NORTH AMERICAN DESIGN GUIDELINES FOR PERMEABLE INTERLOCKING CONCRETE PAVEMENTS PART 2 – BASE SIZING, COLD CLIMATE DESIGN, CONTROL OF WATER QUALITY, CONSTRUCTION, AND MAINTENANCE

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ABSTRACT

The Interlocking Concrete Pavement Institute (ICPI) has introduced a manual for the selection, design, specification, construction, and maintenance of permeable interlocking concrete pavements, also known as permeable concrete block pavements. This paper provides highlights from the manual. The manual synthesizes literature on infiltration trenches, porous asphalt pavement, research on and practical experience with permeable interlocking concrete pavements. The manual is for design professionals and municipal authorities who regulate stormwater runoff. The design procedure utilizes well-established methods for calculating runoff by the United States Soil Conservation Service (SCS), now the Natural Resources Conservation Service (NRCS). This paper is presented in two parts. Part 1 describes benefits, paver types, exfiltration options, site selection criteria, required design data, assessment of soil permeability, and pavement materials. Part 2 discusses base sizing methods, cold climate design, control of water quality, construction and maintenance. References for Part 1 and Part 2 are listed at the end of Part 2.

1. SIZING AN OPEN-GRADED BASE FOR STORMWATER INFILTRATION AND STORAGE

The following design method is adapted from the *Maryland Stormwater Design Manual* published by the State of Maryland Department of the Environment (22). The procedure is from "Method for Designing Infiltration Structures." This method assumes familiarity with SCS (NCRS) TR 55 method (23) for calculating stormwater runoff. References 3 and 4 provide other methods. Provinces, states, and cities may mandate the use of other methods. The Maryland method is provided because it has been refined over many years and it illustrates important aspects of infiltration design.

The catchment for permeable interlocking concrete pavement consists of the surface area of the pavement and an area that contributes runoff to it. A schematic cross-section and the design parameters are shown in Figure 1. The base is sized to store the runoff volume from the pavement area and the adjacent contributing areas.

Soil with infiltration rates or permeability less than 2×10^{-6} m/sec are generally silt loam, loam, sandy loam, loamy sand, and sand. Soils with lower permeability will limit the flow of water through the soil. They will require a high ratio of bottom surface area to storage volume. Therefore, careful consideration should be given to designing drain pipes to remove excess water in these situations.

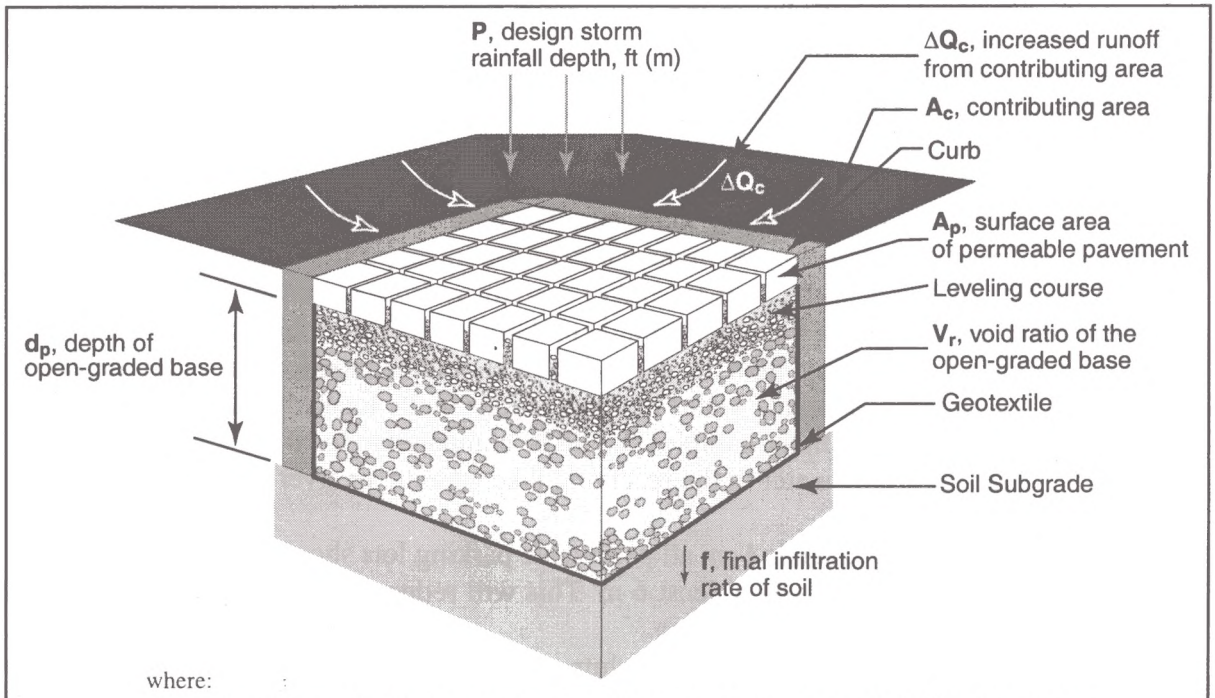
The Maryland method finds the maximum allowable depth of the pavement (d_{max}) for a maxi-

mum storage time of 3 days. Shorter storage times are desirable to minimize risk of continually saturated and potentially weakened soil subgrade for areas subject to vehicular traffic. In that light, calculations should be done for 1 and 2 days, as well as 3 days, tc compare differences in base thickness. In some instances, the calculated depth of the base for storage may be too shallow to support vehicular traffic. In these cases, the minimum base thickness would then be the depth required to accommodate traffic per Figure 2.

The values in Figure 2 are adopted from thickness designs for permeable asphalt pavement (24) (25). Their use rests on the assumption that 80 mm thick concrete pavers provide a similar structural contribution to an equivalent thickness of porous asphalt. The base thicknesses assume that the strength of the soil subgrade is at least 5% CBR (elastic modulus of 7,500 psi or 50 MPa).

The SCS (NRCS) method typically uses 24-hour storm events as the basis for design. Therefore, this design method is based on controlling the increased runoff for a specific 24-hour storm. The specific duration and return period (e.g., 6-months, 1-year, 2-year, etc.) are provided by the locality. If the increase in peak discharge associated with storm event cannot be managed, a first flush event should be the minimum selected for design.

For runoff storage, the maximum allowable base depth in meters should meet the following criteria:



where:

f = the final (design) infiltration rate in m/hr of the soil under the pavement (infiltration rates are determined from permeability tests and engineering judgement);

$\mathbf{T_s}$ = the maximum allowable storage time of 72 hours; and

$\mathbf{V_r}$ = the void ratio of the crushed stone base (typically 0.4)

$\mathbf{A_c}$ = contributing area, m^2

$\mathbf{DQ_c}$ = increased runoff from contributing area, m per a given design storm

$\mathbf{A_p}$ = surface area of permeable interlocking concrete pavement, m^2

P = design storm rainfall depth, m

f = final infiltration rate of underlying soil, m/hr

$\mathbf{d_p}$ = depth of crushed stone base, m

T = effective filling time of the base, hours (2 hours is typical)

Figure 1. Design parameters for calculating the base depth for permeable interlocking concrete pavements.

$$d_{max} = f \times T_s / V_r$$

As shown in Figure 10, the design volume of water to be stored in the pavement base (V_w) is:

the runoff volume from the adjacent contributing area;		plus	the rainfall volume falling on the permeable pavement		minus	the exfiltration volume into the underlying soil
=	DQ_cA_c	+	PA_p		—	fTA_p

Values of f for infiltration rate should be obtained from Figure 3 for preliminary designs and checked against field tests for the infiltration rate of the soils.

1.1 Protection Against Flooding From Extremely Heavy Rainstorms

There may be cases of extreme rainfall completely saturating the entire pavement structure. Drainage pipes should be built into the open-graded base to handle overflow conditions. As an added measure of protection, there should be provision for an overflow area, by-pass, or drainage swale adjacent to the parking lot should it be completely saturated and flood. An example of a drainage swale designed to handle overflows from an adjacent pervious parking lot is illustrated in Figure 4. Placing pre-treatment filter areas upslope from the pavement to reduce pollutants is a recommended when space allows.

1.2 Cold Climate Design

The following design considerations apply to freezing climates with extended winters having large, rapid volumes of snow melt in the late winter and early spring (26). These areas are mostly in the northern U.S. and Canada.

1. Permeable interlocking concrete pavements should not be used in permafrost regions.
2. Chlorides and road abrasives (sand) can be concentrated in snowmelt. It's impossible for any best management practice, including permeable interlocking concrete pavements, to remove chlorides found in deicing materials. The chlorides will kill grass if it used in the joints, and road sand can clog and reduce the infiltration capacity of these pavements. It is best to stockpile snow with chlorides and/or sand away from permeable interlocking concrete pavements. Possible locations include parking lot islands or bioretention areas.
3. If salts are used for deicing, then the groundwater should be monitored for chlorides. This can be done through sampling water in observations wells located in the pavement base and soil. Chloride levels in the samples should be compared to local or national criteria for the particular use of the water in the receiving lake, stream, or river (e.g., drinking water, recreation, fishing, etc.).
4. When the frost depth exceeds 1 m, all permeable parking lots should be set back from the subgrade of adjacent roads by at least 6 m. This will reduce the potential for frost lenses and heaving of soil under the roadway.
5. Permeable pavements subject to large volumes of snowmelt typically could receive large loads of sediment in the form of road abrasives. Therefore, the use of bedding sand, topsoil and vegetation in the joints are not recommended. Crushed aggregate is recommended for the joints and bedding as its tendency to clog is much lower than sand or topsoil.
6. Plowed snow piles and snow melt should not be directed to permeable interlocking concrete pavements if groundwater contamination from chlorides is a concern. However, this may not be possible to avoid in some situations. If high chloride concentrations in the runoff and groundwater are a concern, then consideration should be given to using one or two design options below:
   (a) Runoff from snow melt can be diverted from the pavement during the winter. The diversion of runoff away from the pavement is typically through channels or pipes. They must be operated each winter and spring. Snowmelt, however, is not treated but

diverted elsewhere.

(b) Oversized drainage pipes can be used to remove the runoff during snowmelt, and then be closed for the remainder of the year.
The owner of the pavement must take responsibility for operating pipes that divert snowmelt. This may not be realistic with some designs.

7. Maintenance should include annual inspection in the spring and removal of surface sediment, as well as monitoring of groundwater for chlorides. This is paramount to continued infiltration performance.

1.3 Design for Control of Water Quality

Since urbanization significantly alters the land's capacity to absorb and process water pollutants, an increasing number of localities are regulating the amount of pollutants in stormwater. This is particulary the case when drinking water supplies and fishing industries require protection.

Permeable interlocking concrete pavements designed as an infiltration area over an open-graded base can reduce nonpoint source pollutants in storm water. Figure 5 illustrates the projected average annual pollutant removal capability of infilitration areas. These are useful estimates for permeable interlocking pavements.

2. CONSTRUCTION

The ICPI manual includes a guide specification for construction that follows the Construction Specifications Institute (CSI) format, a standard format for specifications used by design and construction companies throughout North America. Also included in the manual and not provided here is a construction checklist and material specifications for drain pipes.

	Soaked CBR of Subgrade Soil			Frost Conditions			
ESALs* over 20 yrs.	>15	10 to 14	5 to 9	Gravelly Soils	Clayey Gravels, Plastic Sandy Clays	Silty Gravel, Sand, Sandy Clays	Silts,Silty Gravel, Sand, Silty Clays
50,000	125	175	225	175	250	300	**
150,000	150	200	275	250	300	350	**
600,000	175	225	350	300	450	550	**

*ESALs = 18 kip equivalent single axle loads

Note: All thicknesses are after compaction and apply to all exfiltration conditions. Greater thicknesses may be required in soils subject to frost heaving. Pedestrian applications should use a minimum base thickness of 6 in. (150 mm).

**Strengthen subgrade with crushed-stone aggregate sub-base to full frost depth.

Note: Silt soils or others with more than 3% of particles smaller than 0.02 mm in size are considered to be frost susceptible.

Figure 2. Design parameters for calculating the base depth for permeable interlocking concrete pavements.

		Soil Texture/Infiltration Rate m/sec										
		Sand	Loamy Sand	Sandy Loam	Loam	Silt Loam	Sandy Clay Loam	Clay Loam	Silty Clay Loam	Sandy Clay	Silty Clay	Clay
Criterion	T_s (hrs)	$6x10^{-5}$	$2x10^{-5}$	$7x10^{-6}$	$4x10^{-6}$	$2x10^{-6}$	$1x10^{-6}$	$6x10^{-7}$	$4x10^{-7}$	$3x10^{-7}$	$2x10^{-7}$	10^{-7}
fT_s/V_r	24	12.6	3.7	1.5	0.8	0.4	0.25	0.12	0.1	0.07	0.05	0.02
for	48	25.2	7.4	3.1	1.6	0.8	0.5	0.3	0.17	0.15	0.15	0.05
(V_r=0.4)	72	37.8	11	4.6	2.4	1.2	0.8	0.9	0.13	0.2	0.17	0.1

T_s = Maximum allowable storage time V_r = Voids ratio = Lowest values unless base exfiltration is supplemented with drain pipes.

Figure 3. Maximum allowable depths, m of storage for selected maximum storage times (T_s in hours), minimum infiltration rates, m/sec.

2.1 Reducing Clogging

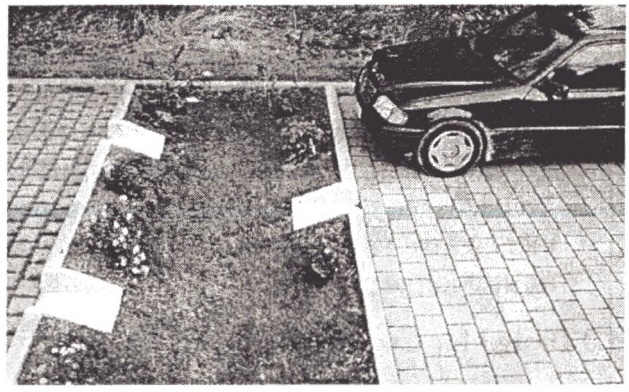


Figure 4. Curbing and drainage swale handle flows that exceed the design rainstorm.

Preventing and diverting sediment from entering the base and pavement surface during construction must be the highest priority. Extraordinary care must be applied to keeping sediment completely away from the area. Simple practices such as keeping muddy construction equipment away from the area, installing silt fences, staged excavation, and temporary drainage swales that divert runoff away from the area will make the difference between a pavement that infiltrates well or poorly. Moreover, the pavement should not receive runoff until the entire contributing drainage area is stabilized. These should be included in the construction drawings and specifications.

2.2 Soils, Geotextile, and Drain Pipes

If the initial undisturbed soil infiltration can be maintained during excavation and construction, there is a high probability that the base will drain as designed. If the soil is inadvertently compacted by equipment during construction, there will be a substantial loss of infiltration. A loss is acceptable if the infiltration rate of the soil when compacted was initially considered during design and in drainage calculations.

Systematic compaction, however, may be necessary to attain sufficient structural support. The soil subgrade should be compacted to at least 95% of standard Proctor density (27)(28) for pedestrian areas and to a minimum of 95% modified Proctor density (29)(30) for vehicular applications. Drains in the open-graded base will likely be required to remove water since compaction will greatly reduce the soil's permeability.

Geotextiles are used in almost all permeable pavement applications. Specifications and minimum physical requirements for geotextiles for separation and drainage can be found in reference 14 by AASHTO. For vehicular applications, high-quality fabric should be specified that resists the puncturing by coarse, angular aggregate from compaction during construction and from repeated wheel loads during its service life.

Bases should have their sides and bottoms wrapped in geotextile. Overlap recommendations are provided in AASHTO specifications (min. 0.6 m). If pavers are placed on bedding sand, geotextile should be used between bedding sand and the No. 8 aggregate base choke course to prevent loss of bedding sand into the surface of the larger No. 8 material.

2.3 Open-graded Aggregate Bases

After installation of geotextile over the soil subgrade, No. 57 base material should be spread in 100 to 150 mm lifts and compacted with a static roller at approximately 1,200 Hz. At least 4 passes should be made with a minimum 9 T steel drum roller. A test section of the base should be constructed and closely monitored during compaction. The section will indicate settlement of the pavement section, and whether crushing of the aggregate is excessive. The area should be used to train construction personnel on these and related aspects.

When all lifts are compacted the surface should then topped with a 75 mm thick layer of moist No. 8 crushed stone. This layer of finer crushed stone is leveled and pressed (choked) into the top of the No. 57 base with at least 4 passes of a 9 T static roller. The No. 8 should be moist to

Pollutant	Infiltration Trench Design Type		
	13 mm of Runoff per Impervious acre	25 mm of Runoff per Impervious acre	2-year Design Storm Treatment
Total Suspended Solids	60-80	80-100	80-100
Total Phosphorous	40-60	40-60	60-80
Total Nitrogen	40-60	40-60	60-80
Biological Oxygen Demand	60-80	60-80	80-100
Bacteria	60-80	60-80	80-100
Metals	60-80	60-80	80-100

Note: These rates are not based on actual data since monitoring what enters and leaves any infiltration facility is dificult to measure. These data are based on land application of pollutants and their treatment through soils. 1 acre = 0.4 ha

Figure 5. Projected Average Annual Pollutant Removal Capability of Infiltration Areas in Percent (from Debo and Reese (3) after Schueler)

facilitate movement into the No. 57. The surface tolerance of the compacted No. 8 material should be ±13 mm over 3m.

The minimum surface tolerance of the compacted, open-graded aggregate or sand used for the bedding should be ±10 mm over a 3 m straightedge. The base surface is typically flat and level. The surface of a dense-graded base should have a 2% minimum slope to facilitate drainage of the water from the bedding sand layer.

The concrete pavers should be placed immediately after the No. 57 and No. 8 base courses are placed and compacted. This will reduce the chance of construction equipment passing over the base and contaminating it with sediment. Equipment drivers should avoid rapid acceleration, hard braking, or sharp turning on the compacted base layers.

2.4 Stabilized Bases

Open-graded bases may be stabilized with asphalt prior to placement. Stablilize the No. 57 layer and not the No. 8 layer used for bedding. The use of asphalt will likely reduce the storage capacity of the base, but stabilization may be necessary in weak soils, those subject to frost, or under high loads. To maintain high void space, only enough asphalt to coat the aggregate is required. For further information on the design and construction of asphalt bases, see reference 31.

Likewise, cement should be applied to only coat the aggregate for the base, and care should be taken not to fill the voids with excess paste. The amount of portland cement required is typically 170 kg/m^3. The water-cement ratio should be controlled to make a paste to coat the aggregate.

2.5 Edge Restraints

Recommended edge restraints for permeable interlocking concrete pavements on open-graded bases are cast-in-place and precast concrete curbs. They should be a minimum of 150 mm wide and 300 mm deep. Consideration should be given to providing a stable footer or concrete haunch under the curbs.

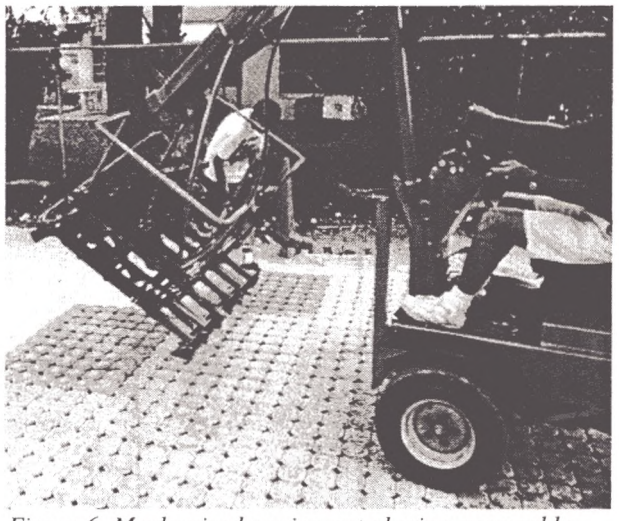


Figure 6. Mechanized equipment placing permeable pavers at a rate as high as three times greater than manual methods. This project is a parking lot.

2.6 Paver Installation

For units 80 to 100 mm thick, the plate compactor should exert a minimum 22 kN at 75 to 90 Hz. For units thicker than 100 mm, the compactor used on them should exert at least 30 kN. After initial compaction, the joints or openings are filled with No. 8 material and the paving units are compacted again. Excess stone is removed by sweeping.

Paver installation can be by hand or with mechanical equipment. Mechanized installation may be a cost-efficient means to install the units and will reduce the installation time. Figure 6 shows mechanized equipment placing permeable pavers for a parking lot adjacent to a baseball field. Figure 7 illustrates mechanized placement of pavers whith widened joints.

Units should be cut to fill spaces along the edges prior to compaction. All installed units should be compacted into the bedding sand or No. 8 aggregate and joints filled with the appropriate material at the end of each day.

3. MAINTENANCE

Permeable interlocking concrete pavements can become clogged with sediment over time, thereby slowing their infiltration rate and decreasing storage capacity. Clogged openings are a major cause of failure. The rate of sedimentation depends on the amount of traffic and other sources that wash sediment into the joints, base and soil. Since the pavement is detaining runoff that contains sediment, there may be a need to eventually remove and replace the base material when the infiltration is reduced to such a degree that the pavement is no longer performing its job in storing and exfiltrating water. Figure 8 provides a checklist to reduce sedimentation and to prevent or repair other problems.

All permeable interlocking concrete pavements with an open-graded base should have an observation well. The well is typically a 150 mm diameter perforated pipe. It has a screw cap below the surface of the pavers at least 25 mm that can be removed to observe the rate of exfiltration. The cap should lock and be vandal-resistant. The depth to invert should be marked on the lid.

Snow can be plowed from pavers as with any other pavement. If a unit cracks from soil or base settlement, it can be re-

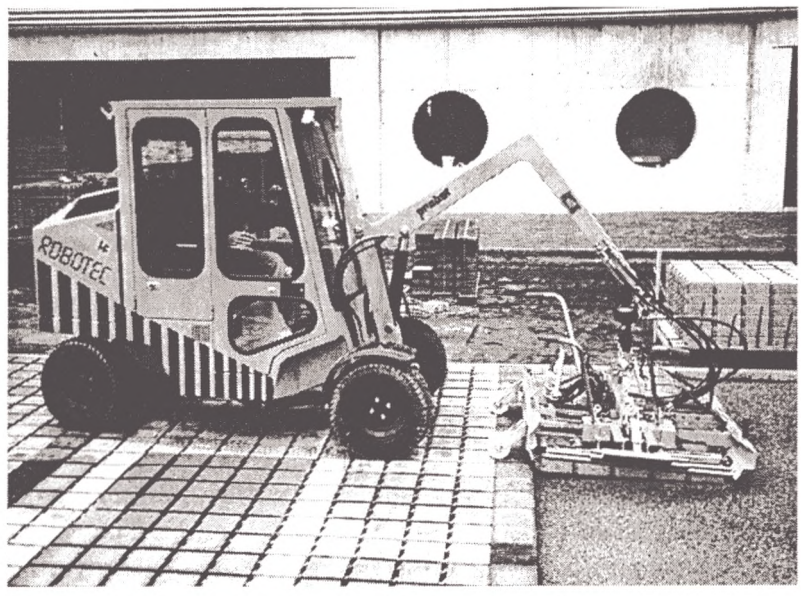


Figure 7. Mechanized placement of pavers with wide joints.

In-service Inspection Checklist

- ❑ Vacuum surface openings to remove dry, encrusted sediment. These appear as small, curled "potato chips."
- ❑ Inspect after at least one major storm per year.
- ❑ Vegetation maintained around pavement to filter runoff.
- ❑ No standing water on the surface after storms.
- ❑ Repair ruts or deformations in pavement exceeding 13 mm.
- ❑ Repair pavers more than 1/4 in. or 6 mm above/below adjacent units.
- ❑ Replace broken units that impair the structural integrity of the surface.
- ❑ Replenish aggregate joint materials as needed.
- ❑ Check drain outfalls for free flow of water.
- ❑ Check outflow from observation well annually.

Figure 8. A maintenance checklist

moved and replaced. Likewise, the same units can be reinstated after repairs to the base, drain pipes, liners, or to underground utilities.

The owner of permeable interlocking concrete pavement plays a key role in maintenance and successful long-term performance of permeable interlocking concrete pavements. The owner should have long-term ownership and oversight of property, and be made aware of the maintenance requirements that follow. As with other BMPs, municipalities may require maintenance agreements with property owners to ensure that the pavement is systematically maintained. Such agreements can include the items listed in this section.

4. CONCLUSION

Sizing the base for permeable interlocking concrete pavement is a straightforward exercise. It relies on design procedures used for infiltration trenches that have been refined over the past fifteen years. The example provided in this paper is taken from a manual published by a state that is considered a leader in stormwater management and nonpoint source water pollution control. Other states have similar methods tuned to local rainfall patterns, materials, and construction practices.

Water exfiltrated from the base and not absorbed by the soil subgrade is removed from the bottom of the base with perforated pipes. Water can be stored in larger underground pipes or directed to a stream, storm sewer, pond or lake. Rain events that exceed the storage and drainage rate of the base and pipes should be handled with overflow channels along the perimeter of the permeable interlocking concrete pavement. This will avoid temporary shallow flooding.

Construction of permeable interlocking concrete pavements is in part a concentrated exercise in erosion and sediment control since sediment brought into the base and soil subgrade from equipment and improper controls will compromise infiltration. Laboratory or in-situ studies that examine the relationship between density and infiltration may be required to gain a better understanding of the infiltration characteristics of the soil, and how much compaction to apply during construction.

As with detention ponds, permeable interlocking concrete pavements cannot be constructed and left unattended for years while expecting them to continue infiltrating stormwater. The maintenance guidelines provided are a framework for application and fine tuning to a particular site location. The ICPI manual provides a model maintenance agreement between an owner of a permeable interlocking concrete pavement and a local municipality. It can be modified to suit local environmental and legal conditions.

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Owners play a key role in keeping permeable interlocking concrete pavements free from sediment, weeds, and spills. This installation filters runoff prior to entering the Chesapeake Bay in Maryland, USA.

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