

## Water Quality Benefits of Grass Swales in Managing Highway Runoff

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### ABSTRACT

Grass swales are a vegetated stormwater management technology that can remove surface runoff contamination through sedimentation, filtration by the grass blades, infiltration to the soil, and likely some biological processes. Two full-scale grass swales in the median of a four-lane highway were monitored during 18 storm events to characterize the overall performance of grass swales as a stormwater management technology and to evaluate the effect of the shallow-sloped grass pre-treatment area adjacent to the swale in most designs. The study was designed as an input/output comparison between the water quantity and quality captured directly from the roadway and the effluent from the swales. Both swales exhibited significant removal of suspended solids (65-71% based on EMCs) and zinc (30-60% based on EMCs). No significant difference in treatment efficiency is noted between the swale with a pretreatment area and the grass swale alone.

### KEYWORDS

Swale; Runoff; Stormwater; Best Management Practice; Total Suspended Solid; Metals; Zinc

### INTRODUCTION

In an effort to reduce the effects of non-point source pollution, which includes overland runoff from agricultural, industrial, and urban areas and accounts for almost 50% of the total water pollution in the developed world (Novotny 1994), engineers and highway administrations have placed an emphasis on cost-effective methods to control runoff pollution. One such LID technology that has been employed for the conveyance of stormwater runoff in highway designs for many years is grass swales. Water quality enhancements can be realized in these swales through sedimentation (due to the low velocity induced by the vegetation), filtering by the grass blades, infiltration, and likely some biological processes. Swales are commonly used on highway projects because they represent an aesthetically pleasing method for linearly conveying runoff. While recent studies have revealed them as an effective stormwater management technology, good performance data and mechanistic understanding of swale design parameters are not available.

Little consistent information on water quality improvements for swales is available, in large part because of the complexity of swale operation. Swales receive flow laterally through vegetated side slopes, which can greatly improve incoming water quality. Infiltration throughout the swale surface area can reduce flow volume and improve quality. Thus, swales have several points of

water input and output, which can complicate simple performance analyses. This is supported by a summary report on swale performances from several states, which has shown sediment removals ranging from -85% (i.e., sediment increases) to 98% (Schueler 1994). These results indicate that many variables can contribute to the pollutant removal efficiency.

A recent study comparing the performance of grass swales to other stormwater best management practices was performed by Barrett (2005). This study evaluated 42 events over 6 grass swales. Results indicated that grass swales removed metals (zinc 54%, copper 24%) and suspended solids (48%) successfully. However, significant export of nutrients (nitrate -28%, orthophosphorus -242%) was noted. Yu *et al.* (2001) compiled results from grass swales from their work and that of others. Length was found to be the most important parameter in insuring good swale performance. A swale length of over 100 meters has proven to be successful in providing very good removal of suspended solids and other pollutants. The authors recommended using slopes less than 3%. Phosphorus removal was scattered, apparently because of phosphorus being contributed by the vegetation in the swale. The use of check dams was found to significantly improve treatment efficiency.

As part of increased focus on stormwater management practices capable of treating non-point source runoff and the great amount of uncertainty regarding the performance and pollutant removal mechanisms of grass swales, a pilot project was constructed. The goals for this project were to systematically quantify the effects of some operational parameters for water quality improvement using grass swales. This project had two objectives. The first focused on the overall efficiency of a grass swale on roadway runoff pollutant removal. The second examined the effect of the shallow sloped grass pre-treatment area adjacent to the grass swale.

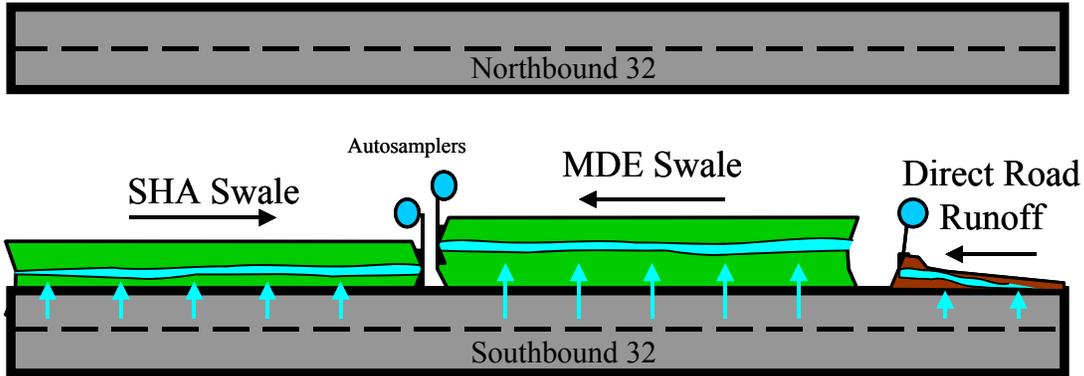
In order to analyze the pollutant removal capability of the swales and to measure the effect of a pretreatment area, two nearly identical swales were designed and constructed; one swale with a pretreatment area adjacent to the swale and one swale receiving runoff directly from the roadway surface. A third sampling site, a concrete channel which received runoff directly from the roadway, was assumed to be equivalent in quantity and water quality to the inputs for the two swales. The study system was constructed to concurrently monitor representative inflow and outflow from the grass swales, allowing the determination of pollutant removal efficiency. Water quality parameters examined included those considered as being most problematic from roadway runoff – suspended solids and zinc. Flow rates were recorded to determine the effect of swales on stormwater quantity and so that total pollutant mass reduction could be calculated.

## **METHODOLOGY**

### **Monitoring Location**

The monitoring location for this study was MD Route 32 near Savage, Maryland. This is a four-lane (two in each direction) limited access highway. The area adjacent to the sampling area is wooded with nearby residential; however, the roadway is raised so that runoff is only created by the roadway.

**Figure 1.** Diagram of Rt. 32 Swale Study Area



Two swales were constructed in the highway median to receive runoff laterally from the southbound roadway lanes (Figure 1). Table 1 shows the specific design parameters for these 3 channels. The first is a swale constructed with a 15.2 m wide sloped grass pretreatment area between the roadway and the swale channel (MDE swale). The pretreatment area was constructed with a 6% slope on the southern side of the swale. The second swale, to the north, was identically constructed, but without the pretreatment area (known as SHA swale). Both swales converge at an inlet where water flow and quality measurements are made. Both swales were constructed with identical cross-section designs, with side slopes of 3:1 (33%) and 4:1 (25%) on either side of the swale. Both swales were constructed with 0.61 m bottom width and the channel slope for both swales is 1%.

**Table 1.** Design Characteristics for Three Sampled Channels

	Direct	SHA Swale	MDE Swale
Roadway Area (ha)	0.271	0.224	0.225
Swale Area (ha)	0	0.169	0.431
Total Area (ha)	0.271	0.393	0.656
Channel Material	Concrete	Grass	Grass
Channel Slope	0.2%	1.6%	1.2%
Channel Length (m)	168	198	137
Pretreatment Slope	-	-	6%
Pretreatment Width (m)	-	-	15.2 (from roadway to channel center)

Because swale input flow is distributed along its length, a third sampling area was designed and constructed to sample runoff directly from the highway (known as Direct), south of the swales. This allows an accurate representation of instantaneous swale input flow and water quality from the roadway surface without disrupting flow into the swales. Sampling areas were designed so that all three channels had nearly identical roadway drainage areas.

### Monitoring Equipment and Protocol

Construction of the grass swales was completed in late October 2004. The sampling program began in November 2004 and continued through May 2006.

In order to monitor flows and sample water quality, a V-notch wooden weir was constructed at the end of each swale and the direct channel. An ISCO Model 6712 Portable Sampler was installed in a secured vault adjacent to each swale. Each sampler has a bubble flow meter calibrated with the corresponding weir to monitor flow rates through the weir. The bubble tube was attached to the weir, level with the V-notch. Depths behind the weir were converted to flow rates by the weir equation (ASTM 2001). A stainless steel strainer was placed just upstream of the weir.

One ISCO 674 Tipping Bucket Rain Gauge with 0.0254-cm sensitivity was installed on top of a sampler vault and connected to one of the portable samplers. This tipping bucket logs rainfall depth in 2-minute increments.

Each sampler contained twenty-four 300-ml glass bottles that are cleaned with wire brushes, acid washed in 10% HNO<sub>3</sub> for at least 20 minutes and rinsed with deionized water before placement in the sampler. The sampling program was set to collect 12 samples per event (filling 2 bottles per sample to ensure adequate volume for all the water quality testing). A sampling event was triggered when the head behind the weir reached 0.0305 m, which corresponds to a flow of about 0.430 l/s. This flow rate corresponds to a rainfall intensity of 0.064 cm/hr, based on the direct sampler with a drainage area of 0.271 ha and a Rational Method coefficient of 0.9. Samples were picked up within 24 hours and transported to the Environmental Engineering Laboratory, College Park, MD. All constituent analyses were performed according to Standard Methods (APHA *et al.* 1995). Samples were immediately analyzed for total suspended solids. One bottle for each sample, containing approximately 100 ml of sample was preserved for metal analyses using six drops of concentrated trace level HNO<sub>3</sub>. Metal digestion was completed within two weeks and analyses were carried out within 6 months.

### Data Evaluation and Loading Calculations

For each pollutant, the total mass (M) present in each storm event is calculated as:

$$M = \int_0^{T_d} QCdt \quad (1)$$

where,  $Q$  is the measured stormwater flow rate and  $C$  is the pollutant concentration for each sample during the event.  $T_d$  is the event duration. The interval between samples is  $dt$ .

Additionally, pollutant removal was compared using the normalized event mean concentration (N-EMC), which represents the concentration that would occur if only runoff from the roadway surface entered the swales and the resulting total storm event discharge was collected in one container. The normalized event mean concentration (N-EMC) is calculated as:

$$N - EMC = \frac{\int_0^{T_d} Q(t)C(t)dt}{\int_0^{T_d} Q(t)dt - A_s \int_0^{T_d} i(t) dt} \quad (2)$$

where  $A_s$  represents the total pervious swale area ( $m^3$ ) and  $i(t)$  represents the rainfall intensity ( $m$ ). The N-EMC is therefore equivalent to the total mass delivered divided by the total volume delivered with the volume of rainfall landing directly on the swale removed. This normalization removes the effect of dilution and allows a direct comparison between influent and effluent flow-weighted mean concentrations.

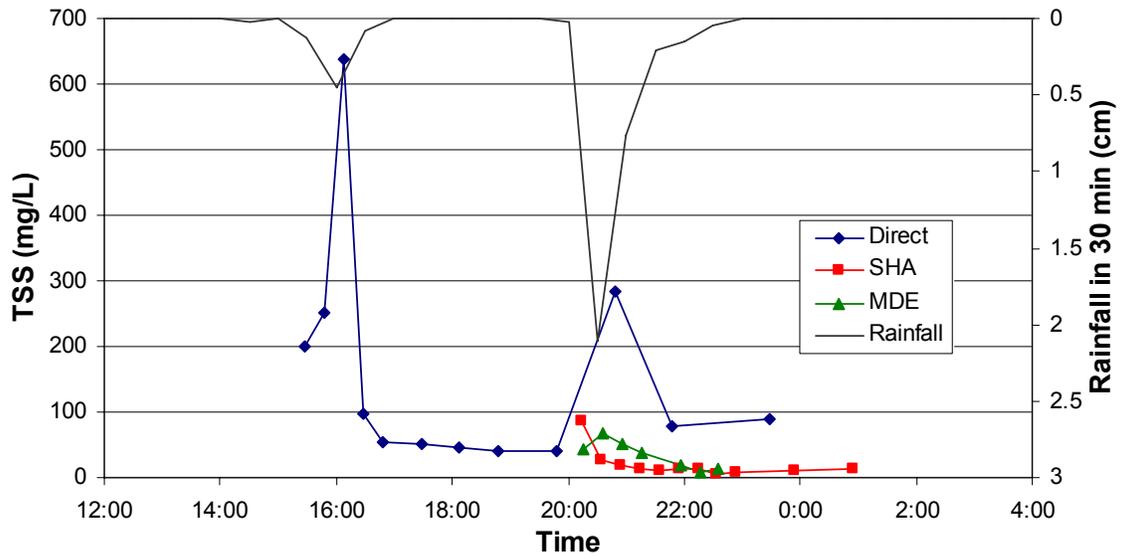
## RESULTS AND DISCUSSION

### Total Suspended Solid (TSS) Removal

Because of the regulatory importance of TSS, special attention was placed on suspended solids removal. Eighteen storm events were analyzed for TSS with 9 events exhibiting complete capture of runoff, an event in which flow was measured in the direct channel, yet no measurable flow was detected at the outfall of the grass swales. A typical TSS data set is shown in Figure 2.

Summary statistics for the N-EMC are shown in Table 2. Table 2 shows almost an order of magnitude difference between the mean values of the influent and effluent N-EMCs, suggesting successful TSS removal. The distribution of N-EMC reduction agrees with the hypothesis that the swales reduce the TSS N-EMC.

Visually, the effect of the swales on TSS N-EMC values is shown in Figure 3, a probability plot showing the distribution of N-EMCs for all three channels. The difference between the Direct N-EMCs and the swale data suggests that both swales are successful in decreasing the resulting concentration from any given storm event. Using a TSS concentration of 100 mg/l for comparison purposes, the inflow concentration will theoretically exceed 100 mg/l during 35% of storm events throughout its lifetime. With the swales, however, the resulting N-EMC for the MDE swale will only exceed 100 mg/l TSS during 4% of storm events and the SHA swale never exceeded 100 mg/l TSS during this study. It appears that SHA and MDE data are similar for most of the storm events, and only differ at a few very high TSS concentrations.



**Figure 2.** TSS Concentrations with Time – 5/11/06 Storm Event

A battery of statistical tests did not identify any outliers or any distributions that were significantly different from the normal distribution. Both swales significantly decreased the N-EMC concentration (94-102 mg/l mean) and had a significant removal percentage (65-71% mean). These results are reasonable when compared to previous studies that showed TSS EMC reductions of 65-98% (Schueler 1994), 85-87% (Barrett *et al.* 1998) and 79-98% (Bäckström 2003). Likewise, both swales exhibited a statistically significant ability to reduce the total TSS mass when compared to the mass entering the swale system. This total suspended solids mass was significantly reduced in terms of absolute mass (2,350 g SHA, 2,230 g MDE) and also in terms of percent (84.4% SHA, 73.1% MDE). Because the swales are capable of both reducing the total mass and N-EMC for suspended solids, it can be concluded that the swales are more dependent on sedimentation and filtration than infiltration.

**Table 2.** Total Suspended Solid Summary Statistics

		Direct Channel	SHA Swale	MDE Swale
Total Mass (g)	Mean (g)	3,120	737	1,220
	Median (g)	1,370	16.9	171
	Standard Dev (g)	4,100	1,930	2,770
N-EMC (mg/l)	Mean (mg/l)	107	10.5	16.6
	Median (mg/l)	93.1	3.71	6.62
	Standard Dev (mg/l)	100	13.9	17.8

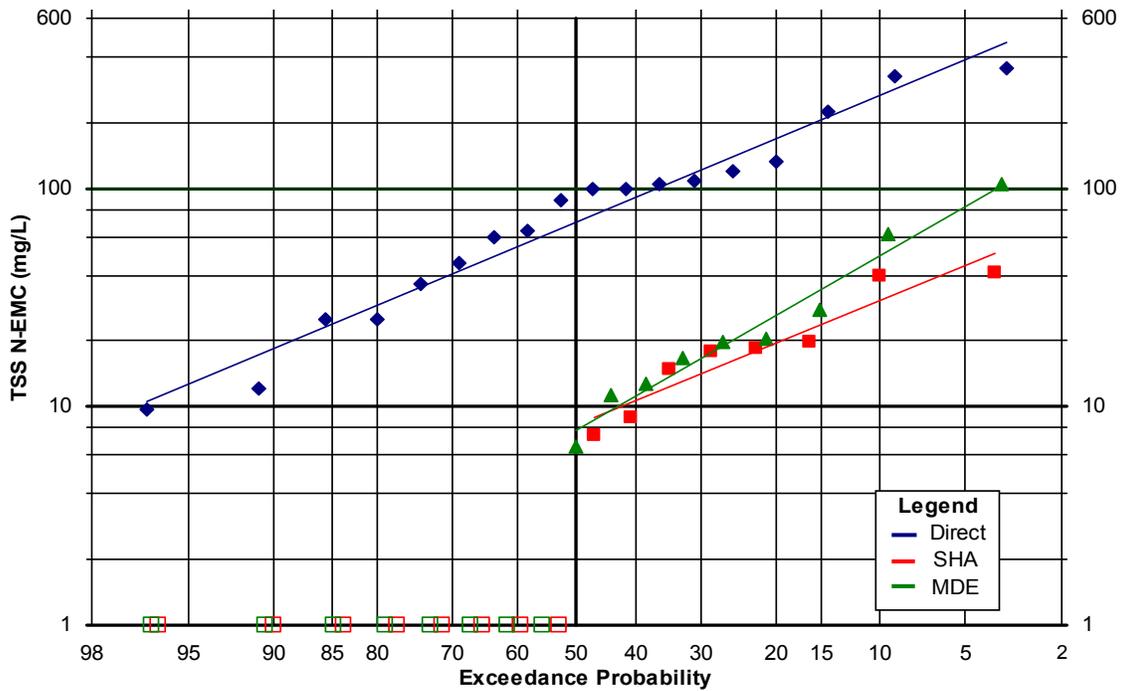
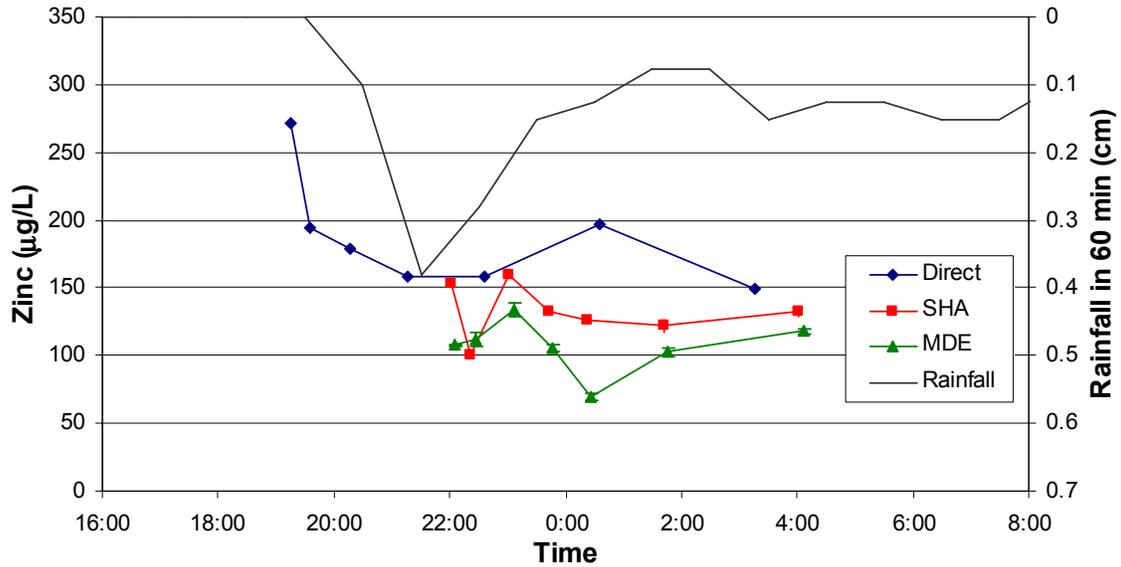


Figure 3. TSS N-EMC values and exceedance probability for swale lifetime

### Zinc Removal

Monitoring zinc removal is an important parameter because zinc generally has the highest concentrations of any other metal in highway runoff and is found primarily in the dissolved form. Therefore, it presumably has a different removal mechanism than suspended solids and other pollutants that are primarily particulate bound. A typical plot of zinc concentrations is given in Figure 4 with the direct runoff showing high initial concentrations. N-EMC removal was on the order of 30-60% and total mass removal was between 75-89%. Removals are summarized in Table 3.

The effect of the grass swales on zinc concentrations is shown visually in Figure 5. In this probability plot, the aquatic toxicity limit for zinc, 120 µg/l, is plotted as a dashed line. This toxicity limit demonstrates the improvement in receiving water quality, showing that 90% of storm events will produce roadway runoff that exceeds this value. However, after swale treatment, only 35% of storm events will exceed the limit of 120 µg/l.

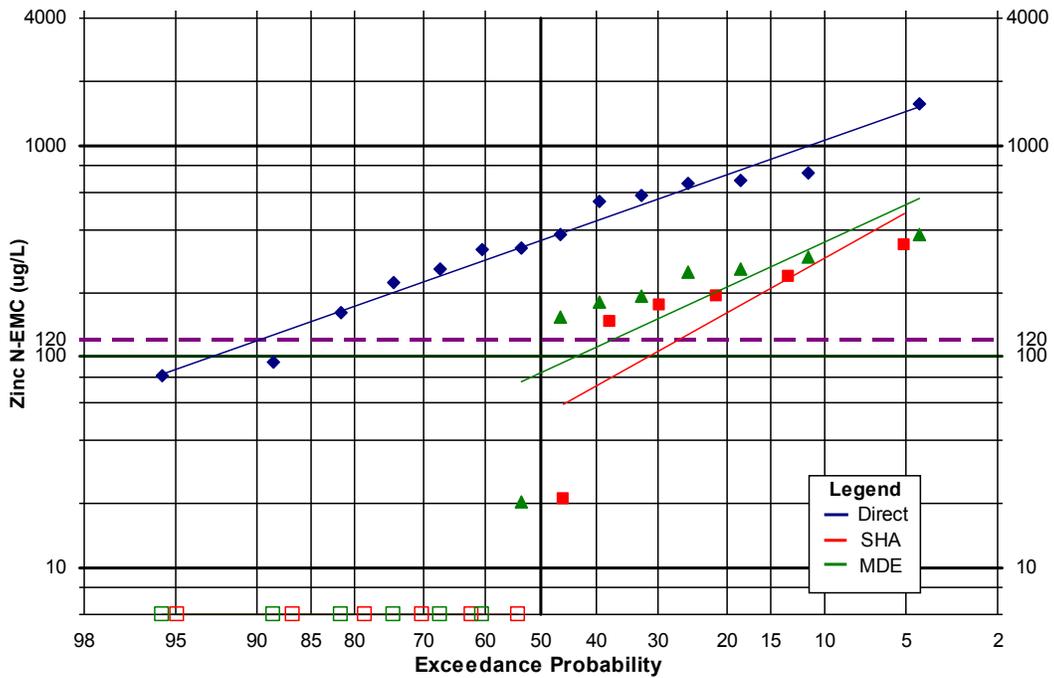


**Figure 4.** Zn Concentrations with Time – 10/24/05 Storm Event

As suggested by Figure 5, both grass swales successfully reduced the mean concentration and total mass for zinc at a statistically significant level. As stated above, zinc is present predominantly in the dissolved state, however, during intense storm events, the distribution of this metal changes to primarily particulate bound because the dissolved metal is easily stripped from the roadway surface and thereby depleted.

**Table 3.** Zinc Summary Statistics

		Direct Channel	SHA Swale	MDE Swale
Total Mass (g)	Mean (g)	10,600	3,770	7,560
	Median (g)	6,730	425	2,400
	Standard Dev (g)	9,498	6,770	12,800
N-EMC (mg/l)	Mean (mg/l)	473	92.7	124
	Median (mg/l)	351	10.5	86.9
	Standard Dev (mg/l)	386	120	136



**Figure 5.** Zn N-EMC values and exceedance probability for swale lifetime

For zinc removal in terms of both mass and mean concentration, the SHA swale shows better removal capability than the MDE swale. The difference between the SHA swale and MDE swale is statistically significant at the 5% level. Presumably, this difference is caused by the extra channel length in the SHA swale. This extra length allows more time for adsorption and more length for sedimentation of particulate bound zinc.

## CONCLUSIONS

By analyzing pollutant removal by grass swales in a field study environment, this study has shown that grass swales are an effective, simple, and cost-effective method for non-point source runoff pollutant removal. Grass swales function by capturing the first flush of high pollutant concentrations through infiltration, and then reducing the subsequent steady-state concentrations by adsorption for dissolved pollutants and sedimentation and filtration for particulates and particulate-bound pollutants.

Both grass swales were effective in reducing TSS and zinc concentrations, which represent two of the more important highway contaminants and two different removal mechanisms. It appears that the grass pretreatment area prior to the grass swales does not make any significant difference in reducing concentrations. The total travel time, which is controlled by roughness, slope, and

channel length, appears to be the most important factor in removing both dissolved and particulate-bound pollutants. Therefore, grass swales should be considered as a cost effective solution for improving highway runoff quality.

## ACKNOWLEDGMENTS

This project was supported by the Maryland State Highway Administration (SHA). The SHA Program Manager for this project was Sonal Sanghavi. Project Manager was Dana Havlek.

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