UNI ECO-STONE®

Permeable Interlocking Concrete Pavement

UNI-GROUP U.S.A.

Manufacturers of UNI Paving Stones

ECOLOC®

DEVELOPMENT, IMPERVIOUS COVER AND IMPACTS OF STORMWATER RUNOFF

With ever-increasing levels of development, natural, open land is rapidly being replaced with impervious surfaces such as asphalt roadways, parking lots, and buildings. As a result, the management of increased levels of stormwater runoff and its impact on the environment has become a major issue for all levels of government throughout the country. Numerous studies indicate that stormwater runoff is the primary source of pollutants found in surface waters and contains a toxic combination of oils, pesticides, metals, nutrients, and sediments. Additionally, research has shown that once a watershed reaches just 10% impervious cover, water resources are negatively impacted.

Stormwater Inlet Drain - Lake Park, FL

In the early 1990s, the United States Environmental Protection Agency (EPA) established the National Pollutant Discharge Elimination System (NPDES) stormwater regulations to comply with the requirements of the Clean Water Act. Compliance with federal, state, and local stormwater programs involves the use of "best management practices" (BMPs) to manage and control stormwater runoff. Effective management of stormwater runoff offers a number of benefits, including improved quality of surface waters, protection of wetland and aquatic ecosystems, conservation of water resources, and flood mitigation. The EPA recommends approaches that integrate control of stormwater and protection of natural systems.

In 1999 and 2001, the International City/County Managers Association (ICMA) and EPA released the framework for "Smart Growth" policies that communities around the country could adopt to meet environmental, community, and economic goals. Simultaneously, organizations such as the Low Impact Development Center and the Center for Watershed Protection began advocating low impact development (LID) as a way to preserve and protect the nation's water resources. They promote comprehensive land planning and engineering design, watershed planning and restoration, and stormwater management approaches that protect water resources and attempt to maintain pre-existing hydrologic site conditions. Their goal is to achieve superior environmental protection, while still allowing for development.

The EPA began working with these organizations in 2006 to promote the use of LID and Smart Growth as a way to manage stormwater runoff. The goal is to protect water resources at the regional level by encouraging states and municipalities to implement policies that consider both growth and conservation simultaneously. These approaches are quickly gaining favor across the country and are being incorporated into local development regulations to help meet stormwater runoff requirements and provide more livable, sustainable communities for residents. One of the

Private Residence - Narragansett, RI

primary goals of LID design is to reduce runoff volume by infiltrating rainwater on site and to find beneficial uses for the water as opposed to utilizing storm drains. LID objectives include the reduction of impervious cover, preservation of natural landscape features, and the maximization of infiltration opportunities. Infiltration helps recharge groundwater, reduces urban heat island effects, and reduces downstream erosion and flooding. This allows development to occur with much less environmental impact.

In addition, "green building" programs are gaining in popularity. The Leadership in Energy and Environmental Design (LEED®) green building assessment system, developed by the U.S. Green Building Council, has been adopted by a number of cities and states that now require municipal buildings to meet LEED® certification standards. Also, the National Association of Home Builders (NAHB) has released a comprehensive guide on green building that promotes mixed-use developments, cluster housing, green technologies and materials, and alternative stormwater approaches.

UNI ECO-STONE®…THE SOLUTION TO STORMWATER RUNOFF PROBLEMS

Permeable interlocking concrete pavements (PICPs) are becoming increasingly popular as more cities and states are faced with meeting stormwater runoff regulations, increased impervious cover restrictions, and the adoption of LID or LEED® practices.

UNI Eco-Stone®

Eco-Stone® is a permeable interlocking concrete pavement system that mitigates stormwater runoff through infiltration. This allows for reduction of volume and peak flows, improved water quality, filtering of pollutants, mitigation of downstream flooding, and recharge of groundwater. Eco-Stone® is a true interlocking paver that offers the structural support, durability, and beauty of traditional concrete pavers, combined with the environmental benefit of permeability. The permeability is achieved through the drainage openings created by its notched design. Measurements of a typical UNI Eco-Stone® paver and physical characteristics are shown in Figure 1.

Physical Characteristics

Height/Thickness	3 1/8"	=	80mm
Width	4 1/2"	=	115mm
Length	9"	=	230mm
Pavers per sq ft		=	3.55
Percentage of drainage void area per sq ft		=	12.18%

Composition and Manufacture

Minimum compressive strength - 8000psi
Maximum water absorption - 5%
Meets or exceeds ASTM C-936
and freeze-thaw testing per
section 8 of ASTM C-67.

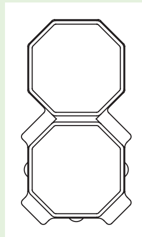

Figure 1

The drainage openings in an Eco-Stone® permeable pavement are created when the pavers are installed (Figure 2). This is what distinguishes Eco-Stone® permeable pavers from traditional interlocking concrete pavers. The drainage openings are filled with a clean, hard crushed aggregate that is highly permeable, allowing for rapid infiltration of stormwater (Figure 3).

Figure 2

Figure 3

ECO-STONE® PERMEABLE PAVEMENT AS AN EPA BEST MANAGEMENT PRACTICE

The EPA encourages "system building" to allow for the use of appropriate site-specific practices that will achieve the minimum measures under Phase II of NPDES. Governing authorities must develop and implement strategies that include a combination of structural and/or non-structural BMPs appropriate for their communities. Structural practices include storage practices, filtration practices, and infiltration practices that capture runoff and rely on infiltration through a porous medium for pollutant reduction. Infiltration BMPs include detention ponds, green roofs, bioswales, infiltration trenches, and permeable pavements. Non-structural practices are preventative actions that involve management and source controls. Many states and municipalities have incorporated the EPA regulations into their stormwater design and BMP manuals as they attempt to deal with stormwater runoff, increased impervious cover, and over-taxed drainage and sewer systems.

PICPs are considered structural BMPs under infiltration practices. From an engineering viewpoint, permeable pavements are infiltration trenches with paving on top that supports pedestrian and vehicular traffic. By combining infiltration and retention, Eco-Stone® permeable interlocking concrete pavement offers numerous benefits over other types of structural systems. Permeable pavements also work well in conjunction with other recommended BMP practices such as swales, bioretention areas, and rain gardens.

Rainwater Runoff Model - Minnehaha Creek Watershed District, MN

ECO-STONE® PERMEABLE PAVEMENT AND LID, LEED AND GREEN BUILDING

According to the Natural Resources Defense Council, LID has emerged as an attractive approach to controlling stormwater pollution and protecting watersheds. With reduction of impervious surfaces a major tenant of LID, permeable and porous pavements, such as Eco-Stone®, are listed as one of the ten most common LID practices. The use of site-scale technologies, such as PICPs that control runoff close to the source, closely mirror the natural process of rainwater falling onto undeveloped areas and infiltrating into the earth. With many areas of the country experiencing water shortages and increasing water pollution, LID and Smart Growth approaches will not only help alleviate these problems, but also create cities that are more energy efficient, environmentally sustainable, and cost effective.

McKinney Green Building, McKinney, TX - LEED® Platinum Certified

Sherwood Island State Park - Westport, CT

The LEED® green building assessment system has become increasingly popular with the North American design community since its inception in 1998. This voluntary building system for rating new and existing commercial, institutional, and high-rise residential buildings, evaluates environmental performance from a "whole building" perspective over the project's life cycle. New green design standards are being considered for neighborhood design and residential homes as well. The minimum number of points or credits for a project to be LEED® certified is 26, though silver (33-38 points), gold (39-51 points), and platinum (52-69 points) ratings also are available.

UNI Eco-Stone® permeable pavements may qualify for up to 14 points under the Sustainable Sites (SS), Material and Resources (MR), and Innovation and Design Process (ID) credits. While traditional concrete pavers also may qualify under some of the credits, PICP can earn LEED® points via Sustainable Sites stormwater management credits by meeting water quality and runoff treatment criteria.

For years, most home builders and developers were wary of green building practices. However, with impervious cover restrictions and the increasing costs of energy now beginning to impact residential projects, the NAHB is encouraging the use of "green" products in single and multi-family developments. Eco-Stone® permeable pavement offers an attractive solution to impervious cover restrictions.

Private Residence - Long Island, NY

ECO-STONE® AND MUNICIPAL STORMWATER MANAGEMENT OBJECTIVES

Municipal regulations for managing stormwater runoff vary across the country. Water quality and/or quantity may be regulated, with criteria for reducing water pollutants such as nitrogen, phosphorous, nitrates, metals, and sediment. Many municipalities now restrict the amount of impervious surfaces for virtually all types of construction, including private residences. Thousands of municipalities have created stormwater utilities to fund the increasing costs of managing stormwater. These fees vary, but are usually based on runoff volumes and impervious cover.

Lafayette Road Office Park - North Hampton, NH

Regional authorities, counties, and municipalities use a number of design goals for managing stormwater runoff:

- Limit impervious cover to reduce stormwater runoff and pollutants from developments
- Capture the entire stormwater volume so there is zero discharge from the drainage area
- Capture and treat stormwater runoff to remove a stated percentage of pollutants
- Capture and treat a fixed volume of runoff, typically 0.75-1.5 in. (18-40 mm), which usually contains the highest level of pollutants
- Maintain runoff volumes generated by development at or near pre-development levels
- Maintain groundwater recharge rates to sustain stream flows and ecosystems and recharge aquifers

Eco-Stone® permeable interlocking concrete pavements may offer solutions for attaining all of these goals. PICP can reduce runoff volumes and flows and recharge groundwater. It also can filter pollutants with removal rates of up to 95% total suspended solids, 70% total phosphorous, 51% total nitrogen, and 99% zinc. Reduction of runoff also may offer property owners reductions in stormwater utility fees.

FEATURES AND BENEFITS OF THE UNI ECO-STONE® PAVEMENT SYSTEM

Eco-Stone® is an attractive pavement that can be used for residential, commercial, institutional, and recreational pedestrian and vehicular applications. It can be used for parking lots, driveways, overflow parking, emergency lanes, boat ramps, walkways, low-speed roadways, and storage facilities. *Permeable or porous pavements should not be used for any site classified as a* ***stormwater hotspot*** (anywhere there is a risk of stormwater contaminating groundwater). This includes fueling and maintenance stations, areas where hazardous materials or chemicals are stored, or land uses that drain pesticides/fertilizers onto permeable pavements.

UNI Eco-Stone® permeable pavements are a site-scale infiltration technology that is ideal for meeting the EPA's NPDES regulations, LID and Smart Growth objectives, LEED® certification, municipal and regional impervious cover restrictions, and green building requirements.

- Can be designed to accommodate a wide variety of stormwater management objectives
- Runoff reductions of up to 100% depending on project design parameters
- Maximizes groundwater recharge and/or storage
- Reduces nonpoint source pollutants in stormwater, thereby mitigating impact on surrounding surface waters, and may lessen or eliminate downstream flooding and streambank erosion
- Allows better land-use planning and more efficient use of available land for greater economic value, especially in high-density, urban areas
- May decrease project costs by reducing or eliminating drainage and retention/detention systems
- May reduce cost of compliance with stormwater regulatory requirements and lower utility fees
- May reduce heat island effect and thermal loading on surrounding surface waters

Glen Brook Green, Jordan Cove Watershed - Waterford, CT

Examples of pollutant removal and infiltration rates for Eco-Stone® are shown in Tables 1 and 2. This data is from the Jordan Cove Urban Watershed Project 2003 Annual Report by the University of Connecticut, who conducted monitoring on this EPA Section 319 National Monitoring Project. It should be noted that these infiltration results were achieved using a dense-graded base. Even higher infiltration rates would be expected with open-graded bases.

Test and Year	Asphalt	Eco-Stone® in./hr (cm/hr)	Crushed Stone in./hr (cm/hr)
Single Ring Infiltrometer test 2002	0	7.7 (19.6)	7.3 (18.5)
Single Ring Infiltrometer test 2003	0	6 (15.3)	5 (12.7)
Flowing Infiltration test 2003	0	8.1 (20.7)	2.4 (6)

Table 1. *Average infiltration rates from asphalt, Eco-Stone® and crushed stone Jordan Cove Urban Watershed Project*

Variable	Asphalt		Eco-Stone Pavement		Crushed Stone	
Runoff depth, mm	1.8	a	0.5	b	0.04	c
Total suspended solids, mg/l	47.8	a	15.8	b	33.7	a
Nitrate nitrogen, mg/l	0.6	a	0.2	b	0.3	ab
Ammonia nitrogen, mg/l	0.18	a	0.05	b	0.11	a
Total Kjeldahl nitrogen, mg/l	8.0	a	0.7	b	1.6	ab
Total phosphorous, mg/l	0.244	a	0.162	b	0.155	b
Copper, ug/l	18	a	6	b	16	a
Lead, ug/l	6	a	2	b	3	b
Zinc, ug/l	87	a	25	b	57	ab

Table 2. *Mean weekly pollutant concentration in stormwater runoff from asphalt, Eco-Stone® and crushed stone driveways*
Note: Within each variable, means followed by the same letter are not significantly different at $\alpha = 0.05$

ECO-STONE® DESIGN AND GENERAL CONSTRUCTION GUIDELINES

UNI-GROUP U.S.A. offers design professionals a variety of tools for designing Eco-Stone® permeable pavements. Research on Eco-Stone® has been conducted at major universities such as Texas A&M, University of Washington, and Guelph University, and ongoing pollution monitoring is being conducted at EPA Section 319 National Monitoring Program sites Jordan Cove Urban Watershed Project in Connecticut and Morton Arboretum in Illinois. We offer design manuals, case studies, and Lockpave® Pro structural interlocking pavement design software, with PC-SWMM PP™ for hydraulic design of Eco-Stone® permeable pavements. Eco-Stone® is featured in the book *Porous Pavements* by Bruce Ferguson, a national authority on stormwater infiltration. And, as members of the Interlocking Concrete Pavement Institute, we can offer additional design and reference information, such as ICPI's *Permeable Interlocking Concrete Pavements* manual, Tech Specs™ and CAD files.

It is recommended that a qualified civil engineer with knowledge in hydrology and hydraulics be consulted for applications using permeable interlocking concrete pavement to ensure desired results. Information provided is intended for use by professional designers and is not a substitute for engineering skill or judgement. It is not intended to replace the services of experienced, professional engineers.

Design Options - Full, Partial and No Exfiltration

Eco-Stone® pavements can be designed with full, partial, or no exfiltration into the soil subgrade. Optimal installation is infiltration through the base aggregate, with complete exfiltration into a permeable subgrade. This allows for not only runoff and pollutant reduction, but also groundwater recharge. For full exfiltration under vehicular loads, the minimum soil infiltration rate is typically 0.52 in./hr (3.7 x 10^{-6} m/sec). Where soil conditions limit the amount of infiltration and only partial exfiltration can be achieved, some of the water may need to be drained by perforated pipe. Where soils have extremely low or no permeability, or conditions such as high water tables, poor soil strength, or over aquifers where there isn't sufficient depth of the soil to filter pollutants, no exfiltration should occur. An impermeable liner is often used and perforated pipe is installed to drain all stored water to an outfall pipe. This design still allows for infiltration of stormwater and some filtering of pollutants and slows peak rates and volumes, so it still can be beneficial for managing stormwater. For extreme rainfall events, any overflows can be controlled via perimeter drainage to bio-retention areas, grassed swales or storm sewer inlets.

Ash Avenue Park and Ride - Marysville, WA

Infiltration Rate Design

Permeable interlocking concrete pavements are typically designed to infiltrate frequent, short duration storms, which make up 75-85% of rainstorms in North America. It also may be possible to manage runoff volumes from larger storms through engineering design and the use of complementary BMPs, such as bio-retention areas and swales.

One of the most common misconceptions when designing or approving PICP is the assumption that the amount or percentage of open surface area of the pavement is equal to the percentage of perviousness. For example, a designer or municipal agency might incorrectly assume that a 15% open area is only 15% pervious. The permeability and amount of infiltration are dependent on the infiltration rates of the aggregates used for the joint and drainage openings, the bedding layer, and the base and subbase (if used). Compared to soils, the materials used in Eco-Stone® permeable pavements have very high infiltration rates – from 500 in./hr (over 10^{-3} m/sec) to over 2000 in./hr (over 10^{-3} to 10^{-2} m/sec). This is much more pervious than existing site soils.

Private Residence - Minneapolis, MN

Though initial infiltration rates are very high, it is important to consider *lifetime* design infiltration of the entire pavement cross-section, including the soil subgrade when designing PICPs. Based on research conducted to date, a conservative design rate of 3 in./hr (2.1 x 10^{-5} m/sec) can be used as the basis for the design surface infiltration rate over a 20-year pavement life.

A number of design methods may be used for sizing of the open-graded base (see references). For designers who use Natural Resources Conservation Service (NRCS) curve numbers in determining runoff calculations, the curve number for PICP can be estimated at 40, assuming a life-time design infiltration rate of 3 in./hr (75mm/hr) with an initial abstraction of 0.2 (applies to NRCS group A soils). Other design professionals may use coefficient of runoff (C) for peak runoff calculations. For the design life of permeable interlocking concrete pavement, C can be estimated with the following formula: $C = I - \text{Design infiltration rate, in./hr} \div I$, where I = design rainfall intensity in inches per hour.

Construction Materials and General Installation

It is preferable that site soils not be compacted if structural strength is suitable, as compaction reduces infiltration rates. Low CBR soils (<4%) may require compaction and/or stabilization for vehicular traffic applications. Drains also would typically be required for low CBR soils. If soils must be compacted, the reduced infiltration rates should be factored into the design. Permeable and porous pavements should not exceed 5% slope for maximum infiltration.

Goodbys Marina - Jacksonville, FL

Permeable interlocking concrete pavements are typically built over open-graded aggregate bases consisting of washed, hard, crushed stone, though a variety of aggregate materials, including dense-graded, may be used depending on project parameters. Typically, stone materials should have less than 1% fines passing the No. 200 sieve.

Current industry recommendations include a subbase of open-graded aggregate (typically ASTM No. 2 or equivalent) at a minimum thickness of 6 in. (150mm) for pedestrian applications and 8 in. (200mm) for vehicular applications. This makes it easier for contractors to install the base materials. A base layer of open-graded aggregate (typically ASTM No. 57 or equivalent) is installed over the subbase. This helps meet filter criteria between the layers. The recommended thickness for this layer is 4 in. (100mm). It may be possible, however, to use a single material for the base and subbase depending on project design parameters and contractor experience. Open-graded materials described here typically have a water storage void space between the aggregates of between 30-40%, which maximizes storage of infiltrated stormwater.

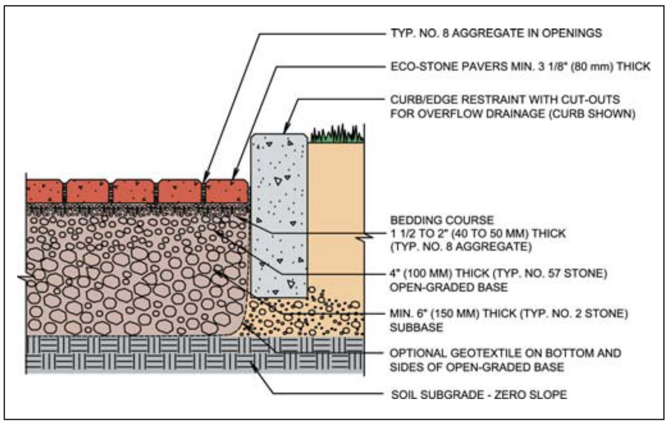

Figure 4 - Typical Cross-Section of an Eco-Stone® Permeable Pavement Full Exfiltration

For the bedding layer, material equivalent to ASTM No. 8 stone is recommended. This same material is used to fill the drainage openings and joints. If desired, material equivalent to No. 9, 10 or 89 stone also may be used to fill the smaller joints between the pavers. Bedding and jointing sand used in the construction of traditional interlocking concrete pavements should not be used for PICP.

Private Residence - Danvers, MA

The College School of Webster Groves - St. Louis, MO

UNI Eco-Stone® can be mechanically installed and trafficked immediately after final compaction, unlike other types of porous pavements. It has been used successfully for many years throughout North America and can withstand repeated freeze/thaw in northern climates due to adequate space for ice to expand within the open-graded base. PICP can be snow plowed, and because water does not stand on the surface, it may reduce ice slipping hazards. Winter sanding is not recommended on PICPs. Permeable interlocking concrete pavement conforms to current ADA requirements that surfaces be firm, stable, and slip resistant. If the openings in the surface are not desirable, solid pavers can be installed in areas used by disabled persons.

Maintenance

All permeable pavements require periodic cleaning to maintain infiltration, and care must be taken to keep sediment off the pavement during and after construction. Studies and field experience have shown that vacuum-type street cleaning equipment is most effective for removing sediment from the openings to regenerate infiltration. Vacuum settings may require adjustment to prevent the uptake of aggregate in the pavement openings and joints. The surface should be dry when cleaning. Replenishment of joint and opening aggregate can be done, if needed, at the time of cleaning. The frequency of cleaning is dependent on traffic levels. It is generally recommended to vacuum the pavement surface at least once or twice a year, though some low-use pavements may not need cleaning as often. As street cleaning is a BMP under EPA guidelines, this also satisfies other criteria in a comprehensive stormwater management program.

If properly constructed and maintained, PICP should provide a service life of 20 to 25 years. Like our traditional interlocking concrete pavers, Eco-Stone® may be taken up and reinstated if underground repairs are needed. If at the end of its design life the pavement no longer infiltrates the required amount of stormwater runoff, PICP is the only type of permeable pavement that can be taken up, the base materials removed and replaced, and the pavers reinstalled.

UNI ECOLOC® HEAVY-DUTY PERMEABLE INTERLOCKING CONCRETE PAVEMENT

Ecoloc® features all the same attributes and features of our Eco-Stone® permeable paver with the added benefit of supporting industrial loads. It can be used together with our industrial traditional interlocking paver, UNI-Anchorlock® to provide design professionals with the option of combining solid pavement areas with permeable areas.

Ecoloc® with UNI-Anchorlock®

Like Eco-Stone®, Ecoloc® features funnel-shaped openings that facilitate the infiltration of stormwater runoff. Physical characteristics are described in Figure 5.

Physical Characteristics

Height/Thickness	3 1/8"	=	80mm
Width	8 7/8"	=	225mm
Length	8 7/8"	=	225mm
Pavers per sq ft		=	2.41
Percentage of drainage void area per sq ft		=	12.18%

Composition and Manufacture

Minimum compressive strength - 8000psi
Maximum water absorption - 5%
Meets or exceeds ASTM C-936 and freeze-thaw testing per section 8 of ASTM C-67.

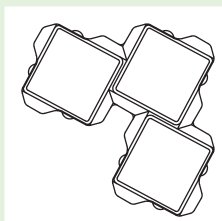

Figure 5

Ecoloc® can be mechanically installed and is ideal for larger-scale projects such as parking lots, roadways, storage and depot areas, and ports. Over 173,000 sf of Ecoloc® was used for an EPA Section 319 National Monitoring Permit Project at Morton Arboretum in Illinois. It also is in use at a test site located at Howland Hook Terminal at the Port of New York/New Jersey that is subjected to heavy, containerized loads, port forklifts and cargo carriers. Another 30,000 sf of Ecoloc® was installed at the East Gwillimbury Go Commuter Train Station parking lot in Newmarket, Ontario.

Seneca College - Toronto, Ontario

Morton Arboretum - DuPage County, IL

In addition, Ecoloc® is undergoing an evaluation at Seneca College in Ontario for the Toronto and Region Conservation Authority to study permeable interlocking concrete pavement performance in cold climates conditions.

Please check with your local UNI® manufacturer for availability of Ecoloc® in your area. Please visit our website www.uni-groupusa.org for updated information, design references and research, a list of manufacturers, and more.

East Gwillimbury Go Commuter Train Station - Newmarket, Ontario

REFERENCES & RESOURCES

- *Annual Report - Jordan Cove Urban Watershed Section 319 National Monitoring Program Project*, University of Connecticut, 2003
- *UNI Eco-Stone® Design Guide and Research Summary*
- *Lockpave® Pro structural design software with PC-SWMM™ PP hydraulic design software*
- *Porous Pavements* - Bruce K. Ferguson, CRC Press, 2005
- *Permeable Interlocking Concrete Pavements* - Interlocking Concrete Pavement Institute, 2006

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