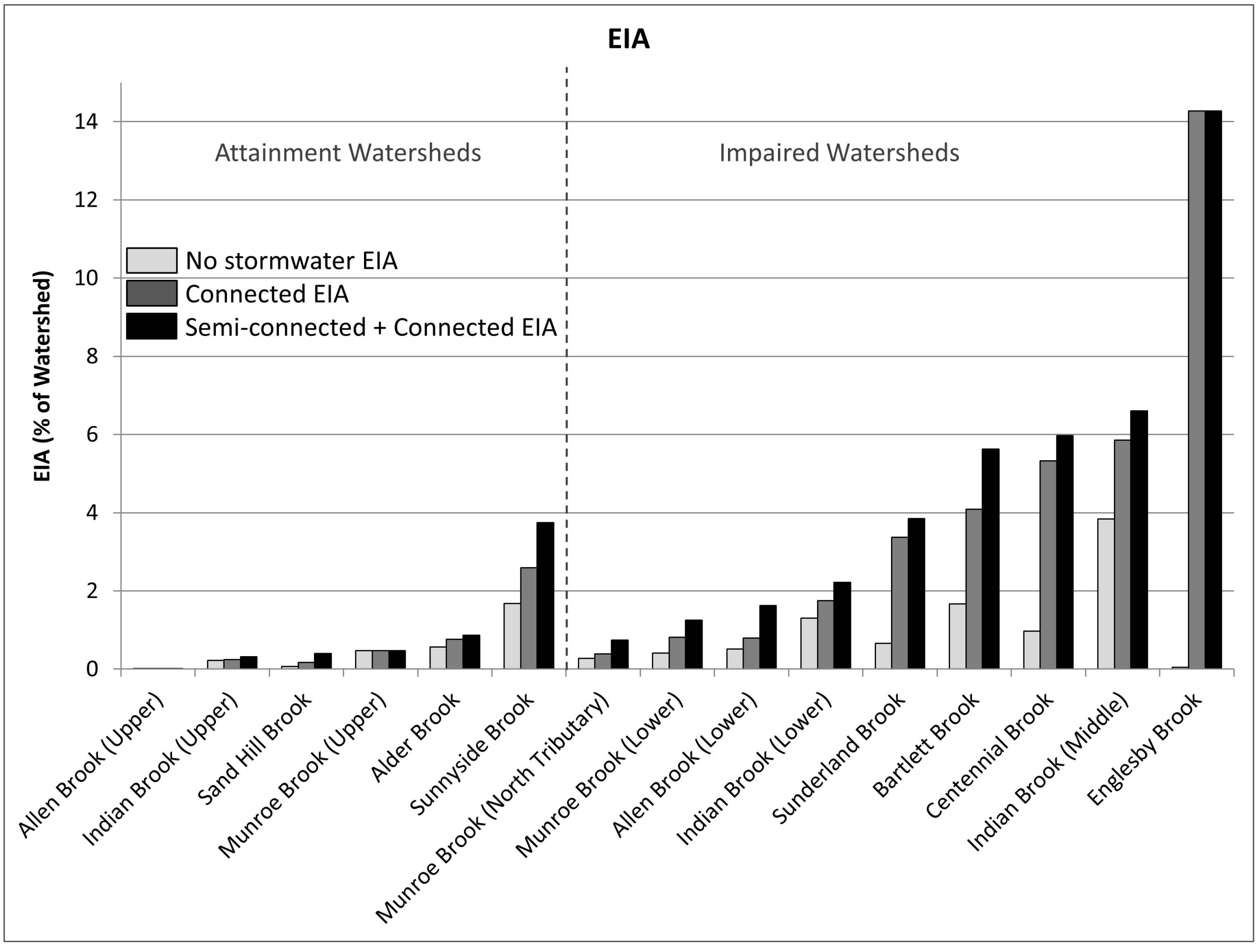

Figure 8. EIA results are shown for no stormwater EIA, connected EIA, and semi-connected EIA. Attainment watersheds are shown on the left of the dashed line while impaired watersheds are shown on the right. Both connected (*Student's t-test*; p=0.03) and semi-connected (*Student's t-test*; p=0.03) EIA estimates were significantly higher for impaired watersheds when compared with attainment watersheds.

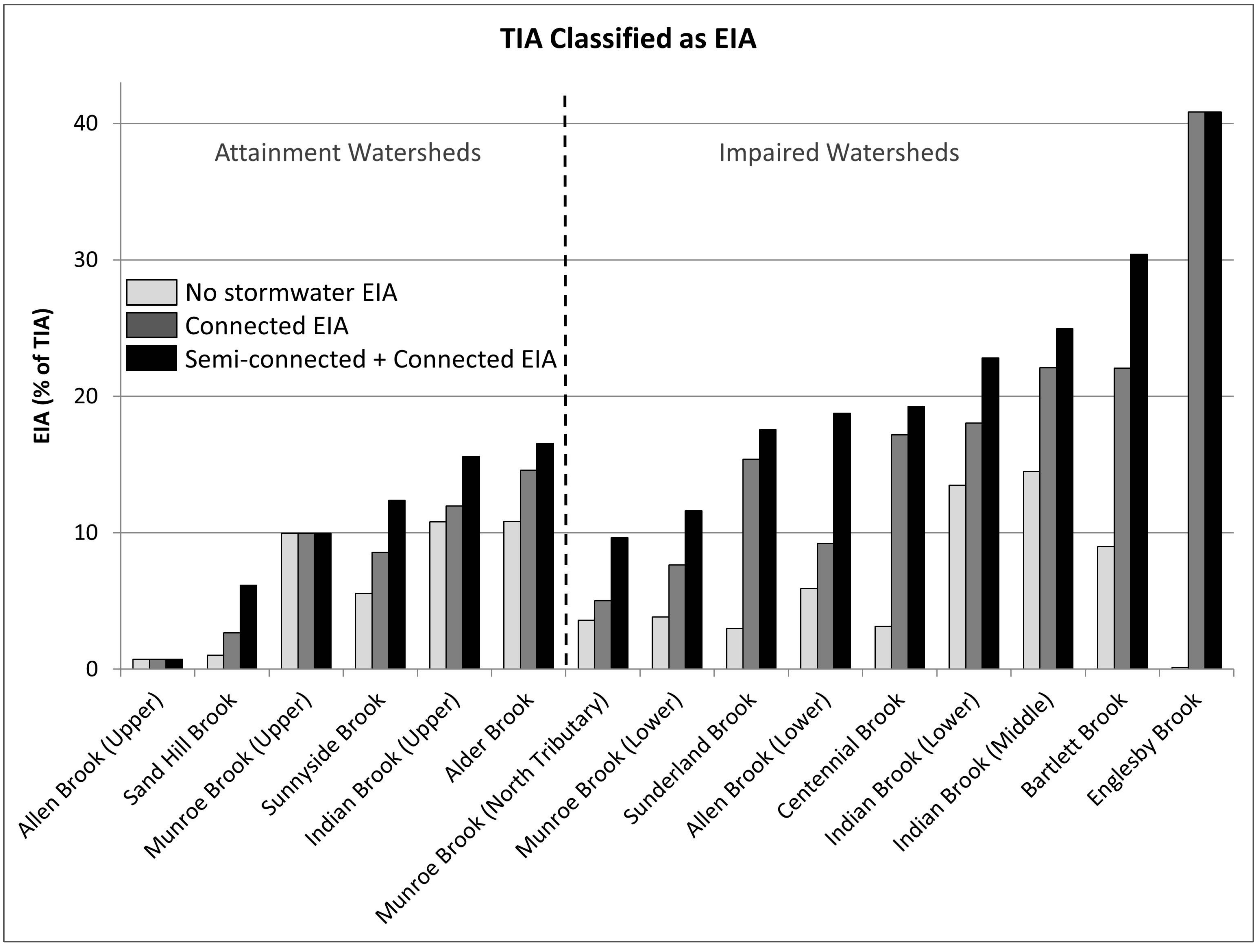

Figure 9. The amount of TIA that was classified as EIA is shown by watershed, divided into attainment (left of dashed line) and impaired (right of dashed line) watersheds. Results between attainment and impaired watersheds are significantly different for only semi-connected EIA (*Student's t-test*; p=0.02).

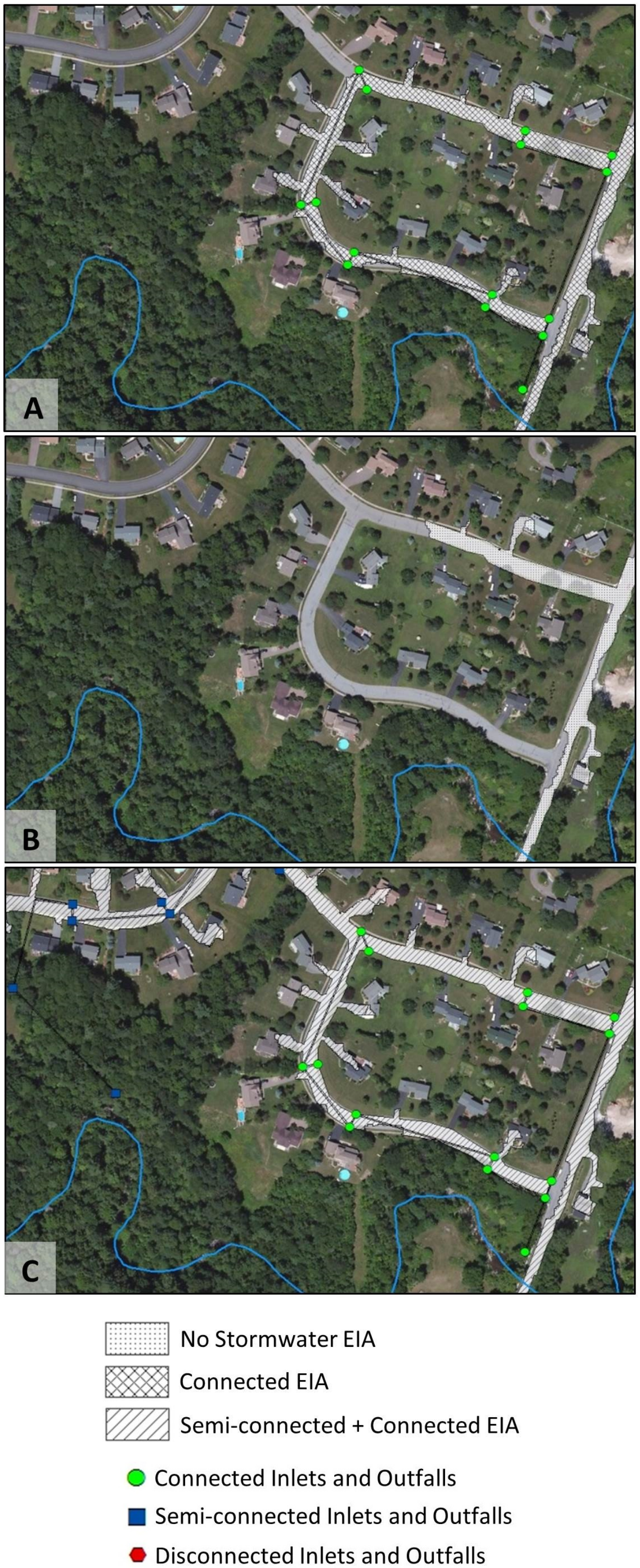

Figure 10. No stormwater EIA (A), connected EIA (B), and semi-connected EIA (C), the three EIA classifications, are shown here for a sample area in Lower Allen Brook.

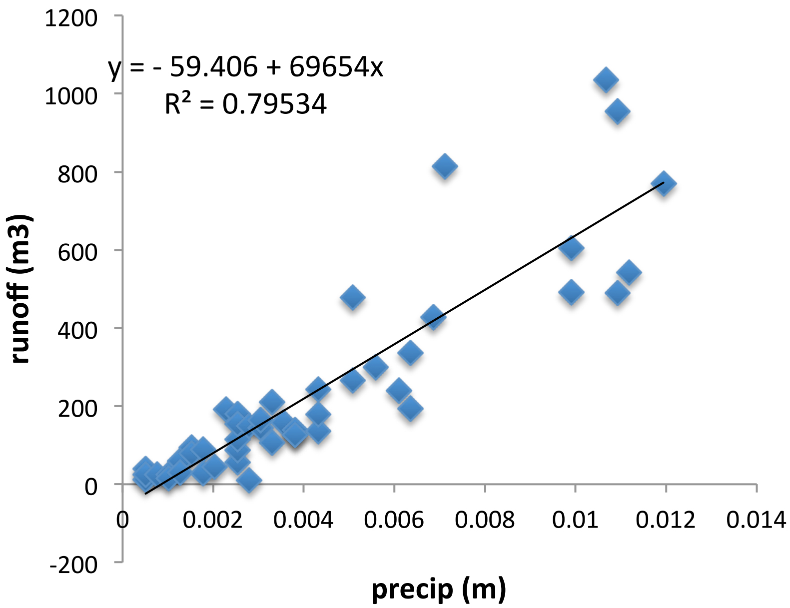

Figure 11. Rainfall runoff relationship for Englesby Brook O8 stormwater catchment for precipitation events <0.5 inches for water year 2007.

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Information Transfer Program Introduction

The following section describes the Information Transfer activities of the Vermont Water Resources and Lake Studies Center in 2013-2014.

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.

In 2014-15 we launched a new collaborative outreach effort with several other Vermont organizations that foster research, education, and outreach on water and other natural resources in the state and region. This new outreach effort is an online portal for ecological research being conducted in Vermont. The purpose of the collaboration is to provide one online portal connecting interested individuals to ecological research, management, policy and monitoring activities in Vermont. The targeted audience is ecological professionals, such as employees and members of conservation districts, municipalities, state agencies, and educational institutions. The initial group that has committed to participate in this initiative includes: Lake Champlain Sea Grant, the Vermont Water Resources and Lake Studies Center, the Northeastern States Research Cooperative, the Vermont Monitoring Cooperative, Vermont Cooperative Fish and Wildlife Unit, the Rubenstein School of Environment and Natural Resources and the Rubenstein Ecosystem Science Laboratory.

The ecoNews VT newsletter will be emailed quarterly to a broad constituent list, with links to the web portal for additional details. Content will include summaries of technical reports, research highlights, upcoming events, and rapid communications of new findings from around the state. Our intention is to translate relevant technical literature into short, readable summaries that provide the essential findings that should be of interest to or target audiences.

Participating organizations will identify a primary contact who will be responsible for soliciting and submitting stories to be summarized and information to be shared to Elissa Schuett, of Lake Champlain Sea Grant and the Vermont Water Center. Ms. Schuett will interpret the contributed content and summarize the report into an accessible, concise story for distribution to ecoNEWS VT subscribers. An online website will contain the current ecoNEWS VT content, archived summaries, links to each of the participating organizations, as well as a calendar of events that coordinates activities from each member of the consortium.

Ms. Schuett works as communicator and administrator for both the Vermont Water Resources and Lake Studies Center and Lake Champlain Sea Grant, strengthening the connection between the two programs to extend communications of each program to a broader audience.

USGS Summer Intern Program

None.

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

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, Eric O., Donald S. Ross, Barbara J. Cade-Menun, Corey W. Liu, 2013, Phosphorus Speciation in Riparian Soils: A Phosphorus-31 Nuclear Magnetic Resonance Spectroscopy and Enzyme Hydrolosis Study, Soil Science Society of America Journal, 77:1636-1647.