Office of Innovation, Partnerships & Energy
Innovation, Research & Implementation Section

Executive Summary Report

Vegetated Biofilter for Post Construction Storm Water Management for Linear Transportation Projects

Start date: October 15, 2007

Duration: 31 months

Completion Date: May 15, 2010

Report Date: May 2010

State Job Number: 134349

Report Number: FHWA/OH-2010/7

Funding: $391,826.31

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Problem

The use of Best Management Practices (BMPs) is required for all Ohio Department of Transportation (ODOT) maintained facilities where an improvement project results in a land disturbance greater than one acre (0.4 ha). Current ODOT policy requires 20% of existing impervious areas to be treated using a BMP, while 100% of new impervious areas are to be treated with BMPs. The various BMPs are generally designed to treat the water quality volume. In Ohio, the water quality volume volume is based on 0.75 in (1.91 cm) of precipitation. This water quality volume is defined in the Ohio Environmental Protection Agency (OEPA) National Pollutant Discharge Elimination System (NPDES) Construction General Permit (CGP) of 2008 as the volume of storm runoff that must be captured and treated from the site after construction is complete. As specified by law, the Ohio Environmental Protection Agency (OEPA) requires that ODOT implement best management practices (BMPs) that reduce pollution from storm water runoff on linear transportation systems sold after March 10, 2006.

The Ohio Department of Transportation utilizes vegetated biofilters as one of several available post construction stormwater BMPs to implement the OEPA NPDES CGP requirements via provisions in ODOT’s *Location and Design Manual*. “The vegetated biofilter consists of the vegetated portion of the graded shoulder, vegetated slope, and vegetated ditch”, according to Section 1117.3 of the *Location and Design Manual*. Pollutants are removed through uptake into the plant matter and into the soils. Vegetated slopes and ditches are already common along Ohio’s highways. Vegetated slopes can range from 8% to 50% gradient, and a given vegetated slope may be suitable as part of a vegetated biofilter as is or with modification, or it may not be suitable. The conditions for making vegetated slopes suitable for integration into an acceptable biofilter need to be determined.

Objectives

The goal of this project was to examine the slope portion of vegetated biofilters to evaluate capture and treatment of the water quality volume for highway storm runoff. This goal was accomplished through the following objectives:

- Performing a review and synthesis of the literature
- Conducting a survey of state DOTs
- Developing a biofilter foreslope prototype and conduct testing to determine:
    - Its ability to capture the water quality volume
    - Its performance in removing typical roadway runoff contaminants
        - Its performance efficiency computed as the percent change between influent and effluent quality
    - The impact of its slope
    - The accumulation of contaminants in the foreslope soil and vegetation
    - The suitability of foreslope designs to accommodate different concentrations of runoff and/or intensity of storms
    - Potential resuspension of particles

Description

A review and synthesis of the literature relative to characteristics of highway runoff and application of BMPs utilizing vegetation were conducted. Literature derived data were used to formulate an artificial storm water runoff for subsequent application to a prototype vegetated biofilter. Also, literature derived data were integrated to develop relational graphs for percent reduction in total suspended solids versus vegetated slope and length.

A two-part survey instrument was developed to query state DOTs on post construction BMPs for managing highway runoff; the first part of the survey addressed all types of BMPs and the second part focused specifically on roadside vegetation. Results from this survey were entered into spreadsheets and analyzed.

The major portion of the effort was directed toward the design, development and testing of a biofilter foreslope prototype. Baseline, pollution removal performance, tracer, and resuspension tests were performed on three test beds, each one devoted exclusively to the study of a particular level of pollutant concentration in the artificial runoff: high, medium, or low. The test beds were each 4 ft (1.22 m) wide by 14 ft (4.27 m) long in the direction of flow. The artificial runoff was applied in a two-stage simulated storm event designed to approximate a 60-minute 2-year medium-flow event (10-year storm for low concentration) or a 30-minute 10 year high-flow event that delivered the Water Quality volume equivalent to 0.75 in (19 mm) in the first 15 min (9 min for low concentration) for the 2-year storm or the first 6 min for the 10-year storm. Delivery of the artificial runoff was accomplished by pumping the runoff from constantly stirred drums through a spray bar onto a splash plate from which the runoff poured onto the bed in a relatively uniform flow. Samples of influent, surface effluent, and groundwater (via an underdrain) were collected for analysis using standard USEPA methods to determine the concentration of total suspended solids (TSS), oil and grease, and various metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) in total and dissolved form. Cores were extracted from the bed both before and after the end of the performance tests. The cores were separated into grass, roots, and soil, and each component was analyzed for the seven metals in the influent.

A final component of the project included developing a field inspection sheet for vegetated biofilters and utilizing the inspection sheet at two field sites. Results from the field inspection, literature, survey and prototype testing were utilized to address performance and maintenance issues.

Results and Conclusions

Survey responses were garnered from 39 states and one Canadian province. Slightly over half of the states reported having a design manual that addresses post-construction stormwater BMPs. Respondents were asked to list factors used in designing BMPs; responses from highest to lowest were: first flush volume (7 responses), drainage area (6 responses), urban location (6 responses), and rainfall/runoff amounts, event rainfall, and rural location, each cited by 4 respondents; only 1 or 2 respondents listed a variety of nine other factors. Relative to specific vegetated type BMPs, 29 responded that their states were permitted to use or were considering using vegetated surfaces as a post-construction BMP with 24 indicating their use without incorporating other BMPs. Responses regarding acceptable foreslope lengths were too varied to classify; however, 6 specified a minimum length, 1 a maximum, and 8 both a minimum and a maximum. Others indicated the length depended on slope, drainage area or site conditions. Responses for slope angles were: 8 responses for < 10%, 4 responses each for 10% to 20% and 25% to 33%, and 3 selected 50% maximum. Questions on grade and width of ditch receiving the flow from the slope noted unspecified grade by 8 respondents, followed by 5 with maximum and minimum (plurality cited < 0.5% and maximum of 4%) and 5 indicating it site specific.

Three prototype vegetated biofilter foreslopes were studied. The beds, designated for “high” and “medium” concentration simulated storm water runoff, performed well at all slopes (8:1, 4:1, 2:1) and flows (medium and high flow storm event simulation) tested. Based on event mean concentration (EMC) calculated data, removals of TSS and the total metals (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) monitored in the influent flow were at or above 80%, except for Cd (75%) and Cr (78%) in the 8:1 slope, medium flow, medium concentration test. Dissolved metals were reduced also.

Oil and grease removal ranged from 30% to nearly 70% for the high concentration bed and 50% to above 90% for the medium concentration bed. For the high concentration bed, deuterated alkanes, used to track the oil concentration, were removed by about 67% at the 8:1 slope and 85% at the 4:1 slope. For the medium concentration bed, removal of deuterated alkanes ranged from about 46% to 94% with the higher removal at higher influent concentrations. The high concentration bed data were influenced by difficulty in delivering the oil and deuterated alkanes to the bed; the oil and grease delivery method was improved for the medium and low concentration beds.

Results for the bed receiving low concentration flow were mixed. This was not surprising since the low influent concentrations were near detection limits of the constituents and near surface runoff concentrations measured in baseline runs with tap water. In addition this bed had a greater infiltration rate than the other two beds, which limited the volume and number of surface samples available for analysis in the effluent. EMC computed TSS removals ranged from negligible to about 50%. With the exception of iron and zinc the best removal of total metals occurred at the 8:1 slope. Zinc removal was near 70 % for all slopes. Removal of Cu was about 90 % at all slopes and flow. Ni removal ranged from 62% to 88% removal and Pb 55% to 78%. Cd, Cr, and Fe had negligible to up to 65%, 85%, and 75% removal, respectively, at various slopes and flow. All dissolved metals were reduced to detection limits or were removed by at least 50%. In order to be able to differentiate influent from effluent values, oil was added at a concentration of 100 mg/l followed by 20 mg/l in the second portion of the flow; removals of 70% to 90% were achieved. Deuterated alkanes in surface samples were near detection limits for all four tests with the exception of two of three samples with elevated concentrations at the 4:1 slope but half the concentration of the influent.

For the high concentration bed, the particle size distribution was primarily about 1 mm (39 mil) or greater in both the influent and surface flow for the three slopes receiving medium flow; samples were not taken for the 2:1 high flow. For the medium concentration bed, influent particle size ranged between about 1µm (0.039 mil) to 100 µm (3.9 mil) for the 8:1 and 4:1 slope, while the 2:1 slopes received particle sizes from 1µm (0.039 mil) to 1000 µm (39 mil) with over 80% above 100 µm (3.9 mil). The effluent surface particle sizes were predominately about 1000 µm (39 mil) for the three slopes at medium flow, but 1µm (0.039 mil) to 100 µm (3.9 mil) at the 2:1 high flow. For the low concentration bed, influent particle size ranged between about 1 µm (0.039 mil) to 50 µm (19 mil) for the 8:1 medium flow and 2:1 high flow tests, while the 4:1 and 2:1 medium flow tests received particle sizes from 1µm (0.039 mil) to 1000 µm (39 mil). The effluent surface particle sizes were consistently between about 1µm (0.039 mil) and 10µm (0.39 mil) for the four tests. Although there is scatter in the data, the suspended sediment in the surface runoff was comprised of larger particles in the high concentration tests than in the lower concentration tests.

Subsequent resuspension tests at the slopes and flow rates studied indicated that for over seven runoff events following suspended sediment deposition, negligible amounts of that original sediment were resuspended from the bed and released in the surface runoff. This was consistently observed for all three beds.

Data indicate that the majority of uptake of metals occurred in the vegetated root structure for the beds receiving high and medium concentration influent. For the high concentration bed, the majority of metal pollutant uptake occurred within the first 6.6 ft (2.01 m) from the inlet, and the majority of the metal mass was concentrated in the roots of the grass for all metals except lead which accumulated in the soil. Based on the core sampling locations relative to the drip line, metal concentrations, excepting Fe, peaked at about 2.2 ft (0.67 m) longitudinally. For the medium concentration flow the highest concentration of metals occurred where the influent flow entered the bed and decreased along the length of bed in the direction of flow with the exception of Fe.

For the bed receiving the low concentration influent, similar to the medium concentration, the highest accumulation of metals was where the influent entered the bed and then generally decreased along the length of the bed. Results were more mixed at this lower concentration, and data were largely not statistically significant.

In summary, the three prototype vegetated biofilter foreslopes provided excellent performance in removal of pollutants (seven metals and suspended material) from a high and medium concentration simulated storm water runoff. Removals of oil were more sporadic. Results of treating a low concentration runoff were mixed, which is consistent with other studies. All BMPs will have a performance threshold for treatment, and if a relatively “clean” influent enters the BMP, minimal or no treatment will be provided. Results from various tests at slopes of 8:1, 4:1, and 2:1 did not indicate declining performance with increasing slope. Integration of data from the literature showed poor correlation on removal of TSS as function of slope. During the testing period, vegetative coverage on all three biofilters was above 80% for all tests except for the 8:1 slope, medium concentration flow at 76% coverage. Data reported in the literature noted the importance of density or coverage of vegetation in removal of pollutants. Hence, for vegetated biofilters with more sparse vegetation it may be expected that slope would be more significant; steeper slopes would experience higher velocity of runoff flow and constituents in the flow would have less opportunity to be captured in the biofilter. This also indicates the importance of maintaining good vegetative coverage for appropriate performance of the vegetated biofilter.

Assessment of accumulation of seven metals in the grass, roots and soil showed uptake of all seven metals with the roots dominating in removal of most metals for the high and medium concentration tests. The accumulation predominately occurred within seven feet of introduction of flow.

Resuspension was insignificant. Again, the coverage of vegetation probably played a major role in this outcome. Overall within the parameters of this study, findings indicated that the foreslope portion of the vegetated biofilter plays a significant role in reducing the quantity of pollutants in the runoff.

Recommendations

Although this study did not indicate significant performance differences in terms of pollutant removal between the slopes at 8:1, 4:1, and 2:1, slopes less than 2:1 would be advisable with the varying rainfall-runoff events that may be experienced in the field. In addition, some of the tests had spikes in the surface effluent data for the 2:1 slopes, which indicated some variability in performance. Based on analysis of cores from the vegetated beds, break through of metals did not occur, and at an applied high concentration of influent, maximum accumulation occurred at about 2 ft (0.61 m) to 3 ft (0.91 m) from the inlet. It was beyond the scope of this study to determine the capacity of a typical biofilter which would provide guidance for longevity.

Since maximum capacity of the biofilters was not reached, it would be speculative to provide recommendations on minimum length for the biofilter. The data from the literature indicated good correlation of percent suspended solids removal with slope length, and lengths greater than about 7 m (23 ft) to 8 m (26 ft) provide greater than 80% removal. The results in this experiment suggest that similar removals may be achievable at lesser lengths with full vegetative coverage.

The current study needs to be expanded to include tests under dormant conditions since for Ohio the biofilter will be expected to perform during the winter. Preliminary assessment of the effects of chlorides present in winter maintenance materials could also be performed. In addition, the results from this study need to be validated with a field study.

Implementation Potential

ODOT can use the information in this report to begin assessing the selected versions of the vegetated biofilter as a best management practice suitable for meeting the OEPA permitting criteria. Some of the findings in this report and from the literature may have application in revising or adding to sections of ODOT's *Location and Design Manual* Volume 2 and *Construction and Materials Specifications* regarding vegetated biofilters. These findings may also be applicable to revising ODOT's storm water and water quality research goals, and also to revising ODOT's Storm Water Management Program.

Items for consideration include the following:

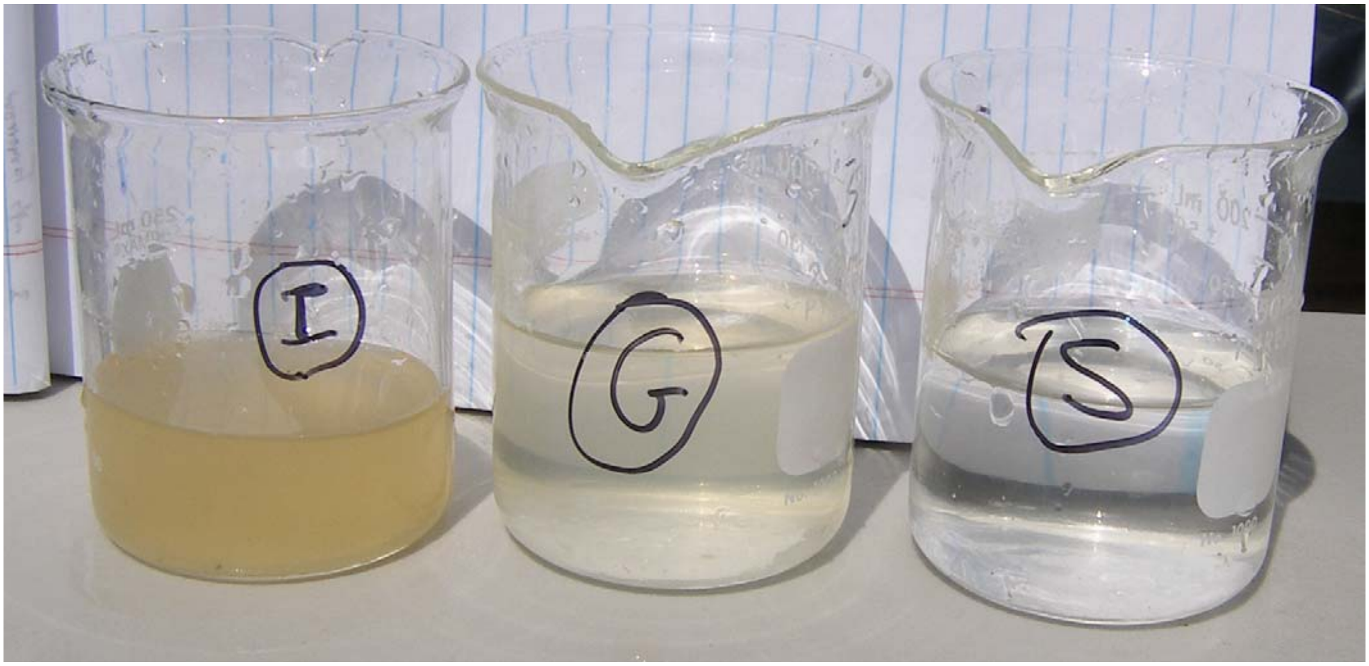
- Recognition that the foreslope provides significant removal of storm runoff constituents.
- Restriction of foreslopes to less than 2:1.
- Establishment of a requirement of minimum coverage of vegetation. The impact of coverage on performance was outside the scope of this study. The vegetated foreslopes studied in this project performed well with a vegetative coverage above 80%; this coverage level is recommended.
- Exclusion of the use of crown vetch.
- Establishment of a standard inspection schedule using a form similar to the field inspection record in the project report.
- Maximization of infiltration along the foreslope.

A field study is recommended to verify these results under actual roadside conditions and to consider long-term issues.

Ultimately changes in the *Location and Design Manual* Volume 2 and *Construction and Materials Specifications* will be distributed to the ODOT Districts so that vegetated biofilters conforming to the updated specifications can be designed and incorporated into future transportation system construction and repair projects.

Implementation will be limited to those sites with sufficient right of way to construct the vegetated biofilter, thus personnel in rural areas would be the primary users of the system. Other impediments to implementation could include the efficacy of the biofilter during the winter season. Appropriate construction and maintenance will be important to the success of the BMP.

Cost components would include purchase of the vegetation and soils, construction of the biofilter, and site maintenance. Costs would be dependent on site characteristics and could be highly variable from site to site.



Comparison of specimens collected during a simulated high concentration runoff event showing influent (I), underdrain or ground (G) and surface (S) water specimens.