PAVEDRAIN Permeable Pavements

Final Report

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Introduction

Project Description

The purpose of this study was to evaluate the performance of different permeable pavement system sections developed by PaveDrain under different conditions. The testing was performed at the Stormwater Management Academy Research and Testing Laboratory (SMART Lab), at the University of Central Florida (UCF), in Orlando, Florida. The different pavement systems examined for this study are presented below in Figure 1. The cross-sections examined are included in Figure 11, Figure 16, Figure 18, and Figure 20. PaveDrain supplied the required materials and installation at the research site.

Figure 1: PaveDrain Testing Site
**Scope of Services**

The goals of this study are to provide information on infiltration rates for different PaveDrain permeable pavement cross-sections and examine the effects of sediment loading and rejuvenation on the infiltration capacity. The different pavement cross-sections were evaluated in the field at the UCF SMART Lab using the Embedded Ring Infiltrometer Kit (ERIK) and the ASTM Surface Test C1701. Both testing methods are discussed in more detail below. The specific goals of this study are as follows:

1. To evaluate the infiltration rates of four different PaveDrain permeable pavement system designs, or cross-sections, under different surface clogging conditions using the short-ring ERIK test
2. To evaluate the infiltration rates of the four different PaveDrain systems under different surface clogging conditions using the long-ring ERIK test
3. To evaluate the infiltration rates of the four different PaveDrain systems under different surface clogging conditions using the ASTM C1701 surface test
4. To determine the effectiveness of the PaveDrain rejuvenation method on removing sediment to improve water infiltration capacity
5. To evaluate the porosity of the PaveDrain block for design porosity recommendations and inclusion into the pervious pavement design aid calculator

The pavement surface conditions evaluated were: newly installed pavement, pavement surface loaded with AASHTO A-3 sandy soil, vacuum rejuvenated pavement surface, pavement surface loaded with AASHTO A-2-4 silty-sandy soil, and finally, after
another vacuum rejuvenation of the pavement surface. Porosity conditions examined included newly installed blocks and clogged with AASHTO A-3 sandy soil.

**Background**

With the rise in urbanization, impervious surfaces are continuously replacing natural permeable surfaces. Examples of such include rooftops, roadways, parking lots, and driveways. These areas reduce the amount of water that can infiltrate into the groundwater, thus reducing recharge of aquifers. This, in turn, creates a deficit in groundwater storage and increases surface runoff, which can create major issues for municipalities such as flash flooding and pollution of surface water bodies due to stormwater runoff (Wang, et al., 2010, Tota-Maharaj, et al., 2010).

To address the pollution of surface water bodies by stormwater runoff, best management practices (BMPs) were developed. BMPs are a set of principles and treatment techniques intended to reduce the volume of stormwater runoff generated and treat stormwater runoff prior to discharge to surface water bodies. More recently, BMPs have been aimed at multi-functionality spaces, such as being underground or creating an aesthetic role (Loperfido, et al., 2014). The criterion for BMP selection and use should include objectives such as cost effectiveness, pollutant removal efficiency, and should scale appropriately to fit a site’s land availability. Some of the most common BMPs include grassed swales, vegetative filter strips, and filtration systems (Yu et al., 2013).

Permeable and pervious pavement systems are considered a stormwater BMP. Typical permeable and pervious pavement systems involve several layers that work together in order to produce an effective structural and functional system; Figure 2
presents an typical system cross-section. They consist of a surface layer of paver blocks that allow for infiltration of stormwater through the open joints that are frequently filled with porous mineral aggregates. A layer of bedding or filler stone lies beneath the porous or permeable blocks in order to allow water to move through the system and break down small biodegradable materials that may enter through the open joints above. The next layer is comprised of a large reservoir that provides retention of the water as it migrates to the parent earth. A geotextile fabric layer separates the reservoir layer from the parent earth in order to minimize interstitial mixing with the reservoir layer and enhance the structural stability of the system.

Figure 2: Typical Permeable/Porous Pavement Cross-Section

These permeable pavement systems are used in appropriate commercial, industrial, and residential applications such as pedestrian footpaths, light vehicular traffic roads, and parking lots. Impervious pavements, such as traditional asphalt and concrete, accumulate water during storm events due to their impervious nature allowing for
transport of pollutants to surface water bodies via stormwater runoff. Permeable pavements can provide treatment for stormwater, as well as significantly reduce stormwater runoff from the pavement during storm events (Imran et al., 2013).

Pitfalls associated with permeable pavement systems arise in applications where there is a lack in availability of permeable soils, depth of parent earth, and maintenance practices (Gogo-Abite et al, 2014). In areas where the soil is not permeable, like clay or rock, such permeable pavement systems are not well suited because it will be extremely expensive to prepare the sub-base (Miller et al., 1997). Additionally, current studies have focused on observing the infiltration rates of newly installed pavements where the infiltration rates are exceptional. However, in order for pavement systems to be deemed ultimately successful, the systems should be tested over several years of operation (Yong et al., 2012).

After periods of use, permeable pavement systems have been found to accumulate sediment in the voids below the surface of the pavement resulting in a dramatic decrease in infiltration rates. Key mechanisms that govern the amount of sediments that enter pavement void spaces include but are not limited to: construction runoff (Tota-Maharaj et al., 2010), agricultural runoff (Tota-Maharaj et al., 2010), climate (Dougherty et al., 2011), vehicular volume (Brown and Borst, 2014), and surrounding vegetation (Brown and Borst, 2014). As the permeable surface accumulates sediment, the stormwater will inevitably bypass the system (Brown and Borst, 2014). Thus, maintenance must be performed in order to ensure these systems perform as intended for the design life of the system.
Infiltration Test Methods

Before delving into the different methods to test infiltration capacity of pervious and permeable pavements, a few definitions need to be introduced. First, infiltration according to the Federal Emergency Management Agency (FEMA), is defined as the downward entry of water into the soil or rock surface. FEMA defines percolation as the flow of water through soil and porous or fractured rock. Infiltration rates will vary significantly as the soil or other media becomes saturated but once the soil, or other media, becomes saturated infiltration rates become an approximation for permeability. Porosity, is typically defined as the ratio of the volume of voids to the total volume of sample. This report measures in-situ infiltration after strata and soil saturation in an effort to approximate the permeability.

There are several test methods which aim to assess the degree of clogging a pavement system has undergone. Single and Double-Ring Infiltrometer Tests use rings that are sealed to the surface of a pavement or that extend into the ground at a given depth. A volume of water is then added to achieve a constant falling head while measuring the time required for the water to fully infiltrate into the ground, this allows for the calculation of the infiltration rate (Nichols et al., 2014). Modifications are utilized in studies such as ring size and shape in order to achieve more accurate infiltration rates (Lucke et al., 2014).

The ASTM standard method (ASTM C1781-13, 2013) is the current industry standard developed by the ASTM Technical Committee. The ASTM method is used to determine when permeable pavement systems are in need of maintenance. Using a single ring infiltrometer, a falling head test is conducted in order to establish the rate of
infiltration. An advantage to this method lies in the fact that it is simple to perform and tests can be performed at multiple locations of a permeable pavement site. However, it does not ensure vertical movement of the water through the test area, i.e. it does not penetrate the areas below the surface. This is problematic since the interface of the parent soils and the system is the bottleneck of the system and controls the rate at which a system can recover its storage volume. Another disadvantage is that the test is subjective to the pourer, making the repeatability of the tests questionable. Due to these reasons, the ASTM C1781-13 test can result in overestimation of infiltration capacity of the system and gives no information on the system recovery.

The Embedded Ring Infiltrometer Kit (ERIK) is another method for monitoring pervious and permeable pavement system performance. The ERIK can give information on the need for system maintenance and recovery. The embedded ring is permanently sealed into the pavement and ensures vertical flow of water through the pavement system. This results in a more accurate representation of infiltration rates. The short embedment (short-ring) only extends through the surface layer and provides information for determining when the system needs maintenance (Gogo-Abite et al., 2014). The long embedment (long-ring) extends through the entire system and is embedded 101.6 mm (4 in) into the parent earth allowing for the determination of entire system recovery (Gogo-Abite et al., 2014). This study uses both test methods to evaluate the performance of varying PaveDrain systems in order to evaluate performance in regards to clogging and rejuvenation.
ASTM Surface Test C1701

The standard method for the determination of the field water infiltration rate of pervious and permeable pavements is the ASTM C1701. This test method uses a single ring (as shown in Figure 3) that is sealed to the surface of the pavement with plumber’s putty. Two lines are marked on the inner surface of the ring at 0.40 and 0.60 inches from the bottom. Using a 5 gallon bucket, 8lbs of water is weighed out. An initial pre-wet stage saturates the pavement for further testing. The 8lbs of water is poured into the ring on the pavement surface between the marked lines. A timer is started as soon as water encounters the test surface (testing in progress shown in Figure 4). The water level is to be maintained in between the two lines until no more water is in the bucket. The timer is stopped when no more water is on the pavement test surface. The time is recorded and the infiltration rate is calculated.

A subsequent volume of water is applied to the test surface which signifies the relevant volume of water which will be recorded as test data. Based on the pre-wet test stage results, the appropriate volume of water to produce reliable results for the test surface infiltration characteristics is determined. The criteria is as follows: 40 lbs of water for elapsed time in the pre-wet stage less than 30s, 8 lbs of water for elapsed time in the pre-wet stage greater than or equal to 30s. The bucket with the appropriate volume of water is poured into the ring on the pavement surface, making sure to keep the water surface level between the marked lines. The amount of time required for the full volume of water to infiltrate into the pavement system is recorded. The timer is started as soon as the water comes in contact with the test surface. The water level is maintained in between the two lines until there is no more water is in the bucket. The timer is stopped
when there is no more water on the test surface. The time is recorded and the infiltration rate is calculated. A second test round is then performed to ensure a robust data set.

Figure 3: ASTM Surface Testing Ring C1701
Embedded Ring Infiltrometer Kit (ERIK)

The Embedded Ring Infiltrometer Kit (ERIK) was developed at the University of Central Florida, Stormwater Management Academy in Orlando, Florida. The ERIK device measures the infiltration rate of pervious and permeable pavements using a constant head. The device is made of 2 inch diameter PVC piping along with valves connected to a hose, as shown in Figure 5. This piping makes up the pipe reservoir and is used to control the rate at which water is added to the infiltrometer ring. Each mark in the 2 inch diameter measurement reservoir is equivalent to a 0.5 inch drop in the 6 inch diameter embedded ring. A specialized ERIK device which utilizes glass tubing with a 4
inch diameter reservoir is used for pavements which have faster infiltration rates. Every mark in the 4 inch diameter measurement reservoir is equivalent to a 5 inch drop in the embedded ring.

Compared to the widely used Double Ring Infiltrometer, the ERIK is more efficient and economical in the utilization of a single ring infiltrometer. The short ring ERIK penetrates through the surface layer and 2 inches into the stone reservoir directly underneath. The short ring infiltrometer allows for the determination of when maintenance is required for the pavement system. In contrast, the long ring ERIK penetrates through the entire system and is embedded 4 inches into the parent earth directly below the system. The long ring infiltrometer measures the entire system recovery.

Using an ERIK device, the procedure to measure the infiltration rate of a permeable/pervious system is as follows. First, the equilibrium needs to be maintained prior to recording data for both the short ring and long ring tests. For the short ring ERIK, a constant head is maintained with a hose prior to adding water from the measurement reservoir (refer to Figure 5, Figure 6, and Figure 7 for views of measurement reservoir). Once a constant head is achieved, water is added from the measurement reservoir to maintain the constant head in the embedded ring, the rate of water added to the embedded ring is measured. A timer is started when the water level in the measurement reservoir passes the top mark. The time taken for the water level to move past each successive mark is recorded. This procedure is repeated 5 times to ensure a robust data set. With this data, the infiltration rate can be easily calculated.
When using the long ERIK, the embedded ring must be fully saturated prior to testing. When water is initially added to the embedded ring, a head of water quickly forms but air bubbles will rise, thus, lowering the head level. The bubbles will cease once equilibrium is obtained. Water is then added to the embedded ring from the measurement reservoir to maintain a constant head of 1 inch over the pavement surface. As the water level in the measurement reservoir passes the top mark, the timer is started. The time it takes for the water level to move past each successive mark is then recorded. This procedure is repeated 5 times to ensure a robust data set. With this data the infiltration rate is then calculated.

The large glass ERIK device (shown in Figure 8) follows a similar procedure as the previous devices. The embedded ring must be fitted with a measurement collar and marked 1 inch from the bottom (1 inch from the pavement surface). After filling the measurement reservoir with water, a bucket filled with water must be obtained. To start the test, the bucket of water must saturate the embedded ring and achieve a constant head of 1 inch above the pavement surface. The nozzle on the ERIK device is then turned on and a constant head of 1 inch must remain. As the water passes the top mark of the measurement reservoir, the timer is started. The time required for water to pass each successive line is then recorded. This procedure is repeated 5 times to ensure a robust data set. With this data, the infiltration rate can be calculated.
Figure 5: Measurement Reservoir for ERIK Device - Elevation View

Figure 6: Measurement Reservoir for ERIK device – Plan View
Figure 7: ERIK Testing in Progress

Figure 8: Glass ERIK device Testing in Progress
Porosity

Porosity is considered to be a measure of how much void space is available in a particular material per unit volume. The available void space for a PaveDrain block is of particular importance for this study as it is indicative of the storage potential of the surface layer of this system. This is important because of reduced infiltration rates of parent soils due to the compaction required for structural purposes. This makes it necessary for the pavement system to hold the stormwater within the system while it slowly infiltrates into parent soils. The experiment is designed to emulate a small section of the pavement that will receive a measured amount water to determine porosity. The ratio of the volume of water added to the concrete blocks to the total volume occupied by the blocks and water will give the unloaded porosity of the block.

Over time, the open space between the concrete blocks and within the porous stone layer can become filled with sediment, resulting in significantly reduced storage capacity and infiltration rates. Depending on the degree of sediment loading, the flow of water into the pavement system can be reduced to such an extent that the pavement system does not capture much stormwater and actually lets the stormwater run off the pavement. This can result in flooding, erosion of nearby soils, and water quality problems for downstream surface water bodies. This loaded condition must be taken into account when designing these systems. It is addressed in this testing by loading the concrete blocks with sediment, resulting in sediment filling the blocks void spaces. Porosity measurements are made under this loaded condition giving the porosity of the pavement in its worst condition.
The operating porosity of the pavement is defined as the average of the unloaded and loaded porosity values. This operating porosity value will better represent the porosity of this system over the operating life since the system will spend a short period of time either completely clean or clogged with sediment relative to the overall operating life of the pavement system.
Methods and Project Setup

*PaveDrain Installation and Setup*

The testing performed at the Stormwater Management Academy field lab consisted of four different permeable pavement system cross-section designs. The different systems were installed by PaveDrain contractors and supervised by Stormwater Management Academy Staff. The site, after initial site work but prior to installation of the PaveDrain systems, is shown in Figure 9. The site after installation of the PaveDrain systems is shown in Figure 10. The four different pavement cross-sections are separated by footers and stem walls. The parent earth at the testing site consists of AASHTO A-3 sandy soil.
Prior to the installation of the pavement sections, the parent earth at the site was compacted to approximately 90% modified proctor. A total of four different pavement systems were installed, each containing several layers of different materials. The cross-section for pavement 1 is shown below in Figure 11. Pavement 1 consists of several different layers of materials providing structural strength and void space for water storage. Additionally, both the long and short ring ERIK monitoring pipes are shown in Figure 11.
The installation process for the pavement 1 system will now be described. First, a filter fabric was installed to keep the parent soils and the stone reservoir separate, significantly reducing interstitial mixing (Figure 12).

Once the filter fabric was installed, a long embedded ring was installed; making sure it penetrated four inches into the parent earth. This required cutting a circle in the
filter fabric where the long ERIK pipe was installed. The circle that was cut out was saved and placed inside the long ERIK pipe on top of the compacted parent earth. A six inch stone reservoir layer, consisting of AASHTO #57 stone, was then added and compacted.

Figure 13). It should be noted that a six inch layer of #57 stone was added and compacted inside the long ERIK pipe as well.

Figure 13: AASHTO #57 installed over filter fabric

The short embedded ring (short ERIK pipe) was installed at this time, making sure to extend two inches into the six inch stone reservoir layer as shown in Figure 14.
Lastly, after ensuring the stone reservoir layer is sufficiently compacted, the PaveDrain pavers were installed (Figure 15). Note that the PaveDrain pavers were cut to fit inside both the short and long ring ERIK monitoring pipes.
The cross-section for the second pavement system is shown in Figure 16. It should be noted that the short and long ring ERIK monitoring pipes are also shown in Figure 16.

Pavement system 2 was installed in a similar manner as pavement system 1. First the parent earth was compacted to approximately 90% modified proctor. A filter fabric
was installed to separate the parent earth from the stone reservoir above. A long embedded ring was installed extending four inches into the parent earth. A six inch stone reservoir of AASHTO #57 stone aggregate was installed directly on top of the filter fabric. A short embedded ring ERIK pipe was installed next, making sure to penetrate two inches into the stone reservoir. The stone was compacted after installation. Next, a second filter fabric layer was placed over the stone reservoir. Lastly, the PaveDrain pavers were installed directly on top of the filter fabric (Figure 17). It should be noted that each relevant layer is also installed inside the short and long ERIK monitoring pipes.

Figure 17: PaveDrain pavers being installed on No.2 pavement
The cross-section for the third pavement system is shown below in Figure 18. It should be noted that the short and long ring ERIK monitoring pipes are also shown in Figure 18.

![Figure 18: Pavedrain Pavement No.3 Cross-Section](image)

Following a similar procedure as the previous pavement systems, the third pavement installation began with the parent earth being compacted to approximately 90% modified proctor. A filter fabric is placed above the parent earth to separate the following layers from the parent earth and prevent interstitial mixing. Next, a 2 inch drain cell (R-Tank XD) is placed on top of the filter fabric. A second filter fabric is laid over the drain cell (Figure 19).
Figure 19: Drain cell (R-Tank XD) installation with filter fabric above

A long embedded ring ERIK monitoring pipe was installed next, making sure that it extends four inches into the parent earth. A stone reservoir of AASHTO #57 aggregate was added to a depth of six inches above the filter fabric. A short embedded ring ERIK monitoring pipe was then installed, making sure to penetrate two inches into the stone reservoir layer. Finally, after the stone aggregate is installed and compacted, the PaveDrain pavers are placed above the stone reservoir. It should be noted that all material layers are installed inside the appropriate ERIK monitoring pipes.

The last pavement cross-section is shown in

Figure 20. The short and long ring ERIK monitoring pipes are also shown in Figure 20.
The pavement 4 section is the deepest of all the systems examined for this study. After the parent earth soil is compacted to 90% modified proctor, a filter fabric (M200 geotextile) is laid above the parent earth. A rain tank (R-Tank SD) is then installed, followed by a second filter fabric layer. A long embedded ring infiltrometer is then installed; making sure it extends four inches into the compacted parent earth. The next layer is a twelve inch deep stone reservoir of AASHTO #57 stone. A structural geogrid is installed next as shown in Figure 21.
A second layer of AASHTO #57 stone was laid to a depth of six inches above the geogrid. A short embedded ring ERIK monitoring pipe is installed next; making sure it is extended two inches into the stone reservoir. Finally, the PaveDrain pavers were placed above the stone reservoir.

Based on information provided by ACF Environmental, Table 1 and Table 2 show the dimensions and capacity, and the specifications, respectively of the R-Tank XD and R-Tank SD.
Table 1: Dimensions and Capacity

<table>
<thead>
<tr>
<th>Unit</th>
<th>Module</th>
<th>Width</th>
<th>Length</th>
<th>Height (Inches / Feet)</th>
<th>Tank Volume (cf)</th>
<th>Storage Volume (cf)</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-Tank XD</td>
<td>Single</td>
<td>19.68</td>
<td>23.62</td>
<td>1.97 / 0.163</td>
<td>.53</td>
<td>.48</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Panel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R-Tank SD</td>
<td>Single</td>
<td>15.75</td>
<td>28.15</td>
<td>9.45 / 0.79</td>
<td>2.42</td>
<td>2.3</td>
<td>10.95</td>
</tr>
</tbody>
</table>

Note: Table based on information provided by ACF Environmental, UCF was not involved in this testing and is not responsible for the content. Further, presentation of this data does not constitute an endorsement of the data presented by UCF, the Stormwater Management Academy, or the principal investigators.

Table 2: R-Tank Specifications

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>R-Tank XD</th>
<th>R-Tank SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Void Area</td>
<td>Volume available for water storage</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>Surface Area Void</td>
<td>% of exterior available for infiltration</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Compressive Strength</td>
<td>ASTM D 2412 / ASTM F 2418</td>
<td>320 psi*</td>
<td>42.9 psi</td>
</tr>
<tr>
<td>Unit Weight</td>
<td>Weight of plastic per cubic foot of tank</td>
<td>7.55 lbs/cf</td>
<td>3.96 lbs/cf</td>
</tr>
<tr>
<td>Item</td>
<td>Description</td>
<td>R-Tank XD</td>
<td>R-Tank SD</td>
</tr>
<tr>
<td>---------------</td>
<td>-------------------------------------------------</td>
<td>-----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Rib Thickness</td>
<td>Thickness of load-bearing members</td>
<td>0.18 inches</td>
<td></td>
</tr>
<tr>
<td>Service</td>
<td>Safe temperature range for use</td>
<td>-14 – 185 °F</td>
<td>-14 – 167 °F</td>
</tr>
<tr>
<td>Recycled Content</td>
<td>Use of recycled polypropylene</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Minimum Cover</td>
<td>Cover required for HS-20 loading</td>
<td>6 inches</td>
<td>18 inches</td>
</tr>
<tr>
<td>Minimum Cover</td>
<td>Cover required for HS-25 loading</td>
<td>6 inches</td>
<td>18 inches</td>
</tr>
<tr>
<td>Maximum Cover</td>
<td>Maximum allowable cover depth</td>
<td>16.7 inches</td>
<td>9.99 feet</td>
</tr>
</tbody>
</table>

* R-Tank XD capacity derived from non-ASTM testing

Note: Table based on information provided by ACF Environmental, UCF was not involved in this testing and is not responsible for the content. Further, presentation of this data does not constitute an endorsement of the data presented by UCF, the Stormwater Management Academy, or the principal investigators.

**Testing Program**

Four different PaveDrain test sections were examined at the Stormwater Management Academy field laboratory. The total area of the site was approximately 1125 square feet, consisting of four test sections of about 281 square feet each. All four test sections had two ERIK monitoring pipes, one short and one long, installed to measure infiltration rates of the pavements. Each of the test sections were loaded with two different sediments, AASHTO A-3 sandy and A-2-4 silty-sandy soil, to study the
effect of sediment clogging as well as the ability of the PaveDrain VacHead to rejuvenate the clogged systems. The specific aim of the sediment loading was to investigate the response of the PaveDrain system to clogging and its ability to rejuvenate its infiltration capacity after vacuuming. Additionally, the porosity was tested to determine the storage of the PaveDrain block.

**Protocol for Infiltration and Rejuvenation Testing**

There were five different conditions tested over the course of this project, newly installed, sediment loaded with AASHTO A-3 sandy soil, rejuvenated with the PaveDrain VacHead, sediment loaded with AASHTO A-2-4 silty-sandy soil, and rejuvenated with the PaveDrain VacHead. The timeline for testing the different conditions were as follows: the pavement systems were installed on 02/24/2014, on 05/27/2014 the pavement systems were loaded with the A-3 sandy soil, on 08/07/2014 the pavement systems were then rejuvenated, on 9/10/14 the pavements were again rejuvenated due to inadequate vacuuming by an inexperienced contractor, on 10/16/2014 the pavements were loaded with silty-sandy soil (AASHTO type A-2-4), and finally on 01/06/2015 they were rejuvenated one last time with the PaveDrain VacHead.

The first infiltration rates were measured immediately after pavements were installed. This was done to establish how the different systems performed under new, unloaded conditions. To perform the ERIK test, a 6 inch diameter testing collar is attached to the embedded PVC pipe and sealed with silicone to prevent water from leaking while testing. This test collar allows for a head of water to be maintained above the pavement surface. The head maintained for ERIK testing was 1 inch. The test collar
was removed after each infiltration test so that vehicles could drive on pavements without obstruction by the collars. After approximately three months, the pavements were loaded with A-3 sandy soil as shown in Figure 22.

![Figure 22: A-3 soil loading on pavements](image)

The sandy soil was loaded and compacted with a bobcat skid-steer loader. Additionally, the soil was washed into the pavements with water to simulate rainfall washing soil particles deep into the pavement system (Figure 23). Testing was then done on clogged pavement systems to observe the effect of soil loading on the pavements.
Figure 23: Washing the A-3 sandy soil into the pavement systems

The PaveDrain VacHead (Figure 24 and Figure 25) and a vacuum truck was used to rejuvenate the pavements after clogging. The pavements were then saturated in order to increase the efficiency of the VacHead, as the soil particles become more plastic and mobile. Infiltration tests were performed after vacuuming in order to observe the effects of rejuvenation on the pavement systems.

Figure 24: PaveDrain Vac Head in Progress
After the completion of the post vacuum tests, the pavement systems were loaded with AASHTO A-2-4 silty-sandy soil. This sediment loading event followed the same procedures stated previously. ERIK testing was then performed to observe the effect of clogging due to silty-sandy sediment, which contains more fine particles. The pavements were again rejuvenated after ERIK testing was completed. Finally, ERIK tests were performed again to observe the effects of rejuvenation of the pavements.

Figure 25: PaveDrain Vac Head sediment removal in progress

*Porosity of PaveDrain Pavers*

To begin, an aquarium with the dimensions of 47.5 x 12 x 5.63 (in.) was used to house the concrete blocks and provide a consistent volume for the testing to be performed. All of the blocks were arranged to cover the entire bottom of the aquarium as to mimic the surface layer of the test sections. The concrete blocks were then fully
saturated with water, measuring the amount of water required to fully saturate the blocks. A wet/dry vacuum was used to remove the water from the blocks and then they were left to air dry for 1, 2, or 24 hours with additional vacuuming periodically. After completion of the dry time, the blocks were then fully saturated again while measuring the volume of water required to achieve full saturation. Three trials were completed for each individual dry time of 1, 2, and 24 hours.

The same testing regiment was used to determine the sediment loaded porosity of the PaveDrain blocks. This test required the addition of sandy soil to the point that no more soil could be washed into the PaveDrain blocks. Two test runs were completed with this configuration due to concerns of soil loss between test runs which would result in skewed results.

Results

Results for ASTM Surface Tests

PaveDrain test system 1 was the shallowest system installed, containing the pavers at the surface, AASHTO #57 stone aggregate underneath, and one layer of filter fabric separating the stone from the parent earth (shown in Figure 11). Results for section one ASTM surface tests are as shown below in Figure 26.
Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.4 in/hr

**Figure 26: Pavement Section 1 ASTM Surface Test Results**

The pavement initially had infiltration rates that ranged from 1429.5 in/hr to 1677.7 in/hr. A significant reduction in infiltration rates occurred when the section was loaded with AASHTO A-3 sandy soil, resulting in infiltration rates ranging from 1.2 in/hr to 4.5 in/hr. The PaveDrain VacHead and vacuum truck rejuvenation restored infiltration rates to a range of 837.7 in/hr to 1169.4 in/hr. While this test showed a significant improvement in infiltration rates, there was compacted soil visible in the joints of the PaveDrain blocks. This was likely due to the inexperience of the VacHead operator, who had no experience with vacuuming pervious pavements. This resulted in a second rejuvenation at the request of PaveDrain representatives. After the second rejuvenation, infiltration rates were similar to after the first rejuvenation. The infiltration rates ranged from 956.1 in/hr to 1143.6 in/hr.
Once the post rejuvenation infiltration testing was complete, the pavement surface was loaded with AASHTO A-2-4 silty-sandy soil. After the soil was compacted and washed into the pavement, infiltration testing continued. The infiltration rates decreased significantly after the AASHTO A-2-4 silty sandy soil loading event, with a range of 0.4 in/hr to 2.5 in/hr. A final rejuvenation event was performed in January of 2014 and resulted in increased infiltration rates, ranging from 504.5 in/hr to 734.9 in/hr.

The PaveDrain test system 2 differed from test section 1 in that the second system contained another filter fabric directly underneath the PaveDrain blocks. The results for the ASTM surface tests on the pavement section 2 are shown in Figure 27.

![Figure 27: Section 2 ASTM Surface Test Results](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.4 in/hr

Initial infiltration rates ranged from 1428.5 in/hr to 1880.3 in/hr. After the pavement section was loaded with AASHTO A-3 sandy soil, the infiltration rates fell to a range of 1.2 in/hr to 4.1 in/hr. After the pavement system was rejuvenated, infiltration rates rose to a range of 778.1 in/hr to 898.9 in/hr. Similar to test section 1, a second
rejuvenation was requested to remove excess soil not removed from the first vacuum event. The infiltration rates rose to a range of 1092.9 in/hr to 1157.9 in/hr. Next, the pavement surface was loaded with AASHTO A-2-4 silty-sandy soil. The resulting infiltration rates were measured at 0.4 in/hr. A final rejuvenation event increased the infiltration rates to a range of 566.6 in/hr to 681.1 in/hr.

PaveDrain test section 3 had a similar cross-section to test section 1, but differed in that it had an R-Tank XD wrapped with an M200 filter fabric in the layer directly above the parent earth (Figure 18). The results for the infiltration rates measured using the ASTM surface test on test section 3 are presented below in Figure 28.

![Section 3 ASTM Surface Test Results](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.5 in/hr

**Figure 28: Section 3 ASTM Surface Test Results**

The initial infiltration rates ranged from 2021.3 in/hr to 2074.2 in/hr. After the sediment loading event with AASHTO A-3 sandy soils, the infiltration rates fell to a range of 1.0 in/hr to 3.1 in/hr. An initial rejuvenation event brought infiltration rates up to a range of 1698.1 in/hr to 3056.5 in/hr. However, at the request of the produce
manufacturer the test section was vacuumed a second time. This second rejuvenation event did not further raise the infiltration rates, but rather they fell to a range of 1059.4 in/hr to 1316.4 in/hr. It should be noted that there may be an outlier data point after the first rejuvenation and the other values are not significantly different from the infiltration rates measured after the second rejuvenation event. Next, the pavement section was loaded with AASHTO A-2-4 silty-sandy soil. The measured infiltration rates again fell to a range of 0.5 in/hr to 1.7 in/hr. After a final rejuvenation event, the measured infiltration rates were in a range of 521.9 in/hr to 666.7 in/hr.

PaveDrain test section 4 was the deepest section installed (had the most void space) and differed from the previous sections in that it was constructed with two layers of AASHTO #57 stone aggregate, a structural geogrid, a 9 inch thick R-Tank wrapped in an M200 filter fabric envelope, and filter fabrics separating each rock layer (cross-section shown in Figure 20). The infiltration rates of test section 4 using the ASTM surface test methods are shown in Figure 29 below.

![Section 4 ASTM Surface Test Results](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.4 in/hr

**Figure 29: Section 4 ASTM Surface Test Results**
Initial infiltration rates were measured at a range of 1849.9 in/hr to 2347.7 in/hr. After the loading event with AASHTO A-3 sandy soil, the infiltration rates dropped considerably to a range of 1.9 in/hr to 2.7 in/hr. After an initial rejuvenation event, infiltration rates increased to a range of 1636.9 in/hr to 2151.35 in/hr. At the request of the product manufacturer, a second rejuvenation event was performed by an experienced operator. The second rejuvenation event did not show an increase in the measured infiltration rates, with a range of 1533.62 in/hr to 1869.5 in/hr. The final loading event was performed using AASHTO A-2-4 silty sandy soil. This loading event resulted in significantly decreased infiltration rates ranging from 0.4 in/hr to 0.6 in/hr. Following the post load monitoring, a rejuvenation event was performed and resulted in the infiltration rates to be increased to a range of 1332.5 in/hr to 1621.2 in/hr.

**Results for Short Ring Tests**

The short-ring ERIK test was developed as a way to test the ability of the pavement system to allow water into the rock reservoir layer where it can infiltrate into the parent soils. The short embedded rings described in previous sections, which embed 2 inches into the rock sub-base layer directly below the surface layer, were tested under new, sediment loaded, and rejuvenated conditions. The results from this testing are presented below.

PaveDrain test system section 1 was the shallowest system installed. Test section 1 contained the PaveDrain blocks at the surface, AASHTO #57 stone aggregate underneath, and one layer of filter fabric separating the stone from the parent earth (shown in Figure 11). The results from the short ring infiltration tests for pavement system 1 are presented below in Figure 30.
The pavement initially had a high infiltration rate that ranged from 10359.6 in/hr to 13535.8 in/hr. A significant reduction in infiltration rates was observed when the section was loaded with AASHTO A-3 sandy soil. The resulting infiltration rates were measured ranging from 2.7 in/hr to 4.4 in/hr. The vacuum rejuvenation event restored infiltration rates to a range of 3037.2 in/hr to 10992.3 in/hr. At the request of the product manufacturer a second rejuvenation event was performed with better trained Vac head operators. After this second rejuvenation event, the infiltration rates ranged from 6256.1 in/hr to 7900.9 in/hr. The pavement section was then loaded with AASHTO A-2-4 silty sandy soil resulting in infiltration rates ranging from 0.8 in/hr to 1.7 in/hr. A final rejuvenation event was performed in January 2015 which resulted in increased infiltration rates ranging from 980.7 in/hr to 1510.5 in/hr.

PaveDrain test section 2 was very similar to test section 1 except test section 2 contained an additional filter fabric directly underneath the PaveDrain surface layer. The
infiltration test results for the short ERIK monitoring pipe embedded into test section 2 are presented below in Figure 31.

![Section 2 Short ERIK Results](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.7 in/hr

**Figure 31: Infiltration Rate vs. Time for Section 2 Short-Ring ERIK**

Initial infiltration rates were observed to range from 9819.3 in/hr to 12312.4 in/hr. After the test section was loaded with AASHTO A-3 sandy soil, the infiltration rates fell to a range of 5.6 in/hr to 7.9 in/hr. The test surface was then rejuvenated with infiltration rates ranging from 35.8 in/hr to 96.1 in/hr. At the request of the product manufacturer, the test surface underwent a second rejuvenation in September 2014. The resulting infiltration rates were measured ranging from 5984.5 in/hr to 7686.8 in/hr. The test section was then loaded with AASHTO A-2-4 silty sandy soil. The resulting infiltration rates dropped to a range of 0.7 in/hr to 4.1 in/hr. A final rejuvenation was performed in January 2015 with the resulting infiltration rates ranging from 6710.2 in/hr to 9578.6 in/hr.
PaveDrain test section 3 had a similar configuration to test section one except test section 3 has the R-Tank XD wrapped with an M200 filter fabric envelope directly above the parent earth (Figure 18). The infiltration rate testing results for the short ERIK embedded monitoring pipe on test section 3 are presented below in Figure 32.

![Section 3 Short ERIK Results](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 5.6 in/hr

**Figure 32: Infiltration Rate vs. Time for Section 3 Short-Ring ERIK**

The initial infiltration rates ranged from 10666.9 in/hr to 16464.3 in/hr. After loading the test section with AASHTO A-3 sandy soil, infiltration rates fell to a range of 10.5 in/hr to 16.4 in/hr. An initial rejuvenation event was performed resulting in infiltration rates ranging from 2665.0 in/hr to 7040.4 in/hr. At the request of the product manufacturer, a second rejuvenation event was performed with better trained Vac head operators. The resulting test section infiltration rates were measured in the range of 7271.4 in/hr to 8142.7 in/hr. The pavement test section was then loaded with AASHTO A-2-4 silty-sandy soil. This resulted in the infiltration rates falling to a range of 5.6 in/hr to 6.5 in/hr. A final rejuvenation event occurred but did not significantly increase the infiltration rates, showing a range of 3.5 in/hr to 10.9 in/hr.
PaveDrain test section 4 was the deepest test section installed. It differed from the previous sections in that it contained two layers of AASHTO #57 stone aggregate, a structural geogrid, and an R-Tank SD wrapped with an M200 filter fabric envelope (cross-section shown in Figure 20). The results for the infiltration rate testing of test section 4 for the short ERIK embedded monitoring pipes are presented below in Figure 33.

![Figure 33: Infiltration Rate vs. Time for Section 4 Short-Ring ERIK](image)

Note: Minimum value occurs after AASHTO A-2-4 soil loading event and is equal to 0.6 in/hr.

Initial infiltration rates were measured ranging from 9619.1 in/hr to 13117.5 in/hr. The pavement section was then loaded with AASHTO A-3 sandy soil. The resulting infiltration rates dropped considerably to a range of 6.4 in/hr to 7.7 in/hr. After a vacuum rejuvenation event, infiltration rates rose to a range of 5762.8 in/hr to 11717.4 in/hr. At the request of the product manufacturer a second rejuvenation event was performed. This did not significantly affect the infiltration rates resulting in a range of 7779.3 in/hr to 8782.2 in/hr. The final clogging event of the test section was done with AASHTO A-2-4 silty-sandy soil and resulted in decreased infiltration rates ranging from 0.6 in/hr to 3.1
in/hr. A final rejuvenation event was performed on January 2015 by the PaveDrain VacHead and vacuum truck. This resulted in infiltration rates ranging from 35.0 in/hr to 38.4 in/hr.

Results for Long Ring Tests

The long-ring ERIK test was developed to measure the recovery of the pavement system. The long embedded ring penetrates completely through the pavement system and 4 inches into the pavement earth. Every material layer outside the embedded ring is also inside the ring, mimicking the pavement cross-section exactly. As a result of how the embedded rings were installed, infiltration measurements are of the slowest layer. In most all cases that is the parent earth. For example, the initial infiltration rates for the short ring ERIK in test section 1 ranged from 10359.6 in/hr to 13535.8 in/hr, whereas the infiltration rate range for the long-ring ERIK in test section 1 was from 17.8 in/hr to 38.4 in/hr. The long ring ERIK infiltration results for the different pavement systems are presented below in Figure 34, Figure 35, Figure 36, and Figure 37.

PaveDrain test section 1 was the shallowest system installed, containing the PaveDrain blocks at the surface, AASHTO #57 stone aggregate underneath, and one layer of M200 filter fabric separating the stone from the parent earth (shown in Figure 11). The long ring ERIK infiltration test results for test section 1 are shown below in Figure 34.
Infiltration rates initially ranged from 17.8 in/hr to 38.4 in/hr. A significant reduction in infiltration rates occurred when the section was loaded with AASHTO A-3 sandy soil. The resulting infiltration rates were measured ranging from 2.9 in/hr to 3.1 in/hr. The test section was then rejuvenated with a vacuum truck and the PaveDrain VacHead. The infiltration rates were restored to a range of 16.1 in/hr to 40.7 in/hr. At the request of the product manufacturer a second rejuvenation event was performed. This resulted in increased infiltration rates ranging from 27.2 in/hr to 59.9 in/hr. A second loading event was then performed with AASHTO A-2-4 silty-sandy soil which resulted in a significant reduction in measured infiltration rates ranging from 0.7 in/hr to 1.4 in/hr. A rejuvenation event was performed resulting in increased infiltration rates ranging from 5.2 in/hr to 10.9 in/hr.

PaveDrain test section 2 was similar to test section 1 except test section 2 contained another M200 filter fabric directly underneath the PaveDrain blocks. The infiltration results for the long-ring ERIK on test section 2 are located below in Figure 35.
Initial infiltration rates ranged from 4.2 in/hr to 15.3 in/hr. After test section 2 was loaded with AASHTO A-3 sandy soil, the infiltration rates fell to a range of 1.3 in/hr to 2.5 in/hr. After the rejuvenation event, test section 2 infiltration rates rose to a range of 5.7 in/hr to 31.6 in/hr. At the request of the product manufacturer a second rejuvenation event was performed by a more experienced operator. The resulting infiltration rates rose to a range of 21.9 in/hr to 78.8 in/hr. The test section was then loaded with AASHTO A-2-4 silty-sandy soil. The resulting infiltration rates dropped to a range of 0.7 in/hr to 0.9 in/hr. After a final rejuvenation event, the infiltration rates had a range of 0.7 in/hr to 2.9 in/hr.

PaveDrain test section 3 had a similar configuration to test section one, but differed in that it had an R-Tank XD wrapped in a M200 filter fabric (Figure 18). The results of the infiltration tests for the long-ring ERIK on test section 3 are presented below in Figure 36.
The initial infiltration rates ranged from 7.4 in/hr to 21.2 in/hr. AASHTO A-3 sandy soil was then loading on the test section resulting in infiltration rates dropping to a range of 1.1 in/hr to 3.1 in/hr. An initial rejuvenation event brought infiltration rates up to a range of 9.6 in/hr to 13.1 in/hr. At the request of the product manufacturer, a second rejuvenation event was performed and resulted in raising the infiltration rates to a range of 28.9 in/hr to 80.6 in/hr. The test section was then loaded with AASHTO A-2-4 silty-sandy soil. The resulting infiltration rates fell to a range of 0.5 in/hr to 1.0 in/hr. A final rejuvenation event increased the infiltration rates to a range of 2.9 in/hr to 3.2 in/hr.

PaveDrain test section 4 was the deepest section installed. It differed from the previous test sections in that it contains two layers of AASHTO #57 stone aggregate, a structural geogrid, and an R-Tank SD wrapped with M200 filter fabric (cross-section shown in Figure 20). The long-ring ERIK infiltration results for test section 4 are shown below in Figure 37.
Note: Minimum value occurs after AASHTO A-3 soil loading event and is equal to 0.2 in/hr

**Figure 37: Section 4 Long ERIK Results**

Initial infiltration rates were measured at a range of 4.4 in/hr to 18.4 in/hr. The test section was then loaded with AASHTO A-3 sandy soil. The resulting infiltration rates dropped to a range of 0.2 in/hr to 2.1 in/hr. A rejuvenation event was then performed resulting in infiltration rates ranging from 0.4 in/hr to 0.9 in/hr. At the request of the product manufacturer a second rejuvenation event was performed resulting in infiltration rates ranging from 27.0 in/hr to 73.7 in/hr. The final clogging event of test section 4 was with AASHTO A-2-4 silty-sandy soil. This resulted in an infiltration rate decrease to a range of 0.4 in/hr to 1.1 in/hr. During the course of testing of this test section, the long ring ERIK for test section 4 developed a crack in it resulting in leakage and incorrect infiltration measurements. Due to this, the long ring ERIK for test section 4 could not be tested after the final rejuvenation. That being said, based on the results of the other test sections, it is expected that the infiltration rates would increase, but not significantly.
Results for Porosity Tests

Porosity testing was performed for the PaveDrain block. The porosity of each pervious/permeable is required to properly design these systems. Since porosity is a measure of a materials capacity to hold water, it is a critical component for design. It is also known that as these types of pavement systems have a tendency to fill or clog with sediment over time. This results in a loss of storage for the pavement system, which must be taken into account when designing these types of systems. The PaveDrain blocks were tested under new and sediment loaded conditions. As described in the methods section, the PaveDrain blocks were cut to fit and installed in an aquarium. The total volume occupied by the PaveDrain blocks was 52.54 liters. A measured volume of water was added to the PaveDrain blocks until they were fully saturated. These volumes were used to calculate the porosity. The equation to calculate the porosity is presented below.

\[
\text{Porosity: } \frac{\text{ml of Water}}{\text{52.54L}} \times 100
\]

The PaveDrain blocks were tested for porosity under new and sediment loaded conditions. The porosity was also measured for different drying times. The results for the PaveDrain blocks is presented below in Table 3.
Table 3: Unloaded Porosity for PaveDrain Block

<table>
<thead>
<tr>
<th>Tested By:</th>
<th>Date</th>
<th>Dry Time (hr)</th>
<th>mL of Water</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Rios</td>
<td>5/9/14</td>
<td>1</td>
<td>12770</td>
<td>24.3%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/13/14</td>
<td>1</td>
<td>12900</td>
<td>24.6%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/20/14</td>
<td>1</td>
<td>12830</td>
<td>24.4%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/20/14</td>
<td>2</td>
<td>12800</td>
<td>24.4%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/8/14</td>
<td>2</td>
<td>12860</td>
<td>24.5%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/12/14</td>
<td>2</td>
<td>12900</td>
<td>24.6%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/15/14</td>
<td>24</td>
<td>13220</td>
<td>25.2%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/19/14</td>
<td>24</td>
<td>13010</td>
<td>24.8%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>5/20/14</td>
<td>24</td>
<td>13040</td>
<td>24.8%</td>
</tr>
</tbody>
</table>

Average: 24.6%

The average porosity for the PaveDrain blocks in the unloaded condition is 24.6%. It can be seen from the results that the drying time had no significant effect on porosity. This shows that the water was readily available to be vacuumed out of the void space within the blocks.

The PaveDrain blocks were also tested for sediment loaded conditions. The blocks were loaded with AASHTO A-3 sandy soil until no more sediment could be
brushed or washed into the void space. The blocks then had the water vacuumed out of the aquarium and were allowed to dry for two months. The total amount of sediment added to the PaveDrain blocks was 1750 mL. The results of this testing are presented below in Table 4.

Table 4: Loaded Porosity for PaveDrain Blocks

<table>
<thead>
<tr>
<th>Tested By</th>
<th>Date</th>
<th>Dry Time (hr)</th>
<th>mL of Water</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Rios</td>
<td>7/24/14</td>
<td>24</td>
<td>7000</td>
<td>13.3%</td>
</tr>
<tr>
<td>A. Rios</td>
<td>8/14/14</td>
<td>24</td>
<td>8000</td>
<td>15.2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Average:</strong> 14.3%</td>
</tr>
</tbody>
</table>

The average loaded porosity value was 14.3%. Only two tests were performed due to issues with the testing equipment.

The porosity is required to design permeable/pervious pavement systems. However, there are several different porosity values appropriate depending on the conditions of the pavement. The new, or unloaded, porosity conditions are appropriate during the beginning of the pavement system life. However, as the pavement ages, the void space decreases due to sediment filling the void space. Toward the end of the pavement life, the loaded porosity value would be appropriate. The new and loaded conditions represent a relatively short period of the pavement life. The majority of the pavements operating life will have a porosity value somewhere in-between these two extreme conditions. Based on this, a new porosity called operating porosity is defined. The equation for operating porosity is presented below.

\[
\text{Operating Porosity} = \frac{\text{Average Unloaded Porosity} + \text{Average Loaded Porosity}}{2}
\]
Based on the results shown here, the appropriate operating porosity value for the PaveDrain block is 19.5%. This is the value that should be used when designing these systems.

**Observations and Conclusions**

The use of pervious and permeable pavement systems is a great way to reduce imperviousness within a watershed. They are appropriate for low speed applications such as parking lots, sidewalks, foot paths, etc. The results of this work show that permeable pavements can be an effective way to prevent the generation of stormwater runoff and be a part of an overall stormwater management plan. However, due to natural erosion processes, these pavement systems can clog with sediment and lose their effectiveness over time.

There are three basic modes of failure for these kinds of systems. First is surface clogging, where sediments clog the surface layer preventing water from entering subbase layers and eventually parent earth. Water must enter these systems for them to be effective. The ASTM C1701 and the short ring ERIK are two methods to evaluate the degree of surface clogging.

The second mode of failure is sealing of the interface between the parent earth and the rock reservoir layers. This results in the pavement system not being able to recover its volume in a timely enough manner. A system that is not able to recover its volume fast enough will fill with water and allow surface runoff during storm events less than what the system was designed for. This type of failure is usually the result of fine sediments such as silts and clays traveling deep into the pavement system and forming a
layer of fine, low permeability, sediments. The long ring ERIK is a test method which can evaluate the ability of the pavement system to recover its volume.

The third mode of failure is loss of void space due to sediment filling. This results in reduced infiltration rates through the entire system and loss of storage capacity. A system that has reduced infiltration rates and loss of storage capacity will not perform as designed and will generate runoff during design rain events. This could result in increased pollutant loading to downstream water bodies and flooding. There currently is not an effective method for field determination of porosity, however the infiltration rate of the system could be an indicator. Additionally, field observation could be helpful in certain situations.

The rejuvenation method selected for this testing was using a custom vacuum head (VacHead) and vacuum truck. The VacHead applies water and a strong vacuum force to the pavement surface to remove any clogging sediments. Due to the PaveDrain blocks not having filler stone, sediment was allowed to enter the system easily but it also allowed for effective removal of sediment that was close to the surface. Visual observation showed that the sediment was removed from the PaveDrain blocks as far as possible to see. There was some inconsistency in the performance of the VacHead, however this seemed to be more related to the individual operating the VacHead. The speed at which the VacHead was moved over the pavement surface played a significant role in the effectiveness. Based on the opinion of the authors, after seeing the performance of the PaveDrain VacHead system compared to the performance of typical vacuum sweeper trucks at removing sediment from these types of systems, it appears that the PaveDrain VacHead system is able to remove sediment better than the typical
vacuum sweeper trucks. It should be noted that this opinion is based on anecdotal evidence as no direct comparison was done as part of this study.

Based on the results of the infiltration tests it can be seen that the PaveDrain system has a high capacity to infiltrate water. Examination of the different cross-sections tested shows that these systems can store a significant amount of stormwater. In all cases, it was observed that sediment loading resulted in a decrease in infiltration rates and vacuum rejuvenation resulted in an increase in infiltration rates, to varying degrees.

The ASTM C1701 infiltration test method was examined as a part of this research. This test method only measures the infiltration rate of the very top of the surface layer. Lateral movement of water was noted for every test performed, especially after loaded with sediment. Due to this reason, this test gives no indication of the rate, or whether or not water is entering the subbase layers. Clogging could exist at lower layers within the system and require maintenance and this test method would not be able to detect it. It is for this reason that this test method is not recommended to evaluate the need for maintenance, or clogging. It should also be noted that, due to the nature of this test method, it was nearly impossible to ensure that each subsequent test was performed at the same location as the previous test. This could result in confounding test results as each specific area will have unique characteristics.

The short ring ERIK infiltration test method was also examined as a part of this research. This test method measures the pavements ability to allow water into the subbase layers. Since the embedded ring penetrates a minimum of 2 inches into the subbase layer, there is confidence that water is going into the subbase layers. Additionally, since the test rings are installed in-situ, there is confidence that each test is
in the same location. It is for these reasons that this test method is recommended as a maintenance indicator for pervious and permeable pavement systems. The infiltration test results indicated that the PaveDrain system allows water into the system at a very high rate, much higher than any natural rainfall event. This indicates that, if there exists sufficient void space, every natural rainfall event will be captured. This means that when runoff occurs from these systems, it is due to water filling the void space within the system.

The long ring ERIK infiltration test method was also examined as a part of this research. This test method measures the recovery of the pavement system, i.e. the rate at which the void space becomes available to hold additional water. It is important that the system be able to recover within a sufficient amount of time that void space is available for the next rainfall event. The recovery is usually dictated by the infiltration rate at the interface between the bottom of the reservoir layers and the top of the parent earth. Since the long ring ERIK pipe penetrates a minimum of 4 inches into the parent earth, it gives information as to how long it will take for this system to recover, or infiltrate captured water. Typical regulation is for these systems to recovery their pollution control volume within 72 hours, which typically results in a minimum infiltration rate of 2 in/hr. The results of this testing shows that all systems remain well above the 2 in/hr minimum infiltration rate when new and after all rejuvenation events. When the pavements were loaded with sediments the infiltration rates were close to this minimum value and sometimes below it. It is for these reasons that this test method is recommended for evaluating the recovery of these systems.
The porosity of the PaveDrain block was also tested as a part of this research. Porosity is an important design parameter for pervious and permeable pavement systems. Knowing the porosity allows for the calculation of the available void space within the pavement system. Taking a depth weighted average of the porosity of each material layer will result in the overall porosity. Since the PaveDrain block is a new product, no porosity data exists for this block. It is for this reason that the porosity was measured for both new and loaded conditions. Using this information, an operating porosity was determined by taking the average of the new and loaded porosity. Based on the results of this testing, the operating porosity for the PaveDrain blocks is 19.5%. The operating porosity is the value that should be used in design of these systems. The 19.5% porosity value is what should be used for the surface block layer. With the amount of void space provided in the typical PaveDrain system design, it can be inferred that these systems will be able to satisfactorily infiltrate stormwater with longer maintenance intervals.

The testing completed on the PaveDrain permeable pavement system show that this system is able to infiltrate rainwater and effectively be rejuvenated by the PaveDrain VacHead if it becomes clogged with sediment. Of the different cross-sections examined, all performed well. Test section 2, which had the M200 filter fabric directly under the PaveDrain block, did show a little more clogging since it held sediment on the fabric. When this layer is included in the design, extra care must be given to the rejuvenation process which is evident when looking at the results presented in Figure 31.
Bibliography


