Cold Climate Performance Evaluation of Permeable Interlocking Concrete Pavement and Porous Concrete Pavement Systems

Project: 12-Unit Condominium Development by Habitat for Humanity Anchorage
West 32nd Avenue, Anchorage Alaska

November 2010

Prepared by Tamas Deak, Landscape Architect for the Anchorage Waterways Council
under USFWS Grant # 701819J028
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NOTICES

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ACKNOWLEDGEMENTS

The porous pavement system that is the subject of this report and the associated rain gardens were designed and constructed with the support of several entities that provided monetary, material and in-kind donations and professional expertise. There were numerous people involved making the project a reality. Although including all of them is not possible in this report I listed the key supporters from each organization for well deserved recognition.

**Habitat for Humanity Anchorage** – Jim Fredrick, Executive Director; Margaret Forbes, Family Services Coordinator; the Board of Directors, the staff and the countless volunteers who participated in the construction

**United States Fish and Wildlife Service Partners for Fish and Wildlife Program** – Bill Rice, Hydrologist and his colleagues in Anchorage.

**Municipality of Anchorage Salmon in the City Program** – David Wigglesworth, Program Coordinator

**Municipality of Anchorage Project Management and Engineering Department Watershed Management Division** – Kristi Bischofberger, Division Manager

Grant funding for the evaluation project was provided by **United States Fish and Wildlife Service** (Bill Rice, Hydrologist) to the **Anchorage Waterways Council** (Cherie Norton, Executive Director, Holly Kent, former Executive Director) under grant #701819J028.

The project design is the collaborative work of **Ron Bateman, Architect** (now Lumen Design-Build) and I with engineering support from **Coffman Engineers** (Dave Gardner – civil, Steve Cegelka – structural), **HZA,Inc** (Calvin Hay – mechanical), **EIC Engineers** (Eric Cowling – electrical), **H4 M Corporation** (Harry Lee – geotechnical), **USKH, Inc** (Tom Reber, Marshal Hetlet and Nick Esposito – survey), **DOWL Engineers** (now DOWL-HKM) (Corey Loyd – environmental).

**R&M Consultants** provided material testing for the porous concrete samples. Special recognition goes to **Chuck Hayter** with whom I have been collaborating from the inception of this project to find the right porous concrete mix and appropriate installation method.

**SF Concrete Technology, Inc.** (Helga U. Piro – General Manager) provided technical support in regards of the permeable paver system installation and their licensed products (VS-5 Drain and Rima) that were used on the project.

**Anchorage Sand and Gravel, Inc.** (Scott Brown, Dave Johnson) produced the porous concrete mix and the aggregate material for the structural fill of the infiltration galleries in the pavement sections.

The porous concrete slabs were expertly installed by **Finishing Edge Alaska, LLC** (Luke Sampson, President).
The permeable interlocking concrete pavers were beautifully installed by Habitat for Humanity Anchorage staff members and community volunteers.

The project also includes six raingardens that – while not the focus of the study – were integral part of the zero runoff concept employed. Patricia Joyner, Program Coordinator of the State of Alaska Department of Natural Resources Division of Forestry’s Community Forestry Program provided vital support for this effort.

The installation of the landscaping for the project, including the rain gardens, was organized and executed by Anchorage TREErific led by Stephen Nickel, ISA Certified Arborist, Community Assistance Forester. The plant material was procured, produced and transported by Northwest Landscaping, Inc. (Bud Hooker, Owner, Landscape Architect) and Seed-N-Tree Farms (Martin Martinez, Owner).

ABOUT THE AUTHOR

Tamas Deak is a Landscape Architect and Intern Architect who lives and practices in Anchorage, Alaska. He is Principal of kpb architects, a 35 person multi-disciplinary design office with architects, landscape architects and interior designers.

Mr. Deak holds a Diploma in Architecture from the Technical University of Budapest, Hungary and a Master of Landscape Architecture Degree from the University of Georgia, Athens, Georgia. Additionally he is a LEED Accredited Professional.

Mr. Deak has been interested in green building technology and site specific/site appropriate project development for building construction and public open space projects throughout his career. A particular focus of his work is the development of site specific solutions that can mitigate watershed-wide impacts associated with urbanization.

Mr. Deak has been working on the 12-unit condominium project evaluated in this report since its inception in the fall of 2004. He collaborated with Ron Bateman, Architect to form the core design team that developed the design concepts for the project. Mr. Deak has seen the project through design and construction to full completion.

Contact Information:

Tamas Deak, Principal, kpb architects

425 G Street, Suite 800, Anchorage, Alaska 99501

Tel: (907) 274-7443, E-mail: tdeak@kpbarchitects.com
PROJECT REPORT

Background

Increased imperviousness is the single greatest contributor to the degradation of developing and urbanizing watersheds. The partial or full disruption of the inherent hydrologic functionality of a watershed leads to the loss of water quality, increased flooding and severe alteration or even destruction of riparian habitats. Buildings and impervious paved areas prevent infiltration. As the impervious area increases within a watershed so declines the health of its natural systems.

Various green technologies emerged in the past decades in response to this problem in Europe and North America with increased awareness to public policy issues. Two of those technologies – porous concrete and Permeable Interlocking Concrete Pavement (PICP) systems - are becoming more common with more technical information available to support their proper use. They have been tested and successfully implemented in mostly moderate climates. This report reviews a project in Anchorage, Alaska that was designed to implement and test these technologies in the sub-arctic in order to gain more insight into their viability and prudent use.

Project Site

The project is in Anchorage, Alaska, a city that lies on the 61st parallel north. The site is the North-East quadrant of the intersection of Spenard Road and West 32nd Avenue located in the Fish Creek watershed. It is an infill site on commercially zoned land surrounded by a variety of land uses including medium density residential, retail and office.

The site was used as snow storage area for adjacent parcels for decades and as an open grassy parking lot partially covered by gravel. A small warehouse-like structure was located here in the 1960s or 1970s that was removed by the 1990s. Temporary storage of Conex containers and trailers was its only use afterwards. The site was partially cleared with an area of successional birch and cottonwood growth remaining on its west end. The estimated age of this stand was about 45 years. The underlying native soils are dense sands and gravelly sands of a glacial outwash formation. They are highly structural and permeable. The soil is saturated at an average depth of 9’ with a seasonal high water table at 7.5’ depth.

Project Design

Habitat for Humanity Anchorage developed 12 units in a multi-family condominium arrangement on this site. The units were sold under standard Habitat for Humanity procedures of family selection, sweat equity investment and zero interest loans.

The project design focused on implementing various “green” building strategies that have the potential of elevating the standard of development in a northern climate. As such the project is designed as a zero runoff project. It is connected to the municipal storm sewer system to allow
emergency overflow for “fail safe” operation of the site. The “fail safe” storm sewer connection requirement was a non-negotiable condition of obtaining a building permit from the local building authority during the design approval process.

The project consists of twelve townhouse-style dwelling units. Four units are organized around a courtyard-like central space creating three pods in the project. Each of these central spaces serves as the primary entrance to the residences and their garages. An access driveway connects each to the street. The buildings are primarily flat-roofed with internal drains combined with shed roof elements. Both types of roofs drain into adjacent raingarden areas.

The stormwater management strategy for the courtyards is infiltration. Each courtyard employs a hybrid pavement system that consists of PICP and porous concrete. There is a conventional dense concrete slab at each of the driveways to the street where the vehicular traffic is most concentrated. The catchment area for each courtyard is limited to its 66’x44’ surface area and half of a 16’x16’ playdeck gable roof that connects two building volumes in the back of the site.

The original design of the pavement section included minimum 16” depth of ASTM C-33 #57 aggregate over undisturbed native soil with minimum 6” of porous concrete slab for the entire courtyard. All courtyards were excavated down to the clean native sands resulting thicker sections for the #57 aggregate up to 24”- 28” depth. The team determined that there was no need for geotextile separation due to the presence of dense native soils. The team researched and tested a number of porous concrete mixes in coordination with the local material supplier to balance compressive strength and permeability derived from sufficient void space. The test results showed that sufficient balance can be achieved with expert installation and a carefully adjusted mix design. The design team modified the courtyard design due to the legal use of metal studded tires in Anchorage from September 16th through April 30th. We judged the risk of physical deterioration of the porous concrete from mechanical damage too high for an owner occupied low income housing development.

In the areas of the courtyards where the most frequent turning movements are expected PICP replaced the porous concrete system. PICP is a flexible pavement system that required modification of the structural support section by stiffening the #57, which is a round aggregate mix. The design of PICP included a minimum 4” layer of locally available crushed aggregate (E-Chips, 1/2” to #8) on top of the #57 aggregate. This base was thoroughly compacted with plate compactors. The bedding for the pavers was a finer crushed material (F-Chips, 3/8” to #8) that allowed better screeding and level placement of the pavers.

Anchorage does not have access to locally manufactured permeable pavers. The inclusion of this material in the design provided the opportunity to test different products as all had to be shipped from an out-of-state location. The area of PICP is 44’x44’ in every courtyard. The design of each courtyard included black VS-5 Drain pavers that created outlines and separation for four 300sf fields that were filled with different kind of natural (gray) color paver products. The three products used were: Eco-Stone, Rima and VS-5 Drain.

Snow maintenance considerations brought about a design that includes a hydronic snowmelt system connected to each dwelling unit. Due to the relatively small size of the units there is
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excess capacity available from the high efficiency condensing boilers used to provide heat. Each quadrant of each courtyard is linked to the corresponding dwelling unit whose owner is responsible to remove snow in his quadrant. The 5/8” PEX tubing that carries the glycol to the area is embedded in the porous concrete slab or in the structural fill. Tubing is tied to welded wire mesh. The owners have the option to manually remove snow or melt it using the system.

Originally each courtyard was designed with level grade since the permeable and porous systems would not generate runoff as designed. This design was rejected by the local building authority during the coordination phases. Their rejection was based on the assumption that winter conditions fully prevent the functionality of the infiltration system regardless of the inclusion of the snowmelt system. Although this assumption has not been tested and proven it forced the design to include a gradient for each courtyard surface. The sloping pavement areas became part of a design based on a surface runoff concept instead of infiltration. In this concept the stormwater follows a clear path to an on-site catch basin to ultimately enter the municipal storm sewer system. This change allowed easier observation of the system after completion, although it added significant cost and complexity for the volunteer-based construction methods employed by Habitat.

Materials and Methods for Observation

The goal of this report is to present findings that can be obtained from a real life cold climate project that employs pervious pavement as part of its infiltration strategy. I conducted the monitoring of the project by on-site observation. I relied on known design and environmental parameters and samples from the porous concrete installation that were submitted for laboratory testing after being subjected to the weather for 2 winter and summer cycles. This project is not part of a controlled science experiment. The information I gained were not evaluated using a control sample. Also, the methods employed for evaluation could not be destructive to the actual finished project site improvements. We created 2’ x 2’ size samples during the installation of the porous concrete slabs in each courtyard. The mix was poured over a 2” layer of #57 aggregate in a wooden box form. The form was made with 2x8 lumber sides and ¾” plywood base. The sample pour used the same raw material and installation techniques as the actual slab during its installation to match it as closely as possible. The samples were set aside in their form on the project site to endure the same environmental conditions as the actual slabs. They were left in place from the installation date of July 11, 2008 to the date of removal from site on May 30, 2010.

The samples were tested under laboratory conditions for void space, flow rate and time and for compressive strength by Chuck Hayter of R&M Consulting using standard methods for testing. The laboratory report is included in the appendices.

I have frequently observed the project site in and after rain and snow events during the two winters and two summers since completion of the pervious pavement systems. The main purpose of the observation under these conditions was to determine whether surface runoff is generated from the porous concrete slabs and PICP systems. Of additional interest was the permeability of the pervious pavements during freezing temperatures under natural conditions.
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Additionally I made periodic site visits in precipitation-free conditions as well. The purpose of these visits was to check for visible signs of changed physical conditions in the pervious systems and the project as a whole. The visits included visual examination of the project elements and site photography as applicable. I also observed the project following special conditions and events like the March 28, 2009 eruption of Mt. Redoubt and the subsequent light ashfall. I conducted 26 photographically documented and more than a dozen additional site visits during the period of July 11, 2008 and August 31, 2010.

Findings

Among all the site visits none concluded that runoff is being conveyed to the impervious slabs from either the porous slabs or the PICP systems in any of the three courtyards. The impervious driveway entrance slab generated surface flow during rain events, spring breakup conditions or even snowmelt operations when the temperature remained close to freezing. The pervious courtyard areas appeared to infiltrate all incoming precipitation under the same conditions. Anchorage had a particularly wet summer during 2010, but – while there was a record breaking stretch of over 30 consecutive days with measurable precipitation - the rain intensity appeared to not come close to the infiltration capacity of the pervious courtyards. Even the new record daily rainfall with 2.76 inches, reached this year on August 21, 2010, did not appear to produce enough water to generate runoff from any of the permeable or porous surfaces.

I observed no surface runoff from any other element of the development (shed roofs, flat roofs, open space and landscaped areas) entering the municipal stormwater system via the storm drain inlet installed on site to meet permit requirements. I observed no standing water in the raingarden at the inlet. The raingarden and the pervious courtyards did not appear to generate enough runoff to overflow into the municipal system even during chinook winds (rapid winter thawing with rainstorm) in the wet and icy winter of 2008/09.

Both the porous slabs and the PICP systems performed well in their everyday use. The porous slabs are intact without any cracks, signs of deterioration or any sign of movement. This is indicative of a stable structural section and the lack of accumulation of water below the slabs that may create ice lenses. It also shows that the permeability of the slabs is sufficient to drain water before it can freeze inside the slab.

The PICP system performs well under vehicular traffic. There are no heaves or differential movement of the pavers. The low speed turning movements do not affect the stability of the pavers and their density appears sufficient to withstand the pitting and scouring caused by studded tires. There is no or limited displacement of the joint aggregate, the components of the system are stable in their proper location.

There was no discernible overall deterioration in the infiltration rate of either system during the observation period. Even the Mt. Redoubt ashfall in March of 2009 was not sufficient in quantity and particle size to clog the system. Subsequent snow and rain events appear to have washed the material away from the surface into the void spaces. Even still as a whole the systems perform as intended without the annual maintenance using a vacuum truck. More infrequent maintenance will most likely be sufficient on a 3 or possibly 5 year cycle.
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Anchorage uses gravely sand to maintain traction on slippery roadways in the winter. The constant pounding of the studded tires pulverizes this material to a size that is easily transported in tire treads. It is clear that this material is tracked onto the courtyard surfaces by vehicles and accumulates at the most heavily travelled areas at the garage entrances. Continuous joint PICPs seem to perform better in maintaining permeability under such conditions. There are cells that show significantly reduced infiltration rates in the Eco-Stone installation, while no similar phenomenon can be observed at the Rima and VS-5 Drain installations where infiltration takes place in contiguous joints.

The laboratory test results obtained for this report show that the original porous concrete mix used in the porous slab (see appendix) produces sufficient strength and the desired permeability for cold-climate projects if installed properly. It can be used effectively on suitable cold climate sites as an infiltration strategy. Similarly PICP systems can also be employed for the same purpose in cold climates as they show great durability and high infiltration potential.

**Recommendations**

The following recommendations for porous concrete slabs and PICP systems are based on the observations and findings of this report. I suggested topics for research and made suggestions to continue monitoring the project for additional data after the recommendations.

It is best to select a PICP system over porous slabs for vehicular areas especially with turning movements. Until further study can evaluate the longevity of porous slabs under different traffic conditions in locations where metal studded tires are legal they will continue to pose an unknown level of design risk when used in vehicular areas.

A PICP system product that uses contiguous joints in its design is recommended over ones with a closed cell design because it may maintain its infiltration rate longer reducing the frequency of required maintenance against clogging.

It is a conservative, but prudent approach to only select porous concrete slabs for sites where the native soil has a high capacity for infiltration. Any site with a potential for heaving may be best served with a flexible PICP system over a rigid porous concrete system. The investment for both is significant enough to expect much longer operational life from each.

Porous slabs and PICP systems should intuitively be designed with level surfaces, but adding shallow gradients of 1% or less can provide redundancy for the design without significantly affecting the infiltration rate of the system in climates with low intensity rain events. This may ease permitting projects in Anchorage where municipal experience with infiltration design projects is severely limited at this point.

Using a hybrid design of PICP systems with porous slabs adds to the longevity and redundancy of a project’s infiltration functionality. It can also reduce the frequency of maintenance needed to keep the system operational.
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Design and install PICP systems and porous slabs in a collaborative manner for which a design-build delivery method appears to be more suitable. Installation, quality, and cost control may be more challenging in a low bid contracting environment.

**Topics for Further Research**

*Infiltration capacity of porous slabs and PICP systems during the winter months under standard maintenance regimes.* This report made cursory observations about the systems’ functionality during the winter and its potential for infiltration during Chinook conditions or breakup. The permitting entity in Anchorage allows no accounting for a system’s infiltration capacity during the winter regardless of the specific site conditions. This leads to more conveyance based approaches in site design with inlets, pipes and underground infiltration solutions that can handle the design flow year around. This approach makes the use of any pervious paver system out of reach for our clients due to the redundancy of cost.

*Porous concrete slab performance in vehicular areas in localities where studded tires are legal.* The rice crispy-like surface and lower compressive strength of porous slabs suggests that they are more vulnerable to vehicular use. Further research is needed to test how much traffic and in what locations porous slabs can withstand before wide cold climate use can be recommended for vehicular areas.

*Monitoring high intensity rain events* (for the Anchorage area) to determine what intensity generates surface runoff from porous slabs and PICP systems.

*Water level monitoring in the infiltration reservoirs.* This report did not have the ability to monitor water levels under the installed pervious pavements. This information is needed for proper sizing of the thickness of the infiltration reservoir with different native soils.

*Methods for maintaining infiltration capacity during the winter months.* This report observed a project where hydronic snowmelt can ensure the functionality of the infiltration system. Research into finding the appropriate methods to maintain full or partial infiltration functionality of pervious pavements would help to promote their use and ease their permitting.
APPENDICES

A. Project Pictures
B. Grading and Drainage Plan
C. Anchorage Sand and Gravel Co., Inc – Pervious Concrete Mix Design 3R661A020B
D. R&M Consultants, Inc. – Habitat for Humanity Pervious Concrete Testing Report
Placement of porous concrete mix over ASTM C-33 #57 aggregate base and hydronic snowmelt tubing tied to wire mesh.

Rolling the mix into the form with heavy roller over plastic sheet.

Tamping the concrete with wood board for additional compaction and smoother surface.

Cutting control joints with rolling cutter.

Finishing the surface by tamping concrete mix in place with trowel, removing excess material and correcting uneven edges.

Slab covered with plastic sheet and left to cure undisturbed for several days.
PEX tubing for snowmelt is attached to wire mesh on top of the ASTM C-33 #57 aggregate material that provides the infiltration gallery.

A min. 4” layer of 1/2” to No. 8 crushed aggregate is placed the the tubing and carefully compacted and leveled.

The perimeter courses of VS-5 Drain pavers are installed over the screeded bedding aggregate.

The Eco-Stone field pavers are placed with string guides to set proper grade. A sloped installation was a requirement from the building department.

3/8” to No. 8 crushed aggregate is placed in the voids and over the completed installation.

Garden hose test shows the system functioning as intended.
Winter storm with snowmelt system on. Minor accumulation can be observed on the pervious slab only at the driveway entrance.

One of the porous concrete samples prior to cutting and transportation to the lab for testing.

Summer storm with no apparent runoff from the courtyard. Concentrated flow can be observed on the street.

Accumulation of fine sediment slows the infiltration rate in some cells of Eco-Stone.

Spring breakup condition showing dry pervious pavement systems and water on the impervious driveway entrance.

Use in a courtyard showing no runoff from the pervious systems to the impervious concrete slab at the driveway.
Anchorage Sand and Gravel Co., Inc.  
1040 O'Malley Road  
Anchorage, Alaska, 99515  
(907) 267-5157

Concrete Mix Design  
3R61A020B [8]  
Design Compressive Strength: 3,000 psi

Contractor : Trial 2  
Project : 6 Sack Pervious Concrete  
Source of Concrete : Anchorage Sand & Gravel Co., Inc.  
Construction Type : General  
Placement : Chute or Bucket

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<th>Quantity</th>
<th>Density</th>
<th>Yield, ft³</th>
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<tr>
<td>High Range Water Reducer(2.0oz/cwt cement), +</td>
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<td>Total Air, %</td>
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TOTAL 27.10

Water/Cement Ratio, lbs/lb 0.27  
Slump, High, in 2.00  
Low, in 0.00  
Concrete Unit Weight,pcf 120.58  
Yield, % 100.4  

Exposure Condition: Severe exposure

1. Air entraining admix may be field adjusted to obtain desired air content.  
2. All aggregates produced at the AS&G Matanuska Valley pit.  
3. Over compaction will reduce the Void % of this material.  
4. Sub-base and subgrade must be specifically desi

Prepared by:  

W. Scott Brown  

7/10/2008
Tamas Deak  
920 W. 16th  
Anchorage, Alaska, 99501  

RE: Habitat for Humanity Pervious Concrete Testing  

Dear Tamas:  

We have completed testing the pervious concreted samples submitted by you with the following results.  

Objective: To test and evaluate the physical characteristics of the pervious concrete placed during construction of the Habitat for Humanity project in the summer of 2008.  

Procedure: Using the samples submitted by you, which were placed as 2’x2’ test slabs on the project site, at the same time and under identical conditions as the actual slab placement, we produced 4 core samples, 2 each from the East and West sections of the paved area. The bottom portions of the samples were saw-cut to produce a flat, measureable surface. The upper surfaces were left intact to represent the in situ characteristics of the slab. After the cores were air dried, the mass was recorded. The cores were then soaked in water and the mass was determined while in suspension. This information was used to calculate the percentage of air voids in each specimen using the following formula: \[ V_{air} = \frac{1-(W_{d}-W_{o})}{(\gamma_{w}*V_{i})} \] x 100. The cylindrical specimens were wrapped with plumbers putty and placed inside a 4’ long, 4” dia. piece of PVC pipe, which was divided into 1’ increments and clamped tight to prevent escapement of water between the PVC walls and the specimen. The first mark was placed 9” from the top of the PVC, the second was 1’9” from the top. The PVC was filled with 55.4°F water, then, as the water flowed past the first mark the timer was started. The timer was stopped as the water reached the second mark, thus enabling us to calculate the infiltration rate of the pervious concrete samples. The 4 specimens were then capped and tested for compressive strength IAW ASTM C-39.  

Observations: Per our discussions, the samples identified as 1W & 2W were placed with the first loads from the concrete supplier and were “drier” in nature than samples 1E & 2E which you observed as being a “wetter” consistency. The concrete producer had held back 1 gallon of water per cubic yard on the first load to insure it was not too wet. After seeing the first load he felt that the concrete could be a wetter. He called back to the plant and increased the water by 1 gallon per yard, which was in fact the quantity prescribed by the mix design, prior to placing the
slab on the East side. The specimens from the West portion were lower in compressive strength than the Eastside specimens due to a higher percentage of air-voids, which in turn produced a higher flow rate than the samples from the East section. During testing, we noted visually that the samples from the East section were much denser on the upper surface. The additional water in subsequent loads may have increased the paste content enough that during the roller compaction phase, the wetter paste collected and "closed off" the surface, which restricted flow.

Test Results:

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<tr>
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<th>1W</th>
<th>2W</th>
<th>1E</th>
<th>2E</th>
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<td>Length (in)</td>
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<td>5.576</td>
<td>5.527</td>
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<td>Diameter 2 (in)</td>
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<td>Average Dia. (in)</td>
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<td>3.749</td>
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<td>4.538</td>
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<td>Flow Rate (in/hr)</td>
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<td>1728.0</td>
<td>237.4</td>
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<td>Flow Time-1' (sec/ft)</td>
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<td>25</td>
<td>182</td>
<td>165</td>
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</table>

Please, feel free to contact us at 907-522-1707 if we can provide any further information.

Thank you for the opportunity to assist you on this project. We hope to work with you again in the near future.

Sincerely,

R&M CONSULTANTS, INC.

Charles E. Hayter
Engineering Technician

Cc: Richard S. Giessel, PE
Attachment: Photos
### Project Photos

<table>
<thead>
<tr>
<th>Image ID</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMG_1618</td>
<td>3.75&quot; cores taken from submitted samples of pervious concrete.</td>
</tr>
<tr>
<td>IMG_1623</td>
<td>Infiltration apparatus used to measure flow rate of water through the cored specimen.</td>
</tr>
<tr>
<td>IMG_1625</td>
<td>Apparatus marked in 1&quot; increments to time flow of water through specimen.</td>
</tr>
<tr>
<td>IMG_1628</td>
<td>Specimens 2W (left) and 1E (right). Note the surface voids are closed on specimen 1E.</td>
</tr>
</tbody>
</table>