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# CONTROLLING POLLUTED STORMWATER RUNOFF FROM ROADS

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## INTRODUCTION

Transportation networks are a critical component of society's infrastructure, providing access to move goods and people through the landscape, but with environmental impacts that affect a range of ecosystem processes, including animal migration patterns, exotic plant propagation, and the production of runoff and water quality contaminants.[2] The linear nature of roads and their tendency to collect, concentrate, and route water and pollutants along the road corridor and roadside-ditch network result in

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2. Richard T. T. Forman & Lauren E. Alexander, *Roads and Their Major Ecological Effects*, 29 ANN. REV. ECOLOGY & SYSTEMATICS 207 (1998).

impacts to watershed processes on a scale far greater than one might expect from the small fraction of land area they occupy.[3] The effects of roads on water quality are linked to the ways in which roads, as impervious surfaces, influence runoff (or stormwater) production and redistribution.[4] Within mountainous or upland[5] settings, where unimproved, gravel or native-surfaced roads are common, these runoff and water quality dynamics involve changes to the processes of rainfall infiltration, groundwater percolation, and delivery of stormwater to streams. The scientific work to document unpaved road impacts on runoff and water quality has been driven by a need to understand land management impacts and the need to mitigate these to comply with federal and state clean water regulations and other environmental regulations.[6]

Within the Lake Champlain Basin, much of the attention on water quality has focused on understanding the important contributions of agricultural runoff to water quality degradation. This has resulted in important new insights from field and modeling studies, helping to identify critical source areas for pollutant production.[7] Within the last two decades, attention in Vermont has also focused on the important role of unstable river channels and adjusting to a legacy of historical land use practices, including deforestation, agricultural production, and urbanization, that result in extensive river bank and floodplain erosion and the contribution of

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3. Charles H. Luce & Beverley C. Wemple, *Introduction to the Special Issue on Hydrologic and Geomorphic Effects of Forest Roads*, 26 EARTH SURFACE PROCESSES & LANDFORMS 111, 111 (2001).

4. Charles H. Luce, *Hydrological Processes and Pathways Affected By Forest Roads: What Do We Still Need To Learn?*, 16 HYDROLOGICAL PROCESSES 2,901, 2,901 (2002).

5. I define "uplands" here generally as areas of higher elevation, as compared to "lowland" settings (used later in this article). In Vermont, the "uplands" are generally located above 1,500 feet, where steeper slopes have led to pattern of landuse and landcover dominated by forests and rural housing. Most of the land cleared for agriculture in Vermont is located in what I refer to as "lowlands," those settings below 1,500 feet, including the Lake Champlain Valley and floodplains of major rivers.

6. Julia A. Jones et al., *Effects of Roads on Hydrology, Geomorphology, and Disturbance Patches in Stream Networks*, 14 CONSERVATION BIOLOGY 76, 78 (2000); COMM. ON HYDROLOGIC IMPACTS OF FOREST MGMT., HYDRAULIC EFFECTS OF CHANGING FOREST LANDSCAPE 67 (2008).

7. *See, e.g.*, VT. AGENCY OF NAT. RES. ET AL., FACT SHEET #1: AGRICULTURAL LANDS MANAGEMENT: VERMONT LAKE CHAMPLAIN PHOSPHOROUS REDUCTION PLAN: TAKING ACTION TO RESTORE LOCAL STREAMS AND LAKE CHAMPLAIN, http://dec.vermont.gov/sites/dec/files/wsm/erp/Champlain/docs/2014-11-10%20Lake%20Champlain%20TMDL%20Factsheet_Agriculture.pdf [https://perma.cc/529Z-ZGHK] (last visited July 3, 2016) (discussing the efforts taken by Vermont farmers, businesses, municipalities, and other stakeholders to reduce phosphorous into the lake); JOHNATHAN R. WINSTEN ET AL., POLICY OPTIONS FOR REDUCING PHOSPHOROUS LOADING IN LAKE CHAMPLAIN 4–12 (2004), http://www.northernlakechamplain.org/wp-content/uploads/2013/08/An-Analysis-of-Policy-Options-for-P-Control-in-the-Lake-Champain-Basin-2.pdf [https://perma.cc/Z69G-GK6E] (discussing and assessing current policy and programs attempting to control phosphorous runoff from agricultural lands).

sediment and sediment-bound nutrients to waterways.[8] Within this context, the uplands of Vermont are largely viewed as protectors of water quality due to extensive forests that blanket the mountain landscape and the important role that forests play in regulating water quality by absorbing rainfall into highly pervious soils and routing it more slowly to receiving waters.[9] However, one need only travel into the uplands of Vermont along any of the unpaved road corridors to see clear indications of water quality impacts associated with the transportation network in this setting, including extensive erosion of road surfaces and roadside ditches and direct discharges of storm water to otherwise pristine mountain streams (Figure 1). This article seeks to outline what we know about the impacts of unpaved roads on water quality in the Lake Champlain Basin and similar settings of the northeastern United States. Section I below lays out the ways in which roads alter processes of stormwater production and routing, with impacts on erosion and water quality. This is followed in Section II by a general description of transportation networks in mountainous landscapes to provide context for both the local reader and for those interested in parallels to landscapes elsewhere. Section III provides a summary of empirical work in Vermont to examine the role of unpaved roads on water quality. Section IV summarizes experimental and retrospective assessments used to evaluate the effectiveness of practices to mitigate against these impacts. Section V ends with comments aimed to place the "road impact" into broader perspective, for those concerned with water quality management, and with comments on barriers to implementation of practices to address road impacts on water quality.

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8. VT. AGENCY OF NAT. NAT. RES., RESILIENCE: A REPORT ON THE HEALTH OF VERMONT'S ENVIRONMENT 8–9 (2011).

9. COMM. TO REVIEW THE NEW N.Y. C. WATERSHED MGMT. STRATEGY, MANAGEMENT FOR POTABLE WATER SUPPLY: ASSESSING THE NEW YORK CITY STRATEGY 76, 386 (2000).

*Figure 1: Evidence of water quality impacts associated with unpaved roads in Vermont's uplands: erosion of rills and gullies on impervious road surface (left panel), eroded roadside ditch resulting from channelized stormwater runoff (middle panel), direct discharge of road runoff to receiving stream from road culvert (right panel).*

## I. PRIMER ON UNPAVED ROAD IMPACTS TO WATERSHED PROCESSES IN UPLAND MOUNTAINOUS SETTINGS

Roads located in rural upland and mountainous settings influence watershed processes through a number of mechanisms. The relatively impervious surface of the roadbed, even when unpaved, reduces the infiltration of precipitation, generating stormwater, which is otherwise rare in these settings.[10] The network of roadside ditches is designed to collect stormwater and route it efficiently to discharge points, but this concentration and discharge of stormwater represents an artificial extension to the natural drainage network and a direct conduit for discharges of sediment, nutrients, or other pollutants to receiving waters.[11] In addition, when roads are constructed on steep slopes in mountainous terrain, shallow groundwater can be intercepted along road cuts and transferred from slow moving pathways in the subsurface to more rapid and concentrated pathways along roadside ditches,[12] resulting in extensive erosion of the road and ditch and discharge of eroded material in to streams (Figure 1). The concentration of water on roads, roadside ditches, and the discharge points

10. *See generally* Charles H. Luce & Terrance W. Cundy, *Parameter Identification for a Runoff Model for Forest Roads*, 30 WATER RESOURCES RES. 1057, 1057–69 (1994); Alan D. Ziegler & Thomas W. Giambelluca, *Importance of Rural Roads as Source Areas for Runoff in Mountainous Areas of Northern Thailand*, 197 J. HYDROLOGY 204, 205, 213–25 (1997).

11. Beverley C. Wemple et al., *Channel Network Extension By Logging Roads in Two Basins, Western Cascades, Oregon*, 32 WATER RESOURCES BULL. 1195, 1195 (1996).

12. Beverley C. Wemple & Julia A. Jones, *Runoff Production on Forest Roads in a Steep, Mountain Catchment*, 39 WATER RESOURCES RES. 8, 8 (2003).

below roads has been shown to destabilize slopes, causing gullying,[13] shallow land sliding,[14] and failure of drainage or stream-crossing culverts under-designed to accommodate the volume of water generated during extreme storm events.[15] Through these various mechanisms, roads generate stormwater and erode soils at levels significantly greater than the undisturbed or lightly disturbed terrain they occupy. An important consequence of these changes in watershed processes is that any solute carried in stormwater and any particulate associated with soils eroded from road surfaces and roadsides may end up discharging to receiving waters and impacting water quality.[16] Salt and sand commonly used in northern latitudes during winter, particulate phosphorus that is naturally associated with soils, and dissolved nutrients (e.g., phosphorus and nitrogen) along with other pathogens (*E. coli* bacteria) move with stormwater and are discharged to receiving waters.[17]

An underappreciated aspect of road impacts on watershed processes relates to the ways in which roads function to connect portions of the landscape they drain, effectively extending natural stream networks. This impact has received more attention recently within the scientific literature[18] as road studies have documented the magnitude of channel network extension and its effects, including consequences for pollutant discharges and impacts on downstream flood production.[19] A recent study in New

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13. Beverley C. Wemple, Hydrological Integration of Forest Roads with Stream Networks in Two Basins, Western Cascades, Oregon 59 (Jan. 21, 1994) (unpublished master's thesis, Oregon State University) (on file with Vt. J. Envtl. L.); I. Takken et al., *Thresholds for Channel Initiation at Road Drain Outlets*, 75 CATENA 257 (2008).

14. D. R. Montgomery, *Road Surface Drainage, Channel Initiation, and Slope Instability*, 30 WATER RESOURCES RES. 1,925, 1,925 (1994).

15. Beverley C. Wemple et al., *Forest Roads and Geomorphic Process Interactions, Cascade Range, Oregon*, 26 EARTH SURFACE PROCESSES & LANDFORMS 191, 191 (2001).

16. JOANNE S. GARTON, MASTER'S PROJECT: EVALUATING THE EFFECTIVENESS OF BEST MANAGEMENT PRACTICES ON RURAL BACKROADS OF VERMONT: A RETROSPECTIVE ASSESSMENT AND COST ANALYSIS 1 (2015), http://scholarworks.uvm.edu/cgi/viewcontent.cgi?article=1005&context=rsmpp [https://perma.cc/6AXF-QM6B].

17. *Typical Pollutants in Stormwater Runoff*, SOIL & WATER CONSERVATION SOC'Y METRO HALIFAX, http://lakes.chebucto.org/SWT/pollutants.html [https://perma.cc/VC4K-A2GN] (last updated Aug. 14, 2015).

18. *See* Christopher D. Arp & Trey Simmons, *Analyzing the Impacts of Off-Road Vehicle (ORV) Trails on Watershed Processes in Wrangel-St. Elias National Park and Preserve, Alaska*, 49 ENVTL. MGMT. 751, 752–53 (2012) (addressing off road trail impact on watersheds in an Alaskan national park); *see generally* DREW COE, THE IMPACT OF FOREST ROADS ON HYDROLOGICAL PROCESSES AND PATHWAYS: A REVIEW OF PUBLISHED LITERATURE (overview of various impact roads have on water pathways with extensive reference to scientific literature).

19. *See generally* Jacky Croke et al., *Sediment Concentration Changes in Runoff Pathways from a Forest Road Network and the Resultant Spatial Patter of Catchment Connectivity*, 68 GEOMORPHOLOGY 257 (2005) (using forest roads to examine the effect of runoff on pathways in stream networks); Louise J. Bracken & Jacky Croke, *The Concept of Hydrological Connectivity and Its Contribution to Understanding Runoff-Dominated Geomorphic Systems*, 21 HYDROLOGICAL PROCESSES

York state showed that a vast majority of the road network in the agricultural landscape discharged directly to streams.[20] This "connectivity" of roads and streams, associated with both unpaved and paved roads across the landscape, may be among the most important design elements of the transportation network to consider in managing impacts to water quality.

To address the adverse impacts of unpaved roads on water quality, a range of best management practices ("BMPs") are recommended. These practices generally include guidelines for locating roads to minimize impacts at stream crossings, recommendations for sizing, spacing, and installing drainage structures (such as culverts and water bars), and strategies for stabilizing roadsides and road drainage points (i.e., culvert outlets) using vegetation or energy dissipating structures, such as check dams or other stone work and turn-outs to direct runoff into vegetated areas along the roadside.[21] Within Vermont, these recommendations are codified in guidance documents provided to municipalities and supported by grants that promote small-scale road improvements and drainage practices executed by municipalities.[22]

## II. A DEMOGRAPHY OF ROADS IN THE LAKE CHAMPLAIN BASIN AND SIMILAR MOUNTAIN SETTINGS

The Lake Champlain Basin is typical of the northern New England landscape in that topography has largely dictated land use patterns and the development of the transportation network. Throughout the basin and much of northern New England, land has been cleared for agriculture in the lowlands and the floodplains of major rivers, leaving the steeper terrain of the uplands covered today primarily by forests.[23] Major transportation corridors follow the river valleys a result of these settings having some of the only flat terrain for locating roads and railroads in this otherwise steep,

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1,749 (2007) (using a road network as an example of a landscape feature that enhances hydrological connectivity).

20. B. P. Buchanan et al., *Hydrological Impact of Roadside Ditches in an Agricultural Watershed in Central New York: Implications for Non-Point Source Pollutant Transport*, 27 HYDROLOGICAL PROCESSES 2,422 (2012).

21. *See generally* BEVERLEY C. WEMPLE, ASSESSING THE EFFECTS OF UNPAVED ROADS ON LAKE CHAMPLAIN WATER QUALITY (2013), http://www.lcbp.org/wp-content/uploads/2013/07/74_Road-Study_revised_June2013.pdf [https://perma.cc/574Z-LYCE] (discussing pollution into Lake Champlain via unpaved roads and assessing the effectiveness of BMPs suggested to reduce sediment runoff).

22. *See generally* N. VT. & GEORGE D. AIKEN, VERMONT BETTER BACKROADS MANUAL: CLEAN WATER YOU CAN AFFORD (2009) (discussing best practices for backroads in Vermont

23. *Agriculture*, FROM THE LAND TO THE LAKE, http://www.henrysheldonmuseum.org/land_to_lake/articles/agriculture.html [https://perma.cc/AK52-WHDR] (last visited July 3, 2016).

mountainous landscape.[24] Roads within the few urban centers and along the major federal and state highway corridors are paved, but many of the roads managed by small municipalities in the region are unpaved and traverse steep land.[25]

The mountainous terrain of the region and location of the transportation infrastructure gives rise to a set of interactions among rivers and roads that have implications both for infrastructure integrity and for water quality (Figure 2). Roads located in the lowlands, especially in the narrow valleys of the region, travel parallel to rivers, occupying floodplains once carved by rivers that moved laterally to accommodate floods but are now constrained by transportation infrastructure. During Tropical Storm Irene in August of 2011, these transportation corridors suffered tremendous damage as roads were undermined by rivers seeking to dissipate the energy of intense flood waters and the debris transported by them.[26] Over the long term, lateral constriction by transportation infrastructure limits the natural migration of rivers that provide important aquatic habitat and allow rivers to use their floodplains to dissipate energy and cleanse floodwaters of sediment and sediment-bound nutrients.[27] Roads located in the uplands traverse steep slopes with frequent crossings of small stream channels. In this upland setting, the mostly forested landscape is covered by soils with high infiltration rates, but steep topographic gradients give rise to higher precipitation rates in the uplands, thus, more water to accommodate. Water concentrated on impervious road surfaces and intercepted along road cuts is routed through a network of roadside ditches and typically discharged to receiving streams. This creates a chronic sourcing of stormwater and pollutants to these otherwise pristine streams but also an episodic risk to infrastructure during extreme storms, when the volume of runoff often exceeds the design capacity of ditches and culverts, leading to the types of infrastructure failure seen so commonly during Tropical Storm Irene and more recent floods in the region (Figure 2).

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24. *Construction of the Railroad (1846-1886)*, LANDSCAPE CHANGE PROGRAM, UNIV. OF VT., https://www.uvm.edu/landscape/dating/railroads/construction.php [https://perma.cc/VFB6-V25M] (last visited July 3, 2016).

25. WEMPLE, *supra* note 21, at ii, 1–3.

26. VT. NAT. RES. COUNCIL, READING VERMONT'S RIVERS 3 (2013), http://vnrc.org/wp-content/uploads/2013/07/Reading-Rivers-reduced.pdf [https://perma.cc/RV9L-NUKK] (last visited May 2, 2016).

27. Paul Blanton & W. Andrews Marcus, *Railroads, Roads, and Lateral Disconnection in the River Landscapes of the Continental United States*, 112 GEOMORPHOLOGY 212, 222–24 (2009).

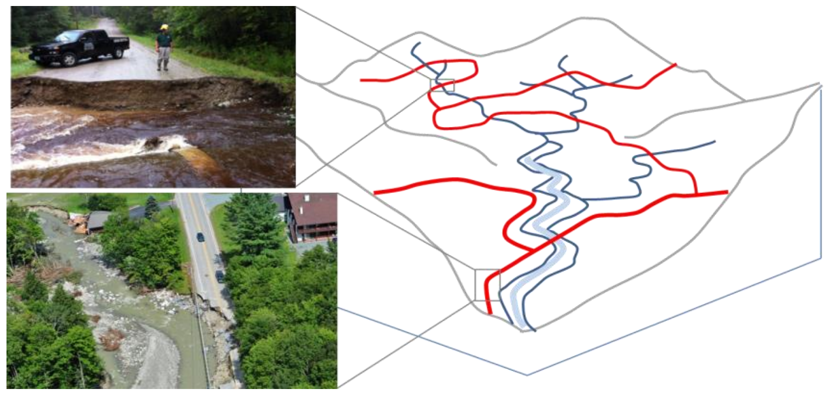

*Figure 2: Right: block diagram illustrating characteristic location of roads in the northern New England and other mountain landscapes. In the lowlands, roads are preferentially situated in floodplains. In the uplands, roads traverse steep slopes and cross small-stream channels. Photos at the left show damage sustained on Vermont roads during Tropical Storm Irene in August of 2011 at a road-stream crossing in the uplands (top) and along a river corridor in the lowlands (bottom).*

Within the Vermont portion of the Lake Champlain Basin, records of road surfacing included in the state Agency of Transportation's digital data layers show that roughly sixty percent of the road network is unpaved, with a greater fraction of unpaved roads (relative to paved road length) in the rural mountainous towns of the state.[28] These roads are largely managed by small municipalities who devote considerable taxpayer resources to annual maintenance and repairs, including snow removal during winter, grading following the snow melt season to provide a safe driving surface, and on-going maintenance of drainage structures and storm damages. Steep gradients on the unpaved road network amplify the drainage and maintenance challenges experienced by municipalities. Within the Winooski River Watershed of Vermont, for example, roughly fifty percent of the road length is five percent grade or steeper, a threshold commonly used to recommend road stabilization measures such as stone lining of ditches to reduce erosion by stormwater.[29]

## III. EXAMINING IMPACTS OF UNPAVED ROADS ON WATER QUALITY IN MOUNTAINOUS SETTINGS IN THE LAKE CHAMPLAIN BASIN

Despite the recognition of the impact of roads on stormwater production and water quality, based on studies cited above and others, little heretofore has been known about the relative importance of roads within

28. WEMPLE, *supra* note 21, at 27.
29. N. VT. & AIKEN, *supra* note 22, at 3.

the context of efforts to address Lake Champlain's water quality. To this end, we initiated a study in 2011 to quantify stormwater and pollutant production on rural roads within the Lake Champlain Basin.[30] Our focus was on unpaved roads in upland settings because of an interest in looking beyond the lowland agricultural landscape for other factors that contribute to water quality degradation and because unpaved roads represent the larger share of the transportation network in the uplands. Results of that work are conveyed in a technical report[31] and summarized here for policy makers and legal scholars.

To quantify stormwater production and the associated sediment and sediment-bound phosphorus generated on unpaved roads during storm events, we studied a set of twelve unpaved road segments in the Mad River Valley of Vermont where an on-going community water monitoring program allowed us to estimate watershed loadings of sediment and phosphorus, placing our estimates from roads in context.[32] Our monitoring involved continuous measurements of runoff during storm events and sampling for water quality analysis using automated water samplers located at each of the road sites. Our observations show that the volume of stormwater generated on roads is influenced by the length of the road draining to a discharge point and that the concentration of sediment carried in that storm water is influenced by the gradient of the road (Figure 3). Longer segments of road generated more runoff during storm events and steeper segments of roads generated higher concentrations of eroded sediments. Measurements of this type, made over successive storm events at each of the monitored road sites then scaled to a unit estimate of annual suspended sediment production, shows the general pattern of higher rates of sediment production on steeper roads (Figure 4). Although the explanatory power of road gradient is modest at best (R2 = 0.35), suggesting that other factors such as the occurrence of shallow groundwater interception, presence of roadside vegetation, condition of the road surface, storm intensity, and vehicle traffic during storm events influence the concentration of sediment in stormwater generated on unpaved roads, this relationship to road gradient provides a means for extrapolating site-scale observations to the watershed scale, as described below.

30. WEMPLE, *supra* note 21.
31. *Id.* at ii.
32. *Id.*

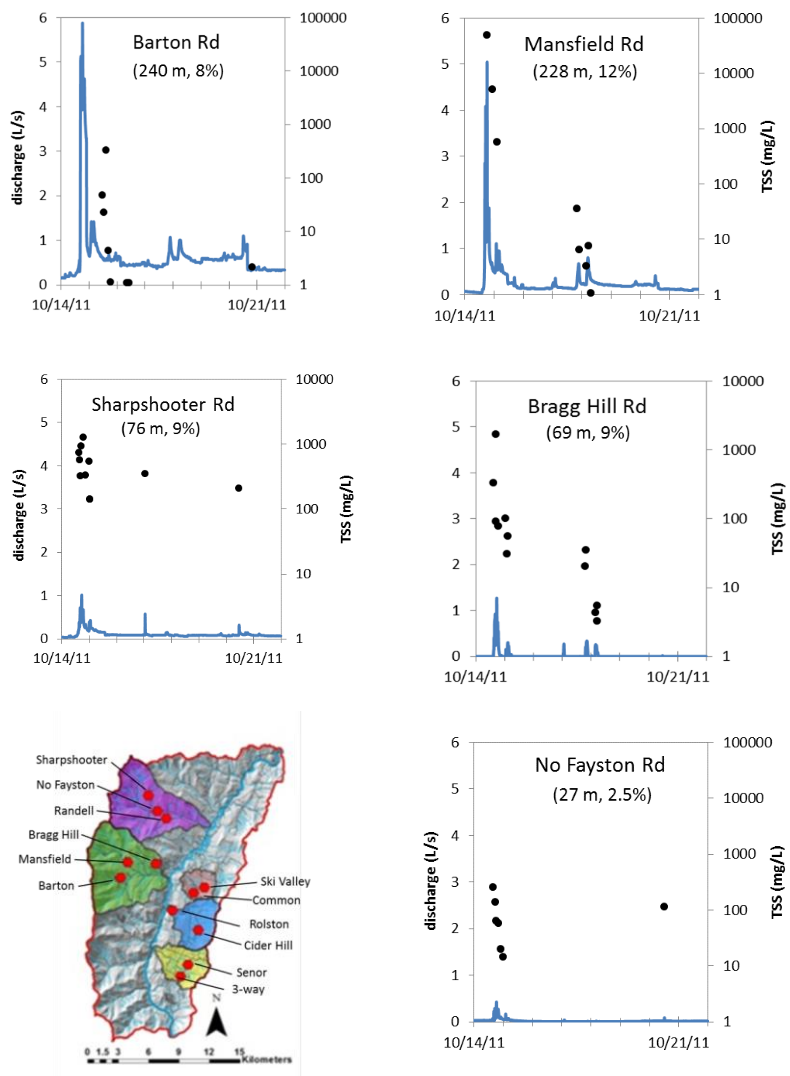


*Figure 3: Measurements of stormwater production and suspended sediment concentrations in stormwater on five unpaved road segments in the Mad River Valley, monitored during an October 2011 storm event. Sites are displayed from upper left to lower right in order of decreasing road length (indicated in parentheses as meters of road draining to the measurement station). Road grade for each segment is also displayed in parentheses. Monitored site locations within the Mad River Valley for this and other storm events are shown in the inset map in the lower left panel within the small watersheds they are located. See Figure 5 for watershed names and loading estimates derived from these and other measurements.*

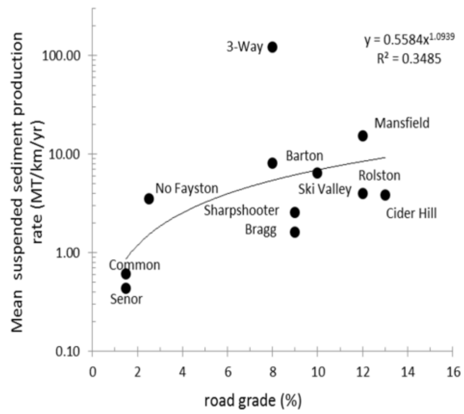


*Figure 4: Plot of total phosphorus concentration verses total suspended sediment concentration in samples collected on roads in the Mad River Valley in 2011 and 2012. TSS to TP relationship was used to estimate total phosphorus loads from roads in the Mad River Watershed.* W*EMPLE*, supra *note 21.*

Sediment eroded from unpaved roads serves as a water quality contaminant in two ways. Fine particulates discharged to receiving waters degrade water clarity and fills interstitial spaces of streambeds, impacting the quality of aquatic habitat for biota macroinvertebrates and fish that spawn in coarse bedded mountain streams, an effect that has been well documented in the western United States.[33] In addition, because phosphorus tends to adhere in particulate form to soils, soil erosion from roads will be accompanied by particulate phosphorus.[34] Stormwater will also have a component of dissolved phosphorus, sourced from groundwater seeps along road cuts or stormwater that entrains phosphorus as it flows over land adjacent to the road corridor.[35] Our samples collected from roads during storm events show a strong positive relationship between total suspended sediment and total phosphorus concentration in road stormwater (Figure 5). It is this particulate and dissolved phosphorus contribution from unpaved roads that leads to concerns regarding water quality impacts within the Lake Champlain Basin where phosphorus has been identified as the pollutant of concern to be managed under the TMDL.[36] Nevertheless, the reader should be aware that sediment is a key water quality contaminant in surface waters

33. William S. Platts et al., *Changes in Salmon Spawning and Rearing Habitat from Increased Delivery of Fine Sediments to the South Fork Salmon River, Idaho*, 118 TRANSACTIONS AM. FISHERIES SOC'Y 274, 274 (1989); Stephen C. Trombulak & Christopher A. Frissell, *Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities*, 14 CONSERVATION BIOLOGY 18, 22 (2000).

34. Lowell Busman et al., *The Nature of Phosphorus in Soils*, U. MICH., http://www.extension.umn.edu/agriculture/nutrient-management/phosphorus/the-nature-of-phosphorus/ [https://perma.cc/LY72-XY8R] (last updated July 2009).

35. Joseph L. Domagalski & Henry Johnson, *Phosphorous and Groundwater: Establishing Links Between Agricultural Use and Transport to Streams*, U.S. GEOLOGICAL SERV., http://pubs.usgs.gov/fs/2012/3004/ [https://perma.cc/8SSW-RT2L] (last updated Jan. 9, 2013).

36. ENVTL. PROT. AGENCY, PHOSPHOROUS TMDLS FOR VERMONT SEGMENTS OF LAKE CHAMPLAIN 7 (2016), https://www.epa.gov/sites/production/files/2016-06/documents/phosphorus-tmdls-vermont-segments-lake-champlain-jun-17-2016.pdf [https://perma.cc/8RJ8-BLTZ] (last visited May 2, 2016).

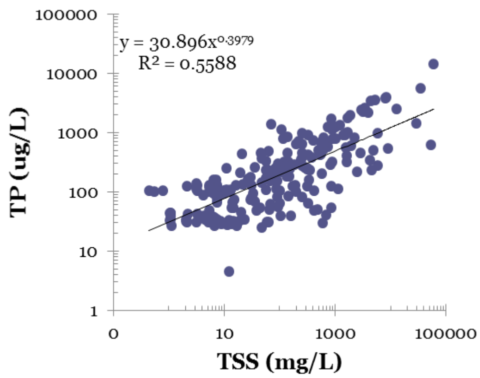


*Figure 5: Plot of site estimated annual sediment production on monitored road segments in the Mad River Watershed of Vermont versus site road gradient. See* W*EMPLE*, supra *note 21.*

of the United States[37] and of particular concern in mountain streams where inputs of fine sediment from erosion degrade aquatic habitat and negatively impact fish and other biota.

To estimate the pollutant loading from roads as a fraction of that flushed from small watersheds of the Mad River, we used a modeling approach as follows and described in a technical report on this work.[38] Water quality monitoring data (measuring suspended sediment and total phosphorus concentrations) provided by the local watershed association were used to develop concentration-discharge relationships for each of the five watersheds in which our road sites were located (Figure 3). These relationships were then used to estimate an annual load of sediment and phosphorus from each of these watersheds. To estimate loadings from roads, we used the relationship displayed in Figure 4 to derive estimates of annual sediment flux from the road network in the five watersheds and the relationship between total suspended sediment and total phosphorus concentration displayed in Figure 5 to estimate annual phosphorus load from road erosion. This approach yields estimates of sediment and phosphorus sourcing from roads of roughly ten to thirty percent of the loads estimated from the watersheds in which they are located (Figure 6). These are the first event-based estimates of pollutant production from unpaved roads in Vermont and provide a basis for evaluating the importance of addressing this pollutant source. Important uncertainties in these estimates warrant consideration and are discussed in the final section of this article.

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37. ENVTL. PROT. AGENCY, THE INCIDENT AND SEVERITY OF SEDIMENT CONTAMINATION IN SURFACE WATERS OF THE UNITED STATES 1–3 (2004).

38. WEMPLE, *supra* note 21.

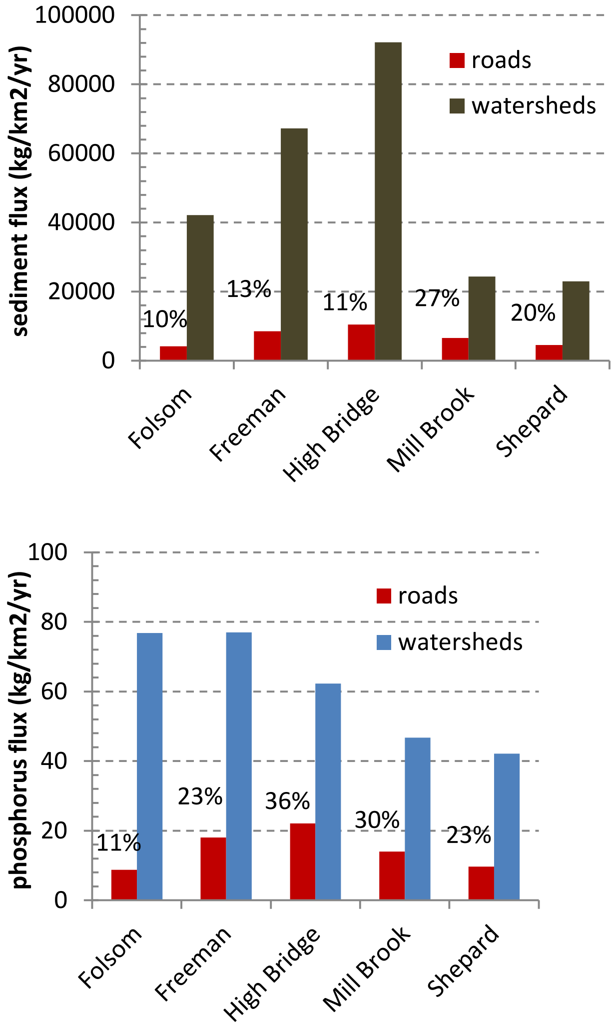


*Figure 6: Comparison of estimated pollutant loads from unpaved roads (red bars) and small watersheds for suspended sediment (left panel) and total phosphorus (right panel). Percentage values above red bars are estimates of pollutant loads from roads as a fraction of estimates from watersheds.*

## IV. EVALUATING THE EFFECTIVENESS OF BEST MANAGEMENT PRACTICES ON GRAVEL ROADS

To mitigate the effects of unpaved roads on pollutant production and water quality degradation, a number of BMPs have been developed and evaluated.[39] Studies of BMP implementation on forested lands in the

39. James A. Lynch et al., *Best Management Practices for Controlling Nonpoint-Source Pollution on Forested Watersheds*, 40 J. SOIL & WATER CONSERVATION 164, 164–65 (1985); Walter F.

Northeastern United States have shown highly variable compliance with recommendations, pointing particularly to instances when the failure to use BMPs on roads resulted in significant hydrologic and erosion impacts.[40] Much of this work is limited to application of BMPs on roads built for logging operations. Although unpaved municipal roads in Vermont are in many ways similar to the low volume, unpaved roads built for large-scale logging operations, little information exists on the efficacy of practices employed by small municipalities, such as those in Vermont and elsewhere in northern New England, to manage their transportation networks and no retrospective assessments have been conducted to evaluate road drainage improvements that have been funded by federal, state, and local investments. To provide insight into these issues, we conducted a study of BMP effectiveness involving two components: an experimental study to evaluate effectiveness of several recommended BMPs used on municipal unpaved roads to control erosion and improve road drainage and a retrospective assessment of BMPs funded by Vermont's Better Backroads Program[41] to determine current condition and efficacy of those practices.

*Figure 7: Silt fence constructed of plastic sheeting to retain sediment and filter fabric to pass stormwater, installed at culvert outlets to trap material eroded from roads and roadside ditches.*

Our experimental study was conducted in the Mad River Watershed, leveraging observations made and relationships built from the water quality study described above. For this work, we selected nine road segments identified by town officials as needing drainage improvements. For each of these, we prepared applications for installation of one of three practices as

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Megahan et al., *Best Management Practices and Cumulative Effects from Sedimentation in the South Fork Salmon River: An Idaho Case Study*, *in* WATERSHED MANAGEMENT: BALANCING SUSTAINABILITY AND ENVIRONMENTAL CHANGE 401 (Robert J. Naiman ed., 1992) (explaining how proper implementation of management practices had potential to reduce sediment yields by forty-five to ninety-five percent); J. N. Kochenderfer et al., *Hydrologic Impacts of Logging an Appalachian Watershed Using West Virginia's Best Management Practices*, 14 N.J. APPLIED FORESTRY 207, 207 (1997).

40. David J. Brynn & John C. Clausen, *Postharvest Assessment of Vermont's Acceptable Silvicultural Management Practices and Water Quality Impacts*, 8 N.J. APPLIED FORESTRY 140, 140–43 (1991); Jamie L. Schuler & Russell D. Briggs, *Assessing Application and Effectiveness of Forestry Best Management Practices in New York*, 17 N.J. APPLIED FORESTRY 125, 133–34 (2000).

41. N. VT. RES. CONSERVATION & DEV., VERMONT BETTER BACKROADS PROGRAM REPORT 2010, http://www.nvtrcd.org/2010_BBR_Report.pdf [https://perma.cc/LED7-RJWP] (last visited May 2, 2016).

experimental treatments: (1) stone lining ditches to reduce erosion and incision along the road margin; (2) check dams and turnouts to dissipate stormwater energy and divert water and sediment into road-adjacent forest; and (3) compost socks (fabric bales of organic material) placed in ditches to act as energy dissipaters and traps for sediment.[42] For each of the experimental sites, we also selected a nearby road segment to use as an experimental control that would be monitored throughout the study period, but not manipulated.[43] Monitoring involved installation of silt fences at the outlets of culverts draining both the treatment and control sites. The silt fences were designed to pass stormwater but trap sediment, allowing us to return to the study sites following storms and excavate material eroded and deposited at the fence during storms.[44] We measured the entire volume of material trapped in the silt fence following storms and then returned a subsample to the lab where we dried and weighed it to convert a volume collected to mass and analyzed subsamples for grain size analysis and concentration of total phosphorus in eroded sediments.[45]

Results from this work provide insights both into the magnitude of material eroded from unpaved roads we studied and the effectiveness of these recommended practices. Depending upon conditions of the site, roads selected by town officials for drainage improvements commonly eroded between 100 – 300 kilograms of dry soil during storm events, with some sites yielding even greater amounts.[46] As expected, sites selected as controls generally had lower erosion rates when compared to the treatment sites in the pre-treatment period.[47] Following installation of BMPs, erosion at the treated sites was substantially reduced in most cases, resulting in sediment runoff that more closely matched the lower rates measured at control sites.[48] In some cases, installation of BMPs proved ineffective.[49] For example, the Grout Road site in Duxbury experienced considerable erosion (up to and in excess of 150 kilograms of material per monitored storm) in the post-treatment period and the check dams and turnouts installed there were insufficient to control erosion of this magnitude (Figure 8). Phosphorus concentrations in eroded soil captured at the silt fences averaged 500 milligram of phosphorous per kilogram of dry soil (Figure 9). A reduction

42. BEVERLEY C. WEMPLE & DONALD C. ROSS, EVALUATING EFFECTIVENESS OF BMP IMPLEMENTATION ON GRAVEL ROADS TO REDUCE SEDIMENT AND PHOSPHORUS RUNOFF 6 (2014).

43. *Id.* at 3.

44. *Id.* at 5.

45. *Id.* at 6.

46. *Id.* at 4.

47. *Id.* at 3.

48. *Id.* at 10.

49. *Id.*

in sediment eroded from unpaved roads will accomplish the added benefit of reducing phosphorus eroded and discharged in to receiving waters.

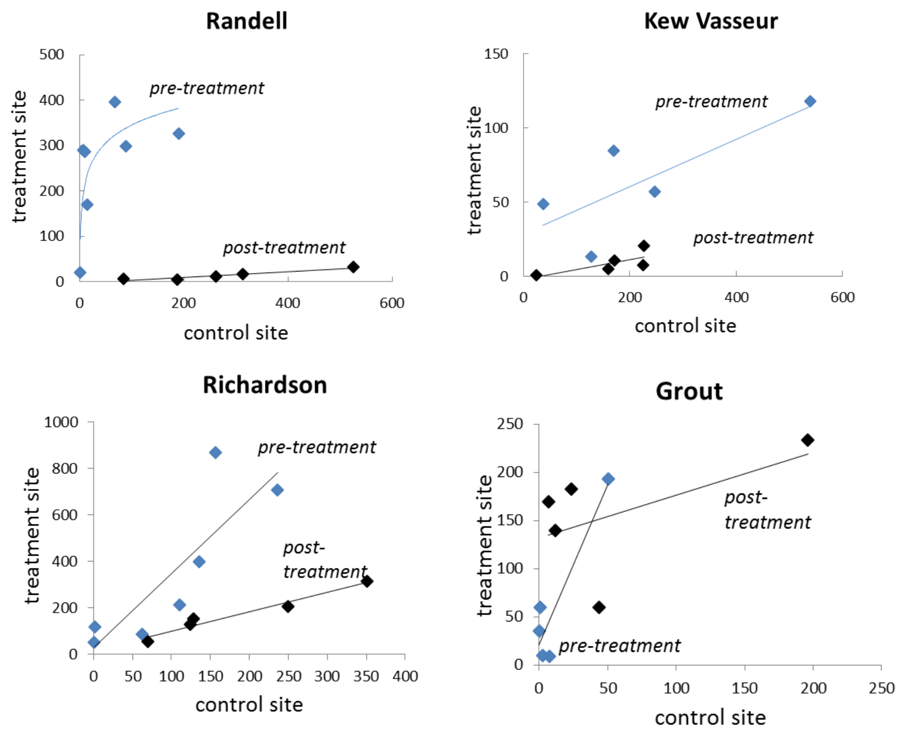


*Figure 8: Examples of results from experimental installations of BMPs on select road segments in the Mad River watershed. Plots summarize mass (in kilograms) of dry sediment collected at silt fences (see Figure 7) at each site for individual storm events and compare a control site, plotted on the x-axis, to a treated site, plotted on the y-axis, for both the pre-treatment and post-treatment period. A downward shift in the relationship between treated and control site, as evidenced at the Randell, Kew Vasseur and Richardson Road sites, demonstrates success of the BMP following installation of the experimental "treatment."*

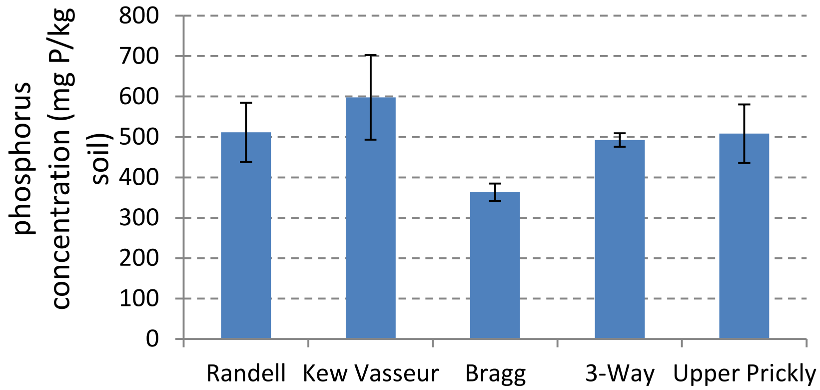


*Figure 9: Total phosphorus concentration in bulk sediment samples collected in silt fences at five road sites in the Mad River Watershed. Bars are means of samples analyzed. Error bars are sample standard deviations.*

To complement this experimental work, we also assessed 100 BMP installations at 43 sites funded by the Vermont Better Backroads Program over the past 8 years (the period for which records of project design and installation have been retained). The assessed sites were located in rural towns of northwestern and north-central Vermont, allowing us a broader geographical view across the state of practices employed and their efficacy. Our assessments involved review of the project design notes and a site visit to inspect conditions. For each BMP installation documented in the project notes and located in the field, we made a qualitative evaluation of condition, rating each as "intact" if the BMP appeared to be functioning to improve drainage and reduce on-site erosion, "compromised" if was some evidence of reduced performance to drain water and prevent erosion and "failed" if the BMP as recorded on the project file had been undermined or destroyed (Figure 10).

*Figure 10: Examples of assessed BMPs—left: intact stone lined ditch; middle: culvert compromised by debris partly plugging inlet; right: failed BMP installation showing evidence that stone and stabilization fabric have been undermined.*

Results of this assessment showed that BMPs funded through Vermont's Better Backroads Program are largely intact and functioning to provide the drainage improvements and water quality benefits for which they were designed (Figure 11). For example, among the one-hundred BMPs assessed, only ten had failed. Thirty percent of the BMPs assessed were compromised in their performance (most of these were stonework projects in the three to five years-since-installation range), but the maintenance required to restore function of these installations can be, and generally is, incorporated into regular activities of municipal road crews. Our assessment showed no longer-term tendency toward failure, even up to eight years after installation of BMPs, suggesting that these practices provide benefits for up to a decade (and perhaps longer) after installation.[50] Among the most vulnerable BMPs were those installed on the steepest roads. Failure rate increased from zero percent of those assessed on the lowest gradient roads, to approximately fourteen percent on roads with grades between five to nine percent to twenty-two percent on roads steeper than nine percent grade.[51]

50. WEMPLE, *supra* note 21, at 2, 63.
51. Wemple et al., *supra* note 11, at 1,204.

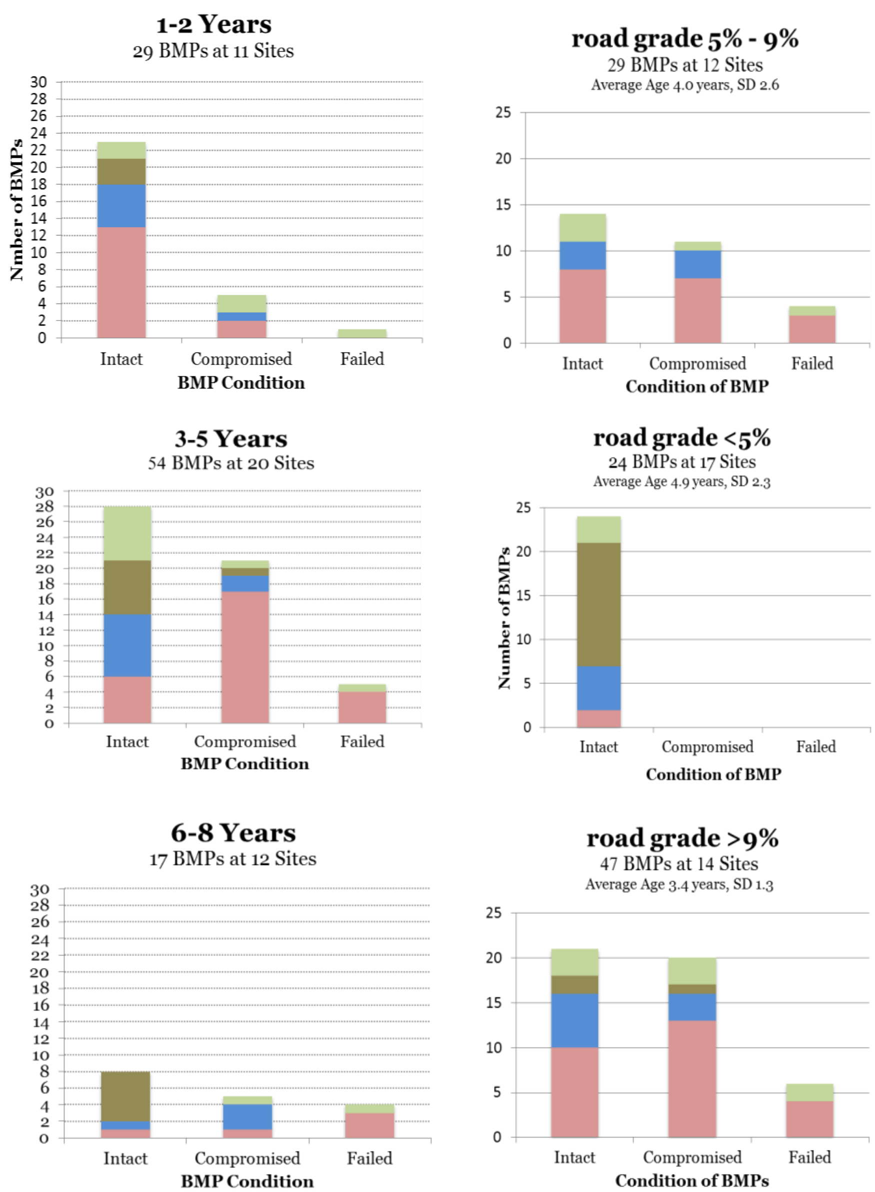


*Figure 11: Condition of BMPs assessed grouped by age of project (left panel) and road grade (right panel). Bar colors are pink = stonework, blue = culverts, dark green = revetments, and light green = vegetative controls.*

Our retrospective assessment also showed that BMPs funded through the Vermont Better Backroads Program weathered extreme storms with considerable success (Figure 12).[52] We coded sites according to whether they had been exposed to an extreme flood since BMP installation by using the database of historical floods in Vermont described in *Flood Resilience in the Lake Champlain Basin and Upper Richelieu River*.[53] Among those BMPs we assessed that had been exposed to flood events documented in this data base, only about fourteen percent had failed.[54] The nearly fifty percent of BMPs exposed to flood events that showed evidence of compromised condition underscores the importance of regular road maintenance to ensure design performance of these structures.[55]

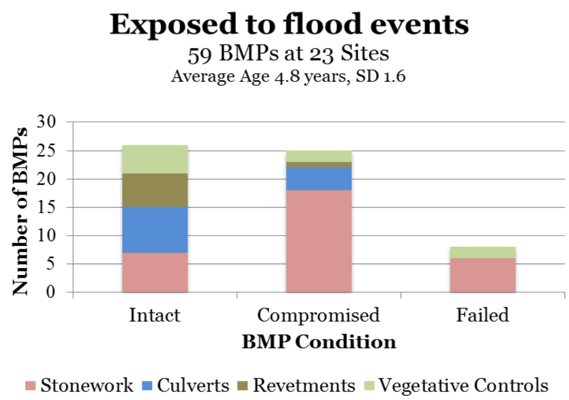


*Figure 12: Condition of assessed BMPs exposed to flood events, as documented in the database of Castle et al,* supra *note 53.*

Collectively, these experimental and retrospective results show that BMPs of the type employed on rural, unpaved roads in Vermont can be highly effective in reducing erosion of soil and associated phosphorus. These practices persist over time and largely withstand the conditions of extreme floods experienced in the last decade. In addition to the water-quality benefits achieved by implementation of these practices, an important benefit is improved flood resilience where roads can withstand extreme events and towns reduce expenditures on costly flood damage repair. These results suggest that within the upland, mostly forested landscape of the Lake Champlain Basin and similar settings, efforts to improve water quality can be achieved by addressing erosion on roads using these types of relatively low-cost practices, effectively targeted at the most vulnerable and highly eroding sites, with important added benefits for

52. GARTON, *supra* note 16, at 23 (states that only a minority of BMPs failed after flooding).
53. STEPHANIE S. CASTLE ET AL., FLOOD RESILIENCE IN THE LAKE CHAMPLAIN BASIN AND UPPER RICHELIEU RIVER 15 (2013).
54. GARTON, *supra* note 16.
55. *Id.*

rural communities who bear the cost of transportation-infrastructure maintenance and repair. In the following section, perspectives on this work are offered based on work conducted with a set of Vermont towns broadly representative of rural communities in the region.

## V. THE ROLE OF GRAVEL ROADS ON WATER QUALITY AND RURAL COMMUNITY RESILIENCE IN VERMONT

The need to maintain rural transportation networks is a key concern of municipalities and one in which they invest considerable resources. Decisions regarding allocation of resources to ongoing maintenance and upgrading of structures to address storm damage are made continually by highly capable road crews and informed by priorities set by municipal governing bodies and the tax payers of those municipalities. Over the period spanning the research described here, I heard many accounts relayed by town staff, select board members, and residents of the challenges they faced in meeting these demands, particularly in light of extreme storms experienced by many of mountain communities in recent years. To explore these decisions and tradeoffs, we conducted interviews and a simple budget analysis with the town administrator or clerk and the road foreman of five Vermont towns who agreed to participate. Our goal was to examine how road budgets were being spent and to consider how these might be balanced against investments in future BMP implementation.

The towns that participated in these interviews were not randomly selected, but are broadly representative of rural upland towns in Vermont with a small taxpayer base, a network of mostly gravel roads they maintain, and a road crew of three to five full- and part-time employees.[56] We reviewed a single year's budget with the town administrator to understand the types of expenses and staffing in the town's road budget then interviewed the road foreman with a set of questions to understand how staff time and materials were distributed throughout the year. We aimed to identify the share of salary and materials spent on unpaved roads during the non-winter period because this would be the time during which expenditures might be directed toward road drainage and water quality improvements either currently or in the future. We asked the road foreman to broadly categorize expenditures into one of five activity types: (1) routine maintenance; (2) mud-season repairs; (3) fixing "problem" roads[57];

56. GARTON, *supra* note 16, at 27.

57. "Problem roads" were defined here as road segments repaired by road crews in response to property owner or resident complaints or in response to on-going evidence of erosion or storm damage that compromised the integrity of the driving surface, ditch or drainage structures.

(4) constructing BMPs; or (5) maintaining BMPs. For each month of the year, we asked the road foreman to estimate the percentage of crew time spent on each of these activities in the budget year we examined. For the materials budget, we asked the road foreman to estimate those materials and the percentages of each allocated to unpaved roads during the non-winter season for each of the five task groups above.

Table 1: Towns participating in surveys and budget analysis of road maintenance and BMP implementation

| | Corinth | Huntington | Hyde Park | Waitsfield | West Windsor |
|---|---|---|---|---|---|
| Total Road Miles | 93.74 | 43.96 | 63.45 | 29.67 | 51.28 |
| % Unpaved | 77 | 75 | 61 | 75 | 85 |
| Population[58] | 1,367 | 1,938 | 2,954 | 1,719 | 1,099 |
| Road Budget (Year)[59] | $1,076,891 (FY 2014) | $867,717 (FY 2013) | $677,707 (FY 2014) | $431,615 (CY 2013) | $876,088 (CY 2013) |
| Budget $/mile | $11,488 | $19,73 9 | $10,68 0 | $14,54 7 | $17,084 |
| Road crew Employees[60] | 3 FT 1 PT | 4 FT | 4 FT 1 PT | 3 FT | 3 FT 1 PT |

58. U.S. CENSUS BUREAU, VERMONT: 2010 POPULATION AND HOUSING UNIT COUNTS 12, 20, 24 (2012).
59. Refers to budget year reviewed in this analysis
60. Includes full-time ("FT") and part-time ("PT") employees.

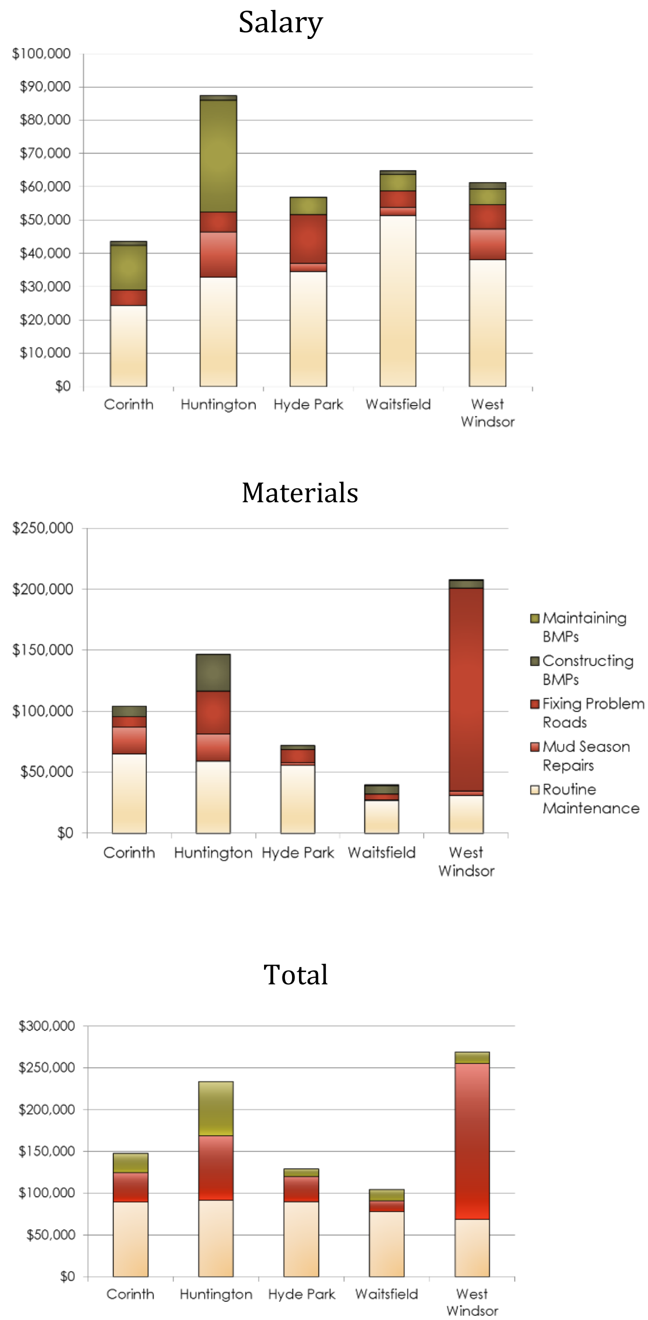


*Figure 13: Graphs of estimated salary expenditures on staff salary (upper panel) and materials (middle panel) for non-winter work on gravel roads based on interview responses for five towns interviewed for this study. Lower panel is total of salary and materials with five expenditure categories summarized into routine maintenance (tan), repairs (red), and BMPs (green).*

Interviews indicated that routine maintenance comprised the largest share of both salary and material expenditures for each of the towns studied (Figure 13). Four of the five towns studied had invested a smaller share of resources in the previous year on repair efforts following the snow-melt period ("mud season") and storm events. One of the towns interviewed, West Windsor, had allocated more than three times the amount spent on routine maintenance to damage repairs in the previous year, an outcome of extensive storm damage that the town had experienced. West Windsor's experience has likely been shared by other Vermont mountain towns impacted by severe storms in recent years based on statewide news reports of storm damage to road infrastructure.[61] Interviews also showed that each of the towns was allocating resources to BMP construction and maintenance, though this represented the smallest share of resource allocation (Figure 13). Huntington reported that they were investing more funds than in the past on BMP implementation in response to drainage improvements and reduced storm damage they had experienced following installation of Better-Backroads funded projects in recent years.[62] In total, the towns interviewed had spent in the budget year analyzed an average of $70,000 on routine maintenance, less than $15,000 to nearly $200,000 on repairs, and between $10,000 and $60,000 on BMP construction and maintenance.[63]

Although the scope of need for BMP implementation on gravel roads in the state is not well known, a recent mapping analysis provides some means of estimating where investments may be best made to improve road drainage and address water quality concerns. The Road Erosion Risk Ranking, developed under contract for the Vermont Agency of Natural Resources, uses a set of risk factors, including road gradient, proximity to streams, and discharge into receiving waters, to rank erosion risks on roads as a means of prioritizing projects that would address water quality concerns.[64] For the five towns interviewed, a summary of high-priority

61. *Storms Wash Out Bridges, Damage Roads in Vermont*, USAToday (June 30, 2006), 10:51 AM), http://usatoday30.usatoday.com/weather/storms/2006-06-30-vermont-flooding_x.htm [https://perma.cc/92JP-HQYB]; *Vermont Flood / Irene Hi-Res Gallery – September 12, 2011*, MANSFIELD HELIFLIGHT (Sept. 12, 2011), http://www.mansfieldheliflight.com/flood/index2.html [https://perma.cc/UA4A-3UCK]; Jack Thurston, *No Holiday for Some in Storm-Beaten Vt.*, WPTZ (July 4, 2014, 11:29 PM), http://www.wptz.com/news/vermont-new-york/burlington/no-holiday-for-some-in-stormbeaten-vt/20847334 [https://perma.cc/6GP8-JTZL]; *Storms Wreak Havoc on Central Vermont*, Times ARGUS ONLINE (July 20, 2015), *Storms Wreak Havoc on Central Vermont*, Times Argus Online.

62. GARTON, *supra* note 16, at 35.

63. *Id.* at 31.

64. VT. DEP'T OF ENVTL. CONSERVATION, VERMONT BETTER BACKROADS: ROAD EROSION INVENTORY ASSESSMENT MANUAL (2015), https://anrmaps.vermont.gov/websites/pdfs/Road%20Erosion%20Risk%20Manual.pdf [https://perma.cc/ZV38-VNTT].

roads is shown in Table 2 along with an estimate of the cost to implement BMPs. When amortized over eight years (the lifetime of many intact BMPs we assessed and described earlier in this paper), the cost of BMP implementation approaches the cost of annual expenditures on ongoing repairs typical in these towns, as shown in Figure 13.

Table 2: Summary of road length classified as at high risk of eroding and degrading water quality taken from recent statewide analysis conducted for Vermont Agency of Natural Resources and estimated treatment costs of BMPs taken from this study.

| Town | High risk road length (miles)[65] | Treatment cost[66] | Treatment cost over 8 years[67] |
|---|---|---|---|
| Corinth | 2.02 | $425,675 | $53,209 |
| Huntington | 1.34 | $282,816 | $35,352 |
| Hyde Park | 1.47 | $311.452 | $38,932 |
| Waitsfield | 1.23 | $260,529 | $32,566 |
| West Windsor | 2.59 | $546,174 | $68,272 |

## CONCLUSIONS

Results of this study demonstrated that erosion from discrete segments of unpaved rural roads generate substantial quantities of sediment and sediment-bound particulate phosphorus during storm events, particularly as the length and gradient of the road segment increases. Experimental results show that the implementation of BMPs on unpaved roads significantly reduces erosion and impairments that threaten water quality of receiving waterways. Retrospective assessment of past practices showed that BMPs employed on Vermont's backroads have remained largely intact for up to nearly a decade after installation, achieving long term benefits for water quality while protecting the integrity of the road way. Costs analysis for a select set of towns showed that addressing erosion control on gravel roads and fixing the types of problems that occur following storm events

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65. *ANR Natural Resource Atlas*, VT. AGENCY OF NAT. RESOURCES, http://anrmaps.vermont.gov/websites/anra/ [https://perma.cc/965N-54WQ] (last visited Mar. 7, 2016) (under the "Watershed Protection" category).

66. Treatment costs are estimated at $40/foot using the standard $10,000 Vermont Better Backroads grant amount and assuming a standard treated length of 250 feet. Actual treated road lengths on these projects vary and road length effectively treated in a $10,000 project may exceed this 250 foot estimate. Values are given here for illustrative purposes only.

67. Treatment costs are amortized over eight years to reflect the lifetime of intact BMPs assessed in this research, given availability of project data files. Actual BMP life may exceed this length of time.

constitute a substantial portion of the non-winter expenditures. These expenditures can be particularly straining in the wake of extreme storms. Taken together, these results suggest that a reallocation of resources from repair of damaged road segments to proactive implementation of BMPs will achieve water quality improvements and long-term cost savings for towns.

Although the empirical observations described in this paper were limited by the set of sites and towns selected for study, the sites examined are typical of upland settings in towns with populations, resources, and road networks that span conditions of the rural settings of the state. The results described here should be broadly applicable across the state and useful for directing resources and policies toward back road improvements.

Within the broader context of water-quality management in Lake Champlain, where control of biologically available phosphorus is needed to reduce the occurrence of harmful algal blooms, controlling erosion on unpaved roads may contribute only incrementally to meeting this regional challenge because phosphorus yielded from unpaved roads is likely less bioavailable than the yields from agricultural lowlands and must be transported over longer distances than from those settings closer to the lake. Nevertheless, mitigating water-quality impacts to our waterways is a broad challenge that requires adaptive interventions across the landscape. Addressing erosion and water-quality impairments on rural, upland road networks will make important contributions to reducing sediment input to our mountain streams, a pro-active measure that will undoubtedly forestall future water quality concerns in this setting. In addition, shoring up unstable and vulnerable segments of the upland road network will ensure the integrity of the infrastructure while building communities that are more resilient to the extreme events affecting Vermont and other settings in the face of climate change.