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

Project type: Research

Focus category: nutrients, non-point source pollution, water quality

Research category: water quality

Keywords: roads, best management practices, BMPs, water quality, sediment, phosphorus

Start date: March 1, 2013

End date: February 28, 2014 (final report by June 30, 2014)

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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.

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

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

Statement of results or benefits

The proposed research will result in measurements that quantify pollutant production from gravel roads typical of those in rural settings throughout Vermont. Data collected through the proposed study will also allow the quantification of pollutant reduction associated with recommended BMPs for gravel roads. Findings from the proposed study should be directly applicable to the mandate under Vermont Act 110[1], passed by the Vermont legislature in 2010, to develop standards and best

[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.

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.

During the first year of the project we worked with staff in the towns of Fayston, Waitsfield, and Warren to select and instrument study sites (Table 1). This has involved collaboration with town road foremen to identify roads they wish to treat with BMPs to target existing erosion and road stability concerns. Each study "site" will include a road segment to be treated with a BMP and a paired nearby road segment to serve as an untreated control. By conclusion of our 2012 field season, we had selected six of these site pairs, giving us a total of 12 monitored road segments to date. We measured bulk sediment flux from the selected road segments during a series of six storm events between August and September 2012, covering a range of precipitation magnitudes (Table 2).

Table 1: Sites selected for study in Mad River Valley and proposed treatments

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

Table 2: Storms monitored at paired treatment and control sites during Year 1 (pre-treatment period)

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

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

Preliminary data (Figure 1) *for the pre-treatment period* during these 2012 summer storms at each site shows a range of sediment production rates. Among the six paired sites monitored, the average sediment flux at the control sites was 40 kg and, at the sites to be treated, 139 kg. Results from these 2012 storms also show that the paired treated-control sites are relatively well matched, in that sediment production increases across both sites as storm size increases. *We expect a downward shift in these trend lines with treatment, with the magnitude of that shift serving as a* *measure of effectiveness of the treatment on that road segment.* We also expect to see a range of phosphorus in the bulk samples collected over storm events, once laboratory analysis is complete.

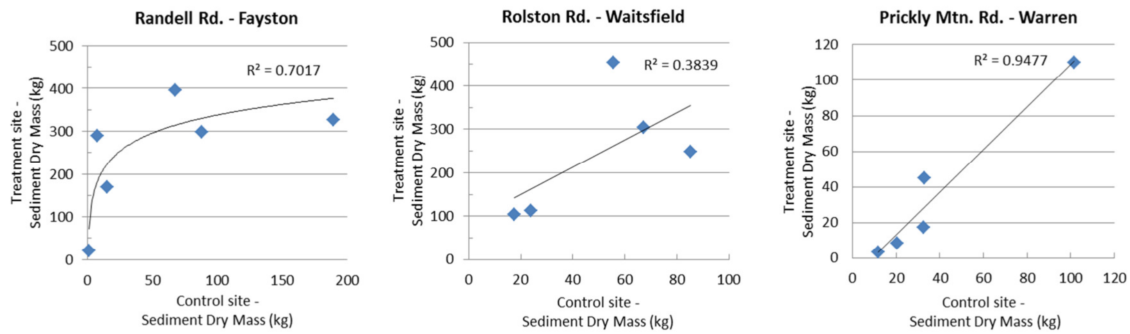

Figure 1: Preliminary dry sediment mass (kg) from three control sites and paired treatment sites monitored in 2012 field season. Each point represents a storm event. All data are from the pre-treatment period. Phosphorus data (one sample per event) not yet available.

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

Using a set of up to 24 road segments, we will measure storm characteristics (total precipitation depth, subhourly rainfall rates, storm duration) and pollutant (sediment, total phosphorus) production for storms that span the range of runoff-producing events in Vermont over a two-year field season (Table3). In collaboration with the Vermont Better Backroads Program (http://www.nvtrcd.org/bbr.html), we will monitor changes in sediment and phosphorus loadings following the installation of BMPs on selected road segments. Our collaboration with the Better Backroads Program brings expertise in BMP design and installation to the project, along with their formal annual application program to identify sites in need of repairs to reduce erosion hazards. The findings from this work will be used to develop a decision support tool to evaluate pollutant reduction options and costs associated with BMP applications.

Table 3: Timeline of project activities

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

* Project year 1 activities completed or in progress at time of submission.
Note: some overlap in installation, pre-treatment monitoring, and post-treatment monitoring shown in table. Silt fence and BMP installation require only 1-3 days during quarter. Pre-treatment monitoring will commence immediately after fence installation and continue up to the BMP installation. Post-treatment monitoring will commence immediately thereafter.

Methods, procedures and facilities

Our proposed methods for quantifying effectiveness of BMP implementation on rural, gravel roads involve bulk sample collection below road drainage outlets (cross-drain culverts) using a before-after treatment/control design. We will work in towns of the Mad River Valley, where we have conducted previous research on the effects of roads on water quality supported by the Lake Champlain Basin Program (LCBP). In collaboration with town staff (town administrator, road foreman) and in consultation with town select boards, we will select 12 study sites for BMP treatment identified by town road crews as in need of drainage improvement. For each treatment site, we will select a nearby untreated control site for paired monitoring, using our LCBP project sites, where possible, to extend the data record. During year 1 of the study, we accomplished the selection and instrumentation of six of the proposed 12 paired sites. Between August and September 2012, we collected samples at each site during six storm events to establish the pre-treatment record. Monitoring at these sites will be on-going in year 2 of the project, as we install BMP treatments and select an additional six paired sites for pre-treatment and post-treatment monitoring.

Bulk sediment samples will be collected at culvert outfalls in a silt fence, fabricated from plastic to retain coarse sediment and water, and landscaping fabric to allow drainage of effluent and reduce risk of failure (Figure 2). During the 2012 field season, we found the fence design to be robust to storms across the range of conditions monitored, with only three installation failures during very high

Figure 2: Plastic and filter fabric silt fence, installed out culvert outfall, with bulk sample collected after storm event in summer 2012

precipitation rain events in mid-summer. This measurement technique misses the finest sediment fraction washed through the landscaping fabric during the storm event, a fraction we are attempting to estimate using grab sampling during storms.

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

By project completion, we will monitor up to 24 sites, including 12 sites treated with BMPs and paired with an untreated control located within a 3 mile distance of the treated site. The control sites will be paired with the treated sites on the basis of similar grade, surfacing material and topographic and land cover (forested, agricultural) setting. For each road pair, we will collect baseline data for up to two months (estimated storm frequency of 3-6 frontal or convective storms per month in late spring and summer) during what we will define as a pre-treatment period. To evaluate BMP effectiveness in reducing total sediment and phosphorus runoff from roads, we will implement one of four BMP treatments (Table 4) on three road segments each, for a total of twelve treatments, with each treated site monitored concurrently with its untreated control (see Table 3). A shift in the relationship between the control and treated site in the post-treatment period, relative to the pre-treatment period, will be used to quantify BMP effectiveness across sites and under a range of storm conditions.

Table 4: Description of proposed BMP treatments to be installed on selected road sites (final treatment design to be refined in consultation with Better Backroads staff).

BMP treatment	Description
1. Rock-line ditch	Install up to 1 mile of rock in ditches lined with geotextile fabric
2. Stone check dams or compost socks and turnouts	Install stone check dams or compost socks and turnouts at spacing in compliance with BMP recommendations from Better Backroads staff to slow erosive ditch flow
3. Cutbank stabilization	Re-contour and stabilize eroding cutbanks above road; improve ditches with grass mix or stone
4. Outboard berm removal	Remove outboard berm from road contour to reduce concentration of flow

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

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

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

Related research

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

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

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.

Training potential

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

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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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.

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PUBLICATIONS:

LAST FIVE YEARS

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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)

Juillerat, J.I., D.S. Ross and M.S. Banks. 2012. Mercury in litterfall and upper soil horizons in forested ecosystems in Vermont, USA. Environ. Toxicol. Chem. 31(8): 1720-1729. DOI: 10.1002/etc.1896.

Ross, D. S., J. B. B. Shanley, J. L. Campbell, G. B. Lawrence, S. W. Bailey, G. E. Likens, B. Wemple, G. Fredriksen, and A. E. Jamison. 2012. Spatial patterns of soil nitrification and nitrate export from forested headwaters in the northeastern USA. J. Geophys. Res. 117, G01009, 14 pp. DOI: 10.1029/2011JG001740.

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Gotelli, N.J., P.J. Mouser, S.P. Hudman, S.E. Morales, D.S. Ross, and A.M. Ellison. 2008. Geographic variation in nutrient availability, stoichiometry, and metal concentrations of plants and pore-water in ombrotrophic bogs in New England, USA. Wetlands 28(3):827-840. DOI: 10.1672/07-165.1.

Hales, H.C. and D.S. Ross. 2008. Drastic short-term changes in the isotopic composition of soil nitrate in forest soil samples. Soil Sci. Soc. Am. J. 72(6):1645-1652. DOI: 10.2136/ sssaj2006.0293.