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Assessing the Effects of Unpaved Roads on Lake Champlain Water Quality

June 2013

Final Report

Prepared by:
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For:
The Lake Champlain Basin Program and
New England Interstate Water Pollution Control Commission

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Executive Summary

The studies described in this report were motivated by an interest in understanding the role of roadside drainage on water quality impairment in the Lake Champlain Basin. The Basin encompasses a 21,326 km^2 (8,234 mi^2) mostly rural land area, with farmland occupying much of the lowlands and forests in the uplands. Monitoring and research within the Basin to date have improved our understanding of the role of agricultural and urban storm water runoff on water quality. Little is known about the effects of the extensive transportation network, especially the network of unpaved roads in the uplands, on water quality. This project was initiated to improve that understanding.

We undertook two studies to quantify pollutant (suspended sediment and phosphorus) production from the transportation network in the Winooski River watershed. We focused on unpaved roads, which dominate the transportation network in the rural uplands and which have been shown in studies from other regions to have important water quality impacts. Within the Mad River watershed, we monitored a set of 12 road segments during summer and fall of 2011 and during spring and summer of 2012. We measured runoff and collected water quality samples during storm events, and quantified the mass of suspended sediment and total phosphorus produced on roads at these sites. We used these observations to scale up to the catchments in which these roads were located, and used monitoring data from the local watershed association to contextualize our estimates of catchment-scale road runoff. Within the Winooski River watershed, we surveyed nearly 100 km of unpaved roads to inventory the type of size of erosional and depositional features evident on roads and to assess the efficacy of best management practices on erosion reduction. We used the inventory to scale up to the entire unpaved road network in the Winooski watershed, and used estimates of sediment and phosphorus loadings from long-term monitoring programs to contextualize our results.

Key findings from these studies can be summarized as follows:

- The flux of sediment and phosphorus from intensively monitored road segments in the Mad River valley was highly variable in time and across sites. Estimates of average annual sediment flux from these sites ranged from 0.43 MT/km/year for the lowest gradient road segment to nearly 123 MT/km/year for the most intensively monitored and highly erosive road segment studied. Concentrations of total phosphorus in samples collected during storm events were positively related to concentrations of total suspended solids, allowing us to estimate phosphorus fluxes from sediment fluxes.
- Estimated catchment scale pollutant production from the unpaved road network in the Mad River valley averaged 5093 kg/km/year of suspended sediment and 10 kg/km/year of phosphorus. Expressed on a unit (watershed) area basis, this equates to an average of 6120 kg/km^2/year of suspended sediment and 15 kg/km^2/year of total phosphorus, equal to approximately 17% of the annual average suspended sediment load and 28% of the annual average phosphorus load yielded from these upland catchments.
- Within the larger Winooski River watershed, extrapolation of road inventory results to the unpaved road network in the Winooski yielded estimates of sediment eroded from unpaved roads in excess of 40,000 metric tons and total phosphorus in excess of 15,000 kg. Assuming these represent annual estimates, sediment production rates on unpaved roads equate to 31% of the annual average Winooski river suspended sediment load phosphorus associated with this bulk sediment eroded equates to 11% of the average annual Winooski River phosphorus load.
- Both site-scale storm monitoring and the watershed-scale inventory showed that the magnitude of erosion and pollutant production from roads was more pronounced as road grade increased. The application of best management practices, including vegetated and stone-lined ditches, turnouts, and energy dissipating measures (rip rap, check dams) were associated with lower frequency and magnitude of erosion on roads.
- Field and GIS-derived estimates of road-stream connectivity indicate that slightly more than half of the road network in the Winooski River watershed discharges pollutants to streams via stream crossing culverts and cross drains sufficiently near streams to route discharge via

overland flow or concentrated runoff in gullies to channels. Road construction and maintenance practices that disconnect roads from waterways can effectively reduce pollutant transfer.

- Evaluation of a recent road inventory for the New York side of Lake Champlain, combined with simple metrics derived for the inventory in the Winooski watershed, suggests that the results reported here should be applicable to upland areas throughout the Basin where unpaved roads traverse similar topographic settings and similar road design and maintenance practices are applied.

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Chapter 1: Introduction and Background

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). 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).

Numerous studies, particularly on forest lands, have documented the application and efficacy of best management practices (BMPs) in reducing runoff and sediment production associated with roads (Lynch, Corbett et al. 1985; Megahan, Potyondy et al. 1992; Kochenderfer, Edwards et al. 1997). These practices vary by jurisdiction but generally 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 recommended BMPs, pointing particularly to instances where the failure to use BMPs on roads resulted in significant hydrologic and erosion impacts (Brynn and Claussen 1991; Schuler and Briggs 2000).

Within the Lake Champlain Basin, considerable effort has been devoted to understanding the role of land use in pollutant contributions to the Lake (LCSC 2003). More recently, attention has focused on urban storm water (Mcintosh, Bowden et al. 2006; Foley 2007) and its role in sourcing pollutants and degrading stream banks (Fitzgerald 2007; Pelletier, Morrissey et al. 2008). Although inventories in the Basin are emerging to document the extent and form of road-drainage problems (VBB 2008; Bartlett, Bowden et al. 2009; LCLGRPB 2012) and Basin action plans call for attention to this issue (VCCAP 2009; VTANR 2010), no attempt has been made to systematically estimate runoff rates and sediment and phosphorus loadings from the extensive network of unpaved roads within the Basin or to evaluate the effect of BMP implementation on mitigating road drainage problems.

The extensive literature on road hydrology and geomorphology suggests that the contributions of the transportation network within the Lake Champlain Basin may be an important vector for pollutant contributions to the Lake. This project seeks to improve understanding of the effects of unpaved road networks on runoff and pollutant production within the Lake Champlain basin and to explore the effectiveness of the application of best management practices in mitigating these deleterious effects.

Chapter 2: Project Objectives and Organization of the Report

The overarching goal of this project is to assess the role of unpaved roads and roadside drainage on runoff and pollutant loadings to receiving waters within a watershed of the Lake Champlain basin. We use the general term ***pollutant*** throughout the report to refer to sediment and phosphorus generated on roads and discharged into receiving waters from the unpaved road network. When referring to the erosion and transport of sediment and associated phosphorus on roads and roadside ditches, we use the term ***production***, and use the term ***load*** to refer to the mass transport of these pollutants in receiving waters. We use the general term ***flux*** in comparing pollutant production on roads and pollutant loads in streams.

Our work, described in this report, was framed around three key objectives as follows:

1. Quantifying runoff rates and loadings of sediment and phosphorus for a range of road types and topographic positions within a selected watershed,
2. Identifying the form and extent of pollutant production and delivery to streams and assessing the effectiveness of best management practices (BMPs) in mitigating these adverse effects, and
3. Extrapolating site specific findings to the watershed scale using spatially-explicit road and landscape variables to inform Basin managers of the potential for load reductions through the mitigation of erosion from unpaved roads.

We focused on unpaved roads, since they dominate upland settings of the Lake Champlain basin, and because unpaved rural roads have been identified in Lake action plans as an area in which non-point source pollutant loading could be reduced through improved management (VCCAP 2009). Despite the perceived role of unpaved roads in affecting water quality, little information exists in the Basin to quantify this effect.

Study area

We situated our work within the Winooski River watershed of the Lake Champlain basin. The Winooski is a 2753 km^2 (1063 mi^2) watershed located in the east (Vermont-side) central portion of the Lake Champlain basin. It includes urban, agricultural and forested land use across a range of topographic settings from the lowlands near the watershed mouth to the foothills and higher elevations of the Green Mountains, providing a good test bed for evaluating pollutant production on unimproved roads in varied topographic and land cover settings.

Organization of the Report

The remainder of this report is organized into three chapters, which address the objectives stated above and describe our field and modeling studies. **Chapter 3** describes the results of monitoring and analysis of runoff and pollutant production on selected road segments within the Mad River watershed during storm events. Results from individual road segments measured during the summer and fall of 2011 and the spring and summer of 2012 are extrapolated to the full unpaved road network for five catchments of the Mad River and compared to estimates of annual suspended sediment and phosphorus loads, derived from the on-going water quality monitoring program implemented by the *Friends of the Mad River*, to contextualize our estimates of pollutant production from unpaved roads. **Chapter 4** describes the results of a watershed-wide inventory of the form and extent of pollutant production on unpaved roads within the Winooski River watershed, documented during the summer of 2011. Results from a survey of 3% of the unpaved road network within the Winooski watershed are extrapolated to the full unpaved road network within the Winooski, using parameters derived from GIS-based topographic and road network data. We compare road estimates derived from this study to annual sediment and phosphorus loads for the Winooski River, estimated from the long-term monitoring program of the *Vermont Department of Environmental Conservation,* to contextualize our estimates of pollutant production from unpaved roads. **Chapter 5** draws on a road erosion inventory on the New York side of the Lake to evaluate applicability of these results to other watersheds of the Lake Champlain Basin. We conclude with a summary and reflections on strategies to reduce pollutant sourcing from the unpaved road network within the Lake's basin.

Chapter 3: Runoff and Pollutant Production during Storm Events on Unpaved Roads in the Mad River Watershed, Vermont

Introduction

Little quantitative data exists to evaluate the runoff and pollutant production dynamics of rural road networks. A recent study conducted in lowland agricultural areas of central New York state documented runoff dynamics and extensive connectivity between the rural road network and the native channel network, underscoring the importance of roads as a conduit for non-point source pollutant transfer (Buchanan, Falbo et al. 2012). The study described in this chapter aimed to document runoff and pollutant (sediment and phosphorus) production dynamics on a suite of rural, unpaved roads in an upland watershed of the Lake Champlain Basin in Vermont. Specific objectives of the study were as follows:

i. quantify the dynamics of runoff, sediment and phosphorus production on a set of roads typical of those located in the rural, upland settings of the Lake Champlain basin,
ii. estimate production raates of suspended sediment and total phosphorus at an annual time scale by scaling up event-based observations, and
iii. place estimates of pollutant production from unpaved roads into a watershed context through comparison to sediment and phosphorus loads for small tributary catchments receiving runoff from roads.

Study Area

This study was conducted in the Mad River watershed of the Winooski River (Figure 1). We selected the Mad River because it is a site of long-term river discharge monitoring by the U.S. Geological Survey, and because the local watershed association has implemented a program of spatially distributed water quality sampling along the river's main stem and at the mouths of its tributary streams.[1] The Mad River, one of seven tributaries of the Winooski River, drains a 370 km^2 (145 mi^2) watershed, encompassing the towns of Fayston, Waitsfield and Warren and parts of Granville, Duxbury, Moretown and Middlesex. The watershed is primarily forested in the uplands, with agricultural lands along the river's floodplain and in some hillside locations. Village centers in Moretown, Duxbury, Waitsfield (including Irasville), and Warren comprise the bulk of impervious areas in the watershed. A network of 454 km (282 mi) of roads traverses the watershed, of which 76% is unpaved.

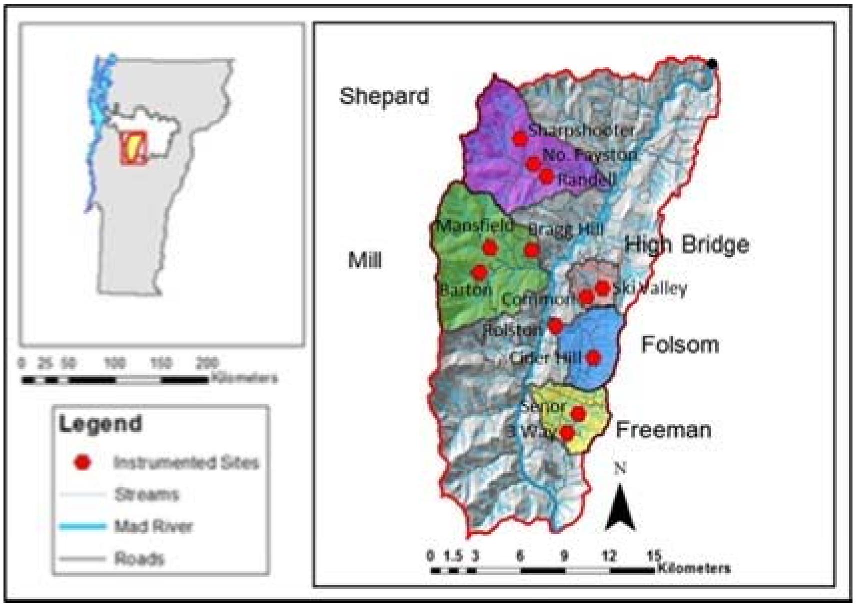


Figure 1: Study area, the Mad River watershed located within the Winooski River watershed in Vermont. Instrumented road sites are shown as red dots. Catchments within which road sites are located are shown as shaded polygons. USGS gage at Moretown (04288000) shown as black dot.

[1] The Friends of the Mad River water quality sampling program is described (and data archived) at http://www.friendsofthemadriver.org/index.php?module=pagesetter&func=viewpub&tid=2&pid=18&topic=8

Methodology

Site Selection, Instrumentation, and Maintenance

Road segments were selected for study in consultation with town road officials. Our criteria for selection included road segments that had an unobstructed culvert inlet for situating monitoring equipment and an outlet with sufficient clearance to allow the placement of a bucket to collect discharge. We attempted to select roads with minimal evidence of subsurface flow interception along the road cut, in order to isolate runoff from the road surface, though this proved to be difficult as evidenced at some sites (Appendix 1). At each selected road segment, a double v-notch weir constructed of 3 mm thick aluminum plate was affixed to the culvert inlet to create a known inlet geometry and to allow for better depth resolution on low flows (Figure 2, Figure 3). A pressure transducer and suction strainer were placed approximately 2 cm above the ground surface in front of the weir and connected to an ISCO model 6712 automated water sampler. Water levels were recorded at 10 minute intervals and checked at least bi-weekly and typically more frequently during field visits. At some sites, sediment deposition during storm events caused the pressure transducer and strainer to be buried, resulting in a loss of data for the event. In these cases, deposited material was removed at regular site servicing intervals to restore the inlet geometry to a consistent form.

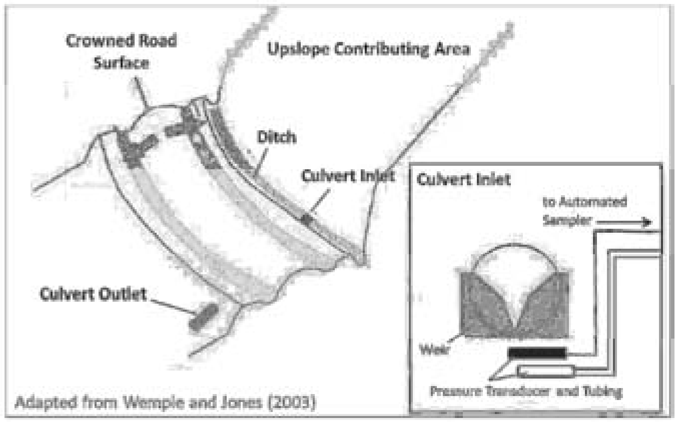


Figure 2: Schematic diagram of a study road segment showing road surface and adjacent hill sides. Inlet diagram shows culvert inlet with equipment installed for monitoring. See also Figure 3.

At each site, a program embedded on the auto sampler triggered sample collection when the water level reached 2 cm above the base of the weir inlet and repeated sampling at half hour or longer intervals until the carriage of 24 sample bottles was filled or the flow had fallen to below the weir base. At each sampling interval, two 1000 mL bottles were collected to be delivered to the Agricultural and Environmental Testing Laboratory (AETL) at the University of Vermont (UVM) for analysis of total suspended solids and total phosphorus. Sampling intervals were fine tuned in the field, based on observations of typical storm length and the length of runoff at each of the instrumented segments.

Figure 3: Photos showing (upper left) installation of double v-notch weir and suction strainer at culvert inlet and (right) flow over the weir during a storm event.

Precipitation was measured at each site using a Taylor® ClearVu® series 2700 rainfall collector to determine the total rainfall depth over an event. At the 3-way, Ski Valley, Bragg Hill, Sharpshooter and Randell Road sites, a Hobo (Onset Corp) model RG3 tipping bucket rain gage was installed to measure instantaneous precipitation rates, resolved to 0.25 mm (0.01 inch) increments.

Rating curves used to convert water level ("stage") at the weir inlet to discharge were constructed by catching flow at the culvert outlet in a set of graduated cylinders and collector buckets ranging in volume from 1 to 19 L (1 quart to 5 gallons). Each stage measurement was achieved by three replicates of timed collections averaged to estimate the discharge rate (volume/time). A regression of stage vs. discharge was constructed for measurements taken at stage values < 10.1 cm. For stage values ≥ 10.1 cm, the regression relation developed by Wemple and Jones (2003) using an identical weir design was used, due to the small number (n=9) of field measurements obtained at these higher water levels.

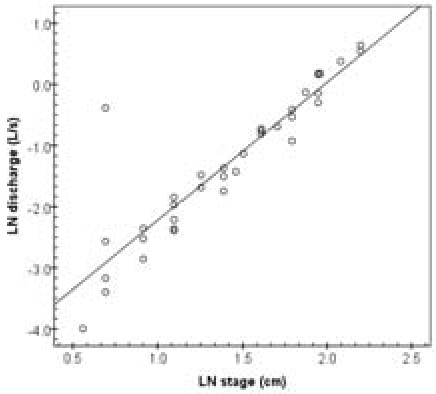


Figure 4: Stage-discharge regression for measurements made at stage values < 10.1 cm. Equation for fit is Y = -4.483 + 2.259 X, where X is the natural log of the stage, measured in cm, and Y is the natural log of the discharge, measured in L/s (R^2 = 0.823)

Sample retrieval and regular site maintenance occurred at least bi-weekly and typically following each storm. During each site visit, field technicians recorded the depth of rainfall the auto samplers and tipping bucket rain gages were downloaded to a laptop computer used for the project and archived to the UVM network for data security.

Sample Processing

Water quality analyses were conducted using standard methods in the AETL at UVM. Total suspended solids were measured on 1-L samples filtered through 1.5 µm fibreglass filters and oven dried overnight at 105 ◦C. Samples were processed for total phosphorus (TP) in the laboratory using a persulfate digestion (4500-P B) and automated colorimetric analysis with ascorbic acid reduction on a Lachat QuickChem AE 8000 (Hach Inc., Loveland CO) flow injection autoanalyzer (4500-P F). Only a subsample of the water quality samples that could be collected and returned to the lab for processing within 24 hours of collection were processed for soluble reactive phosphorus (SRP), after filtration through 0.45µm membrane filters, using method 4500-P F. [2]

Site and road network characterization

Field measurements, photographs, and GIS data were used to develop site characterizations. A schematic map of the road surface area and ditch-line contributing to each instrumented culvert was constructed from measurements and drawings in the field. These schematic maps were used estimate contributing road length and contributing area for discharge and pollutant production analysis. A clinometer was used to estimate road grade. Maps for each site were made using the USDA NAIP imagery and the Vermont Agency of Transportation roads layer (TransRoad_RDS) acquired from the Vermont Center for Geographic Information (VCGI) data data portal (http://vcgi.vermont.gov)[3]. Site descriptions, photos and maps are given in Appendix 1.

To characterize the full road network in the catchments in which our study sites were located and provide a basis for scaling up site observations, we conducted a set of spatial analyses using ArcGIS, with spatial data accessed through VCGI. The Vermont Agency of Transportation road layer (TransRoad_RDS) and bridges and culverts layer (TransStructures_TRANSTRUC) were used to determine road length and culvert locations in each subcatchment in which our monitored road sites were located. Stream crossing culverts were determined through overlay of the culvert layer with the detailed (1:5000) stream network from the Vermont Hydrography layer (WaterHydro_VHD). The Vermont Hydrologically Corrected Digital Elevation Model (ElevationDEM_VTHYDRODEM), which has a nominal grid cell size of 10m, was processed at the Central Vermont Regional Planning Commission using the ET Geowizard Tool to determine elevations along the road network segmented into 120m

[2] Methods cited from Standard Methods for the Examination of Water and Wastewater, APHA, 19th edition, 1995.
[3] All data layer names given in parentheses refer to names posted on the VCGI dataware site, accessed January 28, 2013.

intervals. Road grade was computed as the difference between maximum and minimum elevation along the road segment, divided by segment length.

Road network connectivity was assessed through an analysis of culvert spacing, culvert type and proximity to streams (Figure 5). For each study catchment, we determined the total number of culverts and divided the total road length by culvert number to estimate average culvert spacing. We estimated connected road length as the product of the total number of stream crossing culverts and two times the average culvert spacing (assuming that road segments on both sides of the stream crossing discharge to streams). We further assumed that cross drain culverts located within 50 m of a stream are hydrologically connected to the stream network, through overland flow discharged at the culvert outlet or through an eroded gully below the outlet, based on our field observations (see Results). We determined the number of cross drains within 50 m of a stream using the ArcGIS NEAR function to streams and estimated this connected road length as the product of the total number of cross drain culverts within 50 m of a stream and the average culvert spacing.

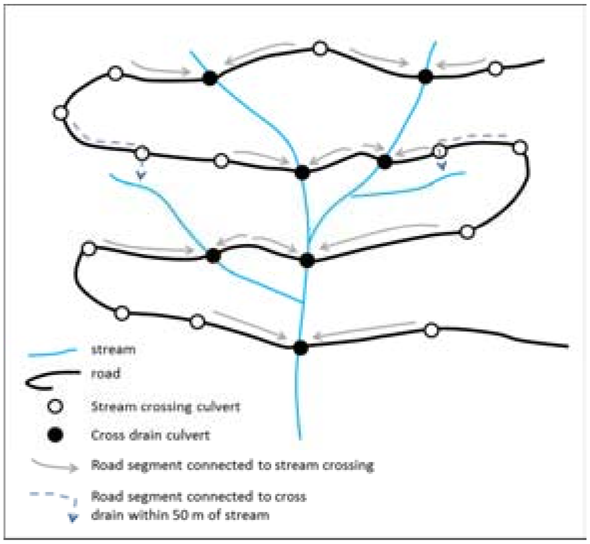


Figure 5: Conceptual diagram of road and stream networks, culverts and connectivity of roads to streams.

Estimation of Pollutant Loads from Unpaved Roads

Estimation of suspended sediment yielded from unpaved roads was accomplished by scaling estimates for event-based observations at each site to the unpaved road network in selected catchments of the Mad River valley (Figure 1). For each storm event for which three or more water quality samples were collected at a site, an *event mass flux of suspended sediment* ($\dot{m}_i$) was computed from continuous discharge (Q) and available TSS concentration (c_{TSS}) data by multiplying concentration by discharge integrated over the storm event and normalizing by the event rainfall depth (r_{event}) and road segment length (l_{road}) for the site as follows:

$$\dot{m}_i = \frac{\int_{t=1}^{t=n} c_{TSS} Q}{r_{event} \times l_{road}} \tag{3.1}$$

where the subscript i refers to the road segment or "site". For all monitored events for which equation (3.1) could be computed, the value of the event mass flux for each site ($\dot{m}_i$) was scaled to an *annual site-estimate of sediment flux* ($\widehat{m_i}$) by multiplying by the average annual precipitation total (R_{annual}) for the Mad River valley, assumed here to be 102 cm (40 inches)[4] as follows:

$$\widehat{m_i} = \dot{m}_i \times R_{annual} \tag{3.2}$$

This approach scales flux estimates from individual events at each site to an annual flux estimate at the site. Variability in these annually-scaled estimates at a site likely reflect other unquantified controls on erosion and sediment production, including storm intensity, antecedent conditions, traffic levels, and vegetation establishment in the ditch. This approach, however, captures a broad range of runoff conditions associated with storm events that span the spring, summer and fall seasons. To capture this range of conditions, we calculated a mean of the estimates from Eq. 3.2 for each site and used the site mean to develop a regression model relating mean mass sediment production to road grade. The regression model was then applied, within the GIS, to calculate sediment flux from the entire road network within the studied catchment, using the ET Geowizard estimates of road grade to predict sediment flux from every road segment. We also used the regression model results to predict 95% confidence intervals on sediment flux from road network segments, in order to establish uncertainty bounds on our estimates.

[4] Annual precipitation total taken from PRISM estimate of mean annual rainfall for Mad River valley, generated by the National Weather Service, Burlington station. Available at http://www.nws.noaa.gov/climate/local_data.php?wfo=BTV . Accessed January 28, 2013.

Estimation of total phosphorus (TP) yielded from unpaved roads was accomplished by multiplying the catchment annual mass production of sediment (expressed as kg/yr) by the median concentration of phosphorus per unit mass of solids (mg/kg).

Estimation of Pollutant Loads from Catchments

Water quality samples collected bi-weekly during the summer period between 2006 and 2012 by the Friends of the Mad River (FMR) were used to characterize pollutant concentrations for streams draining the catchments in which road sites were located (Figure 1). Because FMR measures turbidity, rather than TSS concentration in their monitoring program, we collected 18 samples over a range of turbidity conditions at the mouths of the five catchments in which our road sites were located. We used these samples to develop a turbidity-TSS relationship (Figure 6) and converted the turbidity data in the FMR dataset to estimates of TSS concentration.

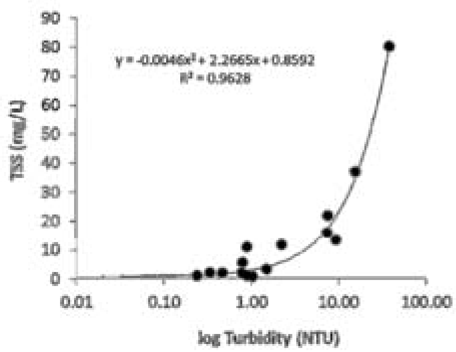


Figure 6: Plot of $\log_{10}$ Turbidity vs concentration of total suspended solids for samples collected at Mad River tributaries.

Mean annual loading estimates for suspended sediment and total phosphorus for the catchments were generated by Eric Smeltzer of the Vermont Department of Environmental Conservation using the U.S. Army Corps of Engineers FLUX program (Walker 1987; Walker 1996). FLUX was used to estimate log-log concentration-discharge relationships for suspended sediment and total phosphorus for each catchment, using daily discharge values at the Mad

River gage at Moretown (station # 04288000)[5] on the date of sample collection, scaled by watershed area, to approximate discharge at the (ungaged) catchments. Loading estimates were then derived by applying the regression models to area-weighted discharge estimates for the catchments. Uncertainty in loading estimates was quantified using the FLUX generated coefficient of variation on the estimates, to produce an approximate upper and lower 95% confidence interval on the mean annual loads.

Results

The sites monitored for this study included roads typical of back roads in rural Vermont. Sites were situated in both forested and agricultural settings with gradients ranging from 1.5 to 15% (Table 1), with drainage ditches that divert flow to adjacent hillslopes and streams (Appendix 1). All of the road segments we studied are actively maintained by town road crews in Fayston, Waitsfield and Warren.

The five catchments in which the monitored road segments were located range in size from 8.64 km^2 to 49.82 km^2 and have road densities ranging from slightly less than 1 km/km^2 to over 2 km/km^2 (Table 2). In all but High Bridge Brook, road density is less than natural drainage density. Average culvert spacing among all five catchments is about 250 meters (823 feet). A portion of the road network in these catchments is directly connected to receiving waters through ditches that drain to stream crossing culverts. An additional portion of the road network drains to cross drains, which discharge to receiving waters under high flow conditions or when gullies are eroded at culvert outlets. During field inspections, we frequently observed gullies at cross drain outfalls, particularly when the outfall was within 50 m of a nearby stream. This phenomenon has been well documented elsewhere (Wemple, Jones et al. 1996; Croke and Mockler 2001). GIS analysis of the road network to quantify road-stream connectivity indicates

[5] Data are available at http://waterdata.usgs.gov/nh/nwis/uv/?site_no=04288000&PARAmeter_cd=00065,00060,72020, last accessed January 28, 2013.

that between 33 and 75% of the road network in the study catchments is connected to streams via stream crossing culverts and cross-drain culverts within 50 m of streams (Table 2).

Runoff and water quality monitoring at sites selected for this study covered a range of storm conditions throughout the study period. Monitoring began at the six sites on the east side (Warren, Waitsfield) of the Mad River valley in mid-July, 2011 and continued through mid-August, 2011 when we began monitoring at five sites on the west side (Fayston) of the valley (Table 1). During mid-spring of 2012, we reoccupied four sites (3-way, Cider Hill, Bragg Hill and Barton) to capture a record indicative of spring conditions and added a 12th site at Randell Road. During the study period, we collected 474 samples for analysis of total suspended solids, ranging from 120 samples at the Senor Road site, where seepage along the road cut sustained runoff for long periods of time to only four samples at the Randell Road site, where sampling was ceased shortly after set up due to town concerns that our equipment would cause the culvert to fail during the intense storms that occurred that summer.

During storm events, peak runoff rates tended to scale with road length (or contributing drainage area, see Appendix 1), and suspended sediment concentrations tended to scale with road gradient. For example, during the 10/14/2011 – 10/21/2011 events monitored at five sites on the west side of the valley, peak discharge ranged from nearly 6 L/s on the 240 m segment of Barton Road to less than 0.5 L/s on the 27 m segment of No. Fayston Road (Figure 7). Despite its shorter length, suspended sediment concentrations on the 12% grade segment of Mansfield Road exceeded concentrations on the 8% grade segment of Barton Road. Concentrations of TSS on No. Fayston Road, the lowest gradient segment (2.5%) monitored during this event, were the lowest among the monitored sites.

Table 1: Record of storms at 12 monitored road sites for which water quality sampling occurred. First six sites are located on east side of Mad River valley in Waitsfield and Warren. Second six sites are located on west side of valley in Fayston. Cell values are numbers of samples collected for analysis of TSS. Bold values are samples used for estimates of event loads. Some storm events excluded from load analysis due to insufficient number of samples collected or suspected errors in site discharge record.

site:	**3Way**	**Senor**	**Rolston**	**Cider Hill**	**Common**	**Ski Valley**	**Mansfield**	**No Fayston**	**Barton**	**Bragg Hill**	**Sharpshooter**	**Randell**
road grade (%):	8	1.5	12	13	1.5	10	12	2.5	8	9	9	15
sampling date												
7/18/11	**4**											
7/25/11	**3**											
8/8-8/10/11		**11**	**6**			**11**						
8/15/11		**24**				**12**						
8/16/11		11				**11**						
8/21-8/22/11		**11**	**4**			**12**						
8/25/11		**10**				**5**						
8/28/11	1	11	1	**12**	**8**	**9**						
8/30/11					8							
9/5-9/6/11		**12**										
9/7-9/8/11		**12**			**8**							
9/9-9/10/11		11										
9/12-9/13/11		5										
9/15-9/16/11						4						
9/24-9/25/11						10						
10/1-10/2/11							**3**	**5**			**4**	
10/13-10/14/11	1	1	1	1		1	**3**	**6**	**7**	**7**	**9**	
10/15-10/16/11									13	3		
10/17-10/18/11							**6**	1		**6**	1	
10/20-10/21/11								**4**	3		1	
10/24-10/25/11									**4**		**4**	
11/30/11	1	1		1			1				1	
4/22-4/23/12	**14**			**3**								
4/24/12	**7**											
4/26-4/27/2012	**10**			**6**								
5/1-5/2/12	**12**			**12**								
5/3/12	**8**											
5/8-5/9/12				**10**								
5/15/12	**13**											
5/30/12	2											
6/2/12	**9**											
6/28/12												**4**
7/17/12										9		
7/23/12	3								**4**	1		
samples collected	88	120	12	45	24	75	13	16	31	26	20	4
no. storms with 3+ samples	9	10	2	5	3	8	3	3	5	4	3	1
no. storms used to calculate flux	9	6	2	5	2	6	3	3	3	2	3	1

Table 2: Characteristics of the study catchments and road network used to estimate road-stream connectivity.

	Folsom	Freeman	High Bridge	Mill Brook	Shepard	average
catchment area (km^2)	18.2	16.96	8.64	49.82	44.61	
stream length (km)	43.3	41.5	18.7	88.1	86.7	
drainage density (km/km^2)	2.38	2.45	2.16	1.77	1.94	2.14
percent of watershed in forest	78.5	73.6	62.2	84.4	91.3	
percent of watershed in agriculture	15.2	16.3	22.7	7.1	3.0	
percent of watershed developed [a]	5.1	8.9	13.5	6.4	3.4	
road length (km)	19.56	30.51	19.88	59.16	37.00	
road density (km/km^2)	1.07	1.80	2.30	1.19	0.83	1.44
mean road gradient (%)	5.95	6.99	7.03	8.15	8.13	
# culverts - all	78	127	81	188	188	
# stream crossing culverts	11	40	16	33	31	
# cross drains w/in 50 m of stream	4	15	11	27	29	
average culvert spacing (m)	250.8	240.2	245.4	314.7	196.8	250.9
average culvert spacing (ft)	822.7	788.2	805.3	1032.4	645.7	823.3
road length connected to stream crossings (km) [b]	2.76	9.61	3.93	10.38	6.10	
road length connected to stream crossings (km) [c]	5.52	19.22	7.85	20.77	12.20	
% road length connected to stream crossings [b]	14.1%	31.5%	19.8%	17.6%	16.5%	19.9%
% road length connected to stream crossings [c]	28.2%	63.0%	39.5%	35.1%	33.0%	39.8%
road length connected to cross drains w/in 50 m of stream (km)	1.00	3.60	2.70	8.50	5.71	
road length connected to stream crossings (both sides) and cross drains w/in 50 m of stream (km) [d]	6.52	22.82	10.55	29.27	17.91	
% road length connected to stream crossings (both sides) and cross drains [d]	33.3%	74.8%	53.1%	49.5%	48.4%	51.8%

[a] includes roads, impervious surfaces and "urban" landcover classes

[b] assumes only one side of road connected to stream crossing

[c] assumes both sides of road connected to stream crossing

[d] assumes both sides of road connected to stream crossing and one side of road connected via cross drain within 50 m of stream

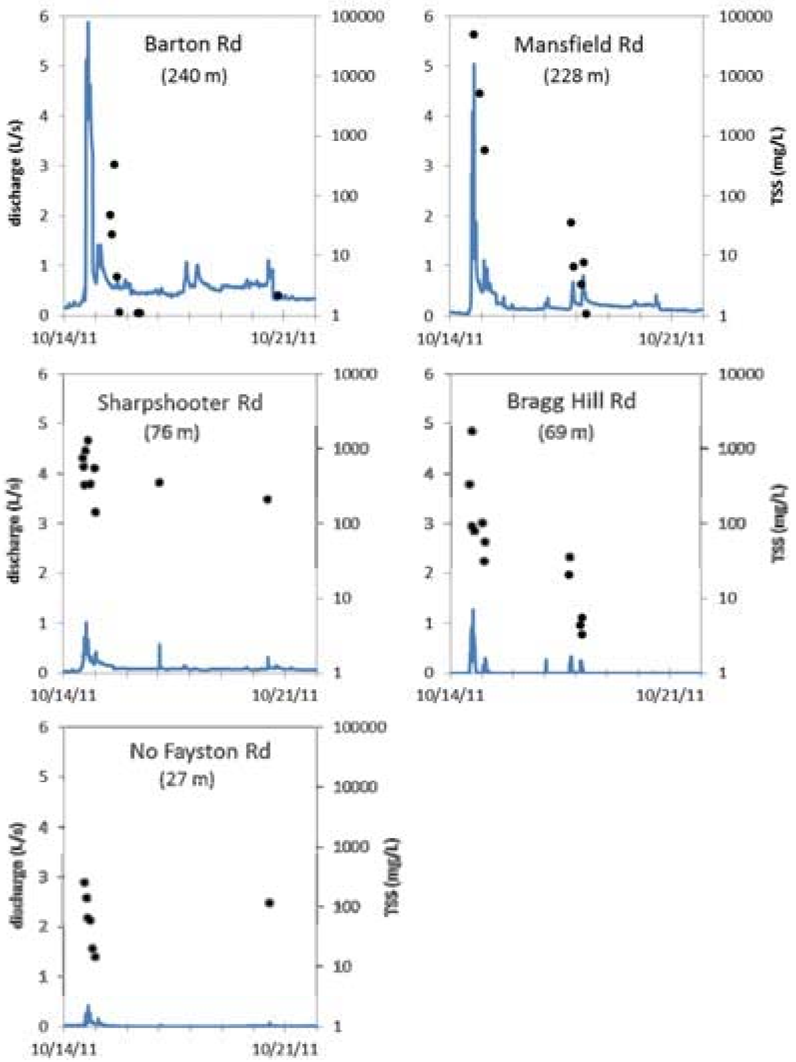


Figure 7: Hydrographs (blue lines) and TSS sample concentrations (black points) for the week of 10/14-10/21/2011 at five sites monitored on the west side of the Mad River valley. Road segment lengths are given in parentheses. Road grade given in Table 1.

Table 3: Suspended sediment loads scaled to annual estimates per unit road length (MT/km/yr) for 12 monitored road sites in Mad River Valley. Cell entries represent values of $\widehat{m_i}$ calculated from Eq. 3.2 and are for events analyzed where three or more TSS samples were available during the event (see Table 1).

site:	3Way	Senor	Rolston	Cider Hill	Common	Ski Valley	Mansfield	No Fayston	Barton	Bragg Hill	Sharpshooter	Randell
road grade (%):	8	1.5	12	13	1.5	10	12	2.5	8	9	9	15
sampling date												
7/18/11	**79.42**											
7/25/11	**68.10**											
8/8-8/10/11		**0.20**	**1.02**			**0.68**						
8/15/11		**0.05**				**0.36**						
8/16/11						**0.78**						
8/21-8/22/11		**0.20**	**6.93**			**10.65**						
8/25/11		**0.06**				**1.57**						
8/28/11				**12.59**	**0.27**	**24.47**						
8/30/11												
9/5-9/6/11		**0.42**										
9/7-9/8/11		**2.72**			**0.60**							
9/9-9/10/11												
9/12-9/13/11												
9/15-9/16/11												
9/24-9/25/11												
10/1-10/2/11							**6.71**	**10.19**			**3.01**	
10/13-10/14/11							**39.38**	**0.37**	**0.05**	**3.21**	**4.17**	
10/15-10/16/11												
10/17-10/18/11							**0.04**			**0.05**		
10/20-10/21/11								**0.14**				
10/24-10/25/11									**0.05**		**0.49**	
11/30/11												
4/22-4/23/12	**596.20**			**0.13**								
4/24/12	**244.04**											
4/26-4/27/2012	**10.61**			**0.14**								
5/1-5/2/12	**3.28**			**0.16**								
5/3/12	**10.70**											
5/8-5/9/12				**6.29**								
5/15/12	**84.08**											
5/30/12												
6/2/12	**8.11**											
6/28/12												**0.63**
7/17/12												
7/23/12									**24.20**			
number of events analyzed	9	6	2	5	2	6	3	3	3	2	3	1
mean	122.73	0.61	3.98	3.86	0.43	6.42	15.38	3.57	8.10	1.63	2.56	0.63
median	68.10	0.20	3.98	0.16	0.43	1.18	6.71	0.37	0.05	1.63	3.01	0.63
standard deviation	192.93	1.04	4.18	5.56	0.24	9.68	21.06	5.73	13.95	2.24	1.88	

Estimates of annually-scaled suspended sediment flux at the monitored road sites varied considerably both within sites and across sites (Table 3). For example, among the nine events available for analysis at the 3-Way site, annually-scaled estimates of suspended sediment flux ranged from 3.28 MT/km/yr to 596 MT/km/yr. Among the two other most intensively monitored sites, annually-scaled estimates of suspended sediment flux ranged from

0.05 to 2.72 MT/km/yr at Senor Road and from 0.36 to 24.47 MT/km/yr at Ski Valley Road. Among all of the sites monitored, the mean of our estimates of annual suspended sediment flux per unit road length was lowest for the low gradient road segments of Senor Road, Common Road and No. Fayston Road, and higher for steeper gradient roads, though road grade explains only about 35% of the variability in the median estimate of suspended sediment flux from the monitored road segments (Figure 8).

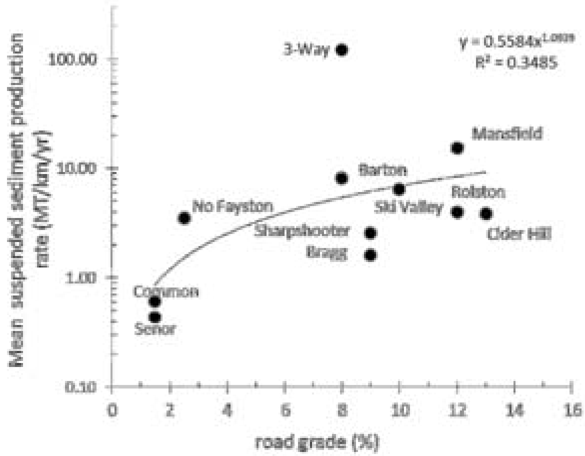
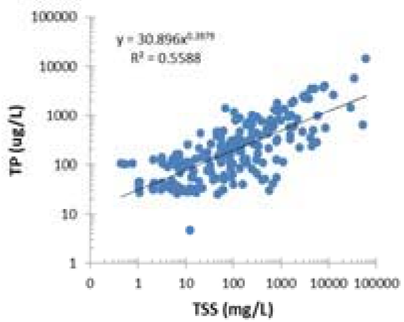


Figure 8: Mean value of the annually-scaled suspended sediment yield estimates (from equation 3.2) for each site vs. road grade. Randell Road site is not shown (only one storm monitored at this site). Regression model without the 3-Way site is $y=0.5128\ X^{0.9683}$.

Phosphorus concentrations in samples collected during storm events were strongly related to TSS concentrations (Figure 9a). Although samples with low TSS concentrations had the lowest concentrations of total phosphorus, the ratio of TP to TSS was inversely and non-linearly related to TSS concentration (Figure 9b). Three samples collected with TSS concentrations < 1 mg/L had TP/TSS ratios exceeding 130 µg P/mg TSS, and 51 samples collected with TSS concentrations between 1 and 10 mg/L had TP/TSS ratios ranging from 10-60 µg P/mg TSS. Among all samples collected, the median ratio of TP to TSS was 2.107 µg /mg.

a



b

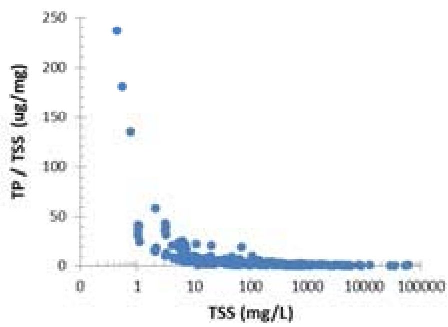


Figure 9: Plots of TP and TSS data collected during storm events at road sites: (a) raw data, (b) ratio of TP to TSS plotted against TSS.

Regression based estimates of sediment production from the road network in the five study catchments of the Mad River range from 75,816 kg/year in Folsom Brook to 330,265 kg/year in Mill Brook. Total phosphorus production estimates, derived from the median P concentration per unit mass of dry sediment in samples collected during storm events, range from 160 kg/year in Folsom Brook to 696 kg/year in Mill Brook. Expressed on a unit area basis, the annual suspended sediment and phosphorus loads generated on roads are highest for High Bridge Brook, the smallest of the catchments for which estimates were generated. Expressed on a unit road length basis, annual pollutant production loads are highest in Mill Brook and Shepard Brook, which have the longest and steepest road networks among the catchments studied.

Sampling conducted by the FMR during the summer season since 2006 provides a picture of water quality variability and average annual pollutant loading. Over the period of record mean suspended sediment and total phosphorus concentrations have been lowest in Mill Brook and Shepard Brook in Fayston and highest in High Bridge Brook in Waitsfield (Figure 10). Modeled estimates of pollutant fluxes using these monitoring data indicate annual suspended sediment loads ranging from 767 metric tons per year in Folsom Brook to over 1213 metric tons per year in Mill Brook and annual total phosphorus loads ranging from 539 kg/year in High Bridge Brook to 2328 kg/year in Mill Brook (Table 4). When expressed on a unit area basis, the annual loads of both suspended sediment and phosphorus are lowest for the mostly forested Mill Brook and Shepard Brook and higher in the more developed catchments where agriculture represents a larger share of the land cover (Table 2).

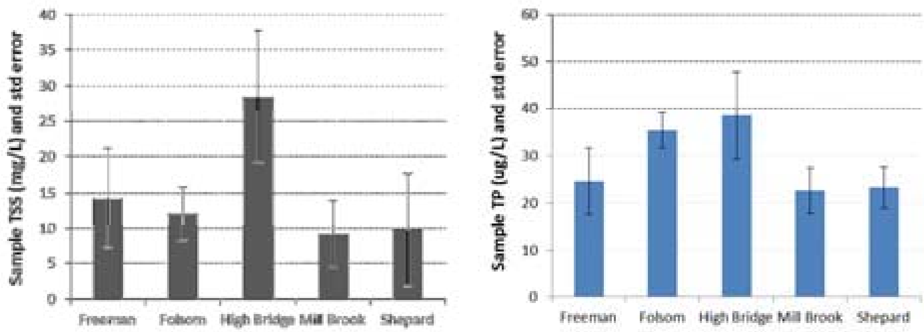


Figure 10: Mean (and standard error) of TSS and TP concentrations for water samples collected on five tributaries of the Mad River (data from *Friends of the Mad River*). Sample size ranges from 35 samples for Mill Brook to 41 samples for Folsom and Shepard Brooks.

A comparison of pollutant fluxes derived from unpaved roads to estimates from tributary streams provides context for assessing the importance of unpaved roads in pollutant production. Our estimates indicate that unpaved roads generate between 10-27% of the sediment load yielded, on average, annually and between 11-36% of the total phosphorus load yielded, on average, annually from the study catchments (Figure 11). Across the five study catchments, these ranges average to sediment production rates on roads that are 17% (6120/35759 kg/km^2/year) of that yielded by streams draining these catchments and phosphorus production rates on roads that are 28% (15/54 kg/km^2/year) of that yielded by streams draining these catchments. It should be noted that the uncertainty bounds for both road estimates and stream estimates are quite large (Table 4), owing to high variability and small sample size, and that our connectivity estimates suggest that only half (51.8%) of the pollutant mass produced on roads is likely discharged into receiving waters (Table 2).

Table 4: Summary of modeled estimates of total suspended sediment (TSS) and total phosphorus (TP) from roads and catchments. Uncertainty bounds are expressed as upper (U95%) and lower (L95%) nine-five percent confidence limits (not available for P estimates on roads).

	Folsom	Freeman	High Bridge	Mill	Shepard	average[a]
Catchment Area (km^2)	18.2	16.96	8.64	49.82	44.61	
road length (km)	19.6	30.5	19.9	59.2	37.0	
road TSS production (kg/yr)[b]	75816	145054	90664	330265	204212	
road TSS production L95% (kg/yr)[b]	3209	6060	3821	13513	8387	
road TSS production U95% (kg/yr)[b]	1812657	3504178	2171538	8228880	5023325	
road TSS production ($kg/km^2/yr$)	4166	8553	10494	6629	4578	6120
road TSS production (kg/km/yr)	3876	4754	4560	5582	5519	5093
Road TP production (kg/yr)[c]	160	306	191	696	430	
Road TP production ($kg/km^2/yr$)	9	18	22	14	10	15
Road TP production (kg/km/yr)	8	10	10	12	12	10
Catchment TSS Load (kg/yr)[d]	767172	1140555	796668	1213521	1024999	
Catchment TSS Load L95%[d]	135600	301832	137777	238622	99928	
Catchment TSS Load U95%[d]	4340353	4309901	4606569	6171400	10513835	
Catchment TSS load ($kg/km^2/yr$)	42152	67250	92207	24358	22977	35759
Catchment TP Load (kg/yr)[d]	1399	1306	539	2328	1880	
Catchment TP Load L95%[d]	535	299	279	1347	132	
Catchment TP Load U95%[d]	3660	5710	1041	4023	26883	
Catchment TP load ($kg/km^2/yr$)	77	77	62	47	42	54

[a] Computed as sum of road load for all five catchments divided by sum of catchment area or road length for all five catchments

[b] Estimate generated using regression model in Figure 7 applied to all road segments in catchment to predict sediment load (yield) and upper and lower 95% confidence limits on prediction

[c] Estimate generated using TSS load estimates and coefficient for concentration of P per unit mass of sediment (no confidence limits for predictions available)

[d] Estimate generated by Eric Smeltzer, Vermont Dept of Environmental Conservation, using monitoring data provided by Friends of the Mad River

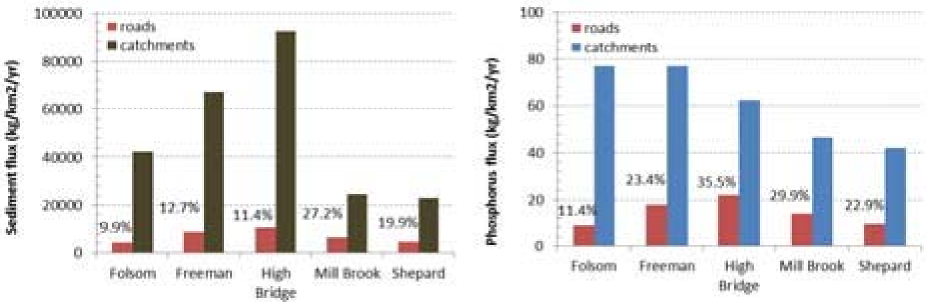


Figure 11: Comparison of pollutant loads from unpaved roads (red bars) and tributary streams for suspended sediment (left panel) and total phosphorus (right panel). Estimates are expressed on a unit area basis. Percentage values shown above red bars are estimates of pollutant loads from roads divided by estimates of pollutant loads from catchments (multipled by 100 to express as a percent).

Summary

Intensive storm-based monitoring of a set of 12 road segments in the Mad River valley produced estimates of mean annual suspended sediment flux from roads ranging from less than 1 MT/km/year for the lowest gradient road segments we monitored to over 122 MT/km/year for the most intensively monitored and highly erosive road segment studied. Total phosphorus concentration in samples collected during storm events was positively related to the concentration of total suspended sediments, allowing us to scale sediment fluxes to estimates of phosphorus fluxes. Extrapolation of the unit-length sediment production from monitored road segments to the unpaved road network in five catchments was used to estimate catchment scale sediment production from the unpaved road network averaging 6120 kg/km^2/year (5093 kg/km road/year) and of total phosphorus production averaging 15 kg/km^2/year (10 kg/km road/year). These road-derived pollutant production rates represent 17% of the total suspended sediment yielded, on average, annually and 28% of the total phosphorus yielded, on average, annually from these catchments. We estimate that slightly more than 50% of the sediment and phosphorus eroded from roads in these catchments is likely discharged directly to receiving waters. Uncertainty in these estimates arises from the relatively small sample size of both monitored road sites and on-going water quality samples from streams in the Mad River watershed, and due to the high level of variability in both water quality and pollutant production rates in these systems.

Chapter 4: Identifying the Magnitude of Hydro-geomorphic Impairments and Efficacy of BMPs on Unpaved Roads in the Winooski River Watershed, Vermont

Introduction

This study aimed to identify the type and magnitude of hydro-geomorphic impairments evident on the rural (unpaved) road network in a tributary watershed of the Lake Champlain Basin. Hydro-geomorphic impairments were defined as features evident within the road right of way that exhibited characteristics of an evacuated erosional scar or an accumulated sediment deposit feature. Specific objectives of the study were as follows:

i. develop an inventory of hydro-geomorphic impairments and the application of best management practices through field observations on unpaved roads,
ii. assess factors that explain the occurrence of these impairments through statistical analysis,
iii. evaluate the effectiveness of BMPs in mitigating against hydro-geomorphic impairments on unpaved roads,
iv. estimate road sediment and phosphorus contribution to streams at the watershed scale, and
v. place estimates of pollutant production from unpaved roads into a watershed context through comparison to sediment and phosphorus fluxes at the mouth of the Winooski River.

Study Area:

The Winooski River watershed drains 2753 km^2 (1063 mi^2) at its mouth into Lake Champlain and encompasses all of Washington County, about half of Chittenden County, and parts of Lamoille and Orange County in central Vermont. The Winooski River Basin constitutes the largest tributary watershed to Lake Champlain and includes almost 10% of land area in Vermont. The river has seven major tributaries including the Little River, North Branch, and Kingsbury Branch (or Headwaters) north of the main stem, and Huntington, Mad River, Dog

River, and Stevens Branch south of the main stem. The land cover in the Basin includes about 72% forested land, 12% agriculture, 9% developed land (including rural roads and built up land), and 5% water area. The majority of the land is privately owned, with 75,600 acres (11%) managed by the state and 12,900 acres (2%) managed by the federal government.[6] There are 4162 km (2586 mi) of road in the Winooski watershed of which 2509 km (1559 miles) or approximately 60% are unpaved (Figure 12).

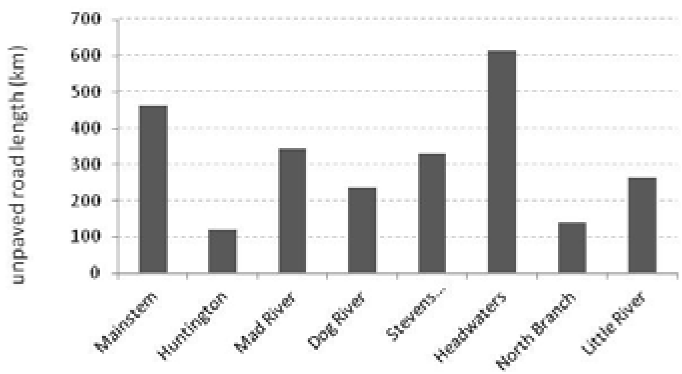


Figure 12: Distribution of unpaved road length in the seven sub-watersheds and main stem of the Winooski River.

Methodology

GIS Analysis

To assess the distribution of roads within the Winooski watershed and select a sample to survey, a geographic information system (GIS) was used. All spatial data were downloaded from the Vermont Center for Geographic Information data portal (http://vcgi.vermont.gov/)[7] between June 1 and July 1, 2011. The Vermont Agency of Transportation road layer

[6] Watershed descriptors taken from http://www.winooskiriver.org/Winooski_Watershed, accessed January 28, 2013.
[7] All data layer names given in parentheses refer to names posted on the VCGI dataware site, accessed January 28, 2013.

(TransRoad_RDS), which included attributes for road class and pavement/surface type, was used for all analyses of the road network. The Vermont Bridges and Structures data layer (TransStructures_TRANSTRUC) was used to identify the location and size of all road culverts. Locations of the stream network were taken from the Vermont Hydrography dataset (WaterHydro_VHD). The 10m Digital Elevation Model (ElevationDEM_VTHYDRODEM, hereafter referred to as “DEM”) was used to represent topography.

The DEM was processed to derive topographic products for analysis and map displays.[8] The standard ArcGIS *HILLSHADE* function was used to derive a shaded relief map of the Winooski watershed for visual display. The ArcGIS *SLOPE* algorithm was used to derive a grid of slope angles for each grid cell of the DEM. The resulting *slope* grid was overlain with the Roads layer to calculate slope steepness across which roads traversed. Road grade was calculated within the GIS by extracting maximum and minimum elevation data (Z- values) for 50-meter road segments along the entire road network using the 10m USGS National Elevation Data (ElevationDEM_DEM10M), then dividing the difference in elevation by road length. The result was a percent grade attribute field for the road layer segments. A binary field to represent steep (>=5 %) roads and not-steep (< 5 %) roads was also created, with values assigned as 1 and 0 respectively.

Hillslope position (ridge, midslope or valley floor) was delineated through a series of DEM-based raster calculations. The ArcGIS *FLOW ACCUMULATION* algorithm was used to derive a grid delineating the upslope contributing area to each grid cell (*flow_accum*). This grid was then used in conjunction with the *slope* grid to derive what has been widely termed a “topographic index”(TI) (Quinn, Beven et al. 1995) as follows:

$$TI = \ln [(\text{flow accum}) / (\text{slope})] \qquad (1)$$

where ln is the natural log transform, taken on the ratio for each grid cell of the flow accumulation value to the slope value. Low values of the topographic index represent areas

[8] All ArcGIS algorithms referred to in ITALICIZED CAPS are documented within the ArcGIS v. 10.0 (ESRI Press, Redlands, CA) software help.

with low contributing area and high slope steepness, positions typical of ridge settings. High values of the topographic index represent areas with high contributing and low slopes, which are typically of valley floor settings. The raster was reclassified based on a geometric distribution with three bins including values between 0-0.1, 0.1-0.3, and 0.3-MAX based visual inspection of the relationship between the index value and the location of ridges, mid-slope, and valley floor positions, respectively, evident on the shaded relief map of the Winooski watershed. These binned values of the TI were subsequently converted to polygon format and recoded to values of 1 representing ridges, 2 representing mid-slopes, and 3 representing valley floors. The Roads layer was overlain with the hillslope position polygons to identify the topographic setting for discrete segments along the entire transportation network within the Winooski watershed (Figure 13).

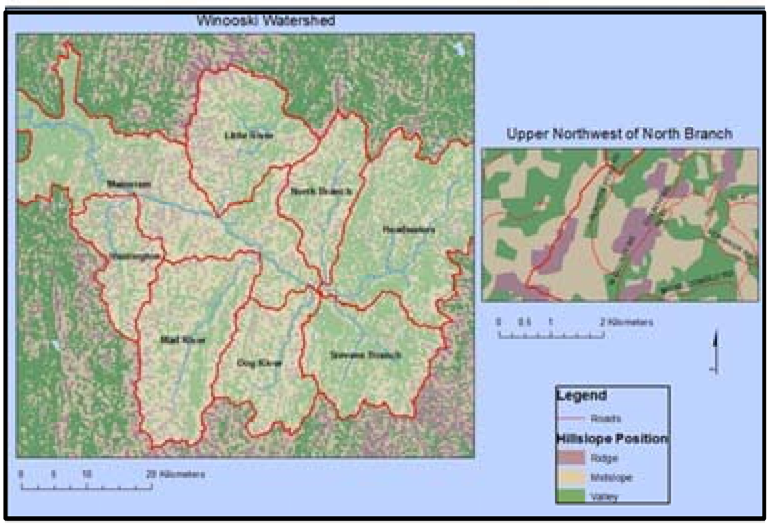


Figure 13: Hillslope delineation for the Winooski watershed with an example road in the upper northwest corner of the North Branch sub-watershed. Roads were coded by discrete segments to annotate hillslope positions they intersect.

Based on the topographic slope position delineations, the Winooski basin road network had 69% of the roads in the valley, about 29% in mid-slope position, and about 1.6% in the ridge line with slight variations across each of the sub-watersheds (Figure 14). Roughly 54% of roads in the basin were classified as steep roads (greater than or equal to 5%) and about 46% are non-steep (less than 5%) (Figure 15). According to attributes in the VTRANS Road layer, 60% of the 4161 km in the Winooski were unpaved at the time of the study.

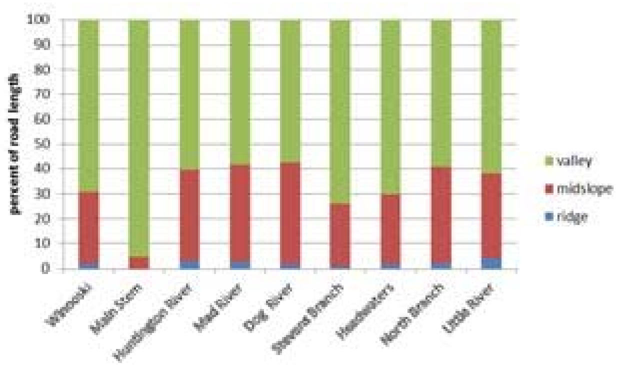


Figure 14: Distribution of road length by slope position in the Winooski watershed and its tributaries.

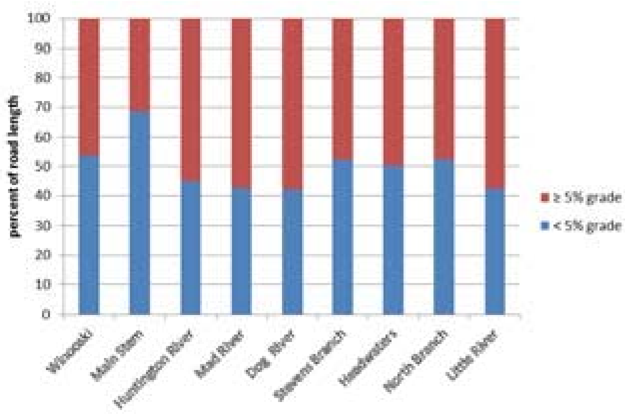


Figure 15: Distribution of road length by grade in the Winooski watershed and its tributaries.

Field Inventory

To develop the methodology for taking inventory of feature types, we conducted preliminary pilot studies over a two-week period from May 23 to June 6, 2011. During this period, we drove and observed unpaved roads taking note of physical evidence of erosion and deposition of sediment along the road right-of-way and photo documenting these features (Figure 16). Past project histories from the Better Backroads program were also reviewed and pilot surveys of these sites were conducted to gain familiarity with the types of hydro-geomorphic impairments evident on unpaved roads and the best management practices (BMPs) employed to mitigate erosion on roads.

The inventory was implemented by selecting Class 3 and Class 4 unpaved road segments of about 2 km (1.6 miles) in length, using a stratified sampling design, by selecting roads proportional to their distribution in the sub-watersheds by [a] hillslope position (valley floor, mid-slope, upper-slope/ridge), and [b] road grade (Table 5). Along sampled road segments, the location and size of hydro-geomorphic impairments were surveyed by walking the length of road with a handheld GPS unit to demark the location of features (Figure 17). Erosional features were coded as locations showing evidence of fluvial (rills or gullies) or colluvial (slumps, slides) transport of sediment. Depositional features were recorded at all culvert inlets with evidence of sediment obscuring at least 10 cm (4 inches) of the inlet. The presence of best management practices (BMPs), including stone lined ditches, rock aprons, stone check dams, log/brush check dams, turnouts, waterbars, riprap conveyance channels, silt fences, erosion control fabric, and retention/ponding areas, were also recorded. BMPs recommended for implementation on Vermont backroads are described in depth in the Better Backroads manual (VBB 2009). Volume parameters (length, average width and average depth of the erosional scar) were measured and recorded for all erosional features and blockage depths of culverts were measured for all depositional features. Location data were recorded for all features using a handheld Trimble® GeoXT GPS unit. Point locations and associated attributes for each surveyed segment were uploaded into a GIS master database, with each surveyed segment representing an observational unit.

All surveyed segments were recorded by a two observers, working either in tandem or alone. Five of the surveyed segments were surveyed by each observer working alone, with results compared to evaluate observer bias. All but five of the surveyed segments were completed between June 30 and August 25, 2011, before Tropical Storm Irene passed over Vermont on August 28, 2011.

Table 5: Strata used in the selection of road segments to survey.

Strata	Class	Comments
Surface	Paved	not used in survey
	Unpaved	60.3% of road length in watershed
Hill slope position	(1) Ridge	See text narrative for methodology
	(2) Mid-slope	See text narrative for methodology
	(3) Valley	See text narrative for methodology
Road grade	Steep	Grade ≥ 5%
	Not steep	Grade < 5%

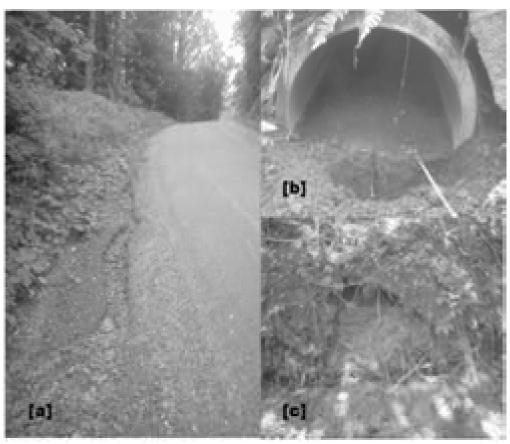


Figure 16: Examples of erosional and depositional impairments on roadways defined as (a) rill or gully incision, (b) plugged culvert, and (c) slump/debris slide.

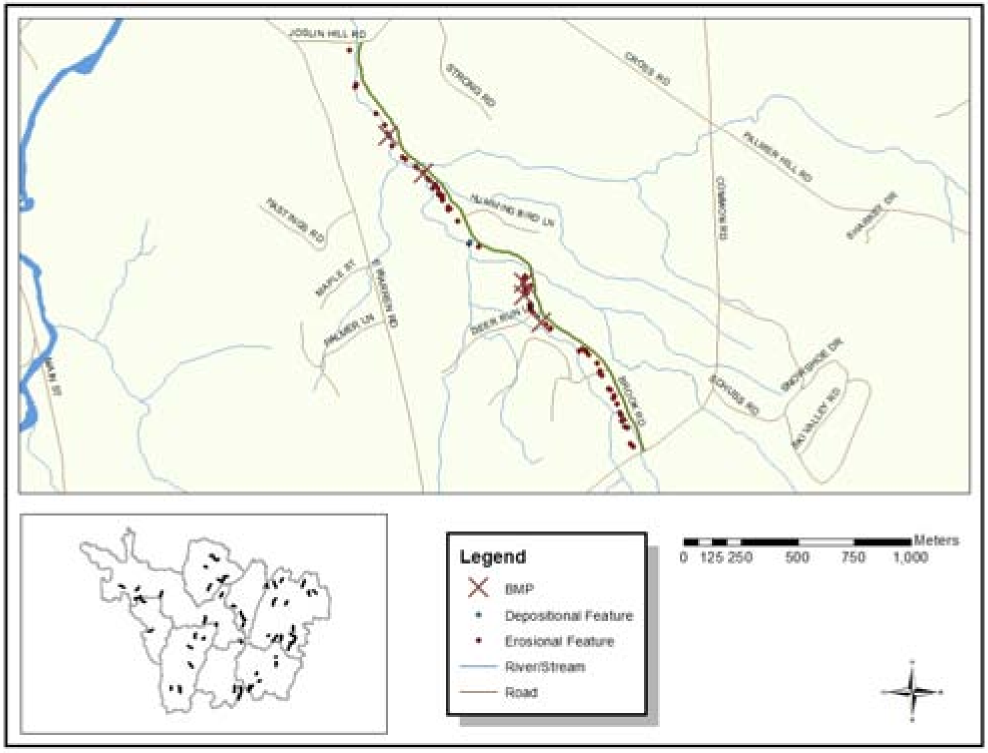


Figure 17: Detail for survey on Brook Road in Waitsfield and location of surveyed road segments (map inset).

Determining mass of sediment and phosphorus eroded from roads

To convert inventoried sediment volumes to mass of sediment and phosphorus, soil samples were collected along roadsides at two hillslope positions (midslope and valley floor) in four different sub-watersheds for a total of eight (8) sites (Figure 18). At each of the 8 sites, 3 samples were collected at the road margin along a gradient from the unpaved driving surface to the native soil of the roadside ditch. These samples were oven dried for 24 hours at 105˚ F and then their dry weight was determined to 0.1 of a gram.   Following oven drying, samples were ground and passed through a 2-mm sieve. Approximately 0.5g of the <2mm fraction was weighed to 0.001g and digested following EPA Method SW846-3051 ("Microwave Assisted Acid Dissolution of Sediments, Sludges, Soils, Oils"). Digests were analyzed for P by ICP-OES (Optima 3000DV, Perkin Elmer Corp, Norwalk, CT, USA).

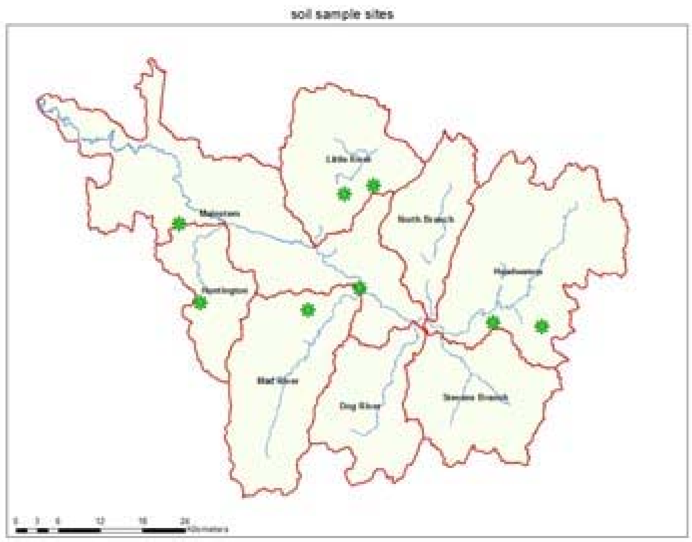


Figure 18: Locations of soil samples taken across 4 different sub-watersheds. 3 samples were taken at each site above.

Mass of sediment eroded from each surveyed segment ($Mass_{road\ sed}$) was estimated as the product of the measured volume (i.e. feature length, width and depth, as described above) of soil eroded from inventoried erosional features (V_r) and the mean bulk density (ρ) of the 24 soil samples collected, normalized by the length of the road surveyed (L_r), as follows:

$$Mass_{road\ sed} = (V_r \times \rho) / L_r \qquad (2)$$

Mass of phosphorus ($Mass_{road\ P}$) in the eroded sediment for each road segment was estimated as the product of the eroded sediment mass ($Mass_{road\ sed}$) and the mean P concentration of the 24 soil samples collected, as follows:

$$Mass_{road\ P} = Mass_{road\ sed} \times c_P \qquad (3)$$

Sediment and phosphorus mass were expressed for each surveyed segment as a mass per unit road length to normalize for varying lengths of surveyed road segments and to provide a basis for scaling surveyed road results to the full unpaved road network.

Connectivity of the road and stream networks were assessed in the manner described in Chapter 3 for the Mad River valley. Across the Winooski watershed, we determined that 19% of all culverts were stream crossings and estimated the road network length connected to streams as two times the average culvert spacing (assuming road segments on both sides of streams discharge to the crossing) times the number of stream crossing culverts. We further assumed that ditch relief culverts within 50m of a stream were hydrologically connected and estimated this length an additional 15% of the road network across the Winooski watershed, based on a GIS NEAR analysis of cross drain culverts to streams in the 1:5000 Vermont Hydrography layer.

Statistical Analysis

Survey data for each segment was organized as three response variables and a set of explanatory variables (Table 6). Response variables represented the frequency and volume (for erosion only) of surveyed features on roads, normalized by the surveyed road length. The explanatory variables were organized into design variables, culvert condition variables, road grade variables, and a set of topographic or gradient variables. Explanatory variables were derived from both field measurements and GIS analysis. A road grade of 5% was used as the break for roads classified as steep and not in compliance with recommended BMPs for stone-lined ditch, if absent, in accordance with recommendations of the Vermont Better Backroads Program (RC&Ds 2009).

Table 6: Variables measured or computed for each surveyed road segment, taken from field or GIS-derived measures (see table footnotes and text)

Response variables	
Erosional frequency[F]	Number of erosional features per surveyed road length
Depositional frequency[F]	Number of depositional features per surveyed road length
Volume eroded [F]	Sum of volume of all erosional features per surveyed road length
Explanatory variables	
Road design	
BMP frequency[F]	Number of BMPs per surveyed road length
Turnout frequency[F]†	Number of turnouts per surveyed road length
Culvert frequency[F]†	Number of culverts per surveyed road length
Percent of road with SL ditch[F]	Measured length of stone-lined ditch divided by surveyed road length
Percent non-compliance[F]	For all roads with grade ≥5% grade, length of road without stone-lined ditch divided by surveyed road length
Culvert condition	
Inlet blockage[F]	Categorical variable: 1 = inlet blockage < 25%, 2 = inlet blockage 25-50%,3 = inlet blockage ≥ 50%
Topographic/gradient conditions	
Road grade[G]	Multiple variables including mean, maximum, standard deviation and mode of grade for 50 meter segments along surveyed length
Dominant grade[G]	Categorical variable coded as 0 = road grade < 5%, 1 = road grade ≥ 5% and taken as mode for 50 meter segments along surveyed length
Percent steep[G]	Percentage of surveyed road length with road grade ≥ 5%
Slope steepness[G]	Average of DEM-derived slope value measured along segments of surveyed road length (measures slope inclination on which road is constructed)
Dominant slope position[G]	Hillslope position (ridge, midslope, valley floor) for longest fraction of surveyed road length

Notes:
[F] Variable measured in the field survey
[G] Variable derived from GIS data for surveyed road segments

† The placement of frequent turnouts and culverts to relieve water from the road are considered best management practices, but calculated separately as variables here to assess their importance in mitigating erosion on roads.

An independent samples t-test was used to determine if there was a statistically significant relationship between the means of the response variables for road segments surveyed independently by the two observers. Analysis of variance (ANOVA) was used compare data across the sub-watersheds of the Winooski.[9] Linear regression analysis was used to examine the relationship between response variables and explanatory variables. For these parametric tests, normality of the variables was assessed using Q-Q plots. Homoscedasiticity (equality of variance across groups) was assessed using Levene's test. Where needed, square root transformations were used to achieve normally distributed datasets and equality of variance across groups. A principal components analysis (PCA) was used to reduce the dimensionality of the explanatory variables. PCA is a multi-variate statistical technique that uses transformations to convert a set of observations of potentially correlated variables into a set of values of linearly uncorrelated variables, referred to as the *principal components*. By definition, the first principal component will explain the greatest share of the variability in the dataset, with each successive component explaining a declining fraction of the variability. Component weighting scores for each independent variable provide a measure of that variable's importance in the derivation of new "axes" of variability in the dataset. Using the results of the PCA, a discriminant function analysis was used to statistically separate low and high erosion frequencies and volumes on surveyed roads.

[9] Data outliers were removed, prior to conducting ANOVA, based on best judgment. East Hill Road (1.25km) was removed due to widely varying results of the two observers, working independently, recorded for this segment. A second outlier, Stony Corners Road (0.92km), was removed because a portion of the surveyed length was determined after the survey to fall on private land, not maintained by town road staff. This was the only unmaintained road in the inventory and the volume evacuated from this section of road was unusually high, positively skewing the dataset.

Results

The field inventory included 52 discrete road segments, totaling 98.4 km (61 miles) and representing 2.2% of the entire road network in the Winooski watershed and nearly 4% of unpaved road network (Table 7). Surveyed segments ranged in length from 0.4-4.5 km (0.3-2.8 miles), with an average length of 1.9 km (1.2 miles). The proportion of road length surveyed in each sub-watershed varied slightly, ranging from 2.8-5.2% of the unpaved road network.

The surveyed segments constituted a representative sample for each sub-watershed. The hillslope position of surveyed roads was similar to the distribution of unpaved roads in the watershed in that approximately 30% of the surveyed roads were in the valley and about 70% were in mid-slope positions (Figure 19). The road grade of surveyed segments was similar to that of unpaved roads in the watershed in that about half the road network had grades greater than or equal to 5% and half the road network had grades less than 5% (Figure 20).

Table 7: Summary road lengths for Winooski River watershed, its tributaries and road inventory (this study).

	Road Length (km)	Unpaved Road Length (km)	Length Surveyed (km)	Percent (%) Unpaved Road Length Surveyed
Mainstem	1230.1	462.5	13.0	2.8
Huntington	152.3	119.4	4.4	3.7
Madriver	453.7	344.4	11.8	3.4
Dog River	344.0	236.7	8.1	3.4
Stevens Branch	644.9	330.2	10.3	3.1
Headwaters	783.5	613.5	31.8	5.2
North Branch	197.0	137.9	6.7	4.9
Little River	356.3	265.1	12.3	4.6
Winooski watershed	4161.8	2509.7	98.4	3.9

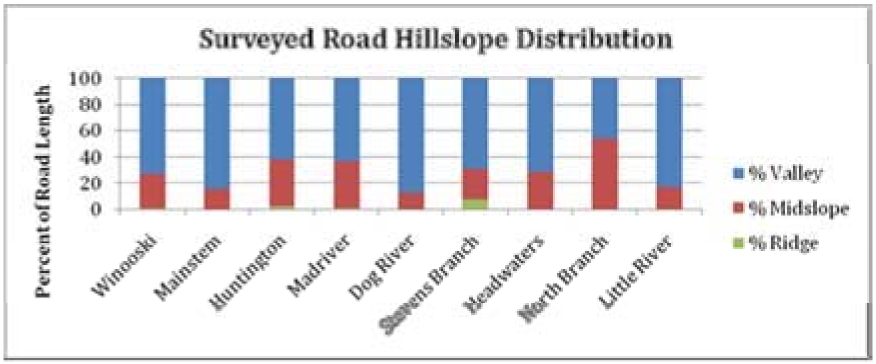


Figure 19: Distribution of surveyed roads by hillslope position. See Figure 14 for distribution of unpaved road network.

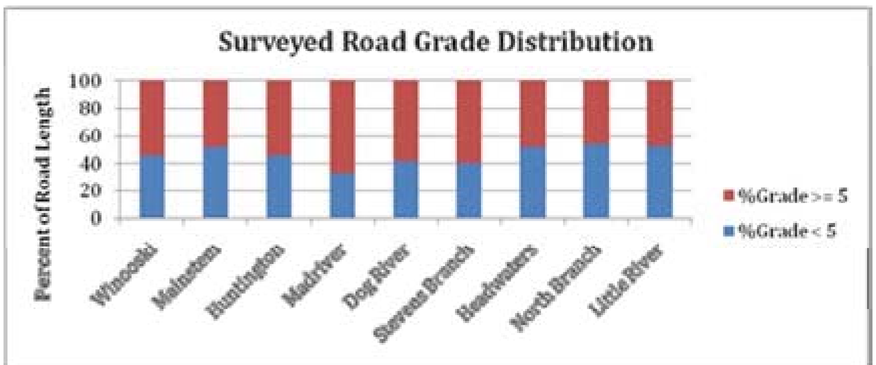


Figure 20: Distribution of surveyed roads by road grade. See Figure 15 for distribution of unpaved road network.

A total of 1,940 hydro-geomorphic impairments were recorded on the 52 road segments surveyed (Table 8). The majority of features (1866, 96%) surveyed were erosional, and occurred between 4 and 87 times per kilometer of road surveyed, with an average of frequency of 21 features per km of surveyed road (Figure 21). These erosional features occurred on the road surface, in ditches, on cutslopes, or on fillslopes with a significantly higher proportion on the road surface (78%). Most of the erosional features in the road right of way were very small in volume, averaging 0.318 ± 0.64 m^3. Many of the individual fillslope erosion features were small in volume as well, averaging 0.24 ± 0.62 m^3. Although there were fewer erosional features recorded in ditches, the average volume was higher (1.66 m^3) than the other erosional features. Depositional features, or culverts that were impaired or plugged by sediment, occurred on average 1.2 times for every two kilometers of road surveyed. Most (46%) of these impaired culverts had more than half of their diameter blocked with sediment and debris, while more than a third (35%) had between 25-50% of their inlet blocked.

There were 609 best management practices recorded on the 52 road segments surveyed. Of these, the most frequently recorded management practice was turnouts (70%), which were recorded in 424 independent locations. The second most frequency management practice was stone-lined ditches (11%). The number of BMPs recorded is shown in Table 9.

Table 8: Erosional and depositional hydro-geomorphic impairments recorded in survey.

Type	Count	Average volume of individual feature (m^3)
Erosional	1866	
-Road surface	1462	0.318
-Ditch	330	1.655
-Cutslope	3	1.583
-Fillslope	71	0.2443
Depositional†	74	
- <25% plugged	14	(n/a)
- 25-50% plugged	26	(n/a)
- >50% plugged	34	(n/a)

† features refer to plugged culverts, where percentage of culvert inlet blocked by sediment is given.

The frequency of erosional features and the length-normalized erosion volume on surveyed roads were related to the average grade of the road segment. As road grade increased, both erosion frequency and volume of material eroded increased exponentially, according to the forms displayed in Figure 22.

Table 9: Best management practices recorded on 52 surveyed road segments

BMP	Count
Turnout	424
Stone lined ditch	64
Rip rap conveyance channel / rock apron	33
Vegetated ditch	28
Erosion control fabric	21
Check dams	13
Water bar	10
Other[1]	16
Total	609

[1] Category "other" included bank stabilization (6), mesh netting in ditch (3), vegetated grass bank (1), logs directing flow of water (1), plastic conveyance at culvert endwall (1), haybale (1), flow directed to retention area (1), and other rock stabilization (2)

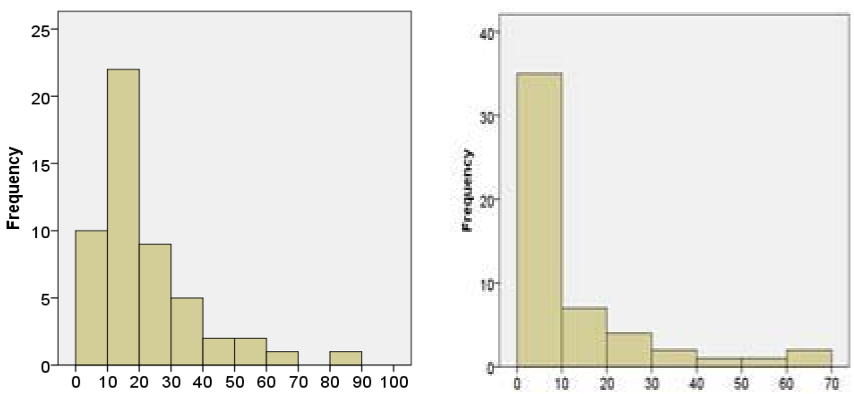


Figure 21: Histograms of (left) erosional feature frequency and (right) depositional feature frequency for the 1866 erosional features and 74 depositional features mapped on 52 surveyed road segments. X-axis on plots is number of features per kilometer of surveyed road.

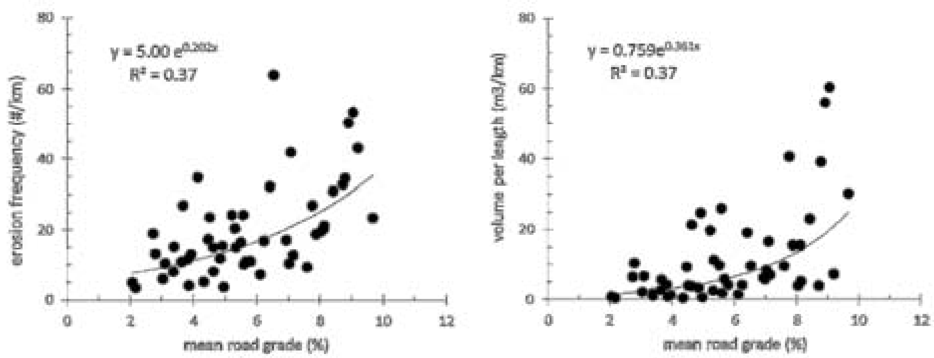


Figure 22: Scatterplots of (left) erosional feature frequency and (right) length normalized erosion volume vs. mean road grade for road segments surveyed.

Among the suite of independent variables we measured in the field and developed in GIS, we found that road grade, measures of slope position, slope steepness and the implementation of best management practices influenced the tendency for erosion to occur on roads. Results of a principal components analysis (PCA) indicated that nearly 70% of the variability in erosional frequency measured on the 52 surveyed road segments could be explained by four new variables (the components) that represent combinations of the original independent variables (Table 10). The first component, which explains 32% of the variability in erosion frequency along inventoried roads is most strongly related to measures of road grade, and to a lesser extent to measures of slope steepness on which the road is situated and to the percentage of the road in compliance with recommended practices for stone-lined ditching. The second component, explaining 15% of the variability in erosion frequency, is related to slope position and slope angle on which roads are constructed. The sign on the weighting scores provides additional insight. The negative score associated with maximum and mean slope suggests that roads on lower gradient slopes had higher erosion frequencies than those on steeper slopes, a finding that supports the notion that as water accumulates near the base of a hillslope profile, it raises the risk of drainage impacts on roads. This notion is also supported by the positive sign of the slope position variable, where higher rates of erosion would be associated with higher values of slope position. Here, slope position was coded as a categorical variable (1=ridge, 2=midslopes, 3= valley floors). Along the hillslope profile from ridge to valley floor, cumulative flow contributions increase and must be accommodated by roads traversing these settings. The third and fourth components, together explaining about 21% of the variability in erosion frequency, are related to best management practices, including overall BMP frequency, turnout frequency, the percent of roads with stone-lined ditch, and culvert frequency. The negative scores of all but the culvert frequency variable indicate that with lower BMP application, higher rates of erosion frequency occur on roads, a finding that is intuitively meaningful and suggests BMPs provide important mitigation against erosion on roads, but that their effect in this study is masked by other more influential variables. The positive score for culvert frequency here suggests the converse – that higher culvert frequency is associated with higher erosion frequency, but the relation here is probably not causal. It is likely that mid-slope roads with frequent stream crossings and drainage conditions that motivated the placement of more frequent culverts correspond with places along the road network that see high rates of erosion associated with abundant runoff on these roads.

Results of a discriminant function analysis showed that we could correct classify more than 75% of the road segments surveyed, with respect to erosion frequency and volume of material eroded, using the independent variables we measured and derived (Table 11, Table 12). Most of the discriminating power revealed through these analyses was provided by measures of road grade and BMP implementation (Table 13).

Table 10: Component weighting scores (cell values) for principal components analysis of 52 surveyed road segments, using independent variables measured in field or derived using GIS. Colors in table cells are used to draw attention to component weighting scores that are highly correlated to independent variables.

Component number:	1	2	3	4
% of Variance in Erosional Frequency Explained	32.295	15.312	12.032	9.330
BMP frequency	0.381	0.611	-0.568	0.031
Culvert frequency	0.316	0.264	0.708	-0.089
Percent road with stone-lined ditch	0.228	-0.077	0.180	-0.788
Turnout frequency	0.358	0.597	-0.614	0.096
Percent road not in compliance[a]	0.577	0.208	-0.227	0.396
Blockage < 25%[b]	0.539	0.252	0.361	0.415
Blockage 25-50%[b]	0.377	0.269	0.496	0.463

Blockage > 50%[b]	0.022	0.211	0.443	0.205
Mean Grade	0.947	0.082	-0.026	-0.168
Max Grade	0.856	-0.112	0.027	-0.153
Standard deviation of Grade	0.774	-0.205	0.037	-0.310
Dominant Grade[c]	0.817	0.090	-0.055	-0.179
Percent Grade	0.851	0.169	-0.008	-0.118
Mean Slope	0.450	-0.641	-0.081	0.214
Max Slope	0.423	-0.748	-0.231	0.230
Dominant Slope[d]	0.514	-0.397	0.228	0.142
Dominant Slope Position[e]	-0.182	0.589	0.263	-0.226

Notes:

[a] defined as proportion of road with slopes ≥ 5% without stone-lined ditch.

[b] Blockage depth= count of culverts on roads with blockage at culvert inlet defined by < 25% plugged, between 25-50% plugged, and > 25% plugged.

[c] binary variable representing grades ≥ 5% or grades < 5% according to avg. grade measurements.

[d] binary variable representing steep slopes or not steep slopes

[e] hill slope position category for the majority of road length (ridge, mid-slope, valley).

Table 11: Results of discriminant function analysis of erosional feature frequency, where analysis separates those surveyed road segments that fall below ("low") and above ("high") the median frequency among the surveyed segments. Bold values refer to correct classification.

			Predicted Membership		
		Erosional Frequency	low	high	Total
Observed membership	Count	low	**23**	3	26
		high	6	**20**	26
	Percent (%)	low	**88.5**	11.5	100.0
		high	23.1	**76.9**	100.0

Table 12: Results of discriminant function analysis of length-normalized erosion volume, where analysis separates those surveyed segments that fall below ("low") and above ("high") the median frequency among the surveyed segments. Bold values refer to correct classifications.

			Predicted Membership		
		Volume/ Length	low	high	Total
Observed Membership	Count	low	**24**	3	27
		high	4	**21**	25
	Percent (%)	low	**88.9**	11.1	100.0
		high	16.0	**84.0**	100.0

Table 13: Weighted within-group discriminant function correlation scores for erosion frequency (left panel) and length-normalized erosion volume (right panel). Variables contributing to the group discrimination are ordered by weighted score, high to low.

Explanatory Variables (erosion frequency)	Weighted Score
Percent Grade	0.584
Mean Grade	0.564
Dominant Grade	0.439
Percent road not in compliance	0.368
Blockage < 25%	0.28
Standard deviation of road grade	0.245
Max Grade	0.23
Turnout frequency	0.212
BMP frequency	0.211
Dominant Slope	0.197
Blockage 25-50%	0.14
Percent road with stone-lined ditch	0.122
Max Slope	0.077
Blockage > 50%	-0.052
Culvert frequency	0.045
Dominant Slope Position	0.042
Mean Slope	0.011

Explanatory Variables (volume/length)	Weighted Score
Percent Grade	0.459
Mean Grade	0.448
Dominant Grade	0.370
Culvert frequency	0.367
Standard deviation of Grade	0.279
Blockage > 50%	0.273
Max Grade	0.263
Percent road with stone-lined ditch	0.251
Mean Slope	0.215
Percent road not in compliance	0.199
Max Slope	0.193
Dominant Slope Position	0.132
Blockage < 25%	0.172
Turnout frequency	-0.160
BMP frequency	-0.149
Dominant Slope	0.190
Blockage 25-50%	0.033

Survey results compiled at the sub-watershed scale reveal important spatial patterns in erosion on unpaved roads and serve as the basis for scaling up results from the survey to the Winooski watershed. Erosional frequency varied across sub-watersheds of the Winooski, with highest mean erosion frequency and the greatest variability in erosion frequency recorded in the Stevens Branch (Figure 23). Analysis of variance on the square root transformation of erosion frequency (performed to meet ANOVA assumptions) indicated there were no significant differences in this variable across sub-watersheds ($F = 1.02$, $p = 0.432$). The mean volume of material eroded per length of road was highest on those road segments surveyed in the Little River and Mad River sub-watersheds and lowest on segments surveyed in the North Branch (Figure 24). ANOVA on the square root transformation of this variable indicated significant differences in the mean normalized volume of material eroded across sub-watersheds ($F = 4.097$, $p = 0.002$). Tukey's HSD post-hoc test revealed that the Little River and Mad River sub-watersheds had significantly higher mean normalized volume of material eroded, when compared to the other sub-watersheds surveyed ($p < 0.05$). These across watershed differences in erosion volume were correlated to median slope steepness of each watershed, with higher mean erosion volumes recorded on sampled roads occurring in the steeper watersheds of the Winooski (Figure 25).

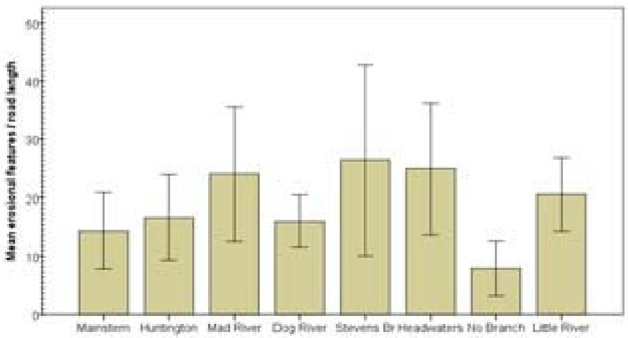


Figure 23: Mean values of erosional feature frequency on surveyed road segments across the 7 sub-watersheds and the main stem of the Winooski River. Error bars are two standard errors of the mean.

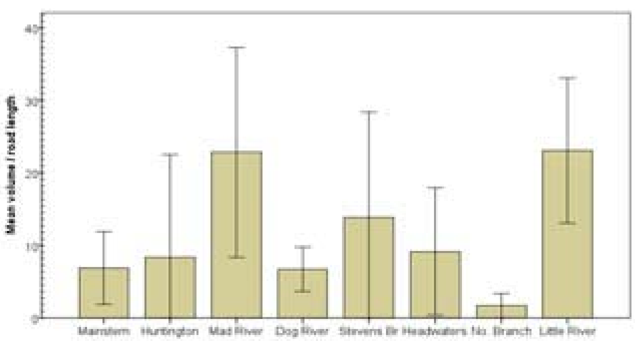


Figure 24: Mean values of the length-normalized erosion volume on surveyed road segments across the 7 sub-watersheds and the main stem of the Winooski River. Error bars are two standard errors of the mean.

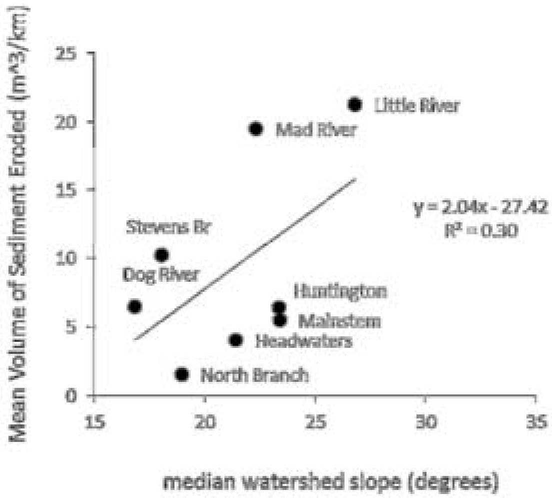


Figure 25: Mean length-normalized erosion volume (Figure 24) vs. median watershed slope seven tributaries and main stem of Winooski watershed

Results for soil samples collected on the roadside margin and in ditches provide additional information needed to estimate the mass of sediment and phosphorus associated with eroded road materials. Bulk density across the eight measured sites varied little, averaging 1731 kg/m^3 (Figure 26). Concentration of total phosphorus ranged from 255 mg/kg at Country Club Road in the No. Branch watershed to 531 mg/kg on Turner Hill Road in the Mad River watershed, and averaged 396 mg/kg across all sites (Figure 27). There was no clear trend in TP concentration across the Winooski watershed from headwaters to mouth. At three of the four sites, TP concentrations were higher on mid-slope sites than on valley floor sites, but this pattern was reversed in the Huntington River watershed.

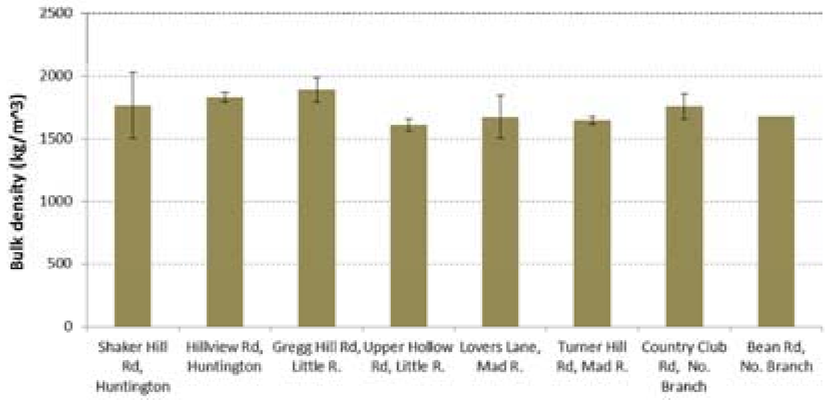


Figure 26: Bulk density estimates for road surface and road side soils collected at eight locations across the Winooski watershed (see Figure 18 for site locations). First bar in watershed pair is valley floor site; second bar is midslope site. Bars are organized from downstream (on left) to upstream (on right) on the Winooski.

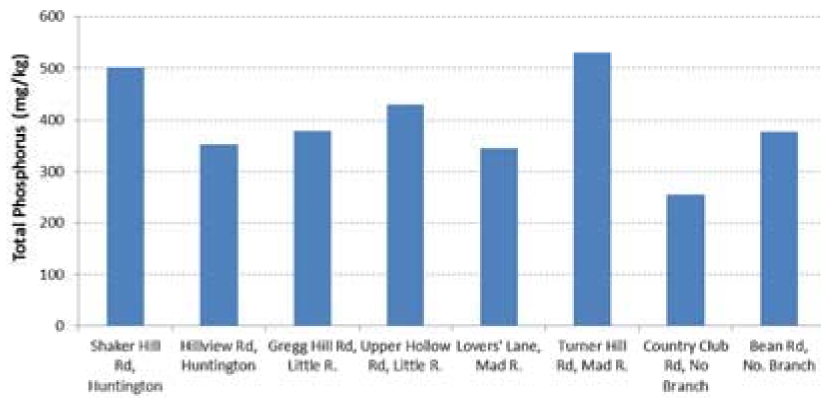


Figure 27: Total phosphorus concentration for road surface and road side soils collected at eight locations across the Winooski watershed (see Figure 18 for site locations). First bar in watershed pair is valley floor site; second bar is mid-slope site. Bars are organized from downstream (on left) to upstream (on right) on the Winooski.

Scaling of the inventory results (expressed as a volume or mass per unit road length) to the road length across the tributary watersheds of the Winooski indicates a mass of eroded sediment in excess of 40,000 metric tons and total phosphorus in excess of 15,000 kg from all unpaved roads in the watershed (Table 14). Summed across the subwatersheds of the Winooski and normalized by road length, these rates of pollutant production on roads equate to 16,080.4 kg/km of sediment and 6.1 kg/km of phosphorus. These production rate estimates are lower for phosphorus and higher for sediment than estimates from storm-based sampling and in the Mad River catchments, though well within the uncertainty bounds of estimates from that study (Table 4).

Although our estimates are not strictly tied to the time over which erosion has occurred, reports from town road crews indicate that at least annual re-grading of the unpaved road network occurs in most towns. This grading activity would create a "clean" road surface, on which new erosional features might emerge in subsequent storms. Assuming at least an annual cycle of road grading, features we inventoried during the summer 2011 would represent those that were eroded since the last road grading occurred. Our survey results should therefore approximate, or perhaps even underestimate (if late summer and fall storms generate additional erosion not captured in our survey), annual sediment and P sourcing from unpaved roads.

Only a fraction of the sediment and phosphorus eroded from roads contributes to waterways, since this material is in some cases stored on receiving hillslopes. We estimate that across the Winooski River watershed 38% of the unpaved road network discharges to stream crossing culverts and 15% of the road network discharges to cross drains within 50 m of a stream. Using these levels of road-stream connectivity, our survey results, extrapolated to the Winooski watershed and expressed as annual rates of pollutant production, suggest that unpaved roads contribute over 21,000 metric tons/year of sediment and over 8000 kg/year of phosphorus to receiving waters. (Table 15).

Despite uncertainties in the time scale represented by the pollutant production estimates captured in our inventory, this study provides at least a first-order estimate of the relative importance of unpaved roads in contributing to sediment and phosphorus discharged from the Winooski River to Lake Champlain. Estimates of annual suspended sediment loads for the Winooski River at the USGS gage, where concentration measurements are made, average slightly more than 130,000 MT/yr, and estimates of TP loads from non-point sources in the watershed average slightly more than 134,000 kg/yr (Table 15). At these levels, sediment production rates on unpaved roads in the Winooski watershed are approximately 31% the annual load of suspended sediment and 11% of the annual load of total phosphorus. Only a fraction (53%, based on connectivity estimates) of these road-derived pollutants are likely contributed directly to receiving waters.

Table 14: Estimates of eroded sediment and phosphorus from unpaved roads for sub-watersheds and the main stem of the Winooski.

Sub-watershed	**Unpaved road length** (km)	**Mean Vol. Sediment per km** (m3/km)	**Estimated Mass of Sediment Eroded** (metric tons)	**Estimated Mass of Phosphorus Eroded** (kg)
Mainstem	462.5	5.55	4443	1693
Huntington	119.4	6.45	1333	508
Mad River	344.4	19.52	11637	4435
Dog River	236.7	6.54	2680	1021
Stevens Branch	330.2	10.21	5836	2224
Headwaters	613.5	4.06	4312	1643
North Branch	137.9	1.51	360	137
Little River	265.1	21.26	9756	3718
Winooski watershed	2509.7		40357	15380

Table 15: Comparison of watershed estimates of suspended sediment and phosphorus with road-derived estimates

	Suspended Sediment (MT/year)	Total phosphorus (kg/yr)
Winooski River watershed †	130,390	134,400
Winooski River unpaved roads ‡		
- maximum estimate (all unpaved roads)	40,357	15,380
- conservative estimate (assuming 53% of road network network connected via stream crossings and cross drains) [a]	21,389	8,151
Percentage of Winooski river load attributable to roads		
- maximum estimate	31%	11%
- conservative estimate	16%	6%

† Estimates taken from Medalie (unpublished) for suspended sediment and from Smeltzer et al. (2009) for total phosphorus.

‡ Estimates taken from this study, see Table 14

[a] See text for methodology used to estimate road-stream connectivity

The results of this study also provide an opportunity to identify "hot spots" of pollutant production from roads. For example, normalizing the unpaved road network distribution and the relative share of sediment mass from unpaved roads to the fraction that each subwatershed contributes to the entire Winooski watershed illustrates that the mainstem, Headwaters, and North Branch together comprise 50% of the unpaved road network in the Winooski watershed and only about 20% of the estimated sediment mass from unpaved roads. In contrast, the steep Little and Mad River subwatersheds together comprise 25% of the unpaved road network in the Winooski watershed and about 53% of the estimated sediment mass from unpaved roads (Figure 28).

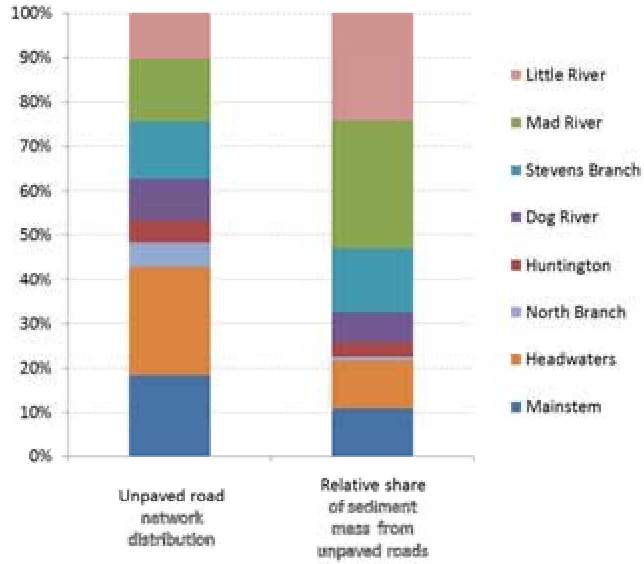


Figure 28: Summary of the distribution of the unpaved road network (left bar) and estimated mass of sediment eroded from unpaved roads (right bar) in the sub-watersheds and the main stem of the Winooski.

Summary

A survey of 52 road segments selected proportional to the distribution of unpaved roads by road grade and slope position was used to document the form and magnitude of hydro-geomorphic impairments and the application of best management practices in the Winooski River watershed. More than 1900 features were inventoried on 98 km of road, largely representing features indicative of fluvial and colluvial erosion of road surface, road-side and ditch materials. The frequency of erosional features was related to the steepness, or grade, of the road and to the absence of best management practices recommended for unpaved roads located in these rural settings. Extrapolation of survey results to the unpaved road network in the Winooski yielded estimates of sediment eroded from unpaved roads in excess of 40,000 metric tons and total phosphorus in excess of 15,000 kg. Assuming these estimates represent an annual contribution of sediment from the unpaved road network, we estimate that the sediment production rate on roads is approximately 31% of the annual suspended sediment load measured in the Winooski and the phosphorus production rate is approximately 11% of the annual phosphorus load on the Winooski. Estimates of connectivity indicate that 53% of the road network is hydrologically integrated with streams, providing a direct conduit for pollutant transfer to receiving waters, and resulting in the delivery of slightly more than half of the pollutant load generated on roads to streams.   Our survey results also identify key areas of the Winooski watershed where reductions in erosion from unpaved roads should yield meaningful water quality improvements and confirm that the suite of best management practices recommended on unpaved roads are effective in reducing pollutant production.

Chapter 5: Evaluating the Application of Study Results to New York watersheds of the Lake Champlain Basin

Introduction

The studies presented in this report provide new insights into the form and magnitude of erosion and pollutant production on the unpaved road network in one watershed (Winooski River) of the Lake Champlain basin. Our results demonstrate that unpaved roads are an important source of sediment and phosphorus for receiving waters. Our findings also highlight the importance of direct connections between the road network and channel network in pollutant transfer and demonstrate the value of BMPs in reducing erosion on road ways. Transfer of these findings to other watersheds of the Lake Champlain Basin should be appropriate where similar topographic settings are occupied by unpaved roads and where similar road construction and maintenance practices are followed. Although a thorough assessment of the application of our findings to other watersheds of the Basin is outside the scope of our efforts, in this chapter we draw on road network data for the New York side of the Basin and on a recent road inventory conducted there to speculate on the broader applicability of our findings within the Basin.

Data Sources

Several sources of transportation data exist for the state of New York. Vector files of public streets compiled from ortho imagery are available through the New York State GIS Clearinghouse (http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=932). The U.S. Census Bureau's TIGER (**T**opologically **I**ntegrated **G**eographic **E**ncoding and **R**eferencing) line files are a widely used source of transportation infrastructure data throughout the U.S. New York's Department of Transportation (DOT) also posts a tabular inventory of roads by county (https://www.dot.ny.gov/divisions/engineering/technical-services/highway-data-services/inventory-listing). This DOT inventory is the only known inventory of NY roads that includes attributes on road surfacing type (paved, not paved) but is far less extensive than the other available transportation network data for the state (Table 16).

In 2012, the Lake Champlain and Lake George Regional Planning Board released an inventory and assessment of roadside erosion for the region (LCLGRPB 2012), providing the best available comparison to the inventory described in Chapter 4 of this report. The LCLGRPB inventory is a comprehensive survey of erosion on the paved and unpaved road network of the region. It ranked features by priority (i.e. need to address impairment and pollutant production), using a set of variables that included the area of exposed soil, slope steepness at the site, level of erodibility, percent vegetation cover, and proximity to or extent of connection to a receiving waterway. The inventory identified the largest percentage of features in the Saranac and Ausable watersheds, mountainous settings similar to the Winooski watershed in Vermont (Table 17).

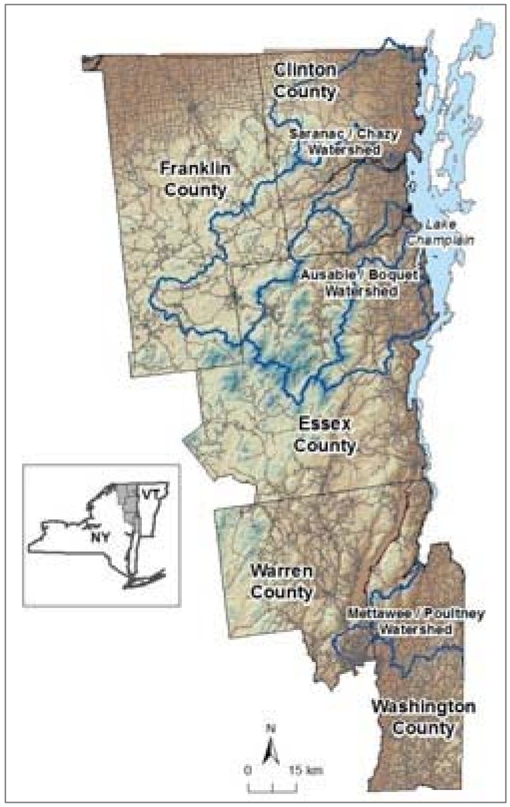


Figure 29: New York counties and watersheds included in the LCLGRPB survey described in this chapter.

Table 16: Lengths of roads for NY counties falling at least partly in the Lake Champlain Basin. Lengths are for entire county, including areas both within and outside the Lake Champlain Basin.

	Road Length - Roads from TIGER line files[1]		Road Length - Roads from NY GIS Clearinghouse[2]		Road Length - Roads from NY Highway Inventory[3]	
County	(km)	(mi)	(km)	(mi)	(km)	(mi)
Clinton	4567	2836	3277	2035	2544	1580
Essex	5856	3636	3353	2082	2256	1401
Franklin	5503	3418	3543	2200	2304	1431
Warren	3779	2347	2747	1706	2031	1261
Washington	3614	2244	3016	1873	2574	1598

[1]Retrieved from http://datagateway.nrcs.usda.gov/GDGHome.aspx (Accessed: 28 January, 2013).
[2]Retrieved from http://gis.ny.gov/gisdata/inventories/details.cfm?DSID=932 (Accessed: 28 January, 2013).
[3]Retrieved from https://www.dot.ny.gov/divisions/engineering/technical-services/highway-data-services/inventory-listing (Accessed: 28 January, 2013).

Table 17: Road erosion features by major subwatershed in the LCLGRPB inventory released in 2012.

Major Subwatershed	Number of Sites per Priority			Percentage of sites in Champlain Watershed
	High	Moderate	Low	
Ausable River	25	17	20	20%
Boquet River	9	7	9	8%
Champlain Canal	1	0	0	0%
Chazy River	2	0	0	1%
Halfway Brook	5	5	4	4%
Lake Champlain	27	18	16	19%
Lake George	16	6	5	8%
Mettawee River	3	4	2	3%
Poultney River	1	0	1	1%
Saranac River	28	20	68	36%

* The data for the Ausable River includes all branches and data presented for Lake Champlain includes north, main and south basins.

Comparative Assessment

For comparison to our study, we developed simple summaries of road length and road density for the New York counties with some land area in the Basin, using the three available road data layers (Table 16). Within the Ausable/Bouquet watershed, we derived an estimate of road grade for the road network, using the most extensive road network data of the TIGER line files and the GIS-based method employed in the Winooski watershed, described in Chapters 3 and 4 of this report. Using the LCLGRPB features inventoried in Essex County,[10] we mapped their distribution and compared grades reported in the inventory to grades we calculated via GIS.

Findings

The only known inventory of road surfacing type places the percentage of unpaved roads (as a fraction of the road network) in NY counties of the Lake Champlain basin on the order of 15-30%. This is a considerably lower than the roughly 60% of roads in the Winooski watershed that are coded as unpaved in the Vermont Agency of Transportation data, but the NY DOT tabular road inventory we accessed undoubtedly excludes some town and local roads, since the network length from this source is the lowest of the road data we accessed (Table 16). The NY subwatersheds of the Lake Champlain basin have road densities ranging from 0.84 – 2.02 km/km^2 (1.36 – 3.25 mi/mi^2), comparable to the 1.51 km/km^2 (2.43 mi/mi^2) of the Winooski watershed (Table 19).

[10] Feature data provided by Andrew Snell, CWICNY Coordinator , Champlain Watershed Improvement Coalition of NY. P.O. Box 765, 1 Lower Amherst Street, Lake George, NY 12845. Email: apsnel@yahoo.com. Phone: (518) 668-5773

Table 18: Summary of road length by surfacing type for New York counties falling in the Lake Champlain basin. Data from NY DOT† (see Table 16 for road length compared to other data sources).

County	Length all roads (km)	Length all roads (mi)	Length unpaved roads (km)	Length unpaved roads (mi)	Length overlay roads (km)	Length overlay roads (mi)	Percent not paved (unpaved + overlay)
Essex	2255.6	1401.6	414.3	257.4	128.6	79.9	24.1%
Clinton	2543.8	1580.6	174.1	108.2	205.3	127.5	14.9%
Franklin	2304.0	1431.6	460.4	286.1	175.5	109.0	27.6%
Warren	2030.6	1261.8	316.7	196.8	127.7	79.3	21.9%
Washington	2573.7	1599.2	566.3	351.9	180.6	112.2	29.0%

†Data retrieved from https://www.dot.ny.gov/divisions/engineering/technical-services/highway-data-services/inventory-listing (Accessed: 28 January, 2013).

Table 19: Watershed area, road length and road density for NY subwatersheds of Lake Champlain.

Watershed	**watershed area** (km^2)	(mi^2)	**Road Length†** (km)	(mi)	**Road density** (km/km^2)	(mi/mi^2)
Ausable River	1333	514	1882	1169	1.41	2.27
Boquet River	708	273	1076	668	1.52	2.45
Chazy River	1122	433	1830	1137	1.63	2.62
Little Ausable River / Salmon River	400	154	809	503	2.02	3.25
Mettawee River / Poultney River	1780	687	1500	931	0.84	1.36
Saranac River	1587	613	2131	1324	1.34	2.16

† road length from TIGER line files

Using a common method of calculating road grade within a GIS framework, it appears that roads in the Ausable, Bouquet, and Little Ausable/Salmon River watersheds are less commonly located on steep (≥ 5%) gradients than roads in the Winooski watershed. Across the 3 subwatersheds we assessed, only 15 to slightly more than 30% of the road network was coded as having a gradient ≥ 5%.

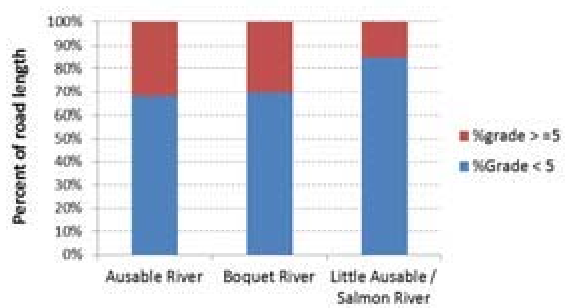


Figure 30: Distribution of roads by gradient class for the Ausable, Boquet and Little Ausable/Salmon River on the NY side of Lake Champlain (see Figure 15 for comparison to Winooski watershed).

Road erosion sites inventoried in the LCLGRPB study occurred largely on roads of moderate and steep grade (Figure 31), a finding consistent with our results reported in Chapter 4. Of the features inventoried in Essex County, 18% occurred on roads classified as "flat" in the LCLGRPB study, 64% on roads classified as "moderate", and 18% on roads classified as "steep".

Hydrological connectivity of roads to streams in the LCLGRPB inventory was on par with the level of connectivity we estimated in the Winooski River watershed. Sixty-seven percent (67%) of the inventoried features in Essex County were coded as having direct connections to waterways. Although we employed a different method to estimate connectivity, our extrapolation of site-scale findings to the road network in the Winooski watershed suggests that approximately 53% of the road network there is hydrologically connected to streams.

Interpretations

Differing inventory methods and study goals make it difficult to compare across the studies described here. Our inventory in the Winooski watershed was conducted on only a sample of the unpaved road network, and aimed to quantify the mass of sediment and phosphorus generated on roads. The inventory conducted by the LCLGRPB includes a

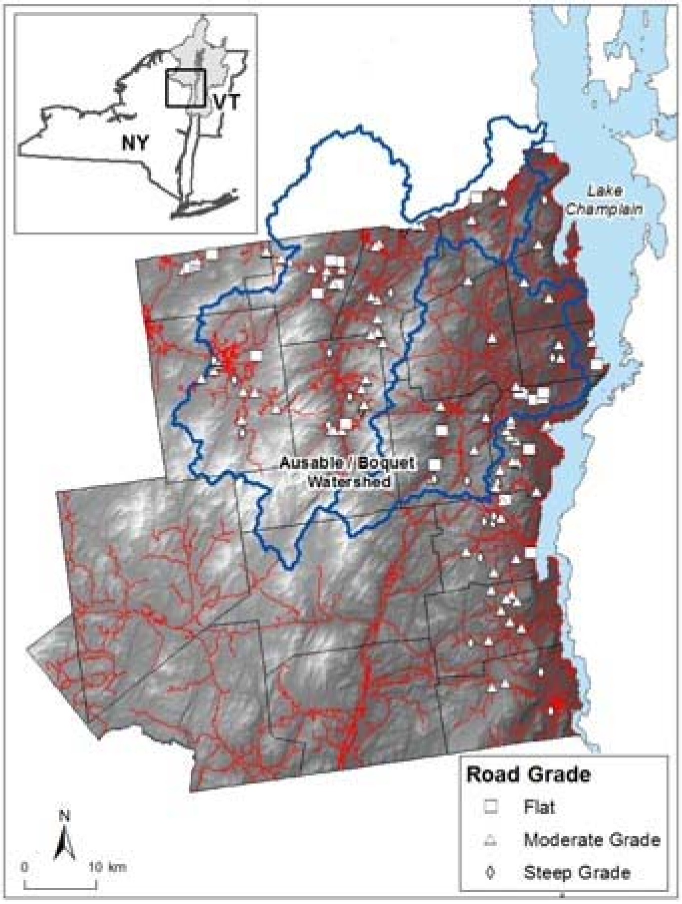


Figure 31: Location of road erosion features inventoried by the LCLGRPB study for Essex County, NY. Points 131 features inventoried in the county. Road grade attribute mapped is from LCLGRPB inventory.

comprehensive survey of all roads within the study area, with the aim of prioritizing and estimating costs of remediation actions. Nevertheless, considered together, the two studies show that road densities are comparable across these two areas (Winooski and Ausable/Boquet) and that road erosion occurs preferentially on steep roads located in upland settings. Applying appropriate management practices to reduce erosion severity and disconnecting road erosion sites from their receiving waters will achieve important gains in water quality improvement.

Future efforts to evaluate the effects of roads on water quality in the Basin might effectively draw from both of these studies. The New York inventory provides an estimate of the density of erosional features across this region and their relative distribution on paved and unpaved roads. The Winooski River inventory that we conducted in Vermont provides an estimate of the pollutant production associated with unpaved roads. Although we could discriminate the role of BMPs in reducing erosion on roads, more work is needed to quantify the magnitude of pollutant reduction through the application of these practices.

Chapter 6: Conclusions and Recommendations

The work described in this report represents a first attempt to quantify pollutant loadings associated with unpaved roads in the Lake Champlain Basin. Results of the studies described here show that unpaved roads constructed in the steep uplands of the Basin can degrade water quality through the erosion of sediment and associated phosphorus. We estimate that sediment production on unpaved roads is up to 17-31% of the annual load of suspended sediment transported by rivers in the Winooski watershed. Similarly, our study results suggest that phosphorus production rates on unpaved roads range from 11-28% of the annual load of total phosphorus transported by the Winooski River and its tributaries. The higher unit area sediment production rate evident in the Winooski River (Chapter 4) study is likely due to the fact that the inventory method used here includes a coarse fraction of material that would not have been sampled using the methods employed in the Mad River (Chapter 3) study. The lower unit area phosphorus production rate evident in the Winooski River study is likely due to the lower P concentration (396 mg P/kg sediment) used here, as extracted from bulk roadside sediments, compared to the P concentration in water samples (2107 mg P/kg sediment) collected during storm events for the Mad River study. The higher concentration of P in storm-event water samples includes a fraction of dissolved P not measured in the Winooski watershed inventory.

Although we have presented pollutant production rates along with river loads to provide a means of evaluating the relative importance of unpaved roads as a pollutant source, some caution should be used in the strict interpretation of these results. First, our estimates of road-stream connectivity suggest that only a fraction (slightly more than 50%) of the unpaved road network discharges pollutants to water ways. Second, little is known about the down stream conveyance and time lags associated with pollutant transfer in the Winooski River and other parts of the Lake Champlain basin. Sediment and phosphorus generated on roads, even when discharged into waterways, probably flow downstream at differential rates are differentially affected by flow impoundments on rivers. Finally, virtually nothing is known in this landscape about the relationship between concentrated runoff generated on the network of hydrologically-connected roads and the scouring flows that induce river bank erosion on Vermont's rivers. This mechanism likely represents an additional cumulative downstream effect of unpaved roads not quantified in this study.

Table 20: Comparison of study results of production rates on roads and pollutant loads from water ways, taken from Chapters 3 and 4 of this report.

	normalized to watershed area ($kg/km^2/yr$)	normalized to road length (kg/km/yr)
Mad River study (Chapter 3)		
Road network suspended sediment production [1]	6,120	5,093
Catchment average suspended sediment load [1]	35,759	
Roads / Catchment [2]	*17.1%*	
Road network total phosphorus production [1]	15	10
Catchment average total phosphorus load [1]	54	
Roads / Catchment [2]	27.8%	
Winooski River inventory (Chapter 4)		
Road network total sediment production [3]	14,659	16,080
Winooski River suspended sediment load [4]	47,363	
Roads / River [2]	*31.0%*	
Road network total phosphorus production	5.6	6.1
Winooski River total phosphorus load	49	
Roads / Winooski [2]	*11.4%*	

[1] Averages from Table 4
[2] Represents the ratio of road production rate to catchment (or watershed) load
[3] Value from Table 14, normalized by watershed area (2753 km^2) and road length (2510 km)
[4] Value from Table 15, normalized by watershed area (2753 km^2)

The inventory of road erosion and BMP implementation in the Winooski watershed demonstrates that best management practices (BMPs) can effectively reduce the frequency and magnitude of erosion on roads, thereby buying important water quality improvements for the Basin. Among the most effective BMPs are stone lined ditches on high-gradient and highly erosive roads, though other less-costly BMPs such as turnouts, water bars and energy dissipating devices also slow the flow of water and reduce the risk of erosion on roads. Another important element of water quality impacts comes through the level of hydrologic connectivity of the road and native channel network. Measures that disconnect discharges from roads from the native stream network will improve water quality. Among these measures, more frequent placement of turnouts and cross-drain culverts to relieve the flow of water in ditches should be considered, along with energy dissipating devices at cross-drain outlets that reduce the risk of gullying on unchanneled hillslopes.

A review of transportation network data and a recent assessment of road erosion on the New York side of the Basin suggest that these results should be transferable to other upland portions of the Basin where similar road construction and maintenance practices are used. Improved insights can be gained from future inventories of the Basin's road network if those attempts include quantitative estimates of sediment and phosphorus eroded from roads and roadside ditches and estimates of road-stream connectivity. The sampling approaches employed in this study, particularly in the inventory described in Chapter 4, could readily be replicated in other parts of the Basin.

Future management strategies to improve water quality in the Basin will undoubtedly involve a set of trade-offs, balancing measures to improve water quality with the costs of their implementation. Water quality data collected for this project, along with spatially-explicit representations of the topographic conditions that influence the production of pollutants on unpaved roads can be used to inform those decisions.

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We are particularly indebted to the people and town officials of the Mad River valley, who allowed us to work on their roads through the summer and fall of 2011 and the spring and summer of 2012. In particular, we thank Waitsfield town administrator Valerie Capels and road foreman Rodney Jones, Warren town administrator Cindi Jones and road foreman Ray Weston, and Fayston town administrator Patti Lewis and road foreman Stuart Hallstrom. We also gratefully acknowledge the hospitality of the residents of the Mad River valley, who often stopped at our sites during field maintenance visits to inquire about our work.

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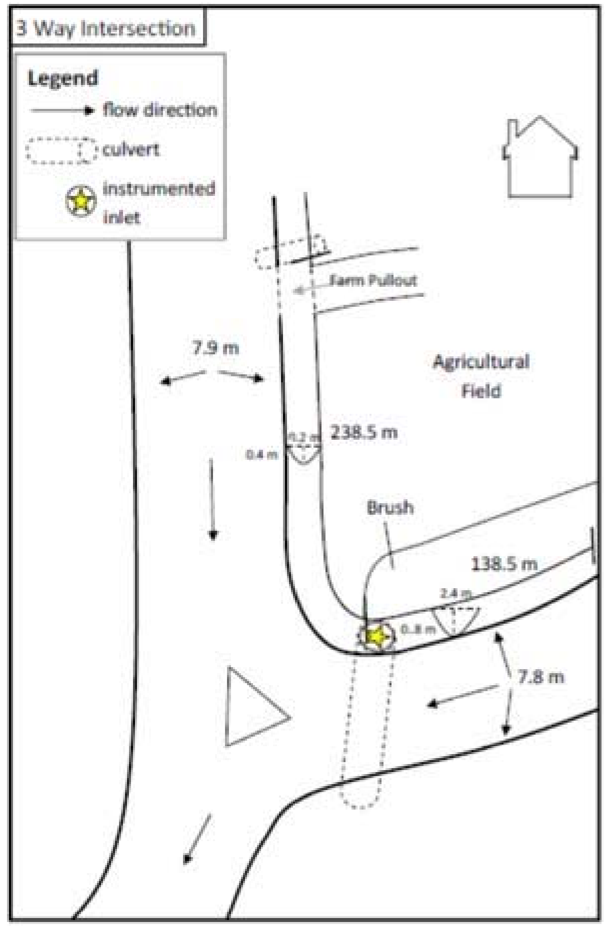
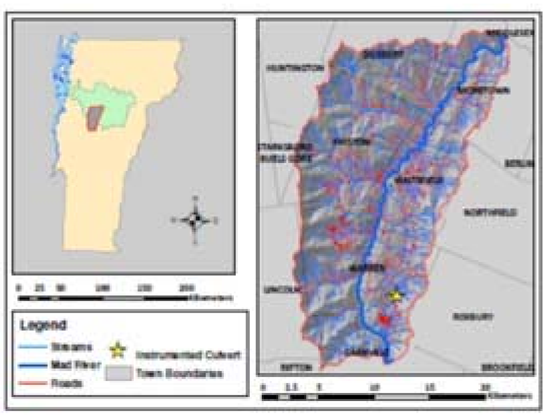
Appendix 1: Site Descriptions

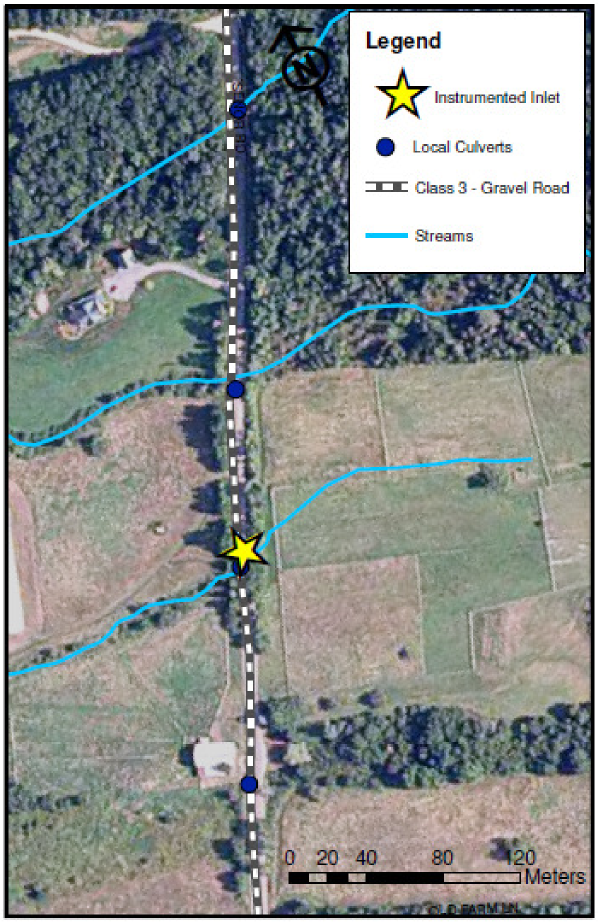
Site Name	longitude	latitude	catchment
3Way	-72.820242	44.08922	Freeman
Senor	-72.810929	44.099984	Freeman
Cider Hill	-72.798821	44.13214	Folsom
Rolston	-72.830559	44.150127	Folsom
Common	-72.804527	44.166648	High Bridge
Ski Valley	-72.789135	44.17113	High Bridge
Mansfield	-72.8858	44.19488	Mill
Barton	-72.8942	44.18052	Mill
BraggHill	-72.8513	44.19345	Mill
Sharpshooter	-72.85645	44.25226	Shepard
NoFayston	-72.84957	44.24221	Shepard
Randell	-72.839777	44.238086	Shepard

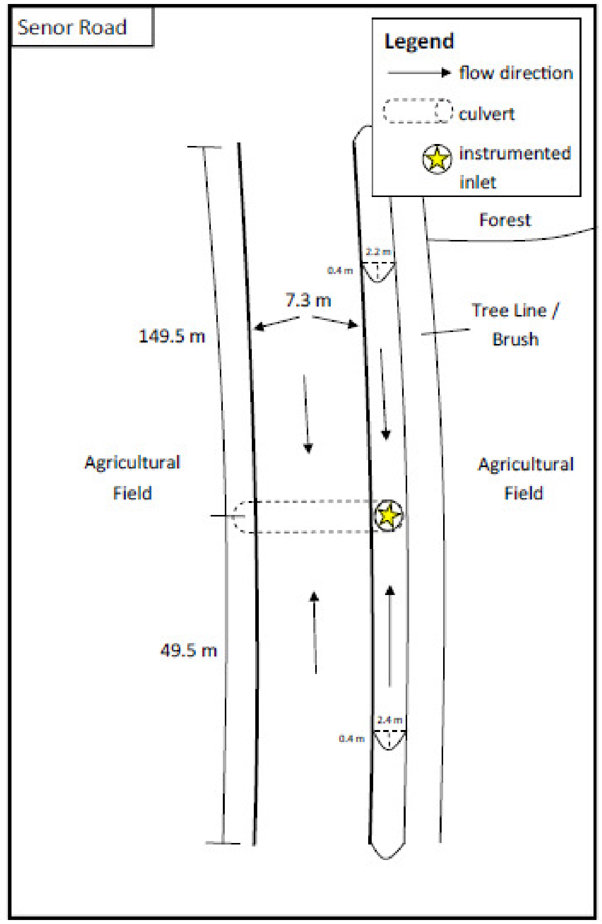

Legend
Instrumented Inlet
Local Culverts
Class 3 - Gravel Road
Private Road
Streams
0 20 40 80 120 160 200
Meters


3 Way Intersection
Legend
flow direction
culvert
instrumented inlet
Farm Pullout
7.9 m
Agricultural Field
0.2 m
0.4 m
238.5 m
Brush
138.5 m
2.4 m
0.8 m
7.8 m

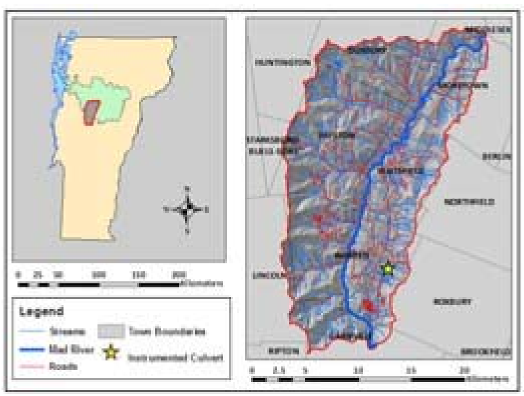
The monitoring station at the **3-Way** intersection of Prickly Mountain, Fuller Hill, and Senor Road was located in the Freeman Brook catchment in the town of Warren, Vermont. These three roads are all Class 3, gravel roads, maintained by the town of Warren. The instrumented inlet sits just below an agricultural field, approximately 14 acres in size, with a residential home at the far upper side of the field. The drainage area for this site extends from an elevation of 1398 feet at the inlet, to 1478 feet at the uphill culvert to cross Prickly Mountain Road (elevations derived from a 30 m DEM). Prickly Mountain Road, the inlets primary channel for runoff, averages 7.9 meters wide and is crowned, resulting in approximately 3.95 m of road width draining to the inboard ditch. Fuller Hill Road averages 7.8 meters in width, and is also crowned, resulting in 3.9 m of road width draining to the inboard ditch. The monitored culvert drains runoff along a 238.5 m segment of Prickly Mountain Road and a 138.5 segment of Fuller Hill Road; the former having a roadside ditch averaging 0.2 m in width and the latter roadside ditch averaging 2.4 m in width. Together the road surface and ditch drainage area total 1862.3 m^2. A farm pullout from the field to Prickly Mountain Road may contribute runoff from the field during intense storm events, and seepage was observed directly from the field near the inlet point during several storm events in the summer and fall of 2011. The road grade is 8% along Prickly Mountain Road leading to rapid transmission of runoff and minor incising of the ditch, and 1% along Fuller Hill Road. At the culvert outlet, runoff is discharged into a wide bare ditch which eventually discharges to a stream which discharges to Freeman Brook. Automated monitoring on this site took place from July 7, 2011 to August 2, 2011, August 18, 2011 to September 9, 2011, and from April 22, 2012 to July 26, 2012.

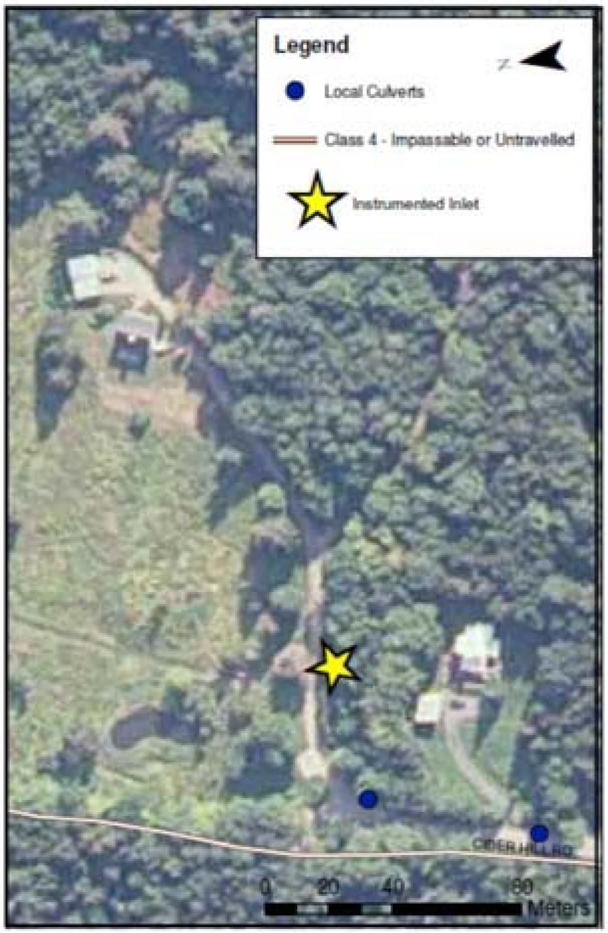


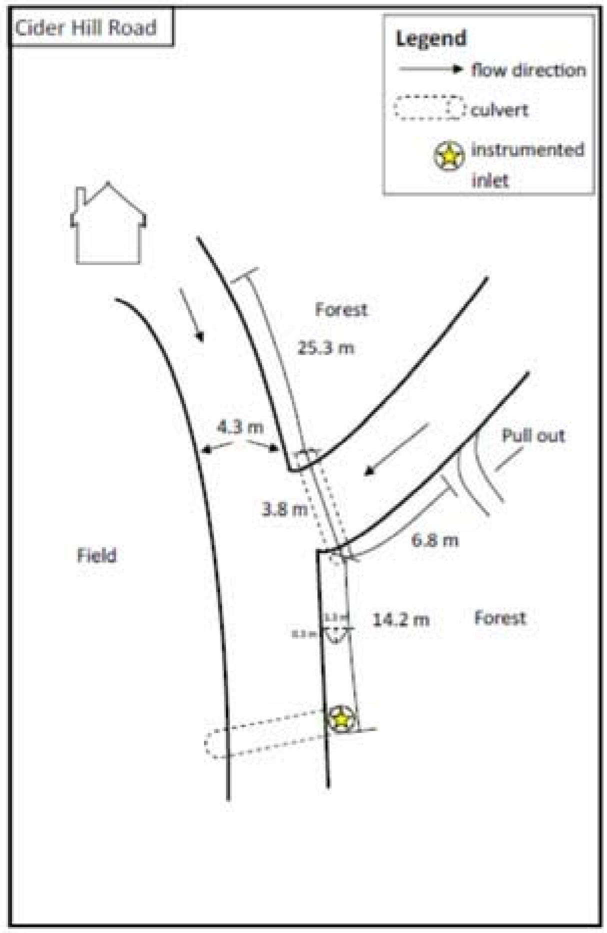

Legend
Instrumented Inlet
Local Culverts
Class 3 - Gravel Road
Streams
0 20 40 80 120
Meters


Senor Road
Legend
flow direction
culvert
instrumented inlet
Forest
2.2 m
0.4 m
7.3 m
149.5 m
Tree Line / Brush
Agricultural Field
Agricultural Field
49.5 m
2.4 m
0.4 m

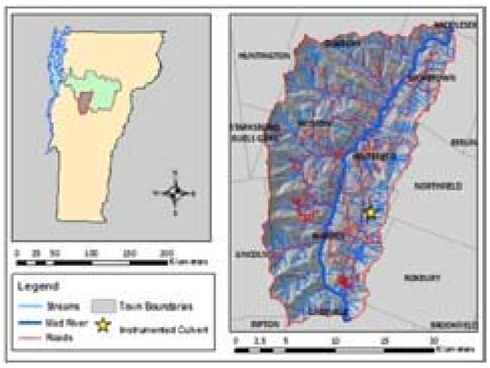
The monitoring station on **Senor Road** was located in the Freeman Brook drainage in the town of Warren, Vermont. The monitored segment of Senor Road is a relatively flat, Class 3, gravel road, the majority of which transects two agricultural fields with a 50 m segment passing through a forested patch of land on the inlet side, and with a 10 m forested buffer on either side of the agricultural segment. The instrumented inlet is at a low point, at an elevation of 1472 feet, where it receives runoff from both the north and south sides which rise with gentle slopes to 1478 feet in the northern direction and to 1472 to the south (an undetectable elevation difference in the 30 m DEM). The road averages 7.3 meters in width and is slightly crowned, resulting in 3.65 meters of the road width draining to the inboard ditch. The monitored culvert drains runoff along a 149.5 m segment to the north and a 49.5 m segment to the south. The adjacent roadside ditch for the north and south segments averages 2.2 meters and 2.4 meters in width, respectively. The total contributing road surface and ditch drainage area is 1174.05 m^2. At least five seepage points were observed, one originating from overland flow, in the fall of 2011 during a minor storm event under wet conditions indicating an additional unmeasured contributing drainage area directly adjacent to the road. Little to no seepage was observed during drier summer condition of 2011. The road grade is 2.5% in the northern direction and 0.5% in the southern direction. At the culvert outlet, runoff is discharged into another agricultural field along a tree-lined ditch, and appears in the Vermont Hydrography Dataset Streams layer to eventually discharge to Freeman Brook. Automated monitoring on this site took place between July 7, 2011 and September 24, 2011.

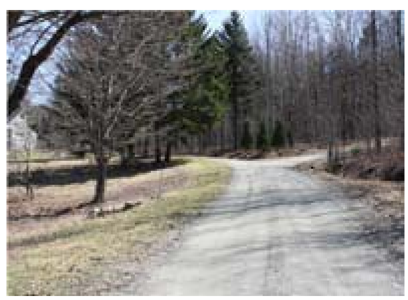


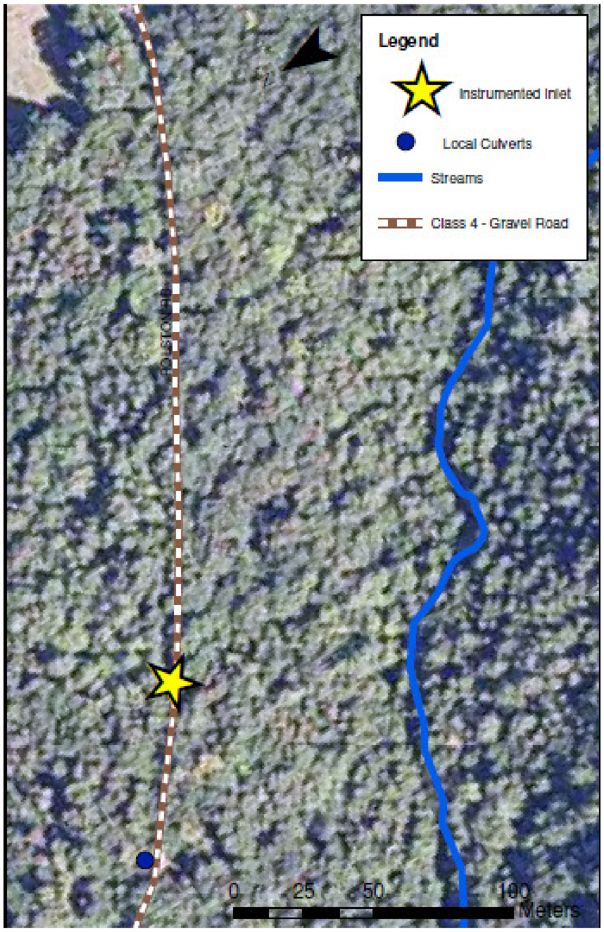

Legend
N
Local Culverts
Class 4 - Impassable or Untravelled
Instrumented Inlet
CIDER HILL RD
0
20
40
80
Meters

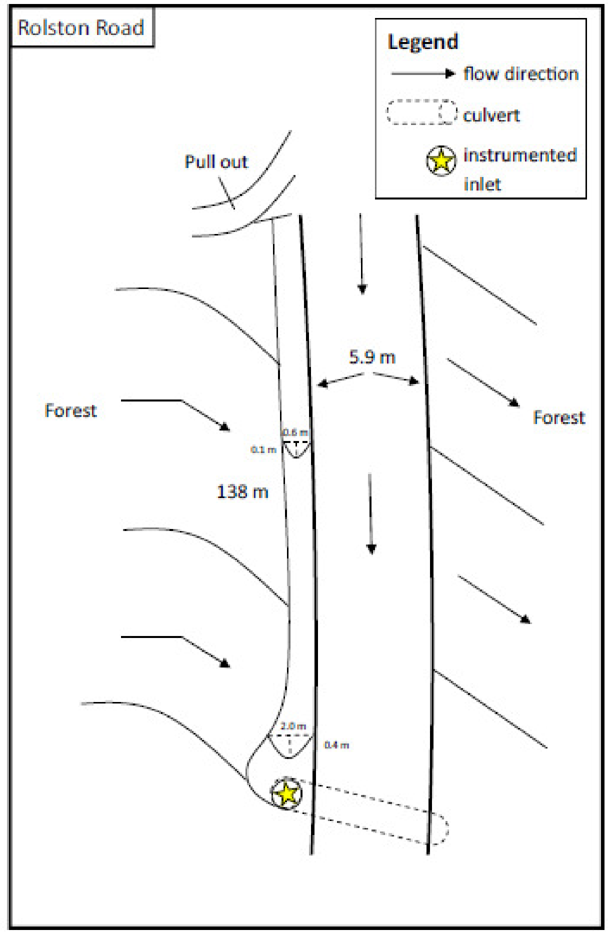

Cider Hill Road
Legend
flow direction
culvert
instrumented inlet
Forest
25.3 m
4.3 m
Pull out
3.8 m
6.8 m
Field
14.2 m
Forest

The monitoring station on **Cider Hill Road** was located in the Folsom Brook drainage in the town of Warren, Vermont. The road is a private, Class 4, gravel road which transverses a forested area to the south and a field to the north. Just east of the instrumented inlet, the road splits with a drivel leading to a residential building used as a second home to the northeast and an extension of the private road to the southeast. The elevation rises from 1592 ft. at the inlet to1624 at the highest drainage point in the northeast direction and 1617 ft. at the highest drainage point in the southeast direction. The upper northeast and southeast roads are both slightly crowned and average 4.3 m and 3.8 meters in width, respectively, resulting in 2.15 m and 1.9 m of road width draining to the instrumented inlet, with respective drainage lengths of 43.3 m and 6.8 meters. The northeast road also has a grassy roadside ditch averaging 1 meter in width above the side road, and 1.3 meters below the side road, leading to a total ditch and road surface drainage area of roughly 149.8 m^2. A source of seepage was not observed at this site, but a minor amount of groundwater did lead to a moist inlet area even during dry seasons. The road grade is 10% on the northern road and 16% on the eastern, resulting in significant rills on both. At the culvert outlet, runoff is discharged into a field from which it flows to a pond. Automated monitoring on this site took place from August 18, 2011 to October 7, 2011 and from April 23, 2012 to June 28, 2012.

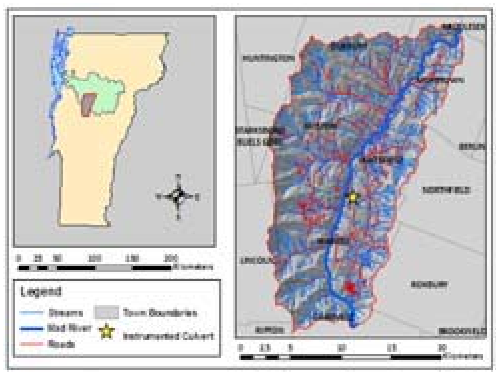


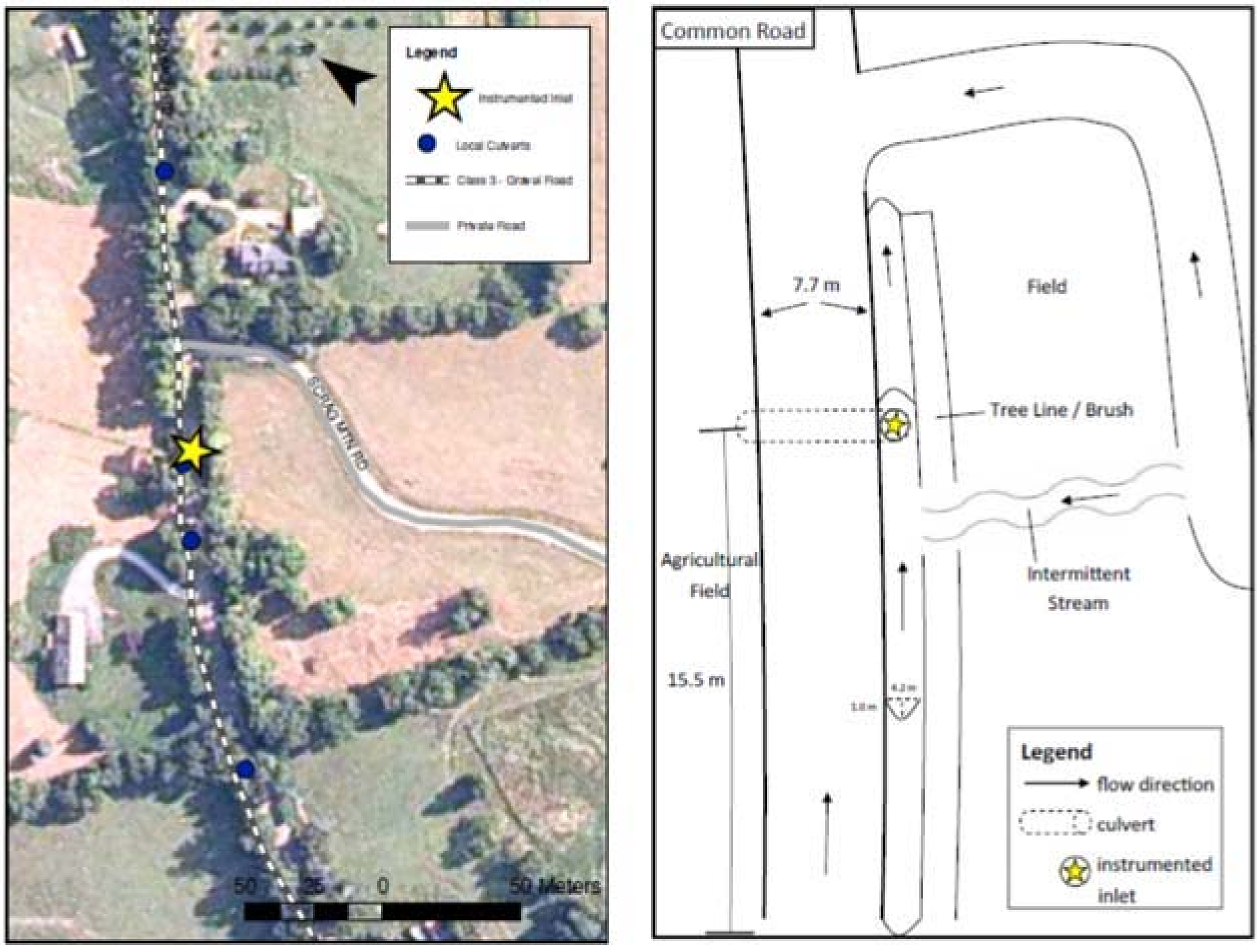



Legend
Instrumented Inlet
Local Culverts
Streams
Class 4 - Gravel Road
0
25
50
100
Meters

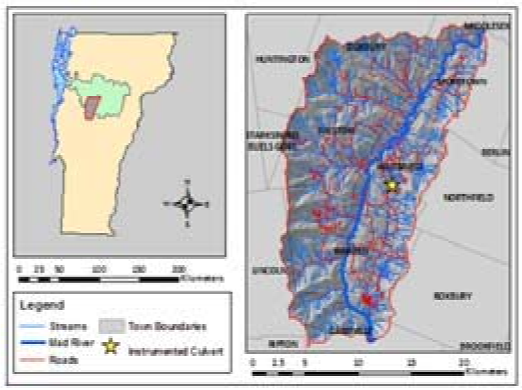

Rolston Road
Legend
flow direction
culvert
instrumented inlet
Pull out
5.9 m
Forest
Forest
0.6 m
0.1 m
138 m
2.0 m
0.4 m

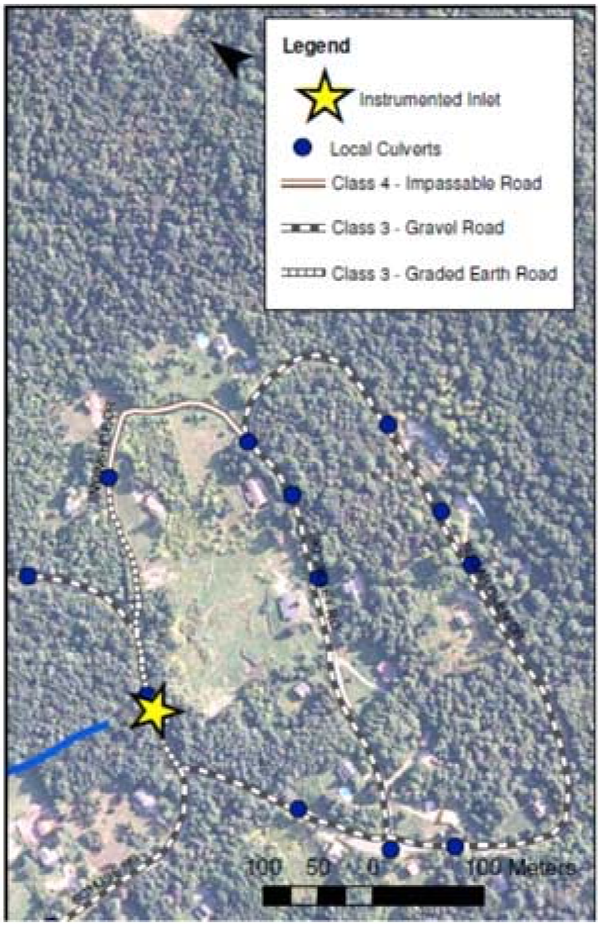
Rolston Road is a steep, gravel road, located in the Folsom Brook watershed in the town of Waitsfield, Vermont. The lower portion of Rolston Road has a steep cutslope and is densely forested on both sides. The road segment draining to this site rises from an elevation of 981 feet to 1029 feet, 138 meters upslope where drainage to the monitored inlet begins. The road averages 5.9 meters in width and is crowned resulting in roughly 2.95 meters of road width draining to the inboard ditch with a weighted average width of roughly 0.7 meters. The resulting total drainage area including ditch and road surface area is 503.9 m^2. For much of the 138 meter road segment the upper road bank is largely bare or moss-covered, leaving much of it very susceptible to erosion. The road grade is 12% along the monitored segment, resulting in rapid transmission of runoff from the road surface and ditch to the inlet and sedimentation was so prevalent at this site that are equipment was regularly clogged and/or buried between site visits in the summer of 2011. At the culvert outlet, runoff is discharged onto a steep forested bank where runoff may, during intense storm events, flow directly to Folsom Brook, approximately 90 meters below. No seepage was observed over the one-month period of automated and manual monitoring that took place between August 1, 2011 and September 1, 2011.

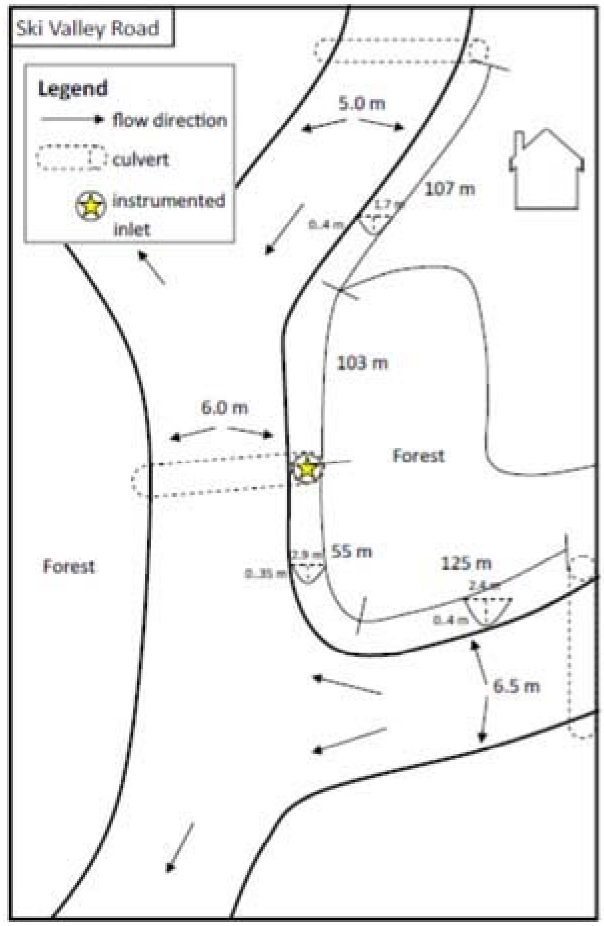



Legend
Local Culverts
Private Road
50
25
0
50 Meters
Common Road
7.7 m
Field
Tree Line / Brush
Agricultural Field
Intermittent Stream
15.5 m
Legend
flow direction
culvert
instrumented inlet

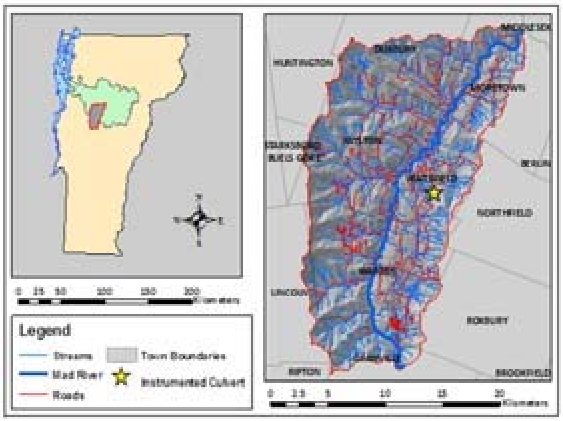
Common Road is a relatively flat, Class 3, gravel road. The monitoring station was located in the High Bridge Brook drainage in the town of Waitsfield, Vermont. This segment of road, mimics Senor Road in that it traverses two fields with an approximately 10 meter tree-line roadside buffer. The inlet rests at 1227 feet and rises to 1244 feet at the height of the southeastern end of the road segment. The road averages 7.7 meters in width, and is crowned, resulting in roughly 3.85 meters of road width draining to the inboard ditch. The monitored culvert drains runoff along a 15.5 m stretch of road, and the adjacent roadside ditch averages 4.2 m in width, giving an estimated road surface and ditch drainage area of roughly 124.8 m^2. The wide vegetated ditch, short contributing road segment, and low road grade of 1.5% leads to little to no observed or measured runoff during medium to low intensity storms. High intensity storm events, however, create an entirely different, larger, unmeasured drainage area, as an intermittent stream develops from Scrag Mountain Road to the ditch (a 12% grade) which leads to the instrumented inlet. At the culvert outlet, runoff is discharged into a field with no visible connection to a stream. Automated monitoring on this site took place from August 1, 2011 to September 15, 2011 and from September 24, 2011 to September 30, 2011.

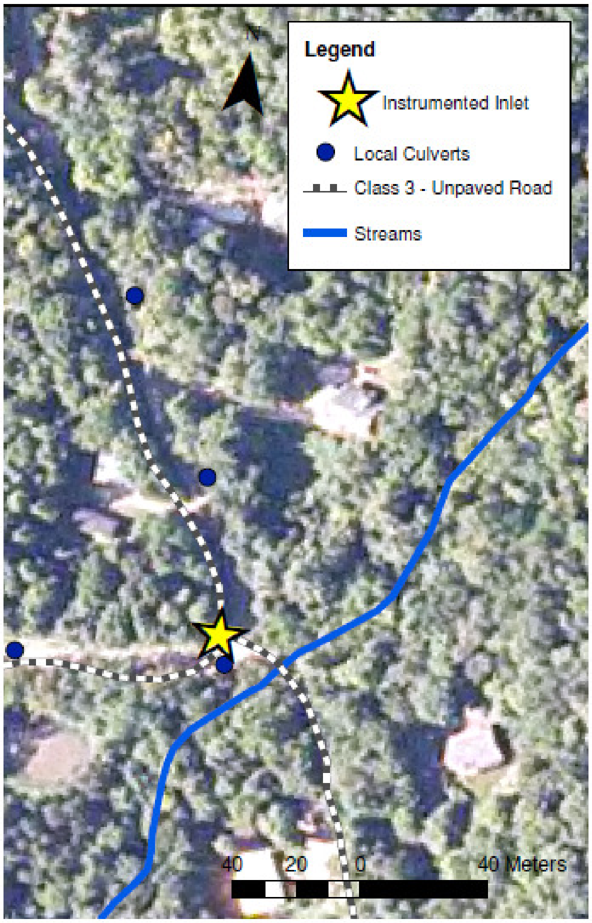


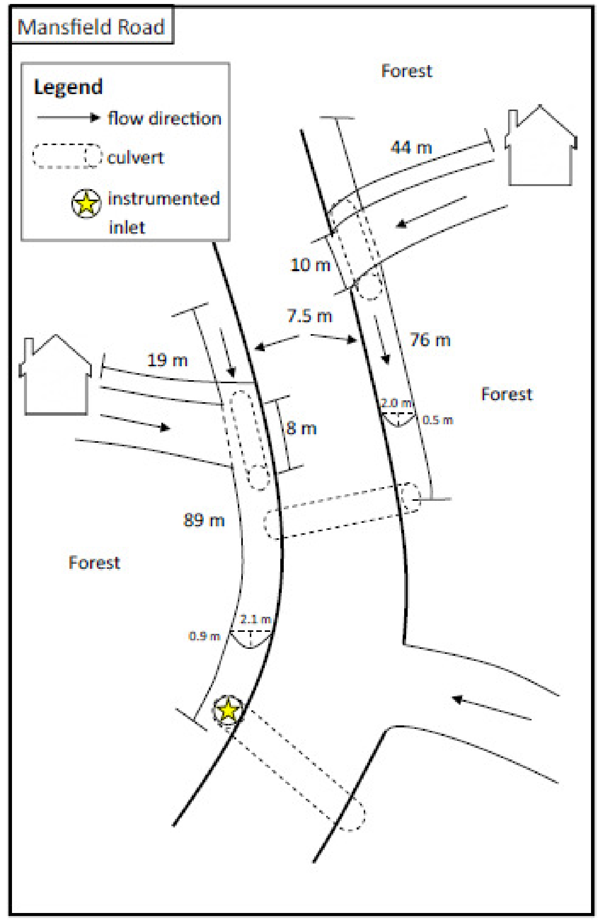

Legend
Instrumented Inlet
Local Culverts
Class 4 - Impassable Road
Class 3 - Gravel Road
Class 3 - Graded Earth Road
100 50 0 100 Meters


Ski Valley Road
Legend
flow direction
culvert
instrumented inlet
5.0 m
107 m
0.4 m
103 m
6.0 m
Forest
Forest
55 m
125 m
0.4 m
6.5 m

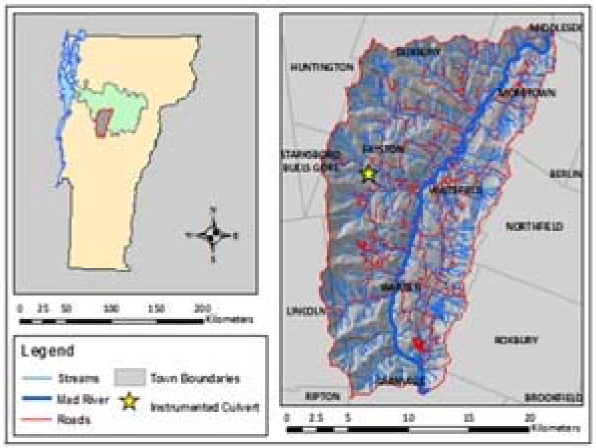
The monitored segment on **Ski Valley Road** included both gravel and graded earth segments of Class 3 road. The monitoring station was located in the High Bridge Brook drainage in Waitsfield, Vermont. The graded earth portion of the road passes through a densely forested area to the northwest (outlet side) and approximately 40 m of dense forest to the southeastern, upland side of the inlet. Roughly 158 m of the graded earth road that extends to either side of the inlet is relatively flat, before rising to the east for another 107 meters. At the southwest end, the road shifts rises more steeply for another 125 meters. The road grade is 5% across the 158 m flatter portion, and 10% and 12.5% at the northern and southeastern extents of the road drainage extent, respectively. The elevation ranges from 1335 feet at the inlet to 1373 to the east and up to 1392 to the south. The road is crowned, and has an average width of 5.88 m, resulting in roughly 2.94 m of road width draining to the inboard ditch. The ditch is roughly 2.4 meters in width, resulting in an estimated total road surface and ditch drainage area of 2087.9 m^2. During storms of medium to high intensity in summer and fall of 2011, overland flow was observed from the forested area above the road. This overland flow indicates that there is, during medium to high intensity storm events, and larger, unmeasured drainage area beyond the road and ditch surfaces. The ditch surface ranges from bare gravel, to grassy vegetation. At the culvert outlet, runoff eroded a gully that discharges to High Bridge Brook. Automated monitoring on this site took place from August 1, 2011 to September 30, 2011.

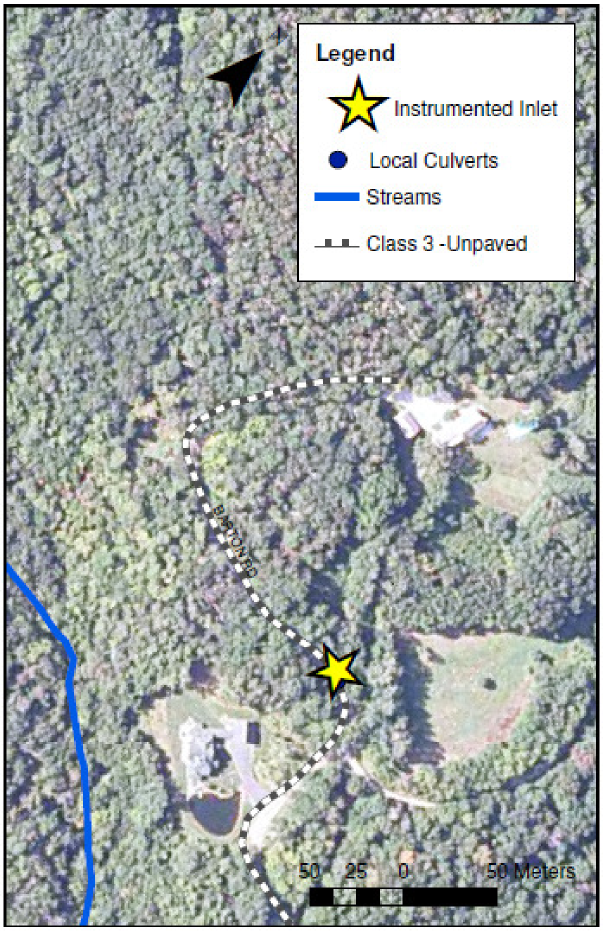



Legend
Instrumented Inlet
Local Culverts
Class 3 - Unpaved Road
Streams
N
40 20 0 40 Meters

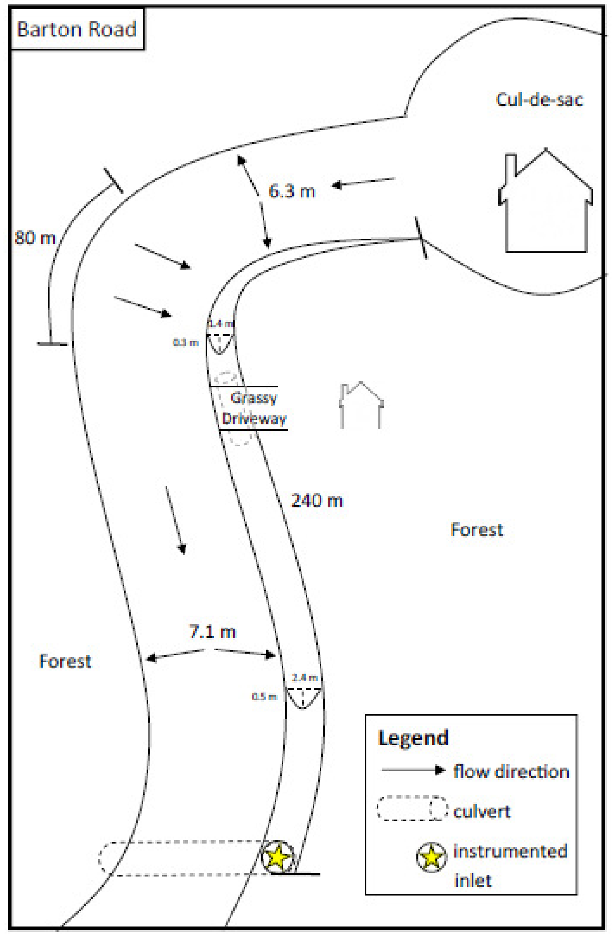

Mansfield Road
Legend
flow direction
culvert
instrumented inlet
Forest
44 m
10 m
7.5 m
76 m
19 m
8 m
2.0 m
0.5 m
Forest
89 m
Forest
2.1 m
0.9 m

Mansfield Road is a Class 3, unpaved road located in the Mill Brook drainage in Fayston, Vermont. The road rises steeply (12% grade), through a forested area with a series of small (< 0.2 acre) clearings accommodating residential building sites, from an elevation of 1149 feet at the instrumented intlet to an elevation of 1200 feet north of a driveway to the east. The monitored inlet receives runoff directly from the western side of the road for an 89 meter length, and from the eastern side of the road for a 76 meter length due to a culvert which crosses under the road at 36 meters above the inlet. The ditch averages 2.1 meters wide on the western side and 2.0 meters wide on the eastern side. Two driveways, one on the eastern side and one on the western side, also contribute to the runoff drainage area, leading to a total ditch and road surface drainage area of roughly 1549.65 m^2. Automated monitoring took place between October 18, 2011 and November 11, 2011. During this time, no seepage was observed, although researchers were not often on site during significant storm events. At the culvert outlet, runoff discharges onto a forested bank which slopes directly to a tributary of Mill Brook.



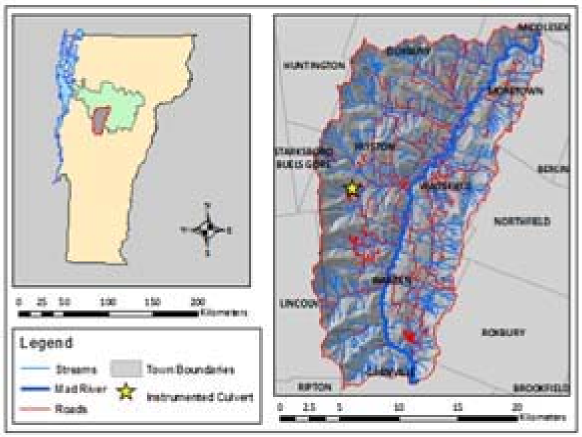


Legend
Instrumented Inlet
Local Culverts
Streams
Class 3 -Unpaved
50 25 0 50 Meters

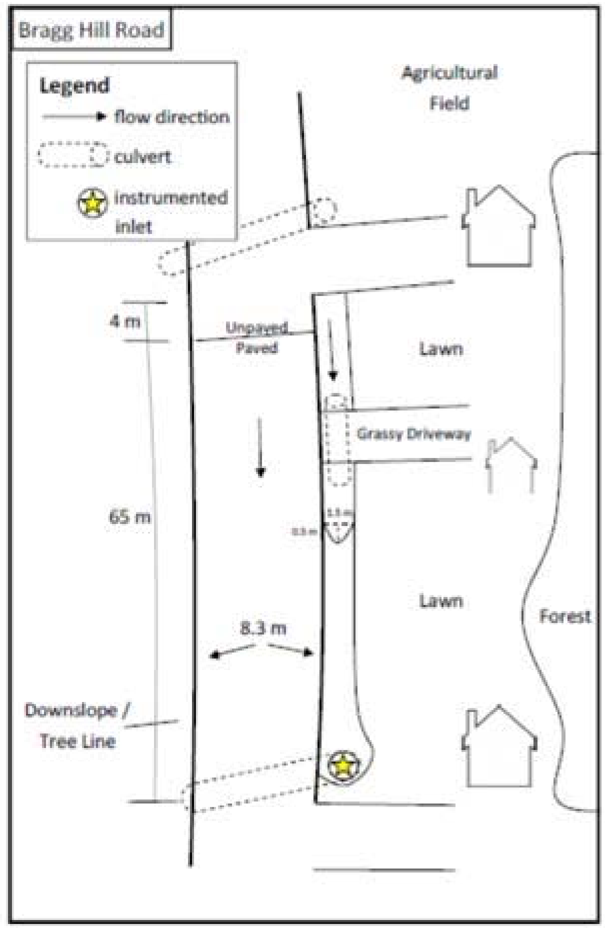


Barton Road
Cul-de-sac
6.3 m
80 m
1.4 m
0.3 m
Grassy
Driveway
240 m
Forest
7.1 m
Forest
2.4 m
0.5 m
Legend
flow direction
culvert
instrumented
inlet

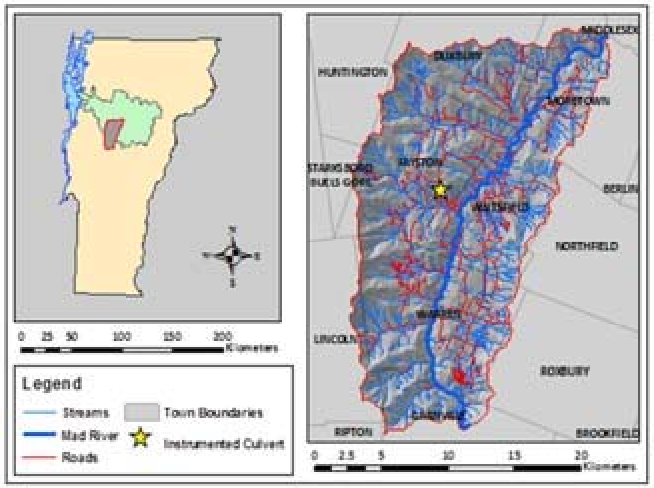
The monitoring station on **Barton Road** was located on a Class 3, unpaved road in the Mill brook drainage in the town of Fayston, Vermont. The road traverses a densely forested area, with a series of small (< 3.2 acre) clearings where residential buildings reside, and climbs from 1465 feet at the instrumented inlet to 1541 feet at the highest extent of the monitored road segment, just below a driveway. The road averages 7.1 meters in width on the lower 77.4 meters, and 6.3 meters in width on the upper 163 meters. The road is slightly crowned, with the exception of an 80 meter stretch around a corner over which the entire road surface drains to the inboard ditch. The ditch averages 2.4 meters in width over the lower 77.4 meters and 1.4 meters in width in the upper 80 meters, with no ditch along the corner or upper reaches of the road just below the driveway. This results in a total ditch and road surface drainage area of roughly 1325.4 m^2. One seepage point was observed during a light intensity storm under saturated conditions in December, indicating that there is a larger, unmeasured drainage area that contributes to the measured runoff at least intermittently. The road grade is 8-11% along the monitored segment, most likely leading to moderately rapid transmission of runoff from the road surface to the inlet. At the culvert outlet, runoff is discharged into a 40 meter wide forested area with no visible connection to a stream though Chase Brook is approximately 140 meters downhill of the culvert, and theoretically may be accessible by runoff during very large storm events. Automated monitoring on this site took place from October 7, 2011 to November 9, 2011 and between July 3, 2012 and July 26, 2012.



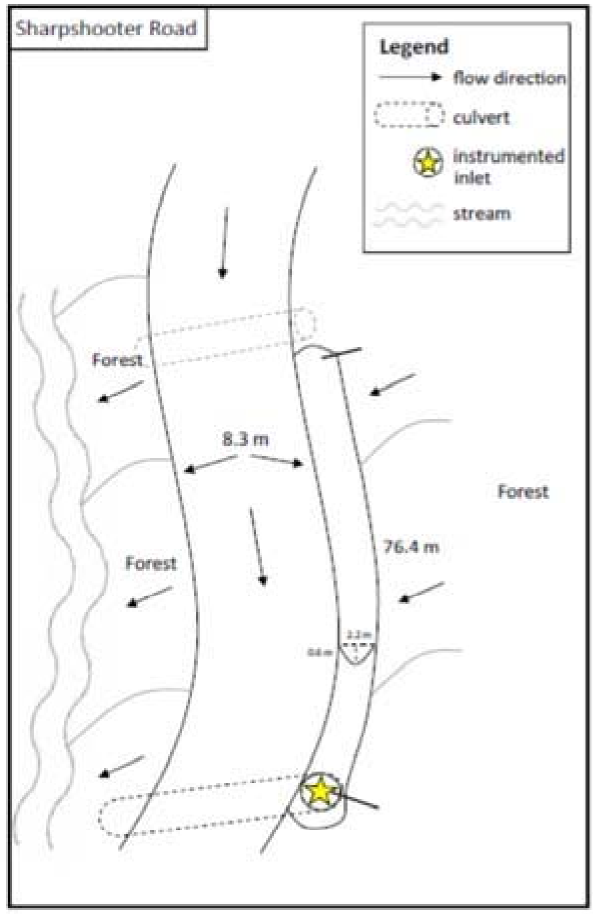

N
Legend
Instrumented Inlet
Local Culverts
Class 3 - Paved Road
Class 3 - Gravel Road
Streams
50 25 0 50 Meters


Bragg Hill Road
Legend
flow direction
culvert
instrumented inlet
Agricultural Field
4 m
Unpaved
Paved
Lawn
Grassy Driveway
65 m
Lawn
Forest
8.3 m
Downslope / Tree Line

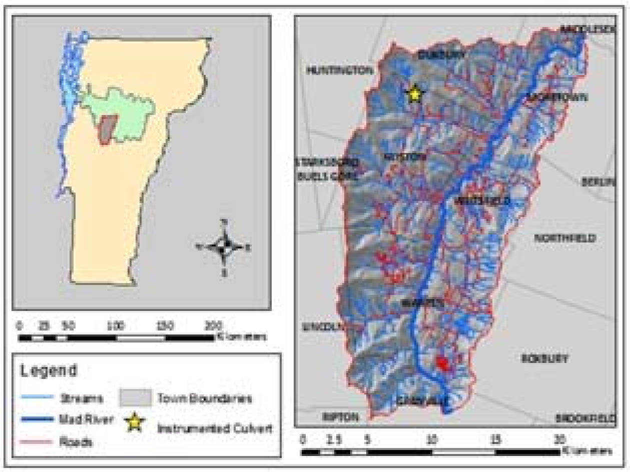
The site at **Bragg Hill Road** was located in the Mill Brook drainage in the town of Fayston, Vermont. The monitored road segment traverses two densely forested areas with a series of small (< 0.4 acre) clearings where residential buildings reside. The short road segment climbs from 1437 feet to 1476 feet with a paved segment extending 65 meters north before become unpaved for an additional 4 meters of the extent of the road drainage length. The road averages 8.3 meters in width, and is crowned, resulting in roughly 4.15 m of road width draining to the inboard ditch, which averages 1.5 meters in width, resulting in a total road surface and ditch drainage area of approximately 389.9 m^2. Under saturated conditions an average storm can lead to seepage through a buried drainage pipe located under the yard of a house on the eastern side of the road, which discharges to the monitored ditch. The road grade is 9% along the monitored segment. Automated monitoring on this site took place from October 1, 2011 to November 11, 2011.

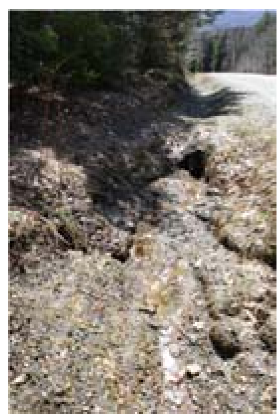


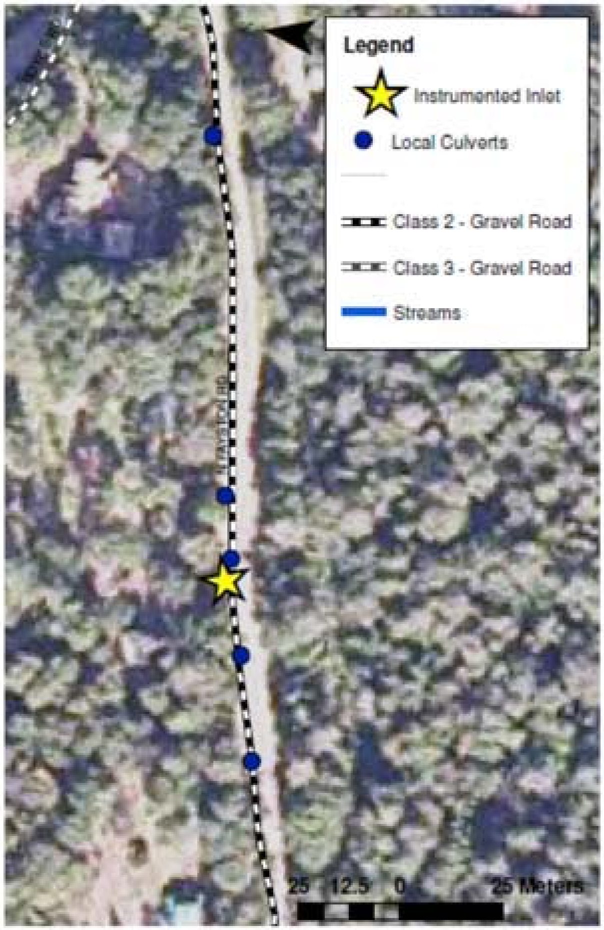

Legend
Instrumented Inlet
Local Culverts
Streams
Class 3 - Gravel
50
25
0
50 Meters

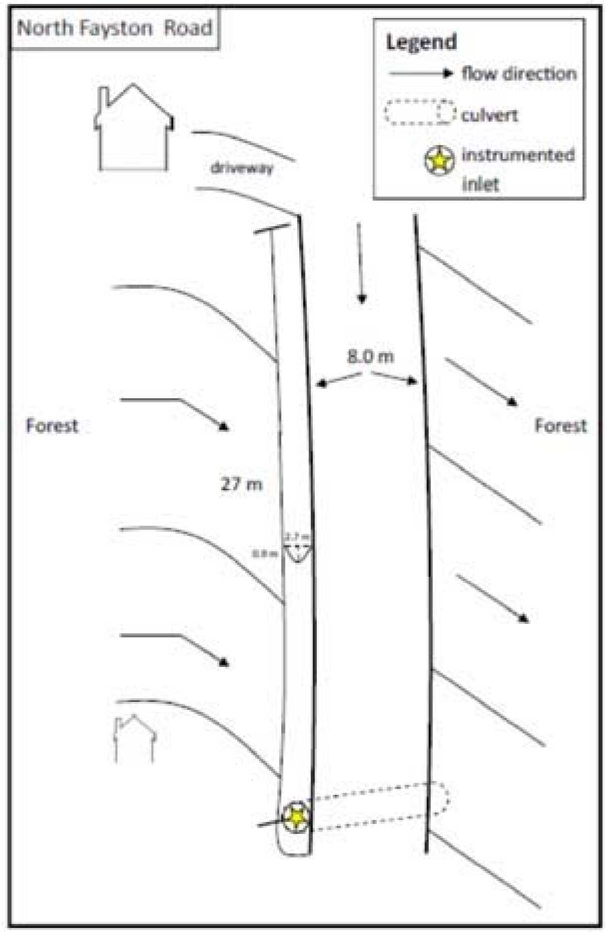

Sharpshooter Road
Legend
flow direction
culvert
instrumented inlet
stream
Forest
8.3 m
Forest
76.4 m
Forest

Sharpshooter Road is a Class 3, gravel road located in the Shepard Brook drainage in the town of Fayston, Vermont. The monitored segment of the road traverses a densely forested area with a few small (< 2.7 acres) clearings accommodating residential buildings. The site climbs relatively steeply (road grade of 9%) from 1417 feet at the instrumented inlet to 1441 feet at the upper extent of the road drainage segment, 76.4 meters upslope. The road averages 8.3 meters in width, and is crowned, resulting in roughly 4.15 meters of the road width draining to the inboard ditch. The roadside ditch averages 2.2 meters in width, resulting in a total road and ditch surface drainage area of 485.1 m^2. The ditch is primarily bare gravel, with some vegetation along some segments. Seepage was observed along the ditch during site visits throughout the fall of 2011, indicating an additional, unmeasured source of drainage beyond the road and ditch surface. At the culvert outlet, runoff is discharged onto a short (~15 meter) bank before reaching a tributary of Shepard Brook. Automated monitoring on this site took place from October 1, 2011 to November 11, 2011.

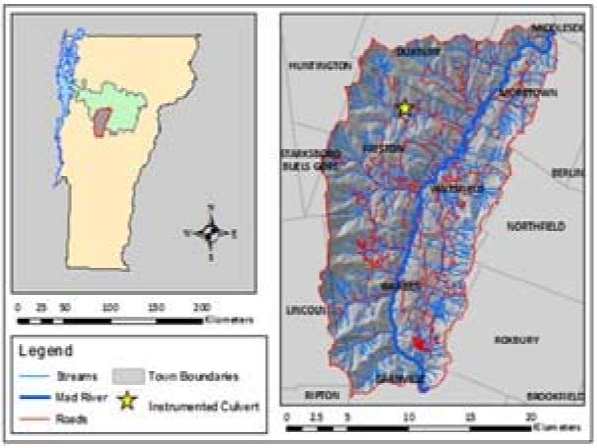




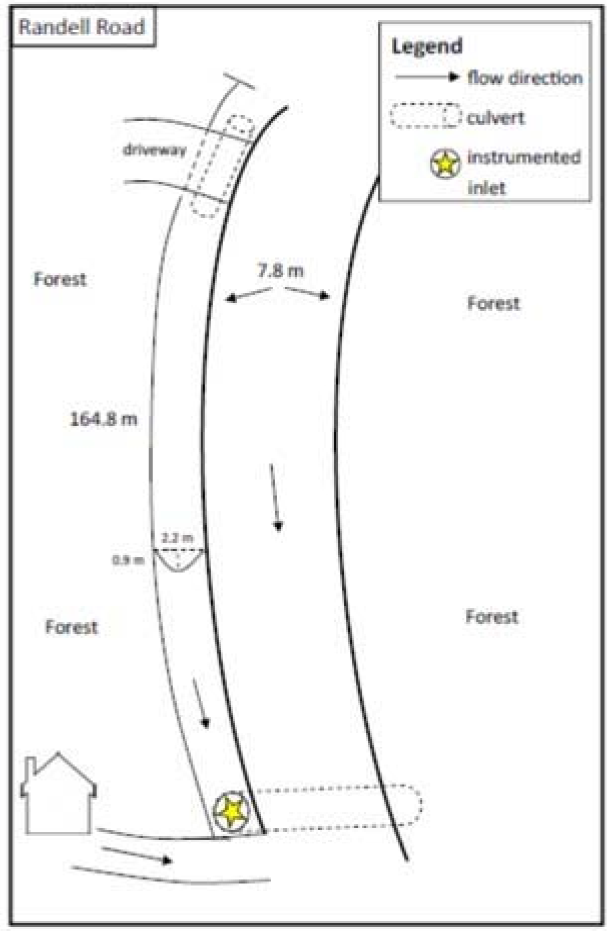

Legend
Instrumented Inlet
Local Culverts
Class 2 - Gravel Road
Class 3 - Gravel Road
Streams
25 12.5 0 25 Meters


North Fayston Road
Legend
flow direction
culvert
instrumented inlet
driveway
8.0 m
Forest
Forest
27 m

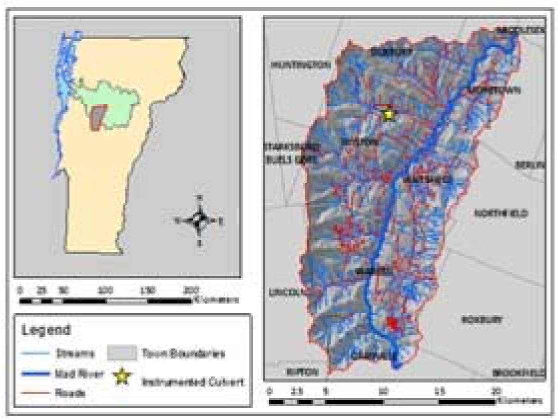
North Fayston Road is a Class 2 gravel road located in the Shepard Brook drainage in the town of Fayston, VT. The monitored road segment traverses a densely forested area, before reaching a public spring and small clearing for a residential building just outside and to the east of the monitored road segment. The monitored road segment is quite flat (road grade of 2.5%) and stretches just 27 meters in length. The road averages 8.0 m in width, and is slightly crowned, resulting in roughly 4 meters of road width draining to the inboard ditch. The ditch is slightly vegetated, and averages 2.7 meters in width, resulting in a total road and ditch drainage surface area of approximately 180.9 m^2. No seepage sources and little to no baseflow was observed at this site during the fall of 2011 and spring of 2012. At the culvert outlet, runoff is discharged down a bank into a forested area, with no visible connection to a stream. Automated monitoring on this site took place from October 1, 2011 to November 11, 2011.

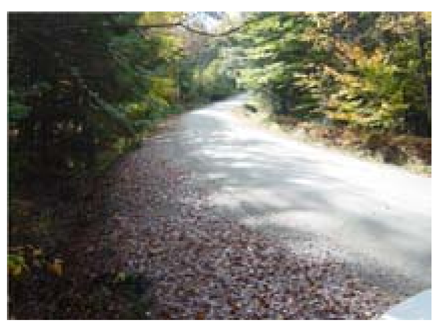



Legend
Instrumented Culvert
Local Culverts
Class 3 - Gravel
Streams
0 12.5 25 50 75 100
Meters


Randell Road
Legend
flow direction
culvert
instrumented inlet
driveway
Forest
7.8 m
Forest
164.8 m
2.2 m
0.9 m
Forest
Forest

The monitoring station on **Randell Road** was located in the Shepard Brook drainage in the town of Fayston, Vermont. Randall Road traverses a densely forested area, with a series of small (< 2.2 ha, 5.5 acres) clearings accommodating residential home sites, climbing from an elevation of 325 m (1066 ft) at its intersection with North Fayston Road to an elevation of m 426 m (1397 feet) at its intersection with Center Fayston Road. The road is on average 7.8 meters wide and crowned, resulting in roughly 3.9 meters of the road width draining to the inboard ditch. The monitored culvert drains runoff along a 164.8 meter segment of the road. The adjacent roadside ditch is 2.2 meters wide. A driveway approximately 30 meters long and 5 meters wide drains to the road and contributes runoff to the monitoring station during storms, giving an estimated road surface, driveway, and ditch drainage area of 1155 m^2. An excavated road cut is not present along the monitored segment, but during intense storm events in June and July 2012, intermittent seepage was observed along the ditch, adding an additional unmapped source from the area directly proximal to the road. Little to no seepage was observed during low precipitation intensity storms in September 2012. The road grade is 15% along the monitored segment, resulting in rapid transmission of runoff from the road surface to the ditch and culvert and visible erosion of the ditch. At the culvert outlet, runoff is discharged into a forested area with no visible connection to a stream. Automated monitoring on this site took place between June 13 and July 26, 2012, with storms sampled on 6/27, 7/4, 7/17 and 7/23-24/2012.





Appendix 2: Quality Assurance Controls

Overview

Standard quality assurance protocols as described in the QAPP were followed with respect to tasks accomplished for this study. Specifically, quality assurance measures included (1) sample custody and handling, (2) quality acceptance criteria for laboratory samples, (3) inspection and correction, where necessary, of digital data files, (4) proper data archiving and back up, and (5) documentation of secondary data used for analysis. Details on these measures are described below. Dr. Don Ross, director of the Agricultural and Environmental Testing Laboratory (AETL), served as Quality Assurance manager with primary responsibility for oversight of laboratory procedures. Dr. Beverley Wemple served as Project Manager and maintained oversight of the collection and archiving of water quality (Task 1) and road inventory (Task 4) data.

1. Sample Custody and Handling

All water samples collected as part of Task 1 were tracked using a chain of custody (CoC) form. Upon retrieval from field sites, sample number and the date, time and place of collection were entered on the CoC form and delivered with samples to the laboratory technician at the Agricultural and Environmental Testing Laboratory (AETL) at the University of Vermont (UVM). Signatures of the field technician and the AETL lab manager were used to track sample transfer. Duplicate copies of the CoC forms were retained in the AETL and in the Project Manager's office at UVM and are available upon request. Digital copies of the CoC forms have been scanned and stored on the project data archive on the UVM central computing network.

Sample handling included transport of all samples on ice to the laboratory and storage in a refrigerated cold room until sample processing was conducted. All samples analyzed for soluble reactive phosphorus were processed within 24 hours of collected. Samples processed for total phosphorus and total suspended solids were analyzed within two weeks of sample collection.

Laboratory technicians employed to process samples received training through UVM's Office of Risk Management and from the AETL manager. Dr. Don Ross served as project QA manager and maintained oversight of laboratory procedures and staff training.

2. Quality acceptance criteria for laboratory samples

With respect to quality performance and acceptance criteria, the QAPP states:

> *Sample analysis results will be accepted if all quality control samples are within 5% of their certified value and all duplicates are within 5% of the sample mean. Exceptions to this criteria will be for low concentrations of SRP and TP (below 0.020 mg/L), in which case less than 10% error in duplication will be accepted, and low concentrations of TSS (below 0.2 mg/L), in which case a value of 0.0*

mg/L will be used. Control samples for TSS will not be used; these samples require the entire volume available in the sample bottles, therefore duplicate samples will not be analyzed. Blank samples should be below the minimum detection limit for this test (0.2 mg/l TSS). All samples measuring 0.2 mg/l TSS or less will be set to zero.

2.1 Total Suspended Sediment

Quality assurance for total suspended sediment samples was evaluated using a set of standards prepared by laboratory QA manager, Dr. Don Ross and run by the laboratory technician responsible for processing TSS samples for the project. Because the analytical method required for TSS sampling consumes the entire sample, no duplicate runs of samples were conducted.

The table below presents results of laboratory standards processed for quality assurance documentation and the error relative to the standard.

Sample No.	tin+filter g	dry sample, tin + filter g	sediment weight g	TSS assuming 1 L vol mg/L	TSS Standard Concentration mg/L	Error
1	2.690	2.931	0.241	241	250	3.6%
2	2.288	2.466	0.178	178	188	5.3%
3	2.700	2.773	0.073	73	80	8.8%
4	2.341	2.777	0.436	436	445	2.0%
5	2.396	3.265	0.869	869	908	4.3%
6	2.322	2.365	0.043	43	51	15.7%

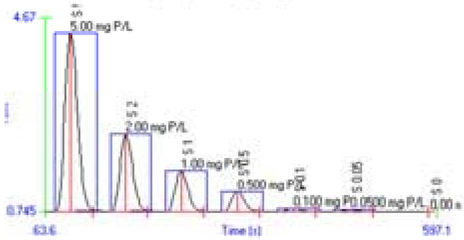
2.2 Soluble Reactive Phosphorus and Total Phosphorus

For each sampling event from each site, one sample was run in duplicate. The Lachat QuickChem AE 8000 (Hach Inc., Loveland CO) flow injection autoanalyzer was calibrated with a series of at least six standards prepared from an NIST-traceable source and bracketing the concentration range of the unknowns. After initial calibration, a series of three calibration QC samples obtained from a different NIST-traceable source were run. These three samples covered the lower 25%, middle 50% and upper 25% of the calibration range. The calibration were deemed accepted if the middle and upper QC samples were within 5% of their certified value and the lower QC sample was within 10% of its certified value. A laboratory blank and the middle QC sample were run after every six unknowns. The analytical run was deemed acceptable if the QC sample was within 5% of its certified value and the blank was less than the MDL. The MDL for both phosphorus methods has been determined to be 0.007 mg/L by the flow injection autoanalyzer's published method.

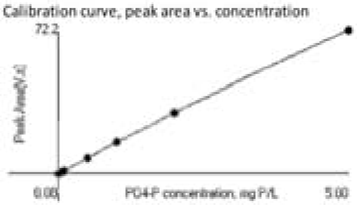
The pertinent data for each laboratory batch of total phosphorus and soluble reactive phosphorus are provided in tabular form on the following pages. For each batch, we present the calibration results, the accuracy of the three calibration QCs and blank throughout the run, the analytical error of sample duplicates and the recovery of a known reference sample. Please refer to notes in the first table that give more detail on the QC reporting.

Total phosphorus (TP) run 4-11-2012

Calibration standard peaks, showing integration area



Calibration curve, peak area vs. concentration



Area = - 0.288 * Conc^2 + 15.9 * Conc - 0.0623
Conc = 9.30e-5 * Area^2 + 0.0625 * Area + 0.00484
Correlation Coefficient (r) = 0.99999

Calibration QCs--results Second column is certified value, columns a-f are QC results

QC	actual	a	b	c	d	e	f
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
upper	5.000	4.930	4.940	4.890	4.960	5.000	4.970
middle	1.000	0.976	0.975	0.970	0.976	0.969	0.967
lower	0.100	0.098	0.097	0.098	0.097	0.096	0.096

Calibration QCs--error Error relative to actual value of each QC

QC	a	b	c	d	e	f	
	error	error	error	error	error	error	
upper	1.4%	1.2%	2.2%	0.8%	0.0%	0.6%	All acceptable, less than 5%
middle	2.4%	2.5%	3.0%	2.4%	3.1%	3.3%	All acceptable, less than 5%
lower	1.9%	2.6%	1.9%	3.5%	4.4%	3.9%	All acceptable, less than 10%

Laboratory blank Columns a-f are blank measurements

		a	b	c	d	e	f	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
blank	0.000	0.005	0.004	0.006	0.005	0.0068	0.004	
MDL	0.007	minimun detection limit, blank should be less than this value						
blank below MDL?		Yes	Yes	Yes	Yes	Yes	Yes	All acceptable, < 0.007

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

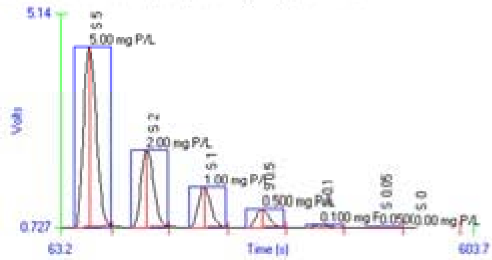
Sample ID	P mg/L	dup mg/L	error	
66	3.130	3.250	3.8%	Acceptable, less than 5%
88	0.052	0.049	5.8%	Acceptable
96	0.144	0.150	4.1%	Acceptable

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

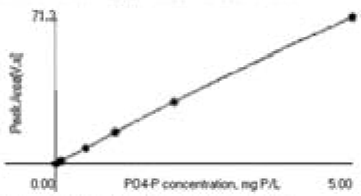
	P mg/L		
NPP actual	5.00		Certified concentration
NPP-1	4.81	96.2% Recovery	Acceptable, with 5% of 100%
NPP-1	4.91	98.2% Recovery	Acceptable

Total phosphorus (TP) run 4-17-2012

Calibration standard peaks, showing integration area



Calibration curve, peak area vs. concentration



Area = - 0.314 * Conc^2 + 15.9 * Conc - 0.151
Conc = 1.04e-4 * Area^2 + 0.0625 * Area + 0.0106
Correlation Coefficient (r) = 0.99999

Calibration QCs--results Second column is certified value, columns a-f are QC results

QC	actual	a	b	c	d	e	f
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
upper	5.000	4.99	4.97	4.92	4.91	4.94	4.93
middle	1.000	0.984	0.979	0.984	0.987	0.979	0.979
lower	0.100	0.098	0.097	0.096	0.097	0.097	0.098

Calibration QCs--error Error relative to actual value of each QC

QC	a	b	c	d	e	f	
	error	error	error	error	error	error	
upper	0.2%	0.6%	1.6%	1.8%	1.2%	1.4%	All acceptable, less tha 5%
middle	1.6%	2.1%	1.6%	1.3%	2.1%	2.1%	All acceptable
lower	2.5%	2.6%	3.9%	2.9%	2.8%	2.1%	All acceptable

Laboratory blank Columns a-f are blank measurements

		a	b	c	d	e	f	average
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
blank	0.000	0.0106	0.0107	0.0099	0.0093	0.0056	0.0009	0.0078
MDL	0.007	minimun detection limit, blank should be less than this value						
blank below MDL?		No	No	No	No	Yes	Yes	

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

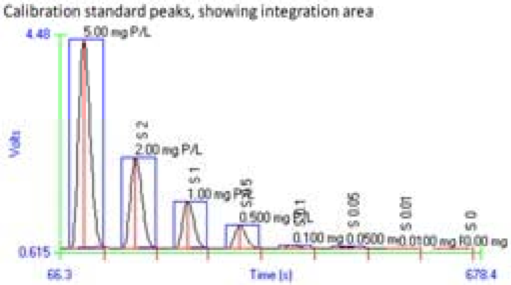
Sample ID	P mg/L	dup mg/L	error	
135	0.089	0.087	1.7%	Acceptable, less than 5%

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

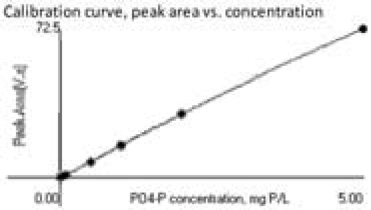
	P mg/L		
NPP actual	5.00		Certified concentrated
NPP-1	4.90	98.0% Recovery	Acceptable, with 5% of 100%
NPP-1	4.87	97.4% Recovery	Acceptable

Total phosphorus (TP) run 4-27-2012

Calibration standard peaks, showing integration area



Calibration curve, peak area vs. concentration



Area = - 0.340 * Conc^2 + 16.2 * Conc - 0.0649

Conc = 1.07e-4 * Area^2 + 0.0611 * Area + 0.00494

Correlation Coefficient (r) = 1.00000

Calibration QCs--results Second column is certified value, columns a-f are QC results

QC	actual	a	b	c	d	e	f
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
upper	5.000	4.98	4.94	4.96	4.96	4.94	4.92
middle	1.000	0.980	0.968	0.975	0.973	0.973	0.972
lower	0.100	0.091	0.094	0.093	0.094	0.093	0.094

Calibration QCs--error Error relative to actual value of each QC

QC	a	b	c	d	e	f	
	error	error	error	error	error	error	
upper	0.4%	1.2%	0.8%	0.8%	1.2%	1.6%	All acceptable, less than 5%
middle	2.0%	3.2%	2.5%	2.7%	2.7%	2.8%	All acceptable, less than 5%
lower	8.9%	5.6%	7.1%	6.2%	6.7%	6.5%	All acceptable, less than 10%

Laboratory blank Columns a-f are blank measurements

		a	b	c	d	e	f	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
blank	0.000	-0.012	0.005	0.005	0.005	0.005	0.004	
MDL	0.007	minimun detection limit, blank should be less than this value						
blank below MDL?		Yes	Yes	Yes	Yes	Yes	Yes	All acceptable, < 0.007

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

Sample ID	P mg/L	dup mg/L	error	
165	0.430	0.407	5.5%	Acceptable, less than 5%

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

	P mg/L	
NPP actual	5.00	Certified concentration
NPP-1	4.84	96.8% Recovery Acceptable, with 5% of 100%

Total phosphorus (TP) run 5-16-2012

Calibration curves identical to those shown in previous runs.

Calibration QCs--results Second column is certified value, columns a-d are QC results

QC	actual	a	b	c	d
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
upper	5.000	4.92	4.95	4.84	4.80
middle	1.000	0.963	0.958	0.944	0.942
lower	0.100	0.107	0.096	0.095	0.095

Calibration QCs--error Error relative to actual value of each QC

QC		a	b	c	d	
		error	error	error	error	
upper		1.6%	1.0%	3.2%	4.0%	All acceptable, less than 5%
middle		3.7%	4.2%	5.6%	5.8%	All acceptable, less than 5%
lower		7.0%	4.1%	5.4%	5.1%	All acceptable, less than 10%

Laboratory blank Columns a-d are blank measurements

		a	b	c	d	average	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
blank	0.000	0.008	0.000	0.006	0.008	0.005	
MDL	0.007	minimun detection limit, blank should be less than this value					
blank below MDL?		No	Yes	Yes	No	Yes	Average acceptable

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

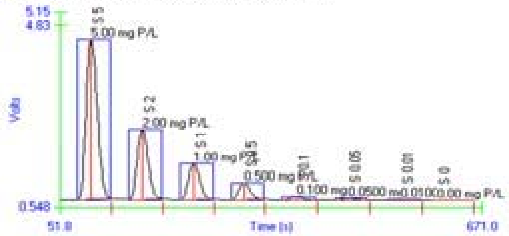
Sample ID	P mg/L	dup mg/L	error	
179	0.453	0.462	2.0%	Acceptable, less than 5%
189	0.546	0.584	6.7%	Marginal
202	0.376	0.406	7.7%	Marginal

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

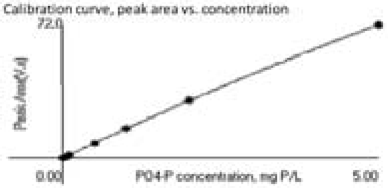
	P mg/L		
NPP actual	5.00		Certified concentration
NPP-1	4.80	96.0%	Recovery Acceptable, with 5% of 100%

Total phosphorus (TP) run 5-22-2012 , 5th and 6th batches combined

Calibration standard peaks, showing integration area



Calibration curve, peak area vs. concentration



Area = - 0.364 * Conc^2 + 16.2 * Conc - 0.0851

Conc = 1.17e-4 * Area^2 + 0.0609 * Area + 0.00637

Correlation Coefficient (r) = 0.99999

Calibration QCs--results Second column is certified value, columns a-i are QC results

QC	actual	a	b	c	d	e	f	g	h	i
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L
upper	5.000	5.06	5.07	5.04	5.06	5.06	5.02	5.01	5.02	5.04
middle	1.000	0.990	1.010	0.997	0.996	0.997	0.993	0.999	0.990	0.994
lower	0.100	0.094	0.093	0.094	0.095	0.094	0.093	0.095	0.095	0.094

Calibration QCs--error Error relative to actual value of each QC

QC	a	b	c	d	e	f	g	h	i	
	error	error	error	error	error	error	error	error	error	
upper	1.2%	1.4%	0.8%	1.2%	1.2%	0.4%	0.2%	0.4%	0.8%	All acceptable, less than 5%
middle	1.0%	1.0%	0.3%	0.4%	0.3%	0.7%	0.1%	1.0%	0.6%	All acceptable, less than 5%
lower	6.3%	6.9%	6.0%	5.4%	6.1%	7.3%	5.5%	5.3%	5.9%	All acceptable, less than 10%

Laboratory blank Columns a-I are blank measurements

		a	b	c	d	e	f	g	h	i	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
blank	0.000	0.0065	0.0069	0.0071	0.0065	0.0062	0.0065	0.0065	0.0080	0.0063	
MDL	0.007	minimum detection limit, blank should be less than this value									
blank below MDL?		Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Average acceptable

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

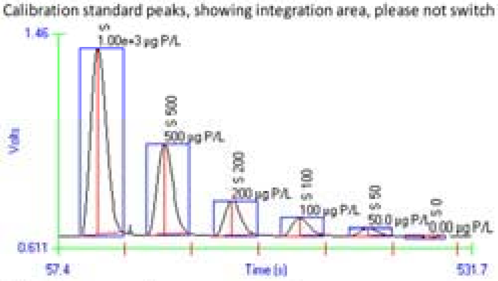
Sample ID	P mg/L	dup mg/L	error	
1	0.362	0.356	1.7%	Acceptable, less than 5%
20	0.19	0.199	4.6%	Acceptable
34	0.126	0.125	0.8%	Acceptable
216	0.216	0.218	0.9%	Acceptable

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

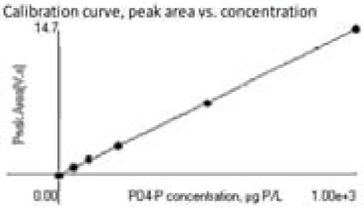
	P mg/L		
NPP actual	5.00		Certified concentration
NPP-1	5.00	100.0% Recovery	Acceptable, with 5% of 100%
NPP-1	4.92	98.4% Recovery	Acceptable

Total phosphorus (TP) run 9-25-2012

Calibration standard peaks, showing integration area, please not switch in units to ug P/L



Calibration curve, peak area vs. concentration



Area = 2.16e-7 * Conc^2 + 0.0145 * Conc - 0.0965
Conc = - 0.0624 * Area^2 + 68.7 * Area + 6.76
Correlation Coefficient (r) = 0.99996

Calibration QCs--results Second column is certified value, columns a-d are QC results

QC	actual	a	b	c	d	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
upper	0.500	0.477	0.479	0.471	0.479	Please note lower range
middle	0.100	0.083	0.082	0.080	0.084	of QCs
lower	0.050	0.042	0.041	0.040	0.040	

Calibration QCs--error Error relative to actual value of each QC

QC		a	b	c	d	
		error	error	error	error	
upper		4.6%	4.2%	5.8%	4.2%	acceptable
middle		17.3%	17.6%	20.2%	16.0%	above limit
lower		15.2%	17.6%	19.2%	19.2%	above limit

Laboratory blank Columns a-e are blank measurements

		a	b	c	d	
	P mg/L	P mg/L	P mg/L	P mg/L	P mg/L	
blank	0.000	0.0075	0.0057	0.0070	0.0064	
MDL	0.007	minimun detection limit, blank should be less than this value				
blank below MDL?		No	Yes	Yes	Yes	Average acceptable

Duplication 2nd column is first run, 3rd column is duplicate run, 4th column is error between the two

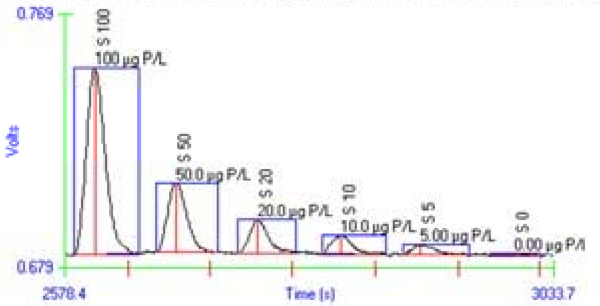
Sample ID	P mg/L	dup mg/L	error	
71	0.259	0.282	8.5%	Marginal
82	0.017	0.018	2.9%	Acceptable

Reference material bis (p-nitrophenyl) phosphate, Na salt (NPP)

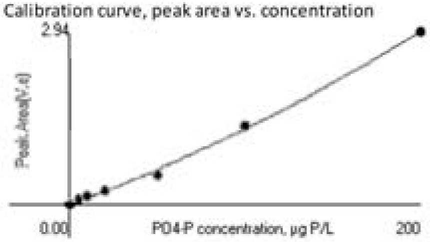
	P mg/L		
NPP actual	0.500		Certified concentration
NPP-1	0.479	95.8%	Recovery Acceptable, with 5% of 100%

Soluble reactive phosphorus (SRP) run 1-21-13

Calibration standard peaks, showing integration area, please not switch in units to ug P/L



Calibration curve, peak area vs. concentration



Area = 2.00e-5 * Conc^2 + 0.0107 * Conc + 0.0154
Conc = - 6.17 * Area^2 + 86.1 * Area - 0.379
Correlation Coefficient (r) = 0.99909

Calibration QCs--results Second column is certified value, columns a-b are QC results

QC	actual	a	b	
	P mg/L	P mg/L	P mg/L	
upper	0.200	0.198	0.198	Please note lower range
middle	0.010	0.012	0.012	of QCs
lower	0.005	0.007	0.007	

Calibration QCs--error Error relative to actual value of each QC

QC	a	b	
	error	error	
upper	1.0%	1.0%	acceptable
middle	19.0%	21.0%	marginal at low concentrations
lower	34.0%	37.0%	marginal at low concentrations

Laboratory blank Columns a-b are blank measurements

		a	b	
	P mg/L	P mg/L	P mg/L	
blank	0.000	-0.002	0.001	
MDL	0.007	minimun detection limit, blank should be less than this value		
blank below MDL?		Yes	Yes	All acceptable

3. Inspection and correction of digital data files

Digital data collected for this project included *precipitation depths* recorded on Hobo automated tipping bucket rain gauges and *water stage* at culvert inlets recorded by pressure transducers connected to Teledyne ISCO water samplers, both components of Task 1. In addition, spatial data files collected via a Trimble GeoExplorer CE series handheld GPS were collected for Task 4.

Precipitation files were scanned for completeness and compared among stations to ensure against anomalous recordings. Bulk rainfall collectors at each rain gauge were used as a secondary check on rainfall totals. Rainfall totals recorded by the automated tippers were deemed valid in all cases where digital totals fell within +/- 10% of the bulk precipitation collected between field visits. For any storm events with missing or erroneous records at a site, the nearest precipitation gauge was used to determine rainfall totals.

Water stage files for each site studied in Task 1 were inspected for errors. Field notes of water level values were used to adjust stage values where necessary. Records deemed suspect and stage heights above 22 cm at the weir on culvert inlets were rejected for analysis, since these exceeded the maximum height for which stage-discharge rating equations were developed.

GPS point file locations were inspected for spatial accuracy using the road centerline data available through the Vermont Center for Geographic Information and employed for analysis under Task 4. All data points were deemed to fall within the error limits of the GPS unit (+/- 10 m positional accuracy) and archived as part of this data set.

4. Data archiving and back up

All project data files were stored on a shared network drive on the UVM central computing network and available to project personnel. UVM maintains a weekly network back up, assuring regular data security and access in case of accidental data loss. Upon completion of this project and delivery of the final report, all project data files will be maintained on the UVM network for a period of no less than two years.

A copy of primary data files generated for this project will be delivered with the final report and will include metadata files with variable descriptions. All spatial data files will be provided in Vermont State Plane coordinates. Latitude and longitude of sites studied under Task 1 are given in a table in Appendix 1.

5. Documentation of secondary data

Three types of secondary data were used in the analysis completed for this report: (1) spatial data accessed from the Vermont Center for Geographic Information (VCGI) and from the

Champlain Watershed Improvement Coalition of New York (CWICNY), (2) water quality data provided by the Friends of the Mad River watershed association, and (3) stream flow data from the US Geological Survey gaging station on the Mad River.

Spatial data file names, access dates and links to the VCGI portal are given within the text. Spatial data files provided by the CWICNY are not archived online and had no accompanying metadata. In this case, we cited the appropriate report for which the data were collected and provide a footnote annotation for the data source contact.

Data access links for water quality data obtained from the Friends of the Mad River and for streamflow data obtained from the USGS online data portal are provided within the text.

In addition, literature values from LCBP Technical Report No. 57 (Smeltzer et al., 2009) and unpublished sediment loading estimates generated by Laurie Medalie of the USGS were used and reported in Chapter 4. These are cited within the report in Chapter 4.