# Evaluating the Effectiveness of Best Management Practices on Rural Back Roads of Vermont: A Retrospective Assessment

Final Project Report Prepared for
The Vermont Agency of Natural Resources
Ecosystem Restoration Program

by

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# Introduction

## Unpaved Roads and Water Quality

A network of over 14,000 miles of unpaved road lines the hills and valleys of Vermont, connecting its communities and providing passage for those who use them. Also called "backroads", unpaved roads often support more than occasional passage for the people who live and work in rural Vermont. While large storms and flood events may catastrophically wash out sections of unpaved roads, typically seasonal rainstorms and snowmelt also contribute to persistent road degradation. The silt, sand and gravel that comprise the road surface travel downhill, either via ditches or directly down the relatively impervious road surface itself. This sediment-laden run-off then adds excess nutrients and phosphorous to the surface water and alters the physical progression of stream channels.

A recent study funded by the Lake Champlain Basin Program and the New England Interstate Water Pollution Commission found that unpaved roads are an important source of water quality degradation in upland settings of the Basin (Wemple, 2013). Although the mileage, slope and connectivity of unpaved roads to waterways varies among watersheds, the effects of unpaved roads as sources and conduits for pollutants into waterways is substantial and detrimental.

In the face of increasing storm events, town road crews find their budgets and staff unprepared to repair and ensure safety on damaged roads. Town officials, in cooperation with state agencies and town road foreman, now promote erosion reduction practices on unpaved roads not only to protect local waterways from non-point source sediment and phosphorus pollution, but also to reduce repeat expenditure on road repairs and maintenance that could be avoided by employing Vermont road and bridge standards (Resources, 2013). Implementation of Best Management Practices (BMPs) mitigates the effect of roads on water quality and include guidelines for locating roads and stream crossings, installing drainage structures and water bars, spacing of structures by road grade, stabilization of road cuts and soil using stonework and vegetation, and the use of energy dissipating and sediment control structures bordering roadsides and at culvert outlets (RC&D, 2009).

## Vermont Better Backroads Program

The Vermont Better Backroads Program (VBBP), established in 1997, was formed as a partnership between the Vermont Local Roads Program, the Vermont Agency of Transportation, the Vermont Agency of Natural Resources and the Northern Vermont and the George D. Aiken Resource Conservation and Development Councils (Vermont Agency of Natural Resources, 2009). The organization provides funding and technical guidance to towns and non-profits addressing chronic erosion problems on their backroads while reducing sediment and pollutant runoff into Vermont waterways.

Maintenance practices employed by Better Backroads include construction or improvement of stone lining and vegetation in eroding roadside ditches, rebuilding and stabilizing inlets and outlets of culverts, stabilization of roadside stream and lake banks, and directing water away from road surfaces. The decision to implement a specific BMP on or alongside an unpaved road depends on the slope of the road, the direction of water flow over or around the road, the proximity of a receiving waterway and the slope of the surrounding landscape. Grants awarded by Better Backroads support either:

A) road inventory and capital budget planning of erosion-related problems and potential best management practices (BMPs), or

B) the implementation of these best management practices, known as erosion control projects.

## Purpose and Objectives of this Study

To date, no comprehensive or formal analysis of historic Better Backroads Category B projects has been completed. **This study aimed to improve understanding of BMP efficacy over time by comparing the condition of BMPs**

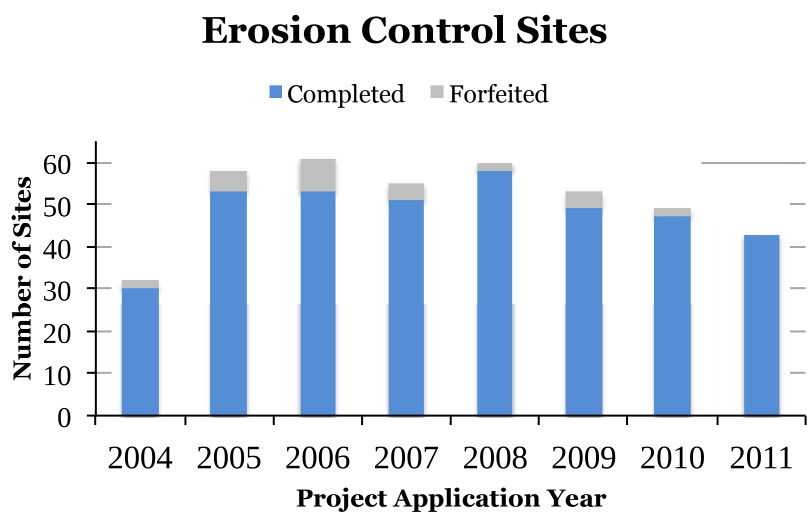
**implemented under the guidance of Better Backroads recommendations to multiple environmental factors that foreseeably affect how long BMPs remain intact in the field**. This study does not quantifiably measure the efficacy of BMPs by, for example, the mass of road sediment or phosphorus retained by a practice; instead, it employed visual comparison of similar BMP types and guidance provided by the Better Backroads program technician to assess whether and how long a BMP has remained intact. By inference, a functional BMP is assumed to provide water quality improvements as designed. A companion study has been designed to quantify pollutant reductions associated with selected BMPs.

## Background of Better Backroads Erosion Control Projects

Some historic Better Backroads project data, including project cost, grant allocation, and local match amount, are recorded in Excel spreadsheets that were provided by Jarrod Becker, Better Backroads business manager. A compiled spreadsheet of this data is provided in *Appendix 1*. However, full project application and reports of project completion exist only as paper files. These folders contain maps, photographs and construction details regarding BMP type and location that the more limited electronic databases do not provide. Files from the 2004 to 2011 application years[1] were accessed at the Northern Vermont Resource Conservation and Development office in Berlin, Vermont until September 2013. Project files prior to 2004 have been discarded and without these files, field assessments of were not possible. As such, this project examines eight years of project data constructed between one and eight years ago.

[1] The filing system used to store and record Better Backroads project applications was initially labeled by the year the application was received. After a project is granted Better Backroads funding, the applicant has 18 months to complete the work. For example, a project approved in the autumn of 2005 may not be constructed until 2006 or the spring of 2007. As such, statistics regarding project applications and funding are categorized by their application year, but the actual age of the project, or number of years since the completion of BMP construction, is used to compare the condition of BMPs. In 2010, Better Backroads began labeling project applications by the fiscal year instead of the calendar year. However, for the sake of consistency, this study labels and discusses projects by the application calendar year only.

Better Backroads funded 414 Category B projects between 1997 and 2011; 375 of those were funded since 2004 (Figure 1). Thirty-six projects have been forfeited and 24 project applications have been denied since 2004. A total of $4,532,402 was spent on Better Backroads Category B projects from 2004 to 2011; $2,356,005 was from Better Backroads grant funding and $2,176,397 was from local match funding, usually in the form of in-kind services.



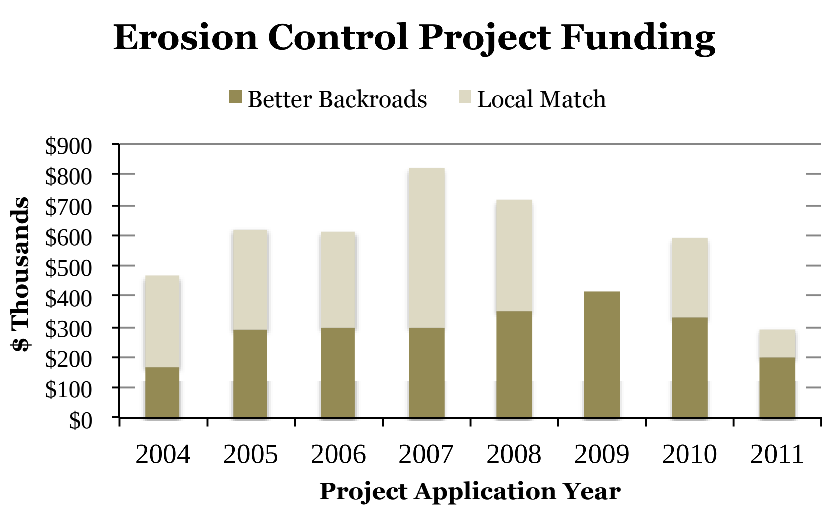




**Figure 1: Distribution of project applications and funding.**

# Methodology

## Field Assessments

To understand how Better Backroads erosion control projects have performed since their implementation, this study assessed best management practices at 45 historic Better Backroads sites, or 12% of the total number of completed VBBP projects. Sites were chosen based on two criteria: first, the availability of paper project files that outlined precise project locations and the work completed during the construction phase and second, geographic proximity to other project sites and to Montpelier, VT, in order to minimize travel time and expense. Project sites were selected regardless of BMP type or age. The geographic and age distribution of assessed sites is shown in comparison to all Better Backroads project sites in Figure 2 and Figure 3.

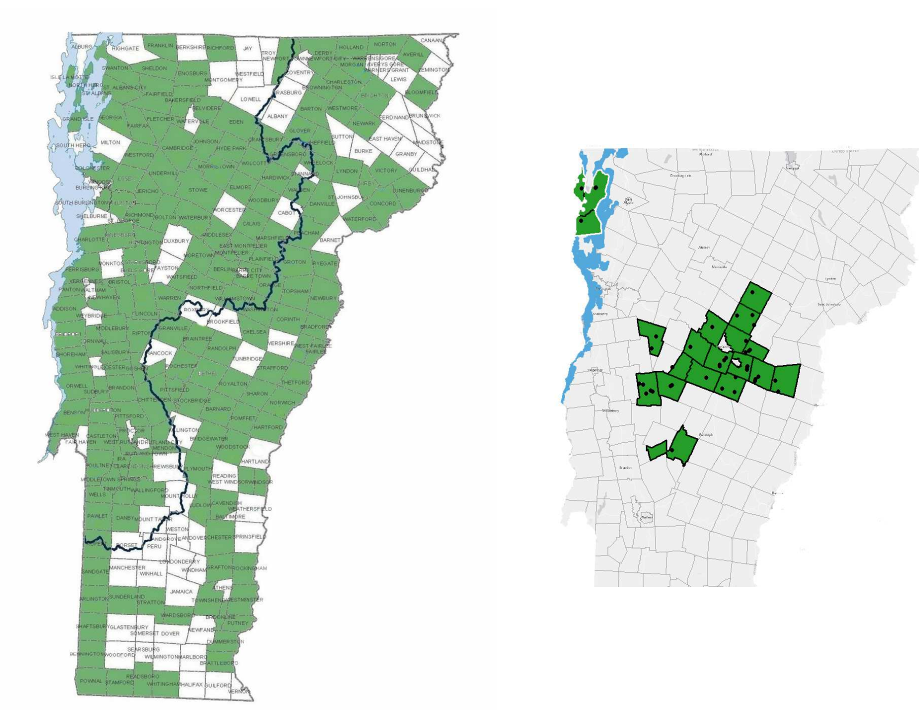


**Figure 2: Better Backroads project locations since 1997 (left) and project locations assessed in 2013 (right).**

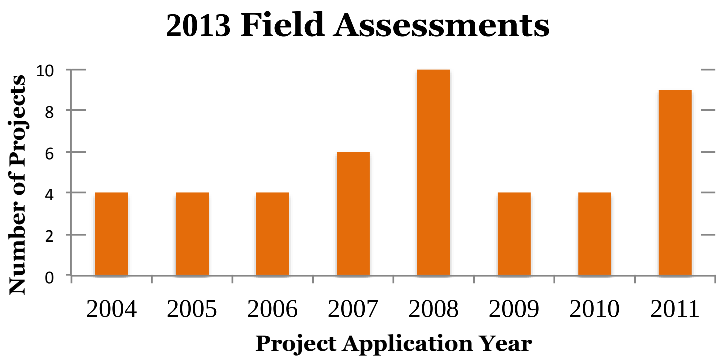
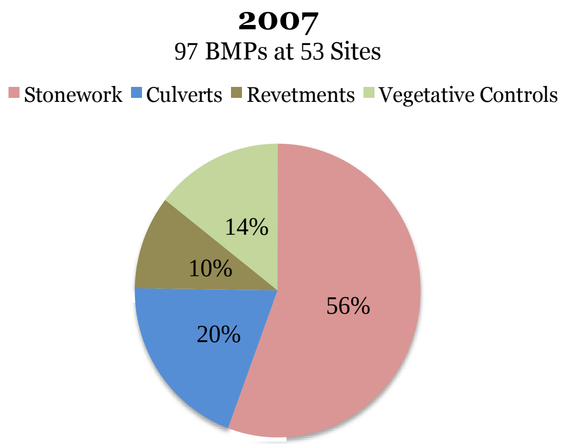
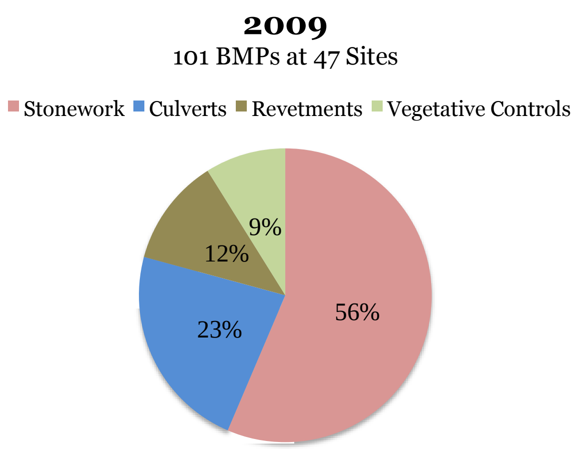



**Figure 3: Distribution of application years of assessed projects.**

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

- **Stonework** includes the following BMPs: stone lined ditches, check dams, turnouts, settling pools, plunge pools, rock aprons, stone dikes and stone water bars.
- **Culvert** work included the installation or replacement of stream and ditch culverts, and any associated headwalls, whether log, stone or concrete.
- **Revetments**, although constructed with stone, were grouped separately from Stonework due to their placement on the landscape with respect to water flow and their behavior over time. Revetments observed in this study were entirely riprap systems placed on the banks of streams or lakes, or above or below roads cutting across steep slopes. Also included in this category, but not observed in the field, were gabion walls, log or timber cribs, and rock walls.
- **Vegetated Soil Stabilization** comprised primarily of grass lined ditching, seeding and mulching, and one log water bar. Included in the category, but not observed in the field, were live wattle/stake placement, sprig or plug planting, and terracing.



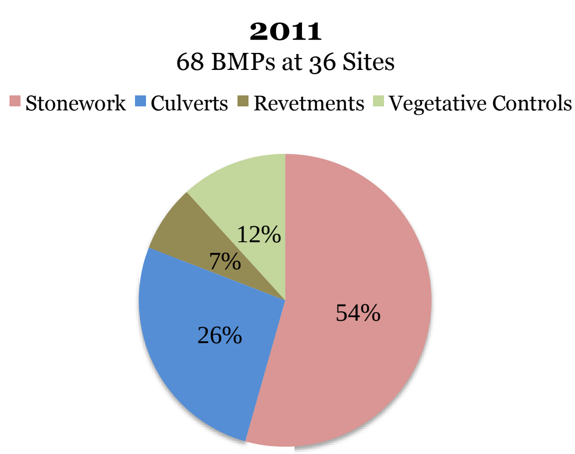




**Figure 4: Distribution of BMP types funded over three application years.**

No electronic records exist of the number of specific BMPs (e.g. stone-lined ditches, culverts, plunge pools, etc.) funded by Better Backroads since its inception. A tally of the BMPs described in the project folders was collected from the paper files of the 2007, 2009 and 2011 application years. The distribution of the BMPs, grouped by BMP types described above, is displayed in Figure 4.

The historical tally shows that Better Backroads typically funds over half its applications for stonework projects, roughly one quarter of the applications for culvert work, and almost equal proportions of the remaining quarter of projects address revetment construction and vegetated soil stabilization.

During the field season of 2013, 106 BMPs were assessed in 45 project locations. The BMP type distribution assessed during the 2013 field season was approximately representative of the total BMP type distribution funded by Better Backroads since 2004 (Figure 5).

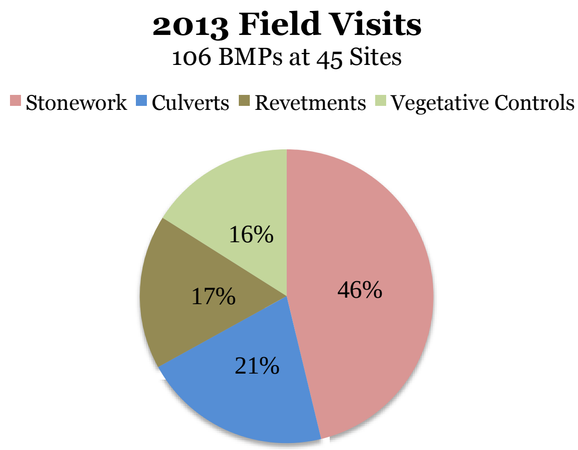



**Figure 5: Distribution of BMP types assessed during field season.**

In order to understand the most relevant factors reflecting the condition of BMPs on unpaved roads prior to the start of formal field assessments, twelve project sites were informally evaluated in May and June of 2013 with aid from Better Backroads technician Alan May. Stone lined ditches, grass lined ditches, stone check dams, culvert replacements and revetments comprised the most commonly observed BMPs. Stone plunge pools, water bars, and compost socks (installed in 2013) also provided context for the longevity assessment of BMPs installed during Better Backroads projects.

A field sheet was created to record a uniform set of data at each site. A set of blank field sheets is included in *Appendix 2*. Project location, description, cost and grant awarded comprised the background data collected for each site. Any erosion of or deposition on BMPs or road surface was noted on the date of the field visit, although recent grading of roads often erased any evidence of erosion or deposition due to over-road flow. Specific data on culverts, namely the condition of the inlets, outlets, headwalls and pipes, was collected to inform any future assessments of culvert longevity. Factors hypothesized to affect BMP condition included the following list of site conditions.

- **The age of a BMP** is the most uniformly applied evaluation criteria that affects BMP condition. Ideally, a field study would follow one particular BMP over multiple years to assess how long it remained functional in its specific location. Due to the brief nature of this field project, the change of BMPs over time was assessed using a chronosequence in which different BMP types between one and eight years old were considered temporally related. For example, the "snapshots" of stonework BMPs between one and eight years old were assumed to represent the progression that a singular stonework BMP would follow over eight years. Although road slope, surrounding landscape, storm exposure and construction technique differ between BMP localities, this study represents this rough progression of BMP conditions over time.

- **The grade of the road** plays a critical role in determining what type of BMP will effectively keep road sediment out of local waterways. Better Backroads recommends grass lined ditches to drain roads with slopes of less than 5% grade; roads steeper than 5% grade generally require stone lined ditches to redirect fast-flowing water without eroding the ditch substrate itself. Project sites were grouped based on road slope of less than 5%, between 5% and 9% (inclusive), and greater than 9%.

- **The placement of the road on the landscape** affects the direction and velocity of both surface water flow and seeps that intersect road cuts. Roads that lie parallel to the slope of the landscape easily channel water down their length unless the road is effectively managed. Roads that lie at an angle to the slope of the landscape may redirect emerging water from upslope into the road. To

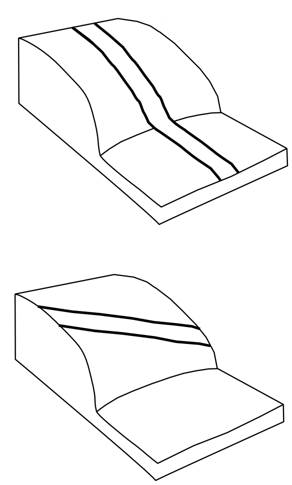


**Figure 6: Parallel-Slope (above) and Cross-Slope (below) roads.**

investigate if BMP longevity is affected by the parallel or angled placement of roads on the landscape, roads at studied sites were classified as either Parallel-Slope or Cross-Slope.

- **The crown of a road** enables quick water movement from the road surface into the ditches and, when sloped correctly, prevents water from running lengthwise down the road. Although road crowning practice is recommended in the Better Backroads Manual, some road surfaces are outsloped (tilted downhill) or insloped (tilted uphill). Roads at each project site was classified as either crowned, insloped, or outsloped.

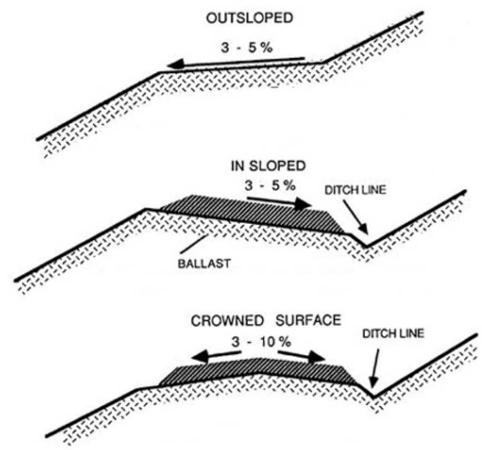



**Figure 7: Road cross section shapes that enable drainage (FAO, 1998).**

- **Vegetation between the BMP and road** provides a free, renewable and biodegradable method to slow water and trap sediment, reducing the burden on the constructed BMPs. This study investigated whether or not an established vegetated border between the BMP and the road increased the longevity of BMPs. The study categorized sites as exhibiting "No Vegetated Border", "Some Vegetated Border" or "Extensive Vegetated Border". Sites were rated based on a subjective comparison to each other and included any type of vegetative cover. Of the 100 BMPs evaluated during the study, only 74 BMPs at 34 sites were evaluated for the presence of a vegetated border. Data collection was omitted at the remaining 9 sites.

- **Extreme flood events** can cause extensive damage to BMPs. Assessing which BMPs are intact after a flood event may aid in determining the most effective placement and types of BMPs used on unpaved roads. To assess flood exposure for study sites included in this project, we used a GIS database, released by the

Vermont Department of Environmental Conservation (Ben Copens, personal communication with Kristen Underwood, South Mountain Research and Consulting), which was based on the recent flood resiliency report prepared for the Lake Champlain Basin Program (Castle et al., 2013). The oldest BMPs assessed in this study were constructed in 2005. Using ArcGIS, the map of project locations was compared to the areas impacted by floods since 2005, yielding a list of assessed BMPs that were exposed to flood events since installation.

Each BMP constructed as part of a Better Backroads funded project was assigned an overall score on page 2 of the Field Check Sheet; 1 = intact, 2 = compromised, 3 = failed. The evaluation criteria were established by comparing the BMPs to other BMPs informally assessed earlier in the field season, by comparing the BMP to date with photos taken immediately after implementation, and through visual evidence of BMPs reducing the volume of sediment traveling to receiving waterways.

Photographs of the project site and BMPs were recorded on page 3 of the Field Check Sheet and are included on CD-ROM in as *Appendix 3.*

## Statistical Analysis

Based on BMP assessments, each of the 43 Better Backroads project sites was assigned an overall project condition of either "All Intact" (i.e. complete project success) or "Some BMPs compromised or failed" (i.e. partial or complete project failure). Reclassifying project condition as a binary variable enabled use of a logistic regression of the field data to examine the likelihood that measured variables could explain project condition. This analysis neglects the type of, or specific, BMP used at the site. Logistic regressions were performed using the SPSS statistical software package.

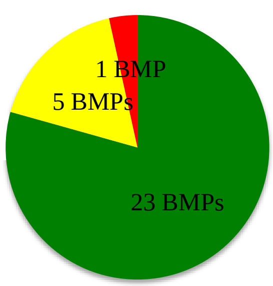
# Results

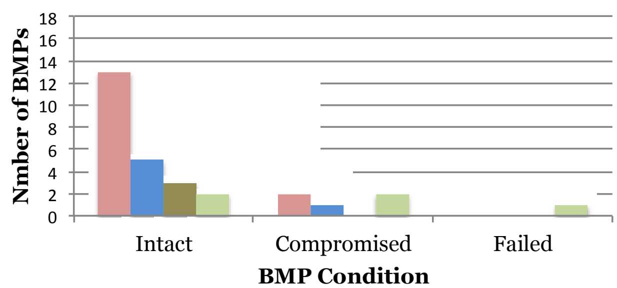
Projects were grouped into three age ranges divided over the eight-year study period. Twenty-nine BMPs at 11 projects were between one and two years old, 54 BMPs at 20 projects were between three and five years old, and 17 BMPs at 12 projects were between six and eight years old. The relatively low sample size of BMPs six-to-eight years old was due in part to the difficulty involved in obtaining complete project files from application years 2004, 2005 and 2006. Six BMPs at two projects constructed in 2013 were omitted from statistical analysis because they had yet to operate through a four seasons.

## BMP Age

### 1-2 Years

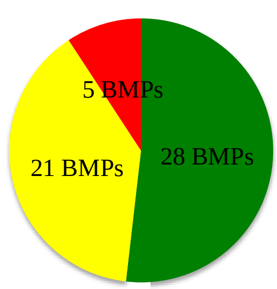
29 BMPs at 11 Projects
Average Age 1.4 Years, SD 0.5

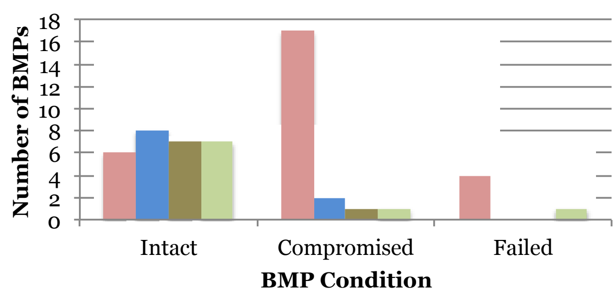



### 3-5 Years

54 BMPs at 20 Projects
Average Age 4.0 Years, SD 0.7



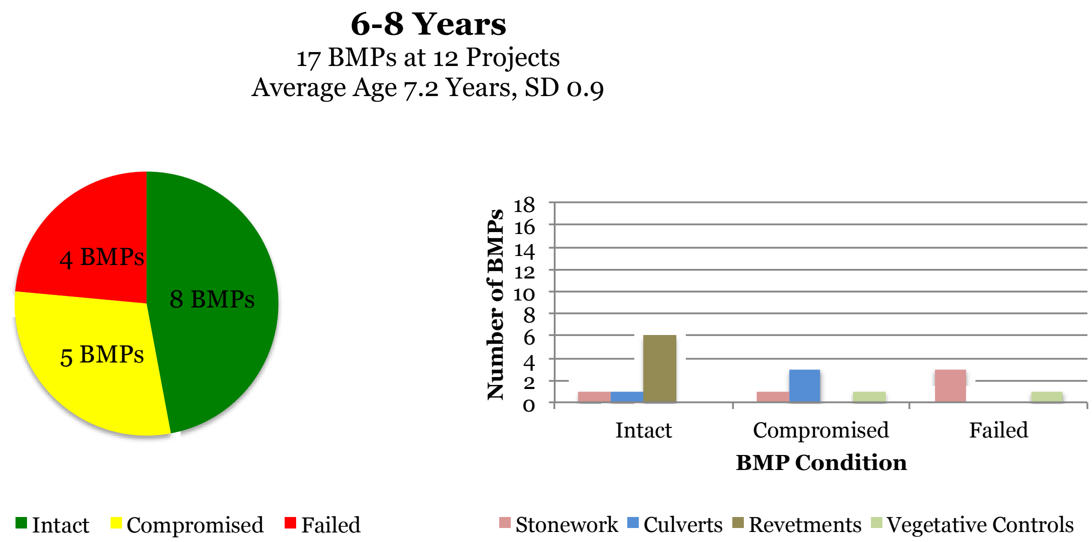



**Figure 8: Condition of BMPs grouped by age.**

The percentage of intact BMPs decreased from 79% to 52% between sites one-to-two years old and sites three-to-five years old while the percentage of compromised BMPs rose from 17% to 39%. Only one BMP (3%), a one-year-old vegetative control, failed within the one-to-two year old age category, while five BMPs (9%) had failed in the three to five year old age category. The number of intact BMPs six-to-eight years old decreased to 47%, while the number of failed BMPs rose to 24%.

Thirteen of the 16 assessed culverts up to five years of age remained intact and only three had become compromised; none had failed. Three of the four culverts aged six-to-eight years were compromised. Culverts degraded where deposited sediment blocked the outlet or where erosion at the inlet altered stream flow away from the culvert and onto the bank or road.

None of the 17 assessed revetments failed over the eight-year sample period. One revetment at a culvert inlet became compromised presumably after high water flow caused sedimentation and dislodged stones. Ten of the 17 revetments stabilized shoreline along Lake Champlain in the Champlain Islands or along Greenwood Lake in Woodbury. Five of the 17 revetments stabilized stream or river shorelines. The remaining two revetments stabilized dry slopes adjacent to road banks.

Vegetated controls degraded quickly compared to all other types of BMPs. Within the projects up to two years of age, Three of the five vegetation BMPs were compromised or had failed in projects one-to-two years old. Within projects between three and five years of age, only two had become compromised or failed, and seven remained intact. However, after six to eight years, no vegetative controls remained intact.

All 24 BMPs assessed on roads with less than 5% grade were intact. The BMPs had an average age of 4.9 years and included 10 revetments installed along lake shores, four revetments along rivers, five culvert structures, three vegetative controls and two stonework BMPs.

The distribution of the condition of BMPs on roads between 5% and 9% grade was roughly equivalent to that of roads of greater than 9% grade. Approximately half of all BMPs on roads greater than 5% grade were intact, three-eighths were compromised, and one-eighth had failed. The average age of BMPs was 4.0 years (SD 2.3) on roads with slopes between 5% and 9% and 3.4 years (SD 1.3) on roads with grades greater than 9%.

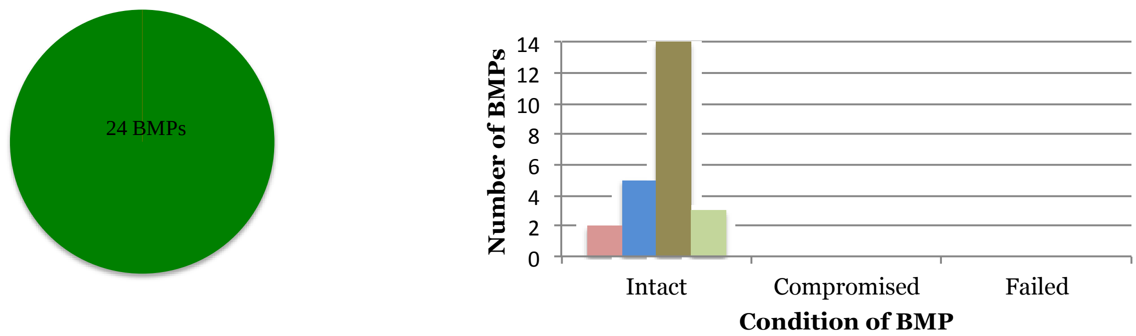
Stonework BMPs accounted for 18 of the 29 BMPs on roads with slopes between 5% and 9% and 27 of the 47 BMPs on roads with slopes greater than 9%. Of note were the 13 compromised and four failed stonework BMPs on roads with slopes greater than 9%. Reductions in the efficacy of stonework most often occurred when sediment deposition buried the rock itself.

Nine of the 15 culverts assessed on roads with slopes greater than 5% were intact. Compromised culverts ranged between two and eight years old; as such, their efficacy is likely not highly influenced by age.

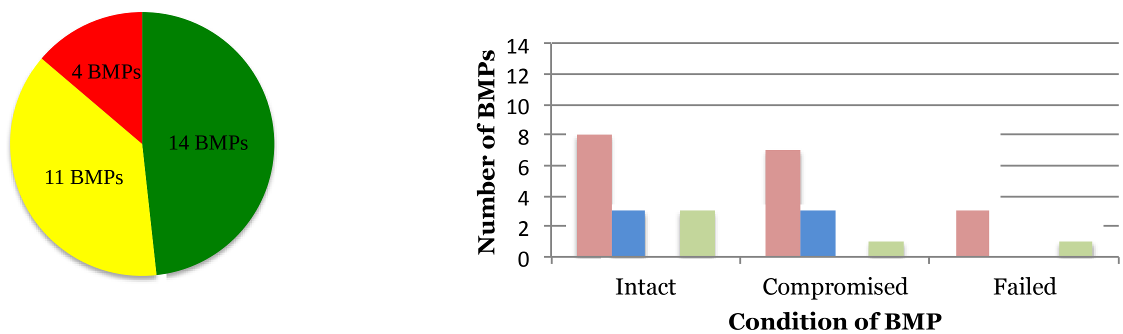
Three of the 17 assessed revetments were built to stabilize road cuts neighboring roads with slopes greater than 9%. Two were intact but one was compromised after some rock had become dislodged from the slope. Not subject to the power of lake ice or river flow, revetments along road cuts are likely to remain intact barring poor construction or excessive downslope water flow.

## Road Grade

**<5%**
24 BMPs at 17 Projects
Average Age 4.9 Years, SD 2.3




**5% -9%**
29 BMPs at 12 Projects
Average Age 4.0 Years, SD 2.6




**>9%**
47 BMPs at 14 Projects
Average Age 3.4 Years, SD 1.3

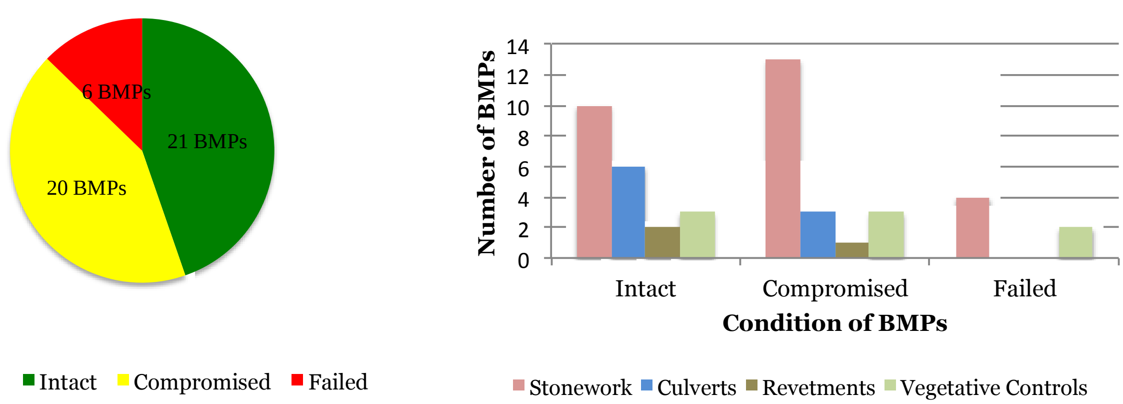



**Figure 9: Condition of BMPs grouped by road grade.**

Seven of the 13 vegetative controls used on roads with slopes greater than 5% were compromised or failed. The success of this type of BMP on steep roads likely depends on the amount and flow of water, but also upon whether or not the vegetation had sufficient time and adequate weather conditions to establish itself before the first storm event.

The distribution of intact, compromised and failed BMPs on parallel-slope roads was comparable to that of cross-slope roads. However, the distribution of age and BMP types differed considerably between the two road placement categories. The average age of the BMPs on parallel-slope roads was 2.9 years and none of the seven- or eight-year old projects in this study were built on roads lying parallel to the hill slope. By contrast, the average age of the cross-slope BMPs was 5.2 years and included BMPs between one and eight years of age.

The distribution patterns of BMP types also varied between parallel-slope and cross-slope roads. Stonework BMPs made up the majority (37 of 57) of BMPs implemented on parallel-slope roads; one revetment was built on a parallel-slope road. By contrast, stonework BMPs made up only 10 of the 43 BMPs assessed on cross-slope roads; revetments made up 16 of the 43 BMPs. This distribution likely reflects the necessity for stonework BMPs to mitigate surface water flowing directly downslope and for revetments to stabilize banks created when roads cut across hill slopes.

Culverts were more common on cross-slope roads than parallel-slope roads, but while only six of the 11 culverts on cross-slope roads were intact, eight of the nine were intact on parallel-slope roads. However, the average age of culverts on parallel-slope roads (2.5 years) was less than that of culverts on cross-slope roads (4.5 years).

Vegetative controls were more common on parallel-slope roads than on cross-slope roads. Five of the ten vegetative controls on parallel-slope roads were compromised or failed, while only two of six vegetative controls on cross-slope roads were compromised or failed.

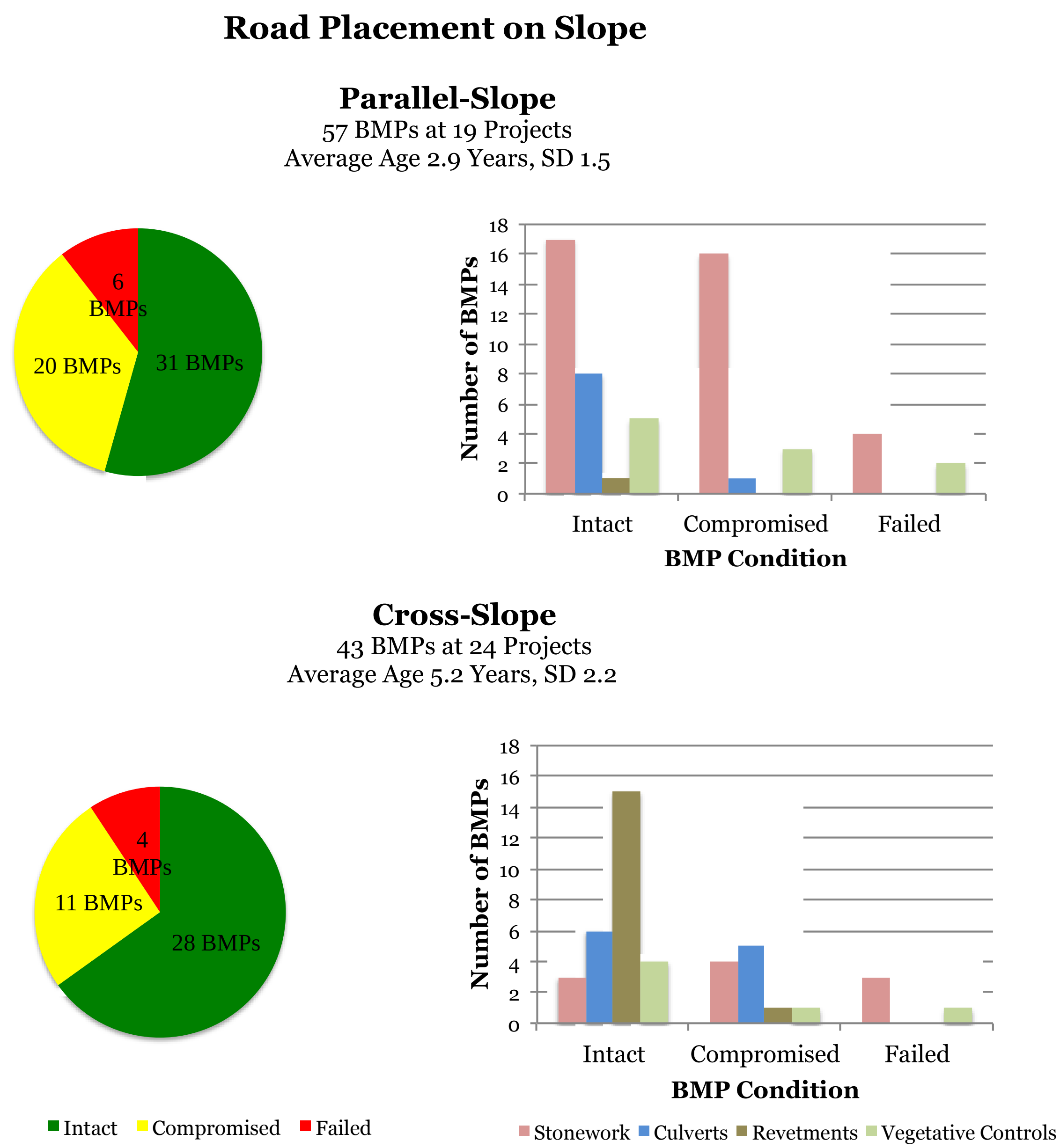



**Figure 10: BMP condition grouped by road position on the landscape.**

Road profiles were crowned at 37 of the 43 project sites, outsloped at five project sites and insloped at one project site. Fifty-one of the 83 BMPs (61%) evaluated on crowned roads were intact, 23 were compromised (28%) and nine (11%) had failed. The relatively small number of BMPs assessed on outsloped roads made comparisons of the effects of road profile difficult to assess. However, less than half of these BMPs (seven of 16 assessed, or 44%) were intact. Eight BMPs (50%)

were compromised and one had failed (6%). The average age of projects on crowned roads was 4.0 years (SD 2.3); the average age of projects on outsloped roads was comparable at 4.6 years (SD 0.8).

Stonework BMPs retained greater efficacy on crowned roads than on outsloped roads, although in both road profile conditions, more than half of the BMPs were compromised or failed. Culvert condition was not clearly affected by road profile; more culverts were intact than compromised in both conditions and none had failed. No revetments were constructed bordering outsloped roads, and all but one revetment were intact on crowned roads. Fourteen of the 16 assessed vegetative controls were constructed bordering crowned roads and eight of the 14 vegetative control BMPs on crowned roads remained intact, three were compromised and there had failed.

Water Road in Northfield was the only insloped road. The uphill tilt directed water away from a revetment constructed on a riverbank and towards a stone-lined ditch on the opposite side of the road. This eight-year-old revetment was intact.

Sites displaying either no vegetated border or some vegetated border exhibited similar distributions of BMP longevity. In both cases, 48% of the BMPs were intact. Forty-three percent of BMPs with no vegetated border and 44% of BMPs with some vegetated border were compromised; the remaining BMPs (8% and 9%) had failed.

In contrast, 96% of the 26 BMPs exhibiting an extensive vegetated border between the BMP and road were intact. The remaining BMP, a stone-lined ditch, was compromised. Projects exhibiting extensive vegetated borders ranged between one and eight years old and averaged 4.3 years of age. Ten of these 26 BMPs were revetments along Lake Champlain where grasses and herbaceous plants had adequate space to grow between the revetment and road.

All three categories of the vegetated border variable contained projects between one and eight years old. The average age of projects with no, some and extensive vegetated border was 4.1 years, 4.0 years and 4.3 years, respectively.

## Road Profile

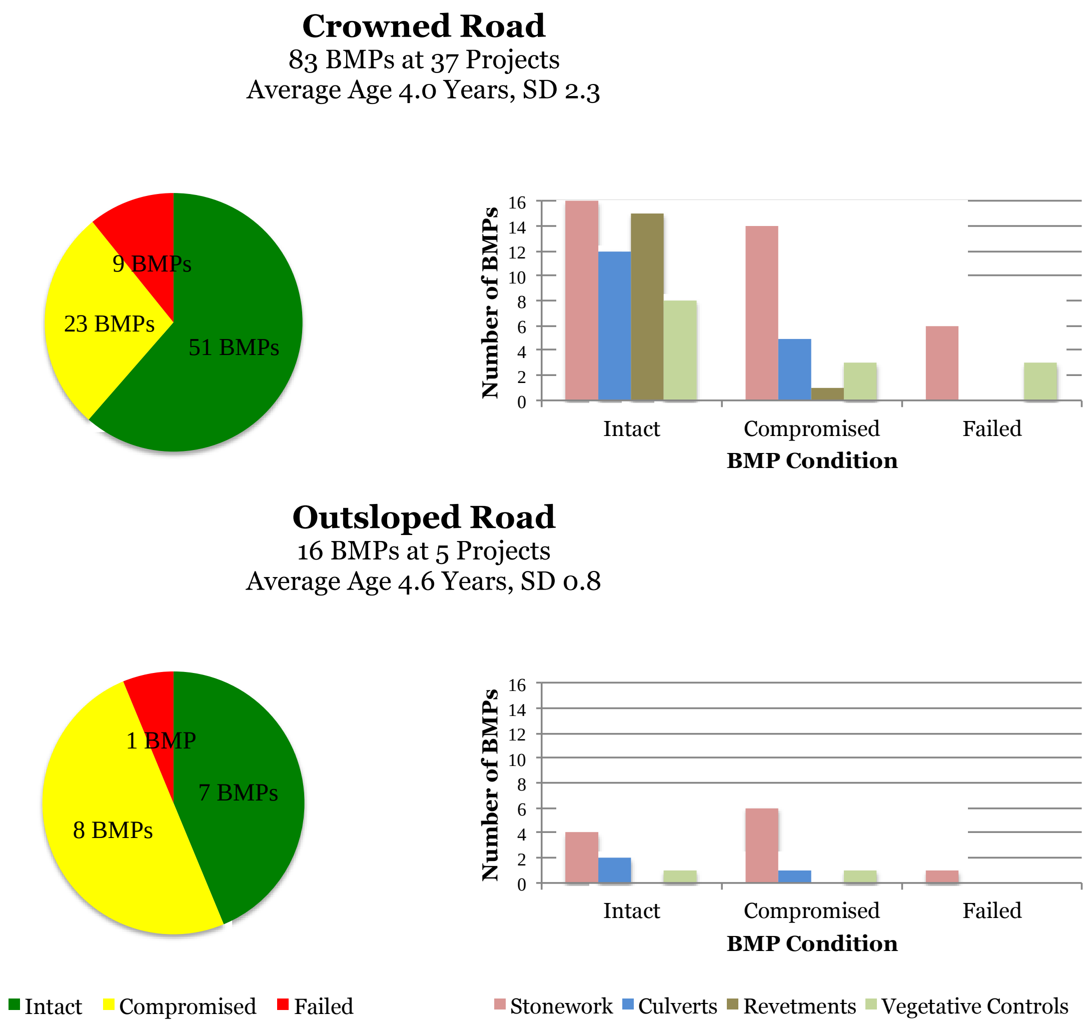
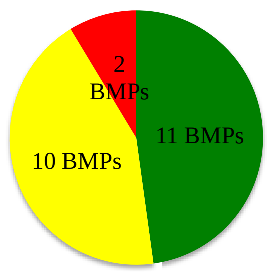
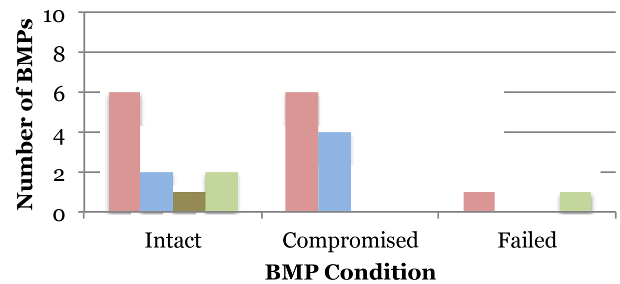



**Figure 11: BMP condition grouped by road surface crown or tilt.**

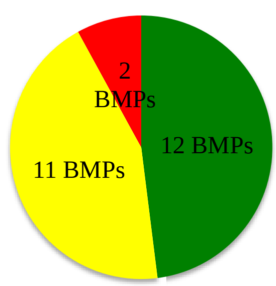
## Vegetated Border

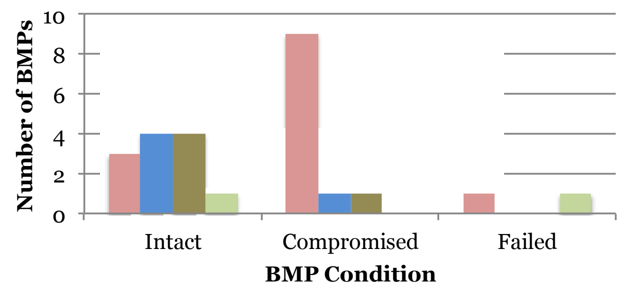
### None
23 BMPs at 8 Projects
Average Age 4.1 Years, SD 2.2



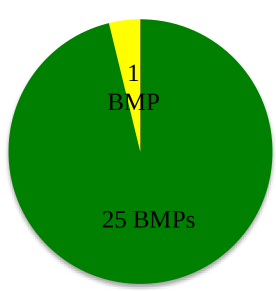




### Some
25 BMPs at 11 Projects
Average Age 4.0 Years, SD 1.7




### Extensive
26 BMPs at 15 Projects
Average Age 4.3 years, SD 2.4



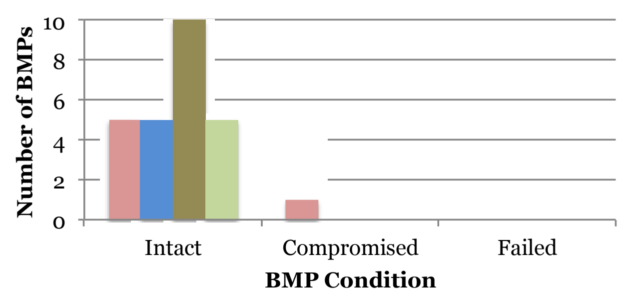




**Figure 12: BMP Condition grouped by the presence and extent of a vegetated border**

Two flood events since 2005 were recorded in the VT DEC database, the first from July 9-11, 2007, the second following Tropical Storm Irene on August 28, 2011. Only one project site, the culvert and grass lined ditches on Weir Street in Williamstown, was impacted by both the 2007 and 2011 floods. Twenty-two projects were in zones affected by 2011 flood only and 20 projects were reportedly unaffected by flood events. However, it is unknown if BMPs damaged during the 2007 or 2011 flood events were repaired before the 2013 field assessments. Similarly, it is unknown which BMPs remained intact after a flood event but were subsequently damaged during a storm or flood event not documented in the VT ANR study.

Less than half (44%) of assessed BMPs impacted by a flood event were intact. An equal portion (42%) of BMPs were compromised; the remaining 14% of BMPs failed. Only seven of the 31 stonework BMPs remained intact; the remaining 24 may have acted to trap sediment but needed maintenance or rebuilding before being able to operate effectively again. In contrast, 13 of the 16 stonework BMPs not affected by flood events were intact; two were compromised and only one had failed.

The distribution of culvert condition was not distinctly different between the two categories. Eight of the 12 assessed culvert BMPs (67%) impacted by a flood event were intact, four were compromised and none had failed. Six of the 8 assessed culvert BMPs (75%) not impacted by a flood event were intact and two were compromised. One revetment on Center Street in Middlesex was compromised, as evidenced by dislodged stones, but the remaining six revetments were intact.

Although vegetative controls easily become compromised when inundated by fast-moving water, five of the nine vegetative control BMPs affected by a flood event were intact. Two vegetative controls were compromised and two had failed. A similar distribution of vegetative control BMP condition existed at projects not affected by floods; four were intact, two were compromised and one had failed.

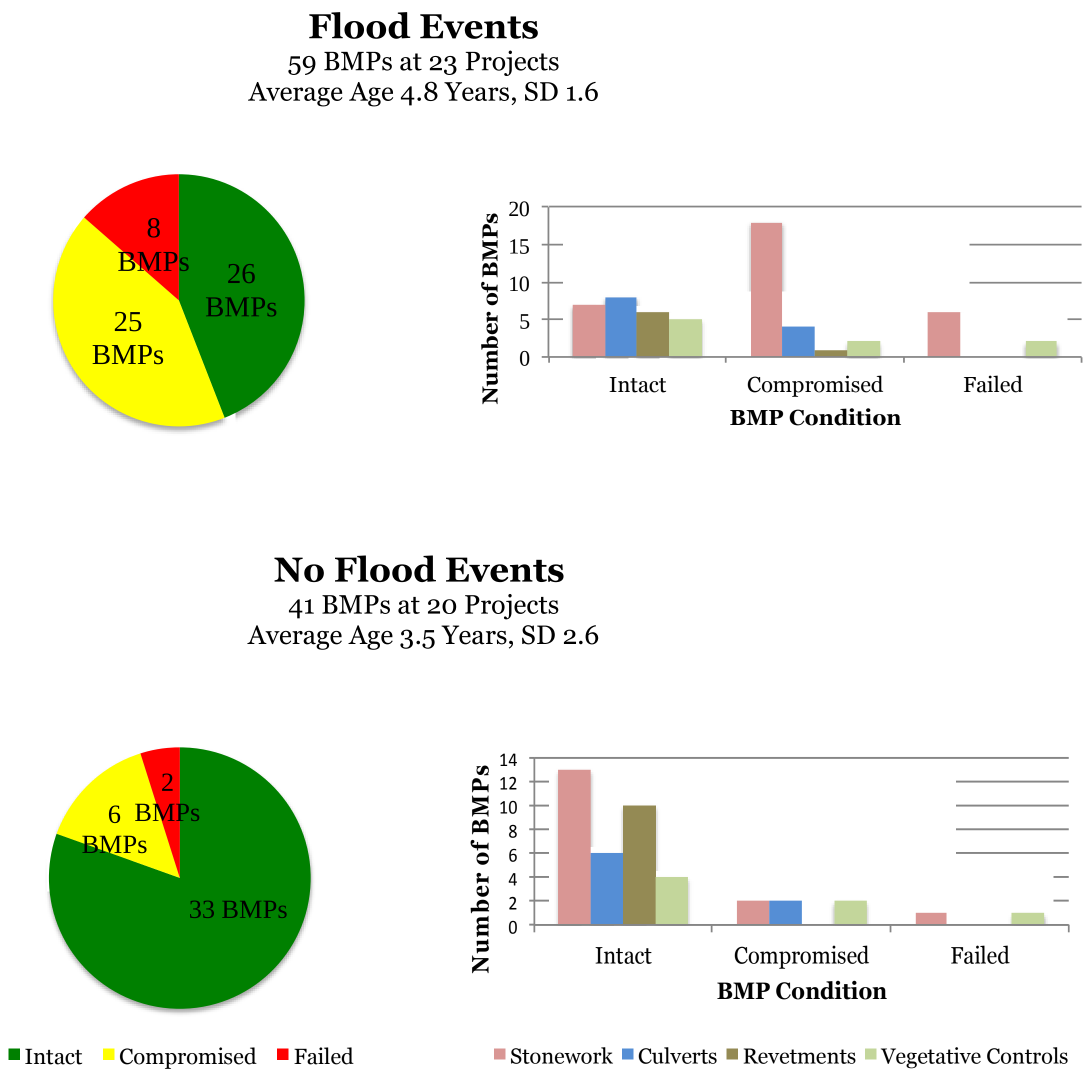



**Figure 13: Impact of flood events documented by VT ANR, 2013, on BMP condition.**

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

When effects of project conditions were combined, increasing grade was still the most likely predictor of compromised or failed BMPs. Increased flood exposure was also a likely predictor, followed by the presence of vegetated border. Road orientation became insignificant when its effects were combined with those of increased grade, flood exposure and an extensive vegetated border (Table 2).

Table 1: Table of variables tested using binary logistic regression for prediction of the likelihood that a project will exhibit compromised or failed BMPs. Probability values (p) for statistically significant predictors of project condition are shown in bold.

| Variable tested | Units or classes | Number of projects | p |
|---|---|---|---|
| Project age | years | 43 | 0.970 |
| Grade | percent | 43 | **<0.001** |
| Road profile | crowned , not crowned | 42 | 0.268 |
| Road orientation | cross-slope, parallel-to-slope | 42 | **0.019** |
| Vegetated border | none, some, extensive | 37 | **0.013*** |
| Flood exposure | Exposed, not exposed ** | 43 | **0.002** |

* The overall statistical significance of the presence and extent of a vegetated border was 0.013. The significance of no vegetated border compared to extensive vegetated border was 0.003; the significance of some vegetated border compared to extensive vegetated border was 0.019.
** Flood exposure expressed as a binary variable with "exposed" including any site exposed to one or more historical flood events since installation.

Table 2: Statistical relevance of combined site conditions that predict the likelihood that a project will exhibit compromised or failed BMPs. Probability values (p) are shown for individual variables in models with two, three and four explanatory variables.

| Variable combinations | Grade and Flood Exposure | | Grade, Flood Exposure and Orientation | | Grade, Flood Exposure, Orientation and Vegetated Border | |
|---|---|---|---|---|---|---|
| No. of Projects | 43 | | 42 | | 37 | |
| P | grade | 0.002 | grade | 0.008 | grade | 0.018 |
| | flood | 0.020 | flood | 0.032 | flood | 0.110 |
| | | | orientation | 0.183 | orientation | 0.589 |
| | | | | | veg_border | 0.103 |

# Discussion

Analysis of field results established the trend that BMP efficacy decreases with age, yet statistical analysis of the BMP sample group as a whole showed that age was not a statistically significant predictor of project outcome. Key predictors of the effectiveness of BMPs, as inferred from the analysis conducted here, include the grade and orientation of the road, the presence of a vegetated border on the roadside, and exposure to extreme flood events.

While the overall condition of BMPs over time did not differ considerably between parallel-slope and cross-slope roads, the study of BMP longevity according to road placement on the hill slope did demonstrate several logical but significant observations regarding the utility of each type of BMP. Revetments, by their nature, stabilize banks cut by roads. Compared to that of other forms of stonework, revetment longevity is high and is likely an effective way of stabilizing slopes where the need arises. Of the 17 revetments assessed in this study, 15 were constructed on cross-slope roads. Revetments on parallel-slope roads were restricted to locations where the road bank ran parallel to a river within a narrow valley or where the road was constructed in a historic valley bottom. By contrast, stone-lined ditches, stone turnouts and other stonework were primarily constructed on parallel-slope roads where fast-flowing water requires more intensive management. The difference in the average age of the two groups (5.2 years on cross-slope roads, 2.9 years on parallel-slope roads), while potentially an artifact of the sampling method, could suggest that BMPs on parallel-slope roads require repeated maintenance to sustain effectiveness or must be reconstructed with greater frequency than BMPs on cross-slope roads. The higher percentage of compromised BMPs on parallel-slope roads compared to cross-slope roads may also support this conclusion.

The longevity of vegetative control BMPs, such as grass-lined ditches, may be affected by road grade and storm events more than by surface water flow and velocity due to road placement. Inherently, BMPs exposed to fast- flowing water in road ditches likely degrade more often than vegetative controls exposed to little or slow surface water. Assessment of vegetative control BMPs by age indicates that grass-lined ditches and restorative seeding and mulching can be effective up to five years after implementation. However, improper planting technique, slope instability, upslope debris slides or early washout of seed due to storms can render the efficacy of the BMP negligible. Yogi Alder, the road foreman in Huntington, VT, stated that he prefers to utilize stone lined ditching wherever water is consistently flowing, even if the road grade is less than 5%. Seeps from hillsides often prevent grass seeds from taking root, undermining the ditches and the road banks. However, the high cost of stone and the associated labor for stone lining, when compared to grass seed and mulching labor, often prevents stone lining on wet but low-slope roadsides.

The success of BMPs that exhibit an established and extensive vegetated border between the road and the BMP suggests that allowing space and circumstances for this plant growth could be an integral part of BMP implementation. The webbed root and stem systems of plants, particularly low herbaceous plants, provide a free, renewable and biodegradable method to slow water and trap sediment. Alan May, the Better Backroads Technician, noted that the presence of vegetation on slopes, within revetments and along the perimeter of roadside ditches is a sign that erosion is minimal or absent and that proximal BMPs are stable. However, large shrubs and trees, while retaining sediment, can be detrimental to road maintenance. Tree crowns shade the road, resulting in ice patches during "mud season" while open road has thawed. During the winter, snow plows often hit trees, damaging the trunks and creating a safety hazard for the plow operator. However, the lack of vegetation between the road and any stonework BMP appears to be a relevant factor in prolonging stonework longevity – only 9 of the 26 stonework BMPs exhibiting no or some vegetated border remained intact within this study period.

Documenting the impact of large flood events on BMP condition established that exposure to these extreme events will likely lead to compromised or failed BMP installations. Achieving a greater understanding of the effects of other severe yet localized storms on all BMPs within a region or town may help town and state offices predict how much time and money should be reserved for maintenance of the most impacted sites, likely those on steep slopes or with no vegetative border. While almost half of the BMPs exposed to one or more flood events had become compromised, only eight of 59 BMPs (14%) had failed. With adequate maintenance, these BMPs could be restored to their initial efficacy.

## Conclusions

We retrospectively assessed 106 BMPs at 45 sites included in the archive of projects funded by the Vermont Better Backroads program. We ranked BMP condition as "intact" if installations showed no degradation in capacity to reduce on-site erosion, as "compromised" if evidence of degradation of the installation was visible, and "failed" if the installation was no longer functioning to provide water quality improvements as intended. To assess factors that might explain the efficacy of BMPs, we independently measured or derived from GIS a set of six variables for each site: *grade* of the road on which BMPs were installed, *orientation* of the road relative to the hill slope, *profile* of the road surface, presence of a *vegetated border* or the roadside, and exposure to one or more *floods* since installation. We also used time since project installation as the *age* for each site. We found that road grade was the strongest predictor of project condition, with BMPs on steeper roads more likely to fail, followed by road orientation, with BMPs on slope-parallel roads more vulnerable than on cross-slope roads. Exposure to extreme floods was also a significant predictor of BMP efficacy, as was the presence of vegetated borders on road sites.

This study is the first attempt to assess the effectiveness of low-cost management practice in reducing erosion and water quality degradation on Vermont's rural back roads. Our results show that BMPs assessed here remain intact or could be maintained when compromised to achieve long-term (up to a decade or more) efficacy in water quality improvements. A companion study will quantify the magnitude of sediment and phosphorus reductions achieved through BMP installations, using an experimental design. Results of that study should be available by December 2014.

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