

# Evaluation of Porous Asphalt Used at a Virginia Department of Transportation Park & Ride Facility

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Final Report VTRC 18-R19

**Standard Title Page - Report on Federally Funded Project**

1. Report No.: FHWA/VTRC 18-R19	2. Government Accession No.:	3. Recipient's Catalog No.:	
4. Title and Subtitle: Evaluation of Porous Asphalt Used at a Virginia Department of Transportation Park & Ride Facility		5. Report Date: June 2018	6. Performing Organization Code:
		8. Performing Organization Report No.: VTRC 18-R19	
7. Author(s): G. Michael Fitch, Ph.D., and Benjamin F. Bowers, Ph.D., P.E.		10. Work Unit No. (TRAIS):	
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		11. Contract or Grant No.: 103980	
		13. Type of Report and Period Covered: Final	
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation      Federal Highway Administration 1401 E. Broad Street                              400 North 8th Street, Room 750 Richmond, VA 23219                                Richmond, VA 23219-4825		14. Sponsoring Agency Code:	
		15. Supplementary Notes:	
<p>16. Abstract:</p> <p>Recognizing the increasing emphasis on reducing stormwater runoff associated with transportation facilities and the changes in the Virginia Department of Environmental Quality's Stormwater Management Program Permit Regulations, the Virginia Department of Transportation (VDOT) has taken the first step in examining ways in which permeable pavements can be used in place of conventional impervious pavement materials.</p> <p>Like many departments of transportation, VDOT has minimal experience using permeable pavements of any type. As a consequence, many questions remain to be answered before VDOT can confidently use these types of pavements as stormwater best management practices in place of more commonly used stormwater control measures. The objective of this study was to develop a better understanding of how porous asphalt would perform when it is maintained using four different protocols: (1) no maintenance, (2) regenerative air vacuuming at 6-month intervals, (3) conventional vacuuming at 6-month intervals, and (4) regenerative air vacuuming at 12-month intervals. To meet these objectives, a Park &amp; Ride facility operated by VDOT was paved with porous asphalt, maintained, and monitored for 4 years.</p> <p>Although infiltration rates slowed substantially over the monitoring period, the lot continued to function as a stormwater best management practice (BMP) with an average infiltration rate approximately 12 times the required minimum of 10 in/hr. The different maintenance protocols tested did not have an effect on the rate of infiltration decline, indicating the reduction in permeability is likely not the result of sedimentation. It is estimated that the lot, constructed in 2013, will continue to function as an effective stormwater BMP until at least 2025 and will cost less than \$1,500 per year to maintain.</p> <p>Based on these findings, the study recommends that VDOT's Location and Design Division continue to consider porous asphalt as a stormwater BMP option for Park &amp; Ride facilities when deciding on the most cost-effective BMP based on site-specific conditions. Further, the study recommends that VDOT's Materials Division oversee the formation of an advisory group to help determine in what settings porous asphalt can be used best by VDOT. This will help ensure that a comprehensive approach is taken when determining if porous asphalt could be used as a stormwater BMP in locations other than Park &amp; Ride facilities.</p>			
17 Key Words: porous asphalt, infiltration rates, maintenance stormwater BMP		18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 22	22. Price:

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OF TRANSPORTATION PARK & RIDE FACILITY**

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In Cooperation with the U.S. Department of Transportation  
Federal Highway Administration

Virginia Transportation Research Council  
(A partnership of the Virginia Department of Transportation  
and the University of Virginia since 1948)

Charlottesville, Virginia

June 2018  
VTRC 18-R19

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## ABSTRACT

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Although infiltration rates slowed substantially over the monitoring period, the lot continued to function as a stormwater best management practice (BMP) with an average infiltration rate approximately 12 times the required minimum of 10 in/hr. The different maintenance protocols tested did not have an effect on the rate of infiltration decline, indicating the reduction in permeability is likely not the result of sedimentation. It is estimated that the lot, constructed in 2013, will continue to function as an effective stormwater BMP until at least 2025 and will cost less than \$1,500 per year to maintain.

Based on these findings, the study recommends that VDOT's Location and Design Division continue to consider porous asphalt as a stormwater BMP option for Park & Ride facilities when deciding on the most cost-effective BMP based on site-specific conditions. Further, the study recommends that VDOT's Materials Division oversee the formation of an advisory group to help determine in what settings porous asphalt can be used best by VDOT. This will help ensure that a comprehensive approach is taken when determining if porous asphalt could be used as a stormwater BMP in locations other than Park & Ride facilities.

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## **INTRODUCTION**

Recognizing the increasing emphasis on reducing stormwater runoff associated with transportation facilities and the changes in the Virginia Department of Environmental Quality's Stormwater Management Program Permit Regulations that took effect July 1, 2014 (Virginia Department of Conservation and Recreation, 2012), the Virginia Department of Transportation (VDOT) has begun examining ways in which permeable pavements could be used in place of more traditional stormwater best management practices (BMPs). In some instances, the use of permeable pavement could occupy the footprint of conventional impervious pavement materials, providing benefits where limited land is available for traditional BMPs. Permeable pavements, of which there are several types, allow for the infiltration of water through voids in the structure of the pavement matrix and into the base material. Depending on the hydraulic conductivity of the sub-base material and the design of the overall pavement system, infiltration may continue into the underlying soil or be discharged to an outlet by way of an underdrain.

The fact that permeable pavements are capable of attenuating stormwater flow is well documented (Drake et al., 2013). Although significant national research has been conducted both on the performance of and environmental benefits related to permeable pavements (Booth and Leavitt, 1999; Brattebo and Booth, 2003; Collins et al., 2008; Rodriguez-Hernandez et al., 2012), widespread acceptance of these pavements has been hindered by questions related to their cost and long-term performance (Roseen et al., 2012).

In addition, and maybe more important, maintenance concerns serve as a major barrier for agencies already grappling with the high and unpredictable costs of maintaining numerous and varied stormwater BMPs. Current research shows that inadequate data are available to predict accurately the cleaning interval necessary to maintain permeable pavements properly (Brown and Borst, 2014; Drake et al., 2013). Adding to the confusion, although valuable work has been done looking at the effectiveness of commercial street sweepers (Drake and Bradford, 2013; Winston et al., 2016b), many of these studies looked at the effectiveness of restoring pavements that were not maintained for a number of years. Therefore, questions regarding the effectiveness of maintenance practices on newly constructed pavements and the interval at which they should be maintained to maximize long-term performance have not been adequately addressed.

Like many departments of transportation, VDOT has had minimal experience using permeable pavements of any type, and as a consequence, many questions remain for VDOT regarding their installation and potential performance. To facilitate the use of these types of pavements, VDOT, along with the Virginia Asphalt Association, developed guidelines for the use of porous asphalt pavement structures. These guidelines build on the Virginia Department of Environmental Quality's Stormwater Design Specification No. 7, Permeable Pavement, Version 1.8 (Virginia Department of Conservation and Recreation, 2011) and also take into account the changes in asphalt binders and mix design in recent years.

Many factors are considered in the selection of which BMPs to use to satisfy stormwater requirements, and cost of construction is one of these. Ideally, life-cycle costs should also be considered. Given that VDOT is already responsible for nearly 2,000 BMPs statewide (Nobles et al., 2017), it is important that VDOT have a clearer understanding of the long-term performance and maintenance responsibilities regarding permeable pavements to determine if, when, and where to use these pavements in the future. This information will help ensure the selection of the BMP that will satisfy the stormwater requirements in the most cost-effective manner.

## **PURPOSE AND SCOPE**

The purpose of this study was to address concerns pertaining to long-term infiltration performance and associated maintenance burdens of porous asphalt for a newly constructed Park & Ride facility. More specifically, one of the primary objectives was to estimate the length of time the lot would serve as an effective stormwater BMP and what maintenance practices were needed to ensure this effectiveness. A secondary purpose was to investigate whether two porous asphalt mixtures with different nominal maximum aggregate sizes vary with respect to stiffness because of the high air-void contents in porous asphalt mixtures.

The scope of the study was limited to a single pilot project at the newly constructed I-66 / Route 234 Bypass Park & Ride Facility in Prince William County, Virginia. The effort consisted of monitoring the changes in permeability over time, maintaining the facility using methods previously used by others to maintain similar pavements. In addition, the change in stiffness of the porous asphalt with time was characterized.

## **METHODS**

### **Site Description**

The Park & Ride facility monitored during this study is 0.97 acres in size and was constructed in the spring of 2013. The soils in the area are predominantly a low permeability silt loam. The area under the entire lot serves as a reservoir with a subbase comprised of 18 to 24 in of AASHTO No. 2 stone placed on top of a woven subgrade stabilization geotextile fabric. Directly above the subbase is 3 in of a porous asphalt mixture with a nominal maximum aggregate size of 19.0 mm, serving as the base. The base mixture is overlaid with 1.5 in of a

porous asphalt surface mixture with a nominal maximum aggregate size of 9.5 mm. Binders used for the base and surface mixtures were a PG 70-22 and a PG 76-22 binder, respectively. The finished lot provides 107 parking spaces and serves as the overflow lot for a larger Park & Ride lot adjacent to the site. Except for a single entrance/exit point, the lot is bounded by a concrete curb and gutter system that limits the risk of the lot having stormwater run-on. There is limited vegetation near the lot with a small number of mature deciduous trees along the south side of the facility. Many of these factors help to minimize the volume of sediment deposited on the pavement (see Figure 1).



**Figure 1. Completed Porous Asphalt Park & Ride Facility**

### **Mixture Volumetrics**

Volumetric analyses were performed to determine fundamental mixture properties. The data collected included asphalt content and gradation; bulk and maximum (i.e., Rice) mixture specific gravities ( $G_{mb}$  and  $G_{mm}$ ) in accordance with ASTM D2041; air voids (VTM); voids in mineral aggregate (VMA); voids filled with asphalt (VFA); bulk and effective aggregate specific gravities ( $G_{sb}$  and  $G_{se}$ ); dust/asphalt ratio; percent binder absorbed ( $P_{ba}$ ); and effective binder content ( $P_{be}$ ).

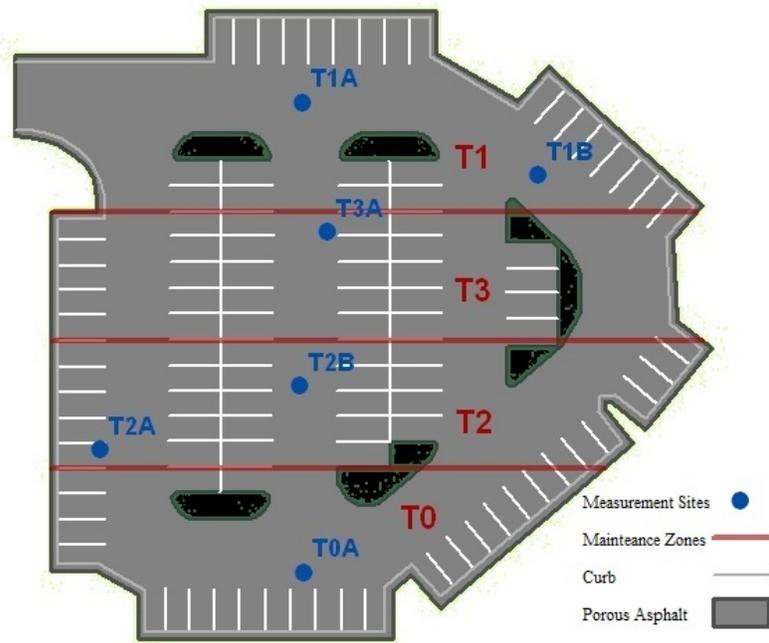
## Measurement of Pavement Infiltration Performance

Following initial construction of the Park & Ride lot, six cores with a diameter of 6 in were collected from the lot using a core rig with a core barrel bit. The sampling locations were randomly selected. The cores were later analyzed for porosity and infiltration capacity in the Virginia Transportation Research Council (VTRC) asphalt laboratory. During plant production, asphalt mixture was collected and returned to the VTRC laboratory so that specimens could be fabricated and fundamental engineering properties could be analyzed. This included volumetric analysis and dynamic modulus. Following the 4-year monitoring period, six additional cores were collected from new locations and underwent the same tests as the cores collected immediately following construction, with the addition of dynamic modulus testing.

Infiltration rates of the pavement were also measured in situ. Field infiltration measurements were taken using an embedded single-ring, falling head infiltrometer as opposed to the more commonly used standard double-ring infiltrometer. Although numerous studies have been conducted evaluating and comparing infiltration testing procedures (Brown and Borst, 2014; Charbeneau et al., 2011; Lucke et al., 2014; Winston et al., 2016a), Chopra et al. (2010) demonstrated that use of an embedded single-ring infiltrometer was more appropriate than the use of a standard double-ring infiltrometer (ASTM D3385-03) for measuring infiltration rates in permeable pavements by eliminating lateral flow and isolating the measurement of vertical flow through the pavement structure. Although much more difficult to install, the embedded single-ring infiltrometer method was thought by Chopra et al. (2010) to provide a more accurate and repeatable measurement of the pavement's permeability—attributes thought to be critical to discerning the changes in permeability over time.

The steel rings were installed at six sampling locations. The lot was divided into four equal sections with two sampling locations each in Section T1 and T2 and one sampling location each in Sections T3 and T0 (see Figure 2). Sampling areas were deliberately selected from the drive lanes and not the parking stall to allow access to the sites even if the lot had heavy use during weekday business hours. The installation of the embedded sampling rings required the cutting of the pavement with the core rig and a 6-in-diameter core barrel to a depth of approximately 4.25 in (see Figure 3). Care was taken to core deep enough to allow the placement of the ring without dislodging the asphalt core. The rings had a sidewall thickness of 0.1 in, an inside diameter of 6.125 in, and a length of 4.125 in. They were placed in the annular space allowing the top of the ring to be flush with the pavement surface. The inside circumference of each ring was then sealed by injecting heated binder in the remaining annular space to eliminate the possibility of preferential flow along the side of the ring.

Infiltration measurements were taken by temporarily placing a plastic-reinforced, graduated acrylic cylinder on top of each permanently installed ring and sealing the joint between the two with plumber's putty. Water was added to the ring and allowed to infiltrate to saturate the full depth of the sample area. Additional water was added to fill the cylinder to the 73 cm mark. The time needed for the water level in the cylinder to drop to the 33 cm mark was recorded. Between three and five consecutive measurements were taken at each of the six locations during sample collection. Samples were taken at various intervals during the 4-year monitoring period. Sampling dates are shown in Table 1.



**Figure 2. Diagram of the Porous Asphalt Park & Ride Facility Showing Different Maintenance Sections and Sampling Locations**



**Figure 3. Installation of a 6-In-Diameter Ring in the Annular Space Following Partial Depth Coring**

**Table 1. Monitoring and Maintenance Schedule**

Date	Section T1	Section T2	Section T3	Section T0
5/8/13	IM	IM	IM	IM
7/29/13	IM	IM	IM	IM
10/31/13	IM, RVAC	IM, CVAC	IM	IM
11/6/13	IM	IM	IM	IM
5/27/14	IM, RVAC	IM, CVAC	IM, RVAC	IM
6/6/14	IM	IM	IM	IM
12/15/14	IM, RVAC	IM, CVAC	IM	IM
5/18/15	IM, RVAC	IM, CVAC	IM, RVAC	IM
5/19/15	IM	IM	IM	IM
12/1/15	RVAC	CVAC	-	-
6/28/16	IM, RVAC	IM, CVAC	IM, RVAC	IM
6/29/16	IM, PW	IM, PW	IM, PW	IM
5/9/17	IM	IM	IM	IM

Section T1 = Test Section 1; Section T2 = Test Section 2; Section T3 = Test Section 3; Section T0 = Test Section 0 (Control); IM = infiltration measurement; RVAC = regenerative air vacuum; CVAC = conventional vacuum; PW = pressure wash.

### **Maintenance**

In order to determine the effectiveness of different maintenance treatments and intervals, each of the four sections was maintained differently over the life of the study (see Table 1). Three maintenance practices were used on three of the sections and no maintenance was performed the fourth section, which was used as a control. The four maintenance treatment sections were as follows:

1. T0: No maintenance (control)
2. T1: Regenerative air vacuuming at 6-month intervals
3. T2: Standard vacuuming at 6-month intervals
4. T3: Regenerative air vacuuming at 12-month intervals.

The regenerative air vacuum and the conventional vacuum truck used in the treatments were manufactured by Elgin Sweeper Company. The units were operated by two different contractors. During each maintenance treatment, multiple overlapping passes were made by the respective units to ensure complete cleaning of the sections.

Cost information for the operation of these units was combined with cost information gathered by way of a telephone survey (see Appendix) of companies that provide street sweeping (vacuuming) services throughout Virginia (n = 23) to gain a better understanding of per hour pricing, minimum time requirements, vacuum type, etc. By way of an Internet search, an attempt was made to find vendors that provide street vacuuming services in each of VDOT's nine construction districts based on their office street address. This was complicated by the fact that some vendors advertised their company's services outside the VDOT district in which they are located (e.g., vendors in Maryland provide services in the Northern Virginia District) and simply either charge a travel fee or count the travel time in the calculation of the time that service is provided (i.e., time spent vacuuming).

At the end of the third year of the study, the three sections, T1, T2, and T3, that had been maintained by regenerative air vacuuming or standard vacuuming were also cleaned with a pressure washing / vacuum system as an additional treatment that the control section did not receive. This system was composed of a 1500 psi, 2 gal/min pressure washer connected to a pressure washer surface buffer and a 5 HP shop vac.

## Data Analysis

### Permeability Calculations

Times measured during the infiltration tests were converted to permeability using Darcy's law and accounting for the change in head during the test by way of Equation 1:

$$k = \frac{aL}{At} \ln \left[ \frac{h_1}{h_2} \right] \quad [\text{Eq. 1}]$$

where

- k = coefficient of permeability
- a = inside cross sectional area of standpipe
- L = thickness of the asphalt matrix
- A = cross-sectional area of sample location
- t = total elapsed time between  $h_1$  and  $h_2$
- $h_1$  = initial head (height of water in column at start)
- $h_2$  = final head (height of water in column at end).

### Comparison of Sample Means

A single factor analysis of variance was performed to determine if the average infiltration rates of the four maintenance sections were equal. Multiple *t*-tests were performed to compare any two averages. The standard error was used to describe the distribution of the values making up the average infiltration rates.

## Dynamic Modulus

The dynamic modulus tests were conducted on laboratory-produced specimens generally in accordance with AASHTO TP 79: Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT). Initial dynamic modulus specimens were fabricated in a gyratory compactor from plant produced mixture. Specimens were 150 mm tall and 100 mm in diameter. The specimen air-void contents were within  $18.0 \pm 0.5\%$  and are shown in Table 2. Three replicate dynamic modulus specimens were tested at 25, 10, 5, 1, 0.5, and 0.1 Hz at temperatures of 4.4, 21.1, 37.8, and 54.4°C.

In addition, in an attempt to evaluate the change in stiffness over the observation period, small-scale cylindrical specimens were taken from road cores for evaluation. Four-year dynamic

modulus specimens, henceforth referred to as “4-year SS” (SS for small-scale) specimens were fabricated from field cores in accordance with Bowers et al. (2015) and Diefenderfer et al. (2015). It should be noted that although the researchers are confident that the dynamic modulus of open graded mixtures can be evaluated using small-scale specimens, open graded mixtures were not investigated as a part of the aforementioned work (Bowers et al., 2015; Diefenderfer et al., 2015). Specimens were 110 mm tall and 38 mm in diameter for the 9.5-mm surface mixture and 100 mm tall and 50 mm in diameter for the 19.0-mm intermediate mixture. The difference in specimen diameter was dictated by the thickness of the layer. Four-year SS specimens were outside of the specification with regard to air voids as shown in Table 2. Three replicate dynamic modulus specimens were tested at 25, 10, 5, 1, 0.5, and 0.1 Hz at temperatures of 4.4, 21.1, and 37.8°C. In all cases dynamic modulus master curves were generated using an average value from the three replicates.

It is important to note that because the initial specimens are laboratory made and the field cores are collected from the field, it is inappropriate to compare initial and 4-year air-void contents. The air-void contents in Table 2 are provided to explain further the differences in dynamic modulus between the initial and 4-year specimens.

**Table 2. Air-Void Contents for All Specimens Used in the Dynamic Modulus Test**

Specimen No.	Initial 19.0-mm <sup>a</sup>	Initial 9.5 mm <sup>a</sup>	4-year 19.0-mm <sup>b</sup>	4-year 9.5-mm <sup>b</sup>
1	17.7	18.1	19.9	23.0
2	17.9	18.2	20.8	20.6
3	17.6	18.2	20.4	20.5

<sup>a</sup>Laboratory-made specimens.

<sup>b</sup>Field cores.

## RESULTS AND DISCUSSION

### Asphalt Mixture Volumetrics

Tables 3 and 4 provide the asphalt mixture volumetric data and the mixture gradations, respectively. Table 3 provides the job mix formula and VTRC laboratory results, and Table 4 provides the VTRC laboratory results.

**Table 3. Mixture Volumetrics**

Property	JMF	VTRC	JMF	VTRC
	PAM 19.0	PAM 19.0	PAM 9.5	PAM 9.5
% AC	5.00	4.97	6.00	5.84
Rice ( $G_{mm}$ )	2.665	2.669	2.641	2.622
% Air Voids ( $V_a$ )	18.7	15.1	19.5	20.1
% VMA	-	25.0	-	31.0
% VFA	-	39.5	-	35.1
Dust/AC	-	0.56	-	0.48
Bulk ( $G_{mb}$ )	-	2.265	-	2.094
Effective ( $G_{se}$ )	-	2.911	-	2.900
Aggregate ( $G_{sb}$ )	-	2.869	-	2.858
% Binder Absorbed ( $P_{ba}$ )	-	0.52	-	0.52
Effective % Binder ( $P_{be}$ )	-	4.48	-	5.34
Effective Film Thickness ( $F_{be}$ )	-	18.3	-	24.0

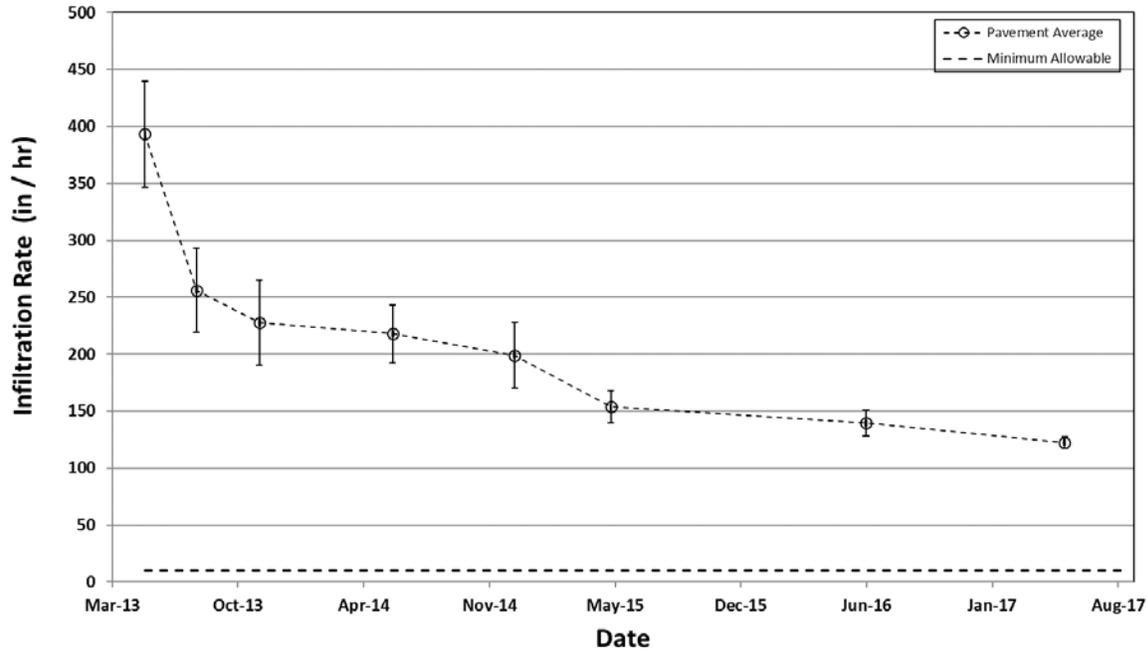
**Table 4. Mixture Gradation**

U.S. Standard Sieve No.	Metric Sieve Size	PAM 19.0	PAM 9.5
		% Passing	% Passing
2 in	50 mm	100.0	100.0
1 1/2 in	37.5 mm	100.0	100.0
1 in	25 mm	100.0	100.0
3/4 in	19 mm	94.9	100.0
1/2 in	12.5 mm	77.6	100.0
3/8 in	9.5 mm	60.7	92.0
No. 4	4.75 mm	22.3	33.7
No. 8	2.36 mm	12.7	10.2
No. 16	1.18 mm	8.9	6.0
No. 30	600 µm	6.6	4.5
No. 50	300 µm	5.0	3.7
No. 100	150 µm	3.6	3.1
No. 200	75 µm	2.5	2.6

### **Average Permeability**

The permeability values for the porous asphalt Park & Ride lot decreased over the 4-year monitoring period. As is evident in Figure 4, the average permeability of the six monitoring locations decreased approximately 35% from a high of 393 in/hr during the 3-month period following initial construction. The Park & Ride lot was exposed to minimal vehicular traffic during this period as the lot was closed for part of this time and experienced minimal use even after it was opened to the public.

Given these factors, it seems unlikely that the initial decline in permeability was due to sedimentation as there was no obvious source of material. Based on subsequent infiltration measurements, the rate of the decline tended to decrease over the course of the study with a total decrease in average permeability of approximately 69% over the entire study period. Despite this large decrease, the average infiltration rate after 4 years was still measured at 123 in/hr. Interestingly, the standard errors associated with the averages also decreased over the 4-year period, indicating the individual infiltration rates of the six sampling locations were getting closer to the average as the pavement aged. This is contrary to what would be expected if the reduced infiltration was due to sedimentation since four of the six sampling locations were exposed to different maintenance treatments. One theory to explain this is that the high variability in the initial infiltration rates was due to non-uniform compaction. Over time, it is assumed that consolidation (densification) possibly because of some aggregate reorientation in the asphalt mixture occurred at all sampling locations. This may have occurred at a rate that was inversely proportional to the original compaction.



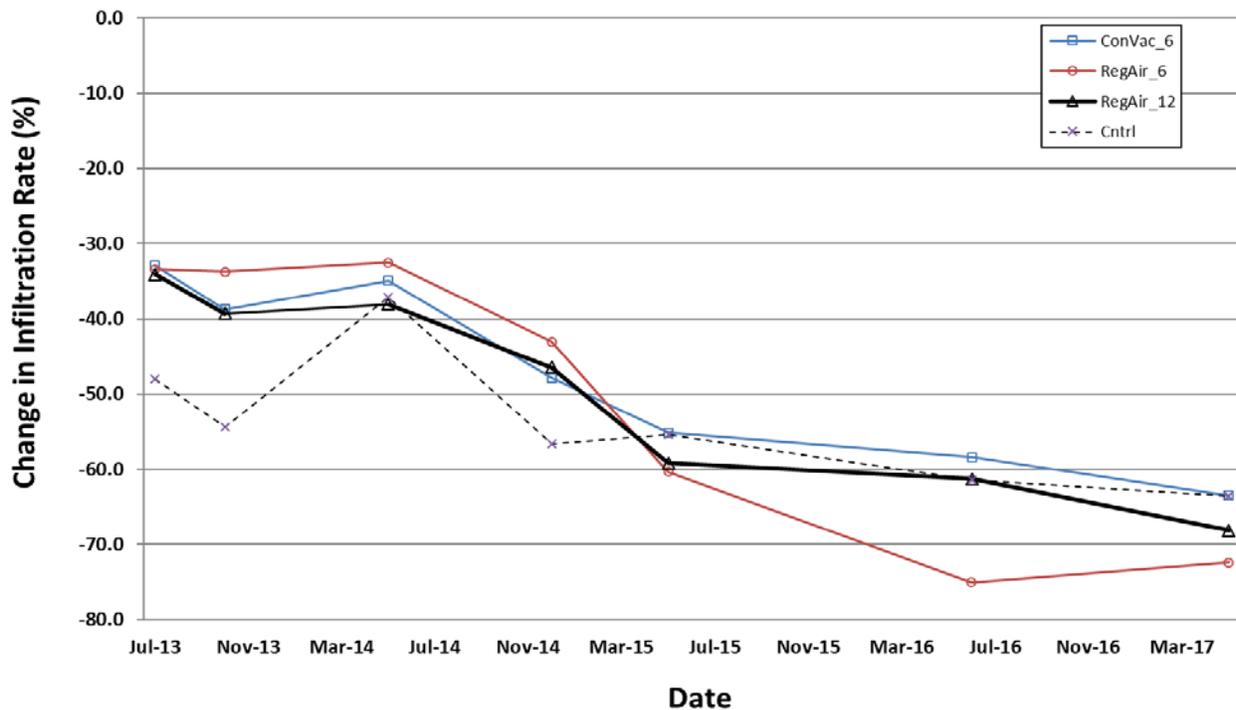
**Figure 4. Average Infiltration Rates and Standard Errors Across All Sampling Sites for the 4-Year Monitoring Period**

### Effect of the Different Maintenance Treatments

The percent change in permeability values for the sections undergoing different maintenance treatments are shown in Figure 5. Overall, the decline in permeability values varied for the different treatments but tended to level off after approximately 2 years, with each section already showing greater than a 50% reduction in permeability by the summer of 2015. One anomaly in the changes in permeability values that cannot be easily explained was the increase in infiltration rates 1 year after installation. Multiple parameters were examined in the hope of explaining these increases (to include water temperature, pavement temperature, barometric pressure, freeze-thaw cycles from the previous winter, deicing salt application, etc.), but no obvious cause was found.

Based on infiltration measurements taken before and immediately after maintenance with the vacuum systems, there were no statistically significant increases in the permeability values for sections maintained with the regenerative air vacuum or the conventional vacuum. The single pressure washing treatment resulted in an infiltration rate increase (9.1%) at only one of the five sampling locations.

At the end of the 4-year monitoring period, the decline in the infiltration rate for the control section was the same (-65.3%) as that for the section maintained with a conventional vacuum on a 6-month interval. Both sections maintained with the regenerative air vacuum (6-month and 12-month intervals) showed even larger declines in permeability (-72.4% and -68.1%, respectively).

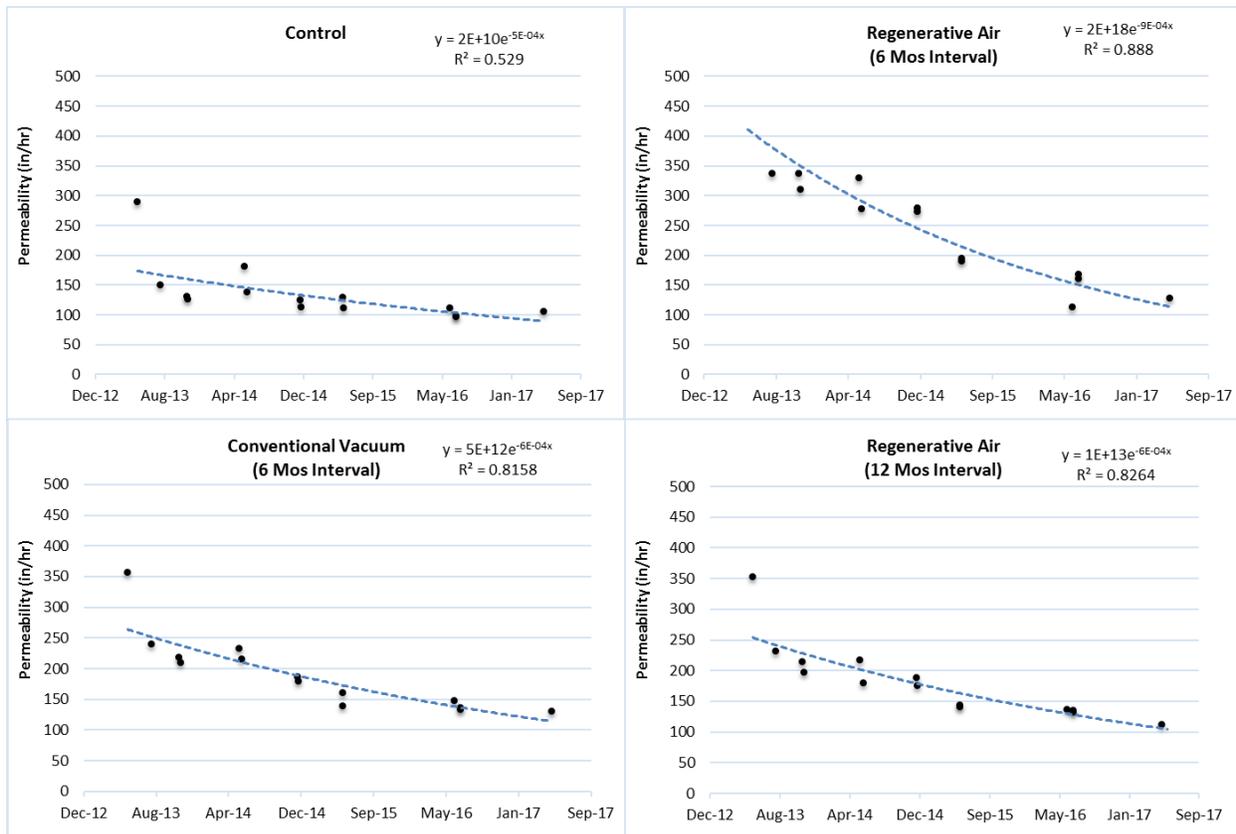


**Figure 5. Percent Change in Infiltration Rates Over the Monitoring Period for Each of the Four Maintenance Treatment Types**

Figure 6 shows the trend lines derived for the permeability values for each of the four treatment sections. A comparison of these indicates that the decline in permeability is somewhat similar for each, regardless of the maintenance type or interval. The trend line for the control section is not as steep (i.e., the infiltration is not declining as rapidly), but this is due in part to its lower initial infiltration rate. Likewise, the rate for the section maintained by the regenerative air vacuum on a 6-month interval had the greatest decline, but this section also had the highest initial rates. As was mentioned in the previous section, this faster decline at the locations with higher infiltration rates may be due to a faster rate of consolidation found in the sections with less compaction at the time of placement. When examined in combination, all of the infiltration measurements collected in conjunction with the various maintenance treatments seemed to indicate that an accumulation of sediment is not the primary cause of the decline in infiltration values at this permeable pavement installation. Thus the effects of the different maintenance treatments in this particular instance cannot be stated with confidence.

Using the regression analysis developed for the infiltration rates, estimates were made for how long the different sections of permeable pavement would have infiltration rates greater than 10 in/hr (the minimum average infiltration value needed for the lot to function effectively as a BMP) (Wisconsin Department of Natural Resources, 2016). Regenerative air (12-month), conventional vacuum (6-month), and the control section are projected to function adequately past 2028 or a total of 15 years from the time of installation. Regenerative air (6 months) is projected to function properly for approximately 11.5 years. Again, these projections are related to the

change in infiltration and, as such, are somewhat inversely proportional to the initial infiltration rates; the locations with the highest initial infiltration values are slowing the fastest.



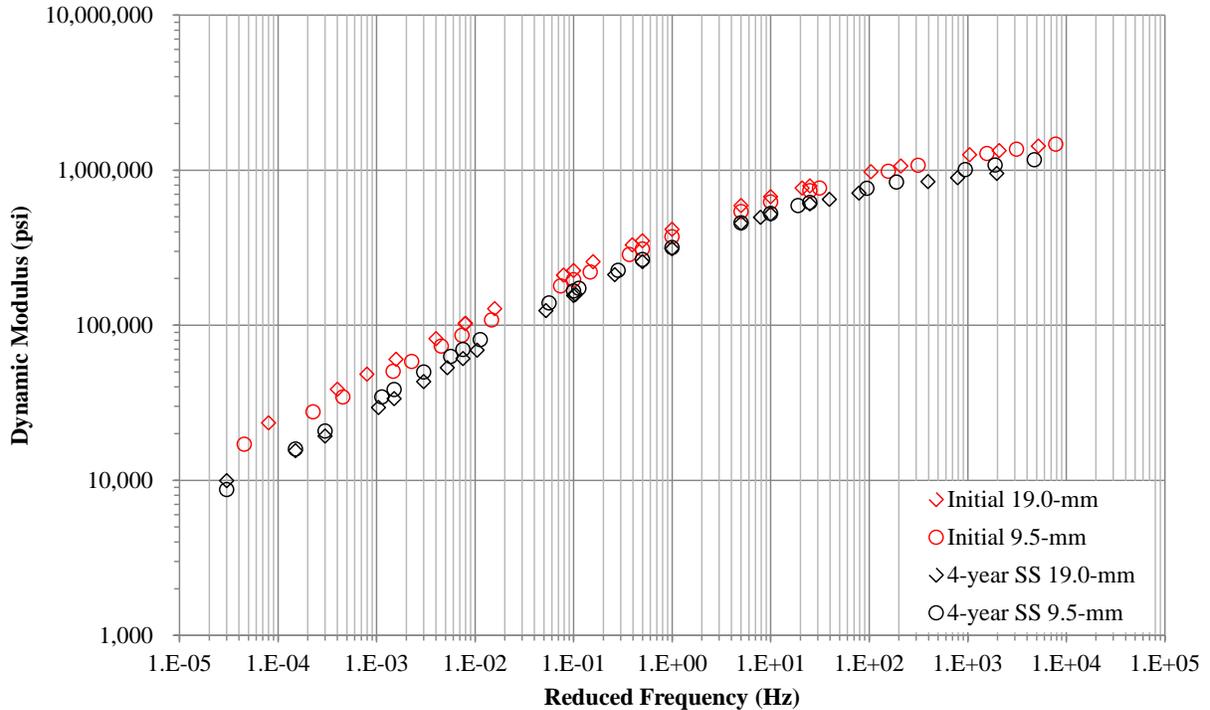
**Figure 6. Results of Regression Analysis for Infiltration Values for Each of the Four Maintenance Treatment Sections**

### Dynamic Modulus

Dynamic modulus master curves for the initial and 4-year SS mixtures are shown in Figure 7. Interestingly, there was very little difference between the 19.0-mm and 9.5-mm mixtures for each of the respective mixtures. Both of the 4-year SS mixtures were lower in dynamic modulus across all temperatures and frequencies than that of the initial mixtures, but this is not surprising considering the difference in air voids as can be seen in Table 2. The higher air-void contents of the 4-year SS mixtures will naturally lead to a lower stiffness.

The 19.0-mm mixture has a lower asphalt binder content of 4.97%, and the 9.5-mm mixture has a binder content of 5.84%. Typically, one would expect this difference of 0.87% binder content to be appreciable in the dynamic modulus test. One hypothesis is that the high level of air voids (>17.0%) in the mixtures yields modulus values that are similar despite the difference in nominal maximum aggregate size and asphalt binder contents. Further, the binders used in the mixture are in fact different. The 19.0-mm mixture used a PG 70-22 binder, and the 9.5-mm mixture used a PG 76-22 binder, which has higher stiffness because of increased

polymer loading. The difference in binder type may be contributing to an increased stiffness of the 9.5-mm mixture, moving it closer to the 19.0-mm mixture despite the higher asphalt content. These three factors could be important when a structural analysis of porous asphalt mixtures is carried out.



**Figure 7. Initial and 4-Year Dynamic Modulus Master Curves**

### Maintenance Costs

High, low, and average costs for regenerative air vacuum and conventional vacuum services provided by 16 of the 23 vendors surveyed responding to the telephone survey are shown in Table 5. Maintenance services for the porous pavement lot were provided by two different vendors to allow for separate testing of the regenerative air vacuum and the conventional vacuum trucks. Vacuuming of each test section took less than 30 min during each maintenance event, but both vendors had a minimum charge time of 4 hr. Based on the area covered during the test section maintenance, cleaning the entire 0.97-acre lot would take a maximum of 2 hr. Therefore, for a facility of this size and configuration, the 4-hr minimum charge would be applicable for calculating the approximate cost of a single maintenance event. Based on the hourly rates, a minimum charge time of 4 hr and twice a year maintenance schedule, the annual cost of the maintenance treatments would range from approximately \$1,300 to \$1,450. Because of the minimum charge time used for this calculation, both smaller facilities and those up to 2 acres and of similar configuration could be expected to have comparable maintenance costs.

**Table 5. Typical Costs for Regenerative Air Vacuum and Conventional Vacuum Services**

Information Source	Price/Hour	Minimum Charge Time	Extras
Vendor 1 <sup>a</sup>	\$180	4 hr	<ul style="list-style-type: none"> <li>• \$50/T dumping fee</li> <li>• \$55/hr travel</li> </ul>
Vendor 2 <sup>b</sup>	\$164	4 hr	
Survey High <sup>c</sup>	\$185	6 hr	
Survey Low <sup>c</sup>	\$85	1 hr	
Survey Average <sup>c</sup>	\$139	3 hr	

<sup>a</sup> Vendor 1 = responsible for maintaining sections T1 and T3 during the study.

<sup>b</sup> Vendor 2 = responsible for maintaining section T2 during the study.

<sup>c</sup> High, low, and average information is based on cost information taken from the responses of 16 of the 23 vendors that answered the telephone survey of street vacuuming providers in Virginia.

This estimated cost range is similar to maintenance costs for other types of stormwater BMPs. Based on records from VDOT’s Northern Virginia District, maintenance costs for bioretention-type stormwater BMPs are approximately \$1,500/year (P. Stark, personal communication, September 27, 2017). In a study conducted by the U.S. Environmental Protection Agency (1999), annual maintenance costs for runoff reduction practices likely to be used by VDOT ranged from 3% to 12% of the initial construction costs. Using construction cost estimates developed by Nobles et al. (2014), it was estimated that the cost to construct an adequately sized BMP for the study site could range from \$79,500 to \$93,000. Based on these estimates, maintenance for the BMPs would cost \$2,400 to \$11,000 per year.

## CONCLUSIONS

- *The average infiltration rate for the porous asphalt Park & Ride lot has slowed substantially over the 4-year monitoring period. However, the lot continues to function as a stormwater BMP with an average infiltration rate of approximately 123 in/hr, well above the minimum of 10 in/hr.*
- *Based on the results of the maintenance treatment evaluation, sedimentation does not appear to be the main factor contributing to the reduction of infiltration rates at this facility. Other factors such as compaction or aggregate reorientation may be the cause of most of the change in permeability over time in an environment where sediment deposition is minimal.*
- *Assuming it is subjected to similar conditions in the future, it is projected that the porous asphalt Park & Ride lot will continue functioning as a stormwater BMP until at least 2025, possibly longer.*
- *Maintaining porous asphalt facilities of similar design and size and in a similar manner 2 times per year should cost no more than \$1,500/year. This is similar to maintenance costs associated with other stormwater BMPs that provide comparable quantity and quality treatment.*
- *There is not an appreciable difference between the dynamic modulus of the 19.0-mm and 9.5-mm mixtures; however, the mixtures tested from 4 years in service did have lower overall modulus values across all temperatures and frequencies. This was likely due to the higher air-void contents as a product of construction variability.*

## RECOMMENDATIONS

1. *VDOT's Location and Design Division should continue to use porous asphalt as a stormwater BMP option for Park & Ride facilities. The long-term performance and maintenance cost information derived by way of this study should be used when porous asphalt is compared to other BMP alternatives during BMP selection and design.*
2. *VDOT's Materials Division should oversee the formation of an advisory group to guide future research, identify data collection needs, and lead the necessary dialogue with key VDOT stakeholders to form policy positions regarding the type of facilities for which porous asphalt will be allowed and can be best used by VDOT.*
3. *VDOT's Materials Division should continue work with VTRC to identify best practices for porous asphalt mix designs and construction practices and to prepare pavement designs beyond those for Park & Ride facilities that use porous asphalt as a stormwater BMP.*

## BENEFITS AND IMPLEMENTATION

### Benefits

With regard to Recommendation 1, having the option to use porous asphalt provides VDOT with another alternative for meeting stormwater quality and quantity requirements. Depending on the site-specific conditions of a given project, porous asphalt has the potential to be less expensive and/or less intrusive than some other stormwater BMP alternatives, primarily because it can be placed within the footprint of the facility and therefore does not require additional right of way for its construction.

With regard to Recommendation 2, the benefit of forming policy decisions will be to initiate a comprehensive approach for determining if there are other areas where porous asphalt can properly function as a cost-effective stormwater BMP, taking into account long-term maintenance and facility structural requirements.

With regard to Recommendation 3, the benefit to continued work by VDOT's Materials Division on porous asphalt mix designs, construction practices, and pavement designs that use porous asphalt will be to position VDOT technically to develop long-lasting, quality pavement designs. This, in turn, will allow VDOT to specify quality materials when porous asphalt pavements are to be used.

### Implementation

With regard to Recommendation 1, this recommendation has already been implemented, as porous asphalt is currently on the list of stormwater BMPs available for use by VDOT. Starting with the facility monitored in this study, VDOT's Location and Design Division has already begun using porous asphalt at Park & Ride facilities. The maintenance cost estimates

and long-term performance information will facilitate the comparison of this option against other BMP alternatives on a site-by-site basis.

With regard to Recommendation 2, this recommendation has already been implemented. In July 2017, VDOT's Materials Division called together a group of individuals from VDOT's Location and Design Division, Maintenance Division, Materials Division, and Land Use Office and VTRC to discuss VDOT's policy with regard to the use of porous asphalt. This group will serve as the advisory group stipulated in Recommendation 2.

With regard to Recommendation 3, the implementation scope and timeframe will depend on annual input from the advisory group and the annual prioritization of research needs from VTRC's Asphalt Research Advisory Committee and Pavement Research Advisory Committee. Based on input from the advisory group in February 2018, it was decided that the use of porous asphalt would remain limited to Park & Ride facilities at this time. The decision on the potential use of porous asphalt in other applications will be revisited by the group on an as-needed basis at the discretion of the chair of the advisory group.

## **ACKNOWLEDGMENTS**

The researchers thank Pete Champney, VDOT Manassas Residency; Trenton Clark, Virginia Asphalt Association; Rob Crandol, VDOT Materials Division; Troy Deeds, VTRC; Linda Evans, VTRC; Affan Habib, VDOT Materials Division; David Shiells, VDOT Northern Virginia District; Aminia Smith, VDOT Manassas Residency; Patrick Stark, VDOT Northern Virginia District; and Chris Swanson, VDOT Location and Design Division for their assistance with this study.

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## **APPENDIX**

### **QUESTIONS ASKED OF VENDORS PROVIDING STREET SWEEPING (VACUUMING) SERVICES**

1. Does your company provide street sweeping services?
2. Do you provide these services in the \_\_\_\_\_ area? (Ask additional details about the area they serve.)
3. What type of sweepers (vacuums) does your company use (regenerative air or conventional vacuum)?
4. What is the per hour price for this equipment and operator?
5. Is there a minimum time requirement for these services?
6. Is there any additional information you can provide that would be helpful in estimating the cost for your services?