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 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
- Examine the effectiveness and design of vegetated biofilters during conditions of dormancy that occur during winter months (December – March) in Ohio.

Description
This supplement reports on a continuation of the main study, entitled “Vegetated Biofilter for Post Construction Storm Water Management for Linear Transportation Projects” (SJN 134349 also). The supplemental work involved an additional set of experiments on the biofilter foreslope prototype during dormant grass conditions in late winter (March), 2010 to determine if the weather and vegetation conditions had a major effect on the filter’s effectiveness.

The procedure and equipment used were the same as for the previous experiments using medium concentration artificial runoff, with some salt added to account for the effects of winter road salting.

The test bed was 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 that delivered the Water Quality volume equivalent to 0.75 in (19 mm) in the first 15 min. 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. Chlorides were also monitored.

Results and Conclusions
At the time of performance testing the dormant bed had about 60% vegetated coverage compared with about 83% coverage under summer conditions. Baseline concentrations were generally higher for all constituents for the dormant bed. Comparison of EMC removals of constituents show lesser removal for TSS, iron and zinc under dormant conditions. Comparisons of removals of other constituents under dormant versus summer vegetation did not appear to be statistically different. Removal of TSS was still above 80% for the dormant bed. Removal of Zn however declined to 50% to 65%, while iron exceeded 60%. Analysis of core data indicated that the roots were providing the greater uptake of metal constituents, which was the previous finding under active growth.

The prototype vegetated biofilter foreslope, labeled Bed 2, 4 ft (1.22 m) wide by 14 ft (4.27 m) long (direction of flow) and further described in the report [Mitchell, Riefler, and Russ, 2010b], was studied under dormant vegetation conditions. The foreslope, receiving a “medium” concentration influent (medium concentration during the water quality portion of the event followed by low concentration influent) storm water runoff, performed well at all slopes (8:1, 4:1, 2:1) under the medium flow storm event simulation. Based on EMC calculated data, removals of TSS and the total metals (Cd, Cr, Cu, Ni, and Pb) monitored in the influent flow were at or above 80%. Under dormant conditions removals of total metals from highest to lowest, averaged over the three slopes, were Pb, Cu, Ni, Cr, Cd, Fe and Zn. For the summer conditions, the highest removals were noted for Fe, Pb, Ni and Cu. Similar to the findings for summer conditions, dormant data indicated slightly lower overall removals for Cd and to a lesser extent for Cr compared to the other metals, such as Pb, Cu, and Ni. In the previous summer, tests for the medium concentration influent Ni, and to a somewhat lesser extent Cd, tended to predominate in the dissolved form. In the dormant tests, Ni, Cd, and Zn had dissolved concentrations similar to total concentrations for most of the influent samples.

Oil and grease removal for the three slopes was 82%-95%, and slightly higher under summer conditions for the medium flow rate.

Removals of constituents computed based on the water quality volume as defined by ODOT [2009], the runoff generated by the first 0.75 in (19 mm) of precipitation, in general, were the same or greater than those computed for the entire runoff event with the exception of zinc.

For the dormant bed, the baseline surface runoff particle sizes ranged from 100-1000 µm, and for the majority of the performance tests the influent and the surface runoff samples were in the range of 1-1000 µm and 1-10 µm, respectively. For the active 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.

Analysis of the La tagged soil added in the first dormant performance test at 8:1 indicated that negligible material was transported to the surface effluent or resuspended. For the summer active grass study that had seven runoff events following the tagged suspended sediment deposition, negligible amounts of that
original sediment were resuspended from the bed and released in the surface runoff.

Data indicate that the majority of uptake of metals occurred in the vegetated root structure, as was found previously for the summer active vegetation tests. For both the dormant and summer active grass, 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 dormant vegetation sodium chloride was introduced into the artificial runoff to simulate winter maintenance on roadways. Over the entire event the chloride was reduced by about 35% at the 8:1 slope with no reduction at the other two slopes. For the water quality portion of the event chlorides were slightly reduced at the 4:1 and 2:1 slopes.

In summary, the prototype vegetated biofilter foreslope under dormant conditions provided fair to excellent performance in removal of pollutants (seven metals, suspended material, and oil and grease) from a medium concentration simulated storm water runoff. Over 80 percent removal was achieved for all constituents except iron, zinc and chlorides. Iron removal averaged about 75% while Zn was about 58%. Chlorides were only slightly removed at all slopes over the water quality portion of the event. TSS removal declined from a summer condition average removal of about 95% to 80% for the dormant condition. Results at slopes of 8:1, 4:1, and 2:1 did not indicate declining performance with increasing slope. For the dormant test vegetation coverage was about 60% contrasted to an average 83% during the summer. This reduced coverage which would be expected during winter conditions contributed to the reduction in removals. Overall within the parameters of this study, findings indicated that the foreslope portion of the vegetated biofilter even during a dormant condition significantly reduces the quantity of pollutants in the runoff with the exception of chlorides.

**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. Laboratory scale breakthrough tests (effluent concentrations = influent concentrations) could be performed to arrive at more definitive results, which could be used to develop a model to extraplate to long range performance. 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.

Removals, as expressed in EMC, under dormant conditions were less than that obtained with summer vegetation but overall were acceptable, particularly for TSS and most metals, 80% or greater. This was primarily attributed to the reduced vegetative coverage since this was the primary variable for the test conditions. Hence, establishment of good vegetative coverage prior to winter or dormant conditions is recommended. Some reduction in chlorides was observed, less than 30% averaged over the three slopes during the water quality portion of the events. If a high quantity of salt (NaCl) accumulated in the biofilter, this could possibly impair growth of the vegetation, however long term effects were beyond the scope of this project and were not investigated.

**Implementation Potential**

ODOT can use the information in this supplement and 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 the report and from the literature may have application in revising or adding to sections of ODOT’s *Location and Design Manual* Volume 2, Section 1117.3 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. Tests of the foreslope prototype conducted under dormant conditions with vegetation coverage about 60% indicated good performance also but less than that under summer conditions and greater vegetative coverage. Also, baseline concentrations were higher under dormant compared to summer conditions.
- Exclusion of the use of crown vetch.
- Establishment of a standard inspection schedule using a form similar to the field inspection record in [Mitchell, Riefler, and Russ, 2010b].
- Maximization of infiltration along the foreslope.

A field study is recommended to verify these results under actual roadside...
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 could include the efficacy of the biofilter during prolonged salt application in winter seasons. Appropriate construction and maintenance will be important to the success of the BMP.

As discussed in the project report, 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.