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

2. Project type: Research

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

4. Research category: water quality

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

6. Start date: March 1, 2012

7. End date: May 31, 2013

8. Principal investigators:

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9. Congressional District: Vermont-at-large

10. Abstract:

Gravel roads in rural settings can adversely affect water quality through the contribution of excess runoff, sediment and sediment-bound nutrients to receiving waters. These contributions can occur through chronic wash off from the road surface and through catastrophic gullying and road bed failure during extreme storms. To mitigate the adverse effects of roads on water quality, a number of Best Management Practices (BMPs) have been developed and tested in diverse settings. Although these practices appear to reduce erosion and mass wasting from roads, evidence of the benefit of any single BMP on pollutant reduction is limited, and studies quantifying these reductions for in rural Vermont do not exist. We propose to implement a set of BMPs on gravel roads, paired with roads we have been monitoring over the past year with support from the Lake Champlain Basin program. The proposed research will allow us to quantify pollutant reduction associated with four recommended BMPs and will 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 the 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.

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 of BMP implementation on forest roads in the region show very low levels of BMP implementation and compliance (Brynn and Claussen 1991; Schuler and Briggs 2000).

The objective of this project is to (1) quantify the reduction in sediment and phosphorus runoff from gravel roads associated with the implementation of selected BMPs, and (2) develop an approach for selecting and targeting BMP implementation to achieve maximum water quality improvement. We will leverage results from an on-going study, sponsored by the Lake Champlain Basin Program, that has resulted in the monitoring and quantification of runoff, sediment and phosphorus contributions on a suite of rural road segments within agricultural and forested settings.

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

management practices for rural 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. Using a set of up to 24 road segments, we will measure runoff and pollutant production for storms that span the spring snowmelt period through summer and fall convective and frontal storms. In collaboration with the Better Backroads Program, we will monitor changes in sediment and phosphorus loadings following the installation of BMPs on selected road segments. The findings from this work will be used to develop a framework for targeting BMP application on gravel roads to reduce pollutant contributions to receiving waters.

Timeline of activities:

Spring 2012 (March, April, May):
- Monitor 12 LCBP project sites[2]
- select BMP installation sites ("BMP sites") in collaboration with Better Backroads staff

Summer 2012 (June, July, August)
- Continue monitoring 12 LCBP sites
- Monitor BMP sites prior to BMP installation

Fall 2012 (Sept, Oct, Nov)
- Install BMPs in collaboration with town administrators/road crew and Better Backroads Program
- Begin monitoring BMP sites post-installation

Winter 2012-13 (Dec, Jan, Feb)
- Lab work and data analysis
- Conduct snow surveys for all sites

Spring 2013 (Mar, Apr, May)
- Monitor LCBP and BMP sites
- Lab work and data analysis

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with town officials and staff of Better Backroads, a program of Northern Vermont Resource Conservation and Development Council.

[2] See explanation of LCBP sites in the Methods, procedures and facilities section below

Methods, procedures and facilities

The work we propose here builds on an on-going study, funded by the Lake Champlain Basin Program (LCBP) to PIs Wemple and Ross, to estimate sediment and phosphorus production from roads. That study has resulted in measurements of runoff, sediment and phosphorus production on 12 road segments located within the Mad River valley (towns of Warren, Waitsfield and Fayston) of Vermont over the period July – November 2011 (Figure 1). By project completion in summer 2012, we will also have measurements of spring season runoff.

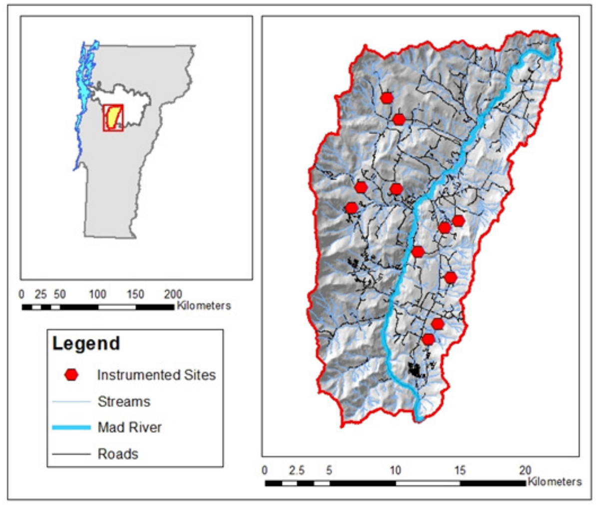

Figure 1: Location of road sites (one site not shown) instrumented for the Lake Champlain Basin Program research project described in proposal text and referred to as "untreated control" sites for the proposed project. Sites are located within the Mad River watershed, a sub-drainage of the Winooski River basin shown in inset map.

We propose using the LCBP road sites as a baseline or untreated controls for the examination of BMP effectiveness. We will select, in collaboration with the Better Backroads Program, twelve additional road sites for BMP installations. Each new site will be "paired" with each of our existing sites on the basis of similar topographic setting, road design, and land cover (agricultural, forest) conditions and selected on the basis of their identification by town road crews and the Better Backroads program as candidates for stability enhancement or erosion reduction. For each of the twelve road pairs, we will have one year of baseline runoff and pollutant data, supported through the LCBP grant. Using resources available through Better Backroads program funds, we will implement one of four BMP treatments (table 1) on three road segments each, for a total of twelve treatments. The research funded under this project will allow us to track pollutant reduction potential associated with the installation of each BMP.

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 turouts	Install stone check dams and turnouts at spacing in compliance with BMP recommendations from Better Backroads staff
3. Cutbank stabilization	Recontour and stabilize eroding cutbanks above road; improve ditches with grass mix or stone
4. Outboard berm removal	Remove outboard berm form road contour to reduce concentration of flow

To estimate pollutant runoff from the road sites, we will install modified dirt bag® geotextile bags at cross-drain culverts. These collector bags, made of porous fabric, will be affixed to a culvert outlet and will allow runoff draining from a roadside ditch into a culvert to be collected and filtered for fine and coarse sediment. Because the bags must be adequately porous to drain water, all dissolved phosphorus in the flow will be lost, along with the finest sediments passing through the filter fabric. We will estimate these fractions of phosphorus and sediment loss through the fabric by intermittently grab sampling the bag effluent during storm events and running samples for total suspended solids and total dissolved phosphorus using standard laboratory methods. We will supplement these measurements with our existing dataset (supported through the LCBP grant) of total suspended sediment and total dissolved phosphorus concentrations collected intermittently throughout storms using ISCO automated water samplers. Following storm events, the dirt bags will be extracted from the field site, oven dried and weighed to estimate sediment yield for the storm. A subsample of the bag sediment will have total P determined by microwave assisted digestion with concentrated nitric acid and Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) using standard methods.

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. Prior to snowmelt, we will conduct snow surveys to quantify water storage in the snowpack for areas draining to monitored culverts. 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. A crest stage recorder installed at each culvert inlet (used in combination with rating curves we have already developed for culverts), will allow us to estimate peak discharge rates for each storm at each site.

We will use a statistical analysis to estimate differences (treated vs. untreated control) in mean sediment and phosphorus production by BMP treatment type across a range of storm and antecedent moisture conditions. 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 and beyond the period of this grant if additional funds become available.

Using the results of our empirical work, we will develop a simple GIS-based approach to estimate pollutant reduction potential from BMP implementation. This approach will be grounded in a set of simplified assumptions regarding sediment and phosphorus production per unit length of road, based on the results of our baseline monitoring funded by the LCBP grant and enhanced by continued monitoring of these sites funded under this grant. Through simple calculus of road length by topographic and land cover setting, we will generate an approximation of sediment and phosphorus produced on gravel roads. Using a conservative assumption that road segments draining to stream crossing culverts contribute pollutants directly to receiving waters, we will estimate the magnitude of sediment yield to rivers. Within a GIS framework, we can then select one or more BMP options and apply them differentially across the road network and calculate the yield or 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 (see for example 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

The proposed project will train a graduate research assistant in Natural Resources or Plant and Soil Science and an undergraduate student in Geography, Geology, Environmental Science, Engineering, Natural Resources or Plant & Soil science. These students will be mentored and co-advised by Wemple and Ross. Training in field and laboratory 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)

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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.

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

PUBLICATIONS:

<u>LAST FIVE YEARS</u>

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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 four years (peer reviewed)

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