Permeable Interlocking Concrete Pavement for Stormwater Management

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Purpose and Learning Objectives

Purpose:

Permeable interlocking concrete pavement (PICP) has the ability to create solid, strong surfaces for pedestrians and a range of vehicular uses; it can help maintain a site's existing natural hydrologic function and reduce the overall impact of development. This course discusses the components of a PICP system and how they work together to manage stormwater in a variety of applications. Also addressed are hydrological and structural factors to consider when designing with PICP and how PICP contributes to sustainable building goals and projects.

Learning Objectives:

At the end of this program, participants will be able to:

- describe the harmful environmental and health effects of impervious surfaces and excessive stormwater runoff
- list the components of a PICP system and describe how they contribute to reducing or eliminating runoff
- discuss the PICP system design considerations for control of water quality, quantity, and/or harvesting and for vehicular use, and
- explain how a PICP system is an EPA best management practice, is part of a low-impact development strategy, and can help earn credits in a LEED® project.

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 judgment. It is not intended to replace the services of experienced, professional engineers.

Contents

Introduction to Stormwater Control

Impervious Surfaces

To make our cities safe and clean, our buildings dry, and our roads secure, we collect water off the impervious surfaces in our cities and towns, draining it to storm sewers and piping it from where it fell to somewhere else.

We deny the land beneath our towns a regular allotment of rain, creating larger amounts of runoff that pick up soils, pesticides, oil, grease, and salt and carry these to the outflow. Surges in downstream rivers during heavy rainfall erode streambanks and damage aquatic systems.

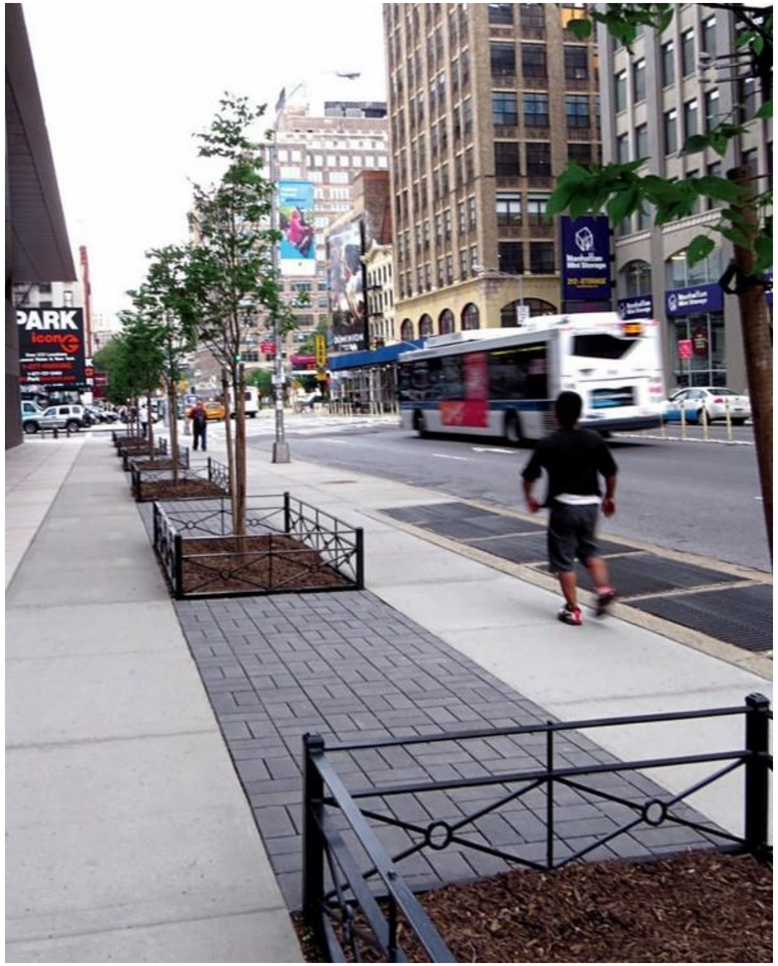
Many believe this tampering with the natural hydrologic systems has made the land unable to respond to the yearly ebb and flow of water, leaving some areas with regular large-scale flooding and others in drought.

Impervious Surfaces

Urban areas typically have 75–100% impervious surface cover. Only 15% of precipitation infiltrates the ground, and a full 55% remains on the surface as stormwater runoff (as opposed to 10% in an area of natural ground cover).

The effects of this type of stormwater management are evidenced in our polluted water bodies and damaged aquatic habitats, to name only two impacts. Consequently, there has been a rethinking of the stormwater design philosophy, apparent in guidelines from organizations such as the EPA in its National Pollutant Discharge Elimination System (NPDES) program and USGBC’s LEED® rating system.

Many municipalities have turned these guidelines into regulations within their stormwater management plans with an eye to reducing the amount of runoff—thus minimizing pollutant discharge and protecting downstream water bodies. For many municipalities, the overarching goal is to maintain a site’s existing natural hydrologic function and reduce the overall hydrological impact of development.

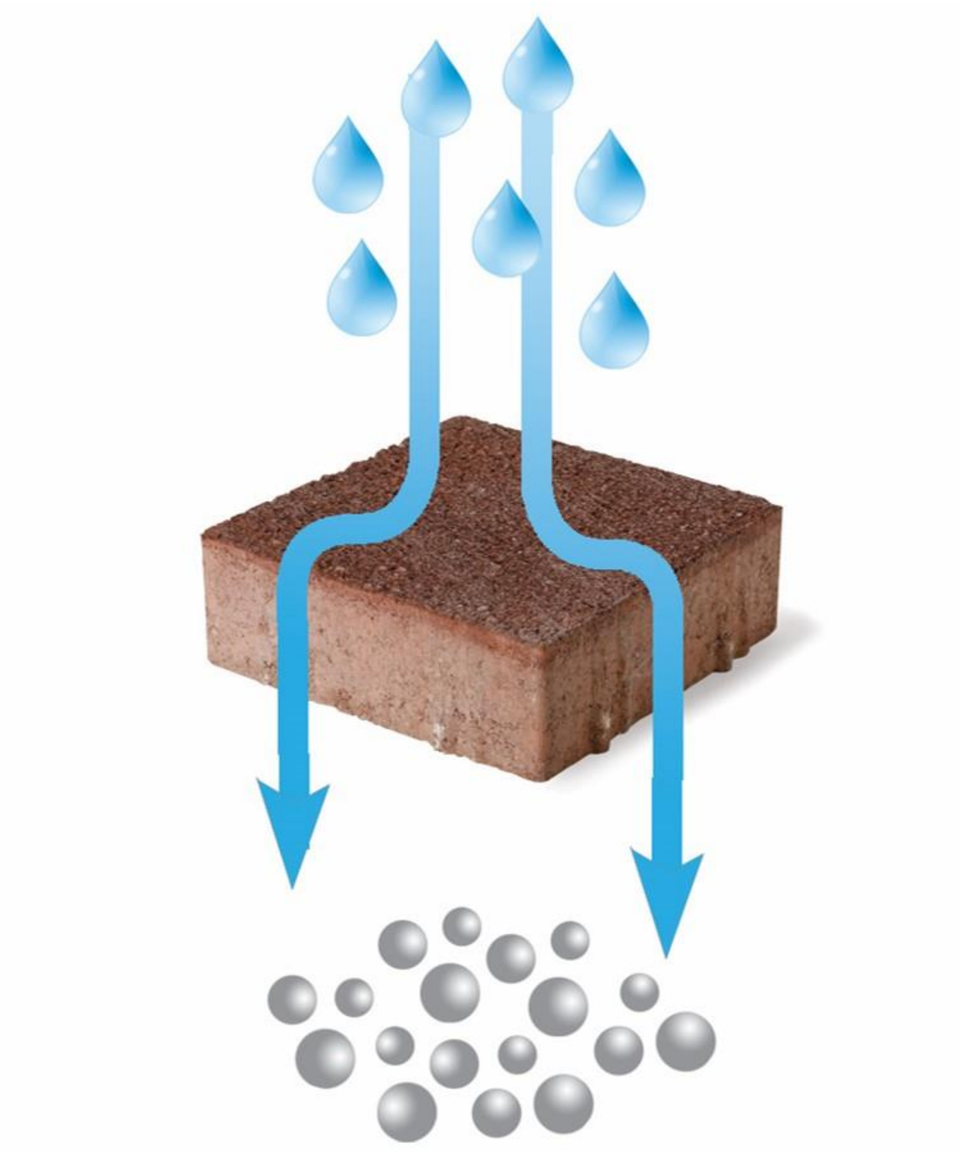


Permeable/Pervious Surfacing Materials

There is no doubt that to really understand natural hydrologic patterns, we cannot simply look at a particular site as detached from its surroundings. A watershed does not stop at a lot line. However, once a regional or watershed examination is done, small changes made at the site level can do much to either restore or maintain natural patterns. Many of these changes include using materials that allow rain to infiltrate where it falls.

These materials fall into the category of permeable or pervious surfaces. Used in conjunction with bioretention, dry wells, filter strips, grassed swales, and other management practices, they contribute to reducing runoff, increasing infiltration of rainwater, and reducing pollutants, thereby working towards maintaining the predevelopment hydrology of a site.

The type of pervious surfacing material we'll take a look at in this course is permeable interlocking concrete pavement (PICP).



Permeable Interlocking Concrete Pavement

PICP

Permeable interlocking concrete pavement (PICP) is surfaced with unit block pavers that allow for an expanded joint between units. The joint size is usually controlled by enlarged spacer bars cast into the units or by the predetermined shape of the individual unit. The joints range in size from ⅛″ to ½″.

The openings in the paved surface typically compose 5% to 12% of the paver surface area. The joint is then filled with open-graded aggregate, making the pavement surface permeable.

PICP Design

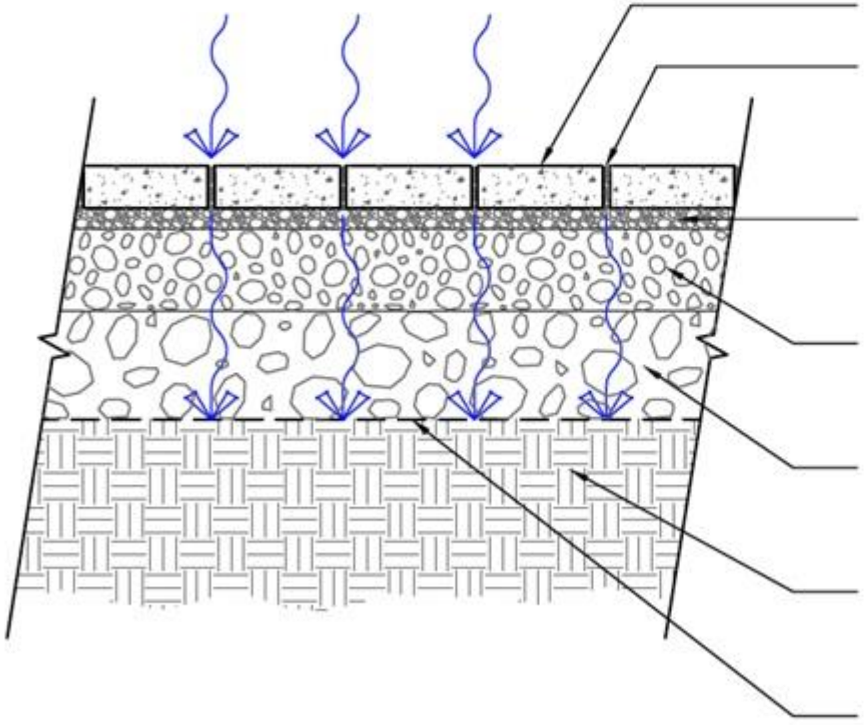
With various aesthetically pleasing colors and textures, PICP does not compromise design and creativity. Concrete pavement is a very durable product, requires little maintenance, and can withstand heavy loading. Pavers can be manufactured in different shapes, colors, and finishes without added customization expenses.

PICP System

The units form part of a pervious paving system composed of the layer of concrete pavers with open-graded permeable joints and an open-graded base (crushed stone).

PICP is considered a structural best management practice (BMP) under the EPA's infiltration guidelines.

PICP System



PICP Benefits

The benefits of using permeable interlocking pavement over impermeable surfaces go beyond simply reducing or eliminating runoff.

PICP uses open-graded aggregates in the setting bed, base, and subbase that allow for water detention before exfiltration into the ground below. PICP can be designed to reduce the size of, or eliminate completely, retention basins used in traditional infrastructure design.

The use of PICP means more water absorption by the soil, increased recharge of groundwater, reduced peak discharges, reduction of downstream flows and stream bank erosion, elimination of flooding of paved areas, and lowered temperatures of the stormwater leaving the system.

PICP Benefits: Infiltration

With infiltration rates of greater than 500″ per hour, these systems are typically able to eliminate runoff completely for frequent, short duration storms, which make up 75–85% of all rainstorms in the US (Smith, 2000). But the infiltration rate of the soil below obviously plays a big role in the efficacy of the system.

Most soils, even clay, allow for infiltration (see chart). Soils with high porosity, like sand, can have a higher infiltration rate than the actual rate of rainfall, as most rainfall events only generate up to 0.5″ (12.7 mm) of water.

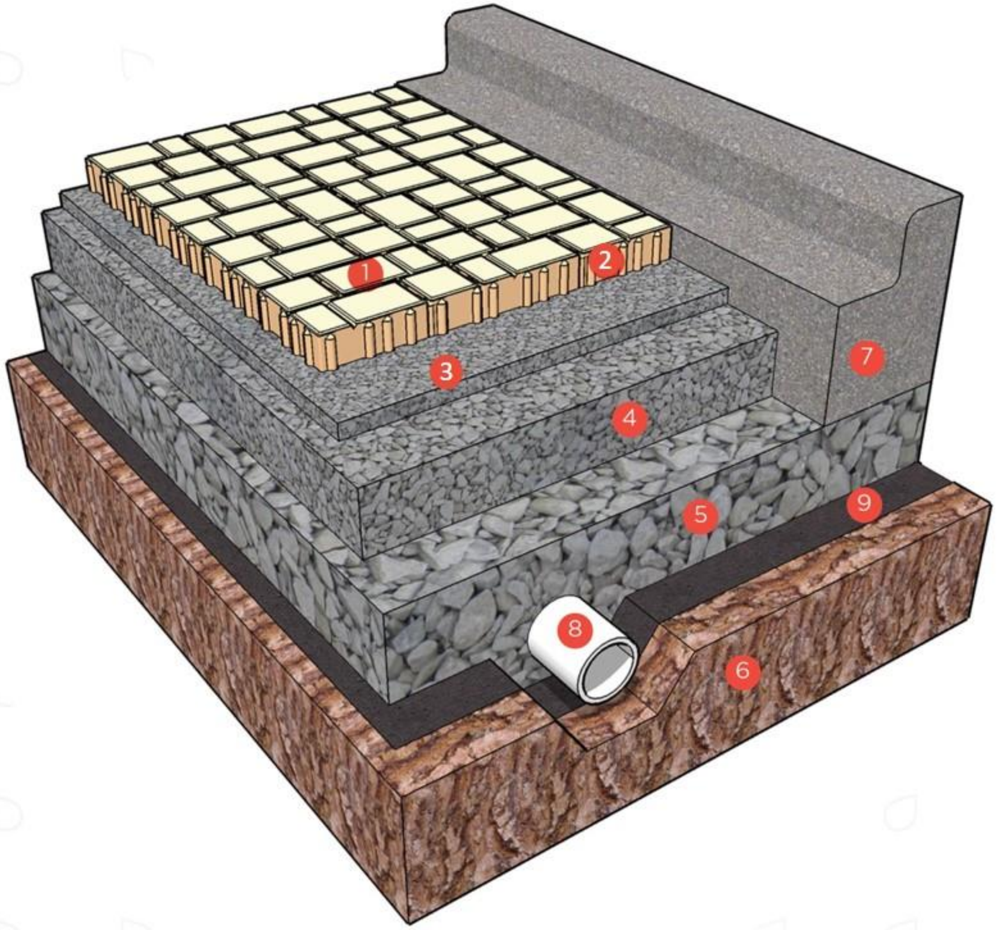
Typical Infiltration Rates of Various Soil Groups

Soil Conservation Service Group	Typical Soil Type	Saturated Infiltration Rate	
		in/hr	mm/hr
A	Sand	8.27	210
A	Loamy Sand	2.41	60
B	Sandy Loam	1.02	26
B	Loam	0.52	12.7
C	Silt Loam	0.27	6.8
C	Sandy Clay Loam	0.17	4.3
D	Clay Loam & Silty Clay Loam	0.09	2.3
D	Clay	0.06	1.5

PICP Benefits: Exfiltration Options

Full exfiltration means water infiltrates into the granular base and exfiltrates into the soil below. When rainfall amounts are expected to exceed the infiltration rate of the soil below the pavement, the system can be designed for partial or no exfiltration.

Partial exfiltration does not rely solely on the soil to absorb the water. A system of perforated pipe can be laid in the subbase layer to direct water to sewers, streams, or other basins.



In diagram:

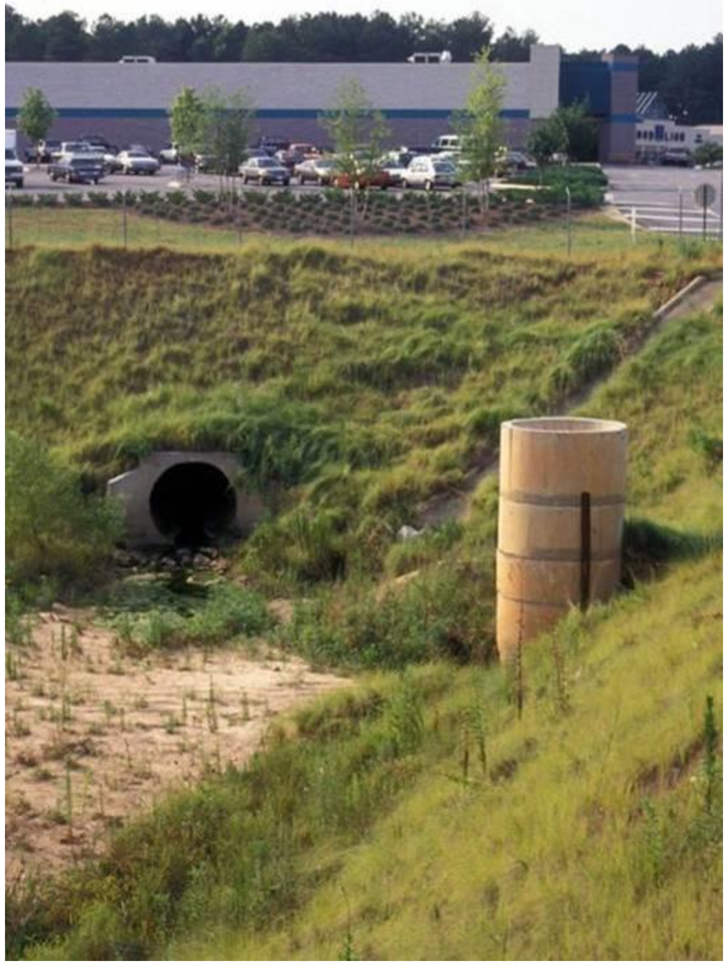
1. Concrete pavers
2. Joint aggregate ASTM No. 8 or 9
3. Open-graded bedding course
4. Open-graded base reservoir
5. Open-graded subbase reservoir
6. Soil subgrade
7. Concrete curb
8. Underdrain pipe
9. Optional geotextile

PICP Benefits: Exfiltration Options

No exfiltration systems are used when the soils below have very low permeability or there are site conditions that require water not to exfiltrate. If either of these conditions occurs, an impermeable liner is used at the bottom and sides of the system to contain the water. Perforated pipes within the system connect to sewers or streams.

In this situation, the PICP system acts as a detention pond and eliminates exfiltration into the ground below the PICP. This scenario is used when the depth from the bottom of the base to the high level of the water table is less than 2 feet, when there is not adequate depth of soil to filter pollutants from the water, or when the PICP system is built directly over solid rock.

Alternatively, this scenario can be used for **rainwater harvesting**. PICP is capable of storing water for on-site irrigation or building graywater use. It can be designed with underground stormwater storage systems over many slower-draining clay soils or an impermeable liner on the bottom and sides of the open-graded base.



PICP Benefits: Pollutant Reduction

Runoff from impervious areas carries pollutants such as phosphorus, metals, and sediment into surface waters where they adversely impact water quality. These types of pollutants are called **non-point source pollutants** as they do not come from one specific source, such as a manufacturing plant. Permeable pavement has been shown to both reduce the quantity and improve the quality of stormwater runoff.

Median Pollutant Removal (Source: ICPI)

Pollutant	Runoff			Infiltration Trenches & Porous Pavement
	0.5″ (13 mm) of Runoff per Impervious Acre	1.0″ (25 mm) of Runoff per Impervious Acre	2-Year Design Storm Treatment	Median Pollutant Removal
Total Suspended Solids	60–80%	80–100%	80–100%	95%
Total Phosphorous	40–60%	40–60%	60–80%	70%
Total Nitrogen	40–60%	40–60%	60–80%	51%
Biological Oxygen Demand	60–80%	60–80%	80–100%	—
Bacteria	60–80%	60–80%	80–100%	—
Metals	60–80%	60–80%	80–100%	99 (Zn)%

PICP Benefits: Pollutant Reduction

PICP reduces pollutants through a number of methods. The aggregate filters the stormwater and allows sedimentation to occur, reducing the amount of total suspended solids (TSS). Subgrade soils also contribute through bacterial treatment of the pollutants and cation exchange, specifically in clay soils. (Sandy soils, though fast to infiltrate water, do not contribute to pollutant removal as much as clay soils.) Also, beneficial bacteria growth has been found on established aggregate bases.

Water temperature is another important quality issue. Because the rainwater infiltrates immediately into the PICP system, it maintains a lower temperature compared to surface runoff. Increased water temperatures in runoff can lead to increased bacteria and algae. The rapid influx of warmer water into natural streams and lakes can produce a thermal shock and death in fish and other aquatic life.

The EPA recognizes permeable paving as a BMP for non-point source pollutants. Using this method is a simple step to ensuring cleaner water.

PICP Benefits: Heat Island Effect Reduction

As the built environment expands and replaces natural settings, the cooling effects from both shade and evapotranspiration are eliminated. This leads to areas with ambient temperatures up to 10°F higher than their surroundings, called **heat islands**. The use of dark, nonreflective materials for roofs, roads, walkways, and other surfaces contributes to this effect because the materials absorb the heat from the sun and radiate it into the surroundings.

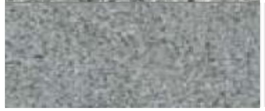
Solar reflectance index (SRI) is a measure of a material's ability to reject solar heat, as shown by a small temperature rise. It is defined so that a standard black (reflectance 0.05, emittance 0.90) is 0 and a standard white (reflectance 0.80, emittance 0.90) is 100.

Solar reflectance (SR) is the fraction of solar energy that is reflected by a surface, measured on a scale of 0 to 1. Black paint has a solar reflectance of 0; white paint (titanium dioxide) has a solar reflectance of 1. The standard technique for its determination uses spectrophotometric measurements, with an integrating sphere to determine the reflectance at each wavelength. The reflectance is then determined by an averaging process using a standard solar spectrum, as documented by ASTM E903 and E892.

PICP Benefits: Heat Island Effect Reduction

PICP, as a concrete product, can be manufactured in a wide range of colors including light-colored, high-albedo materials. The chart at right shows a sample of colors generally available and their related SRI and solar reflectance values.

Rule of thumb: An increase in SR of 0.10 produces a decrease in pavement temperature of about 7°F (+/- 2°F) (Lawrence Berkeley National Laboratories: Pomerantz, 2000).

Color	Finish Type	Solar Reflectance	SRI
	Smooth Aggregate	0.35	38
	Smooth Aggregate	0.30	32
	Exposed Aggregate	0.39	44
	Exposed Aggregate	0.35	38
	Exposed Aggregate	0.31	33
	Exposed Aggregate	0.28	29

Where Not to Use PICP

PICP is not appropriate for all pavement locations. PICP should be sited at least 100 feet from water supply wells, streams, and wetlands. Designers should always verify compliance with local jurisdictional authorities. Also, PICP should not be used where storm runoff contains pollutants that may contaminate groundwater, e.g., vehicle salvage yards, industrial facilities that store hazardous wastes, or fueling stations.

Even though the infiltration rates of the PICP system are extremely high, maintaining this rate over the lifetime of the system will depend on the intensity of use, and especially the degree to which the system receives sediment. PICP should not be installed near a source of sediment or fines, and prevention of sediment or fines getting into the base and pavement surface during construction should be the highest priority.

PICP in Cold Climates

PICP installation remains stable during freeze/thaw cycles in cold climates and is used extensively in the northern US and Canada.

In cold climates, chlorides and sand are used for driver safety. Both of these materials are of concern when using PICP. Sand should never be used with PICP as it can clog the openings and reduce the infiltration capacity of the pavement. If salts are used for deicing, groundwater contamination could result.

If contamination is a concern, groundwater in the area of the PICP using salts should be monitored, or snow piles and snow melts should not be directed to PICP areas.

PICP and ADA Requirements

Open space between pavers varies. Many manufacturers produce pavers with joint sizes in the range of ¼″ (6.35 mm) to ½″ (12.7 mm). Although the ADA Accessibility Guidelines (ADAAG) do not specifically address openings between pavers, the ½″ horizontal maximum specified by the ADAAG for gratings is a good rule of thumb for these openings as well.

Pavers with ¼″ to ½″ joints will meet this guide and also allow a minimum of 100″ (2540 mm) per hour of surface infiltration.

PICP Durability

PICP is the most durable of any porous pavement material. The standard used for manufacturing dimensional pavers in the US is ASTM C936, "Standard Specification for Solid Concrete Interlocking Paving Units." This requires:

- the compressive test strength to be at least 8000 psi with no sample testing at under 7200 psi
- an average absorption no greater than 5%, and
- resistance to at least 50 freeze/thaw cycles with average material loss not exceeding 1%.

Some manufacturers exceed these requirements.

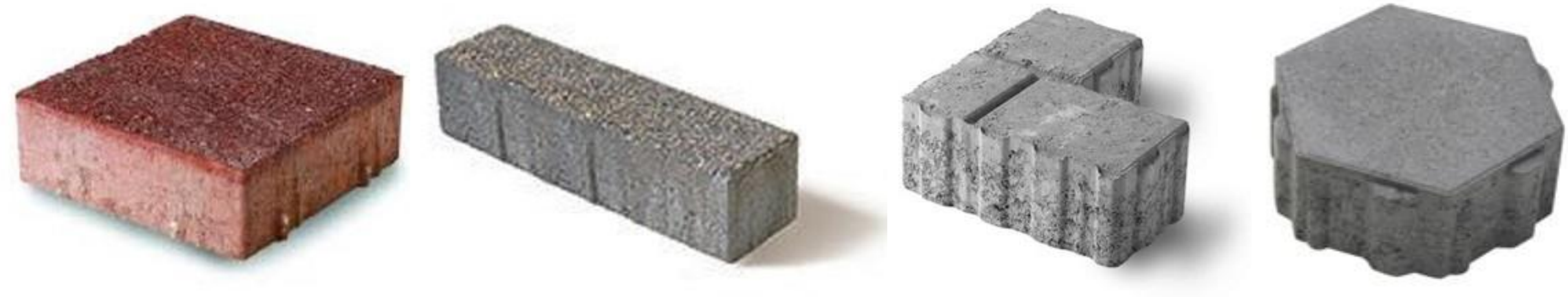
Pavers are typically manufactured 3 ⅛″ (80 mm) thick for vehicular areas and 2 ⅜″ (60 mm) thick for pedestrian areas.

The Canadian standard is CSA-A231.2. Please see the following website for details: https://www.csagroup.org/store/product/2700204/. (Accessed Jan. 2021.)

PICP Shapes

Since permeable pavers are manufactured, many different shapes are available. They are generally square, rectangular, L-shaped, and now even hexagonal. Some manufacturers will produce a paver style with varying joint widths to satisfy different project requirements.

The L-shaped and hex units prevent shifting or twisting due to vehicles braking and turning. This benefit increases the structural performance of the paver system and reduces annual maintenance costs.



PICP Surface Finish Options

Manufacturers offer a number of surface finishes to suit different applications. Options include an exposed aggregate finish, which provides longer-term wear and stronger structural performance, as well as standard, riven, brushed, mottled, smooth, and easy-maintenance finishes.

Review Question

How can PICP reduce the heat island effect?

Answer

The use of dark, nonreflective materials for roofs, roads, walkways, and other surfaces contributes to the heat island effect because the materials absorb the heat from the sun and radiate it into the surroundings.

PICP, as a concrete product, can be manufactured in a wide range of colors including light-colored, high-albedo materials, which absorb less heat.

PICP Design Considerations

PICP Design Goals

In contrast to the design of conventional pavement systems, when designing with PICP, both structural and water management design must be considered. Defining the application and use of the system will affect the type and thickness of paver and the type and amount of base materials. For instance, the system can be designed as a reservoir if harvesting is a requirement, or it can be designed for maximum pollutant removal by allowing for the settling of silts and small particles.

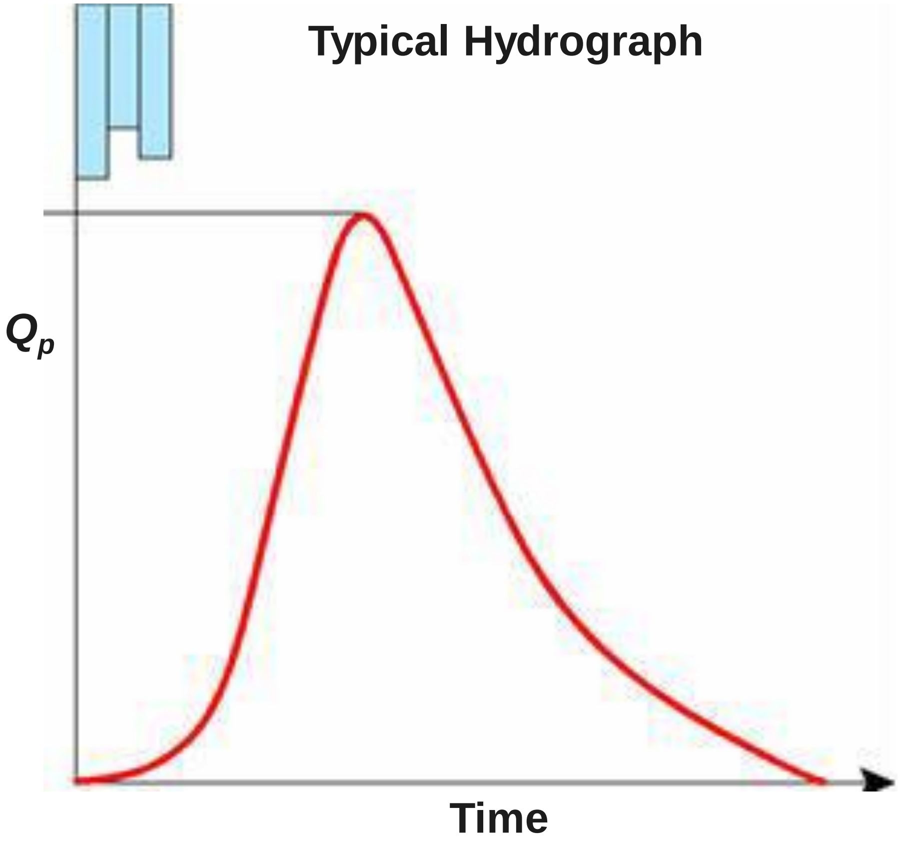
Typically, these systems are designed by a qualified engineer, but we will provide a brief overview of the considerations here.

The first steps are to determine the hydrologic design goals—whether the system is being designed for control of water quantity, for control of water quality, for water harvesting, or for any combination of these. A thorough understanding of the local regulations will identify type and minimum amount of control required.

Design Goal: Control of Water Quantity

Most systems are designed for control of runoff volume and peak flows. In natural areas, excess runoff is essentially the amount of rainfall not infiltrated into the ground or not held in “depressional” storage such as puddles, etc. In each watershed or drainage basin, runoff will flow downhill to small channels or streams and then further to larger bodies of water.

As the runoff accumulates, the quantity and speed of the water in any of these channels increases and then diminishes as the rainfall slackens. The figure at right shows a traditional runoff hydrograph. The peak discharge rate is shown as Q_p and the volume of runoff is the area under the curve.

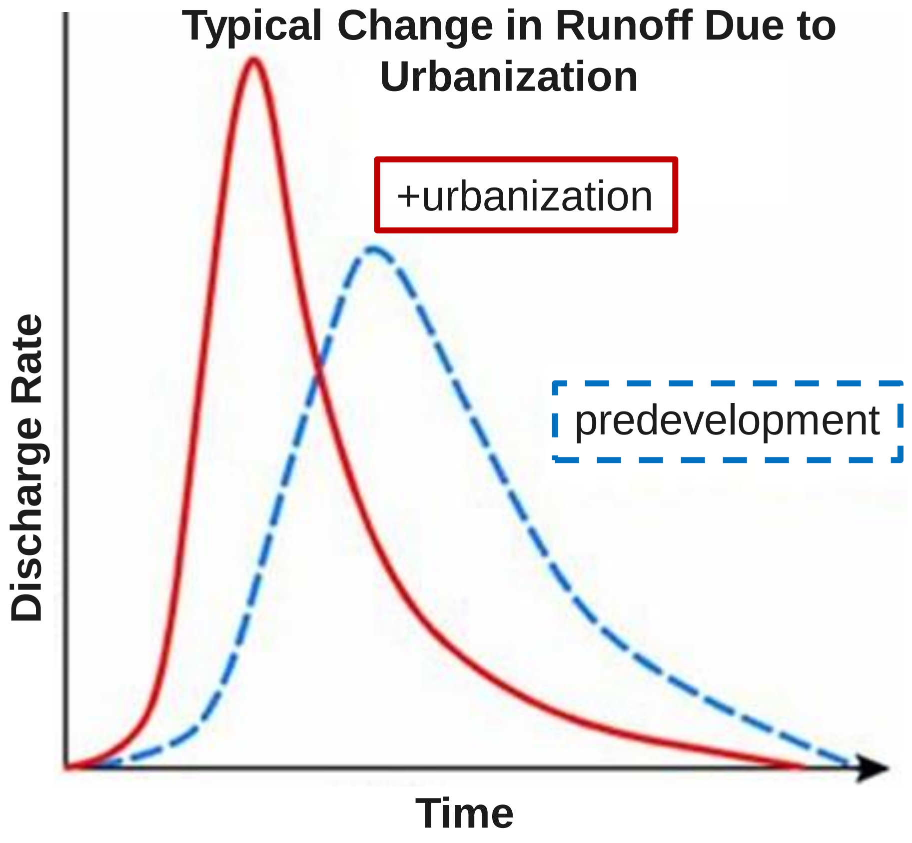


Source: “Hydrological Design of Pervious Concrete.” *Pervious Pavement Design*. http://www.perviouspavement.org/design/hydrologicaldesign.html

Design Goal: Control of Water Quantity

Contrast this curve to a runoff hydrograph in an urban setting. Here the peak discharge rate occurs much more quickly after the start of rainfall, and the rate of discharge has increased. The volume of water also increases, as there are more impervious surfaces and less infiltration.

It is the goal of PICPs within stormwater management plans to reduce peak runoff and create more infiltration opportunities.



Source: "Hydrological Design of Pervious Concrete." *Pervious Pavement Design*. http://www.perviouspavement.org/design/hydrologicaldesign.html

Design Goal: Control of Water Quantity

When peak runoff is controlled through infiltration, groundwater is also recharged and downstream flooding and erosion are lessened. A system designed to balance inflow and outflow is used when water is to be removed as quickly as possible.

Another design option is to reduce the outflow rate in relation to inflow, creating some water storage area within the system. This type of system is used when the control of stormwater runoff is required, or water quality is a concern.

In areas called “hot zones” where runoff may pick up pollutants, regulations will often require capture of the entire amount of runoff.

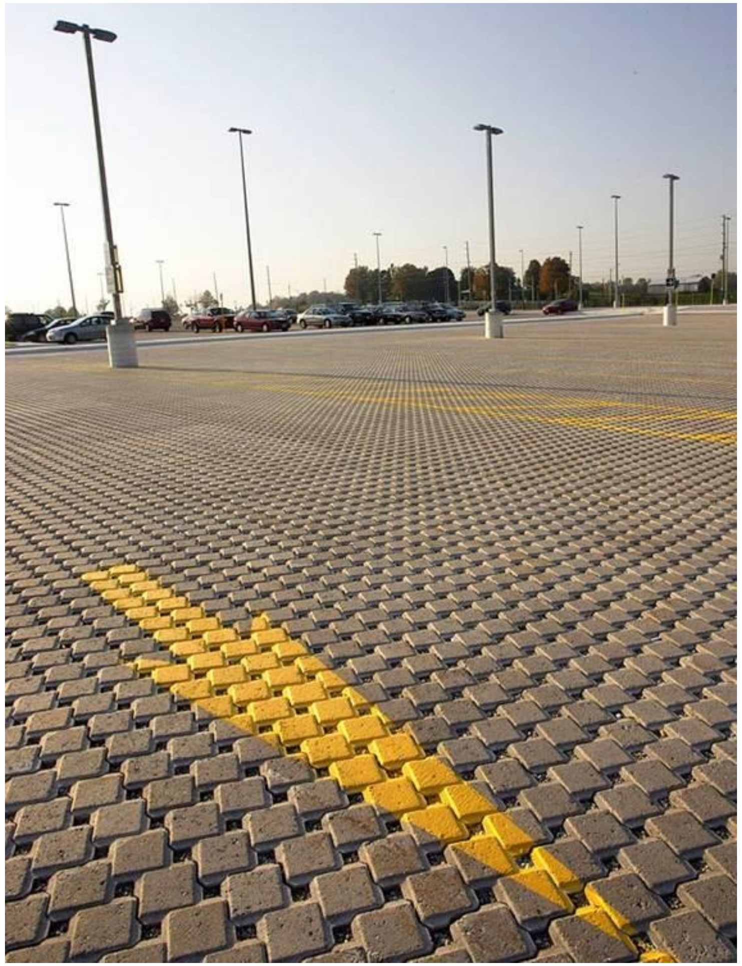
Municipal regulations may also require the system to maintain runoff at predevelopment levels, or to maintain groundwater recharge rates to sustain stream flows and ecosystems and recharge aquifers.

Design Goal: Control of Water Quantity

Release rate refers to the volume of water, usually in cubic feet per second, that is allowed to be discharged into a municipal system or waterway.

Many stormwater regulatory agencies require the postdevelopment release rate not to exceed predevelopment conditions. Permeable paving slows and detains stormwater in the open-graded base so that it can be gradually released.

Contact the proper jurisdiction for required release rates.



Design Goal: Control of Water Quality

Water quality regulations may require the capture of a volume of runoff for treatment in order to improve water quality. This amount is typically the first flush of runoff or 0.75–1.5″.

Hydrologic studies show that small sized, frequently occurring storms account for the majority of rainfall events that generate stormwater runoff. In fact, it is said that 98% of all rainfall events are less than 2″. Consequently, the runoff from these storms also accounts for a major portion of the annual pollutant loadings. Therefore, by treating these frequently occurring smaller rainfall events and a portion of the stormwater runoff from larger events, it is possible to effectively mitigate the water quality impacts from a developed area. Typically, a 6″ base will meet the needs of this type of rainfall but will not satisfy structural (vehicular) demands.

A water quality treatment volume is usually specified by local regulatory bodies to size structural control facilities, to treat these small storms up to a maximum runoff depth and the “first flush” of all larger storm events.

Design Goal: Control of Water Quality

PICP itself has been shown to be able to reduce total suspended solids (TSS) and remove some pollutants by up to 80%. Compared to impervious pavement, the PICP system will remove:

- zinc: 62–88%
- copper: 50–89%
- total suspended solids: 60–90%, and
- total phosphorous: 65%.

Most often, pollutant removal is accomplished by designing the PICP in conjunction with a filtering system, sand filters, organic filters, bioretention, swales, and channels. Runoff can be captured within the PICP system, piped to a pretreatment settling bed, and then to a sand or biofilter area external to the pavement area.

If groundwater contamination is possible and underlying soils are permeable, both the filter and the PICP catchment area will be lined. Infiltration through clay soils has also been known to reduce pollutants. Stormwater should infiltrate through at least 18″ of high cation exchange capacity clay soil. Limitations to this method include the fact that clay soils are not highly permeable.

Design Goal: Water Harvesting

If water harvesting is being considered, infiltrated water can be captured within the system and piped to a larger water storage area for use in another application, such as landscaping.

Collecting Data

When beginning the design of a PICP system, the first step is to gather preliminary site data through research or testing.

Many of the tests cited here should be carried out by an experienced professional engineer. Existing soil materials will determine the performance capabilities of the PICP system. Preconstruction soil analysis including percolation, California bearing ratio (CBR), and penetrometer measurements (blow counts) are mandatory for proper design.

Subsoils with less than 0.5″ per hour rate of infiltration may require underdrainage, scarification, and potentially, amendments. Subsoils with infiltration rates greater than 0.5″ per hour are considered highly permeable.

Preliminary Data

Hydrological characteristics of site
• Design storm data based on design storm chosen by local authorities
  • Duration: 20 min, 1 hr, 2 hr, 24 hr
  • Return period: 2 yr, 10 yr, etc.

Traffic data
On-site sampling • Test pits, soil moisture content, soil classification • Soil should be analyzed to determine USCS or NRCS* soil classification, moisture content, infiltration rate, bearing capacity
Aggregate base materials • Sieve analysis • Void space

*USCS: Unified Soil Classification System
NRCS: Natural Resources Conservation Service, an agency of the US Dept. of Agriculture

Site Data

To determine the characteristics of an existing site, investigation should include:

- mapped soils
- existing geology
- streams or nearby water bodies
- topography
- land use, and
- natural or manmade conditions that may impact the design, such as past uses or nearby structures.

On-site testing through test pits, soil borings, and infiltration tests reveals the soil conditions, the infiltration rate of the soils beneath the PICP, and also the soil's structural bearing capacity. These tests are most important when vehicular traffic or clay soil is expected, as these will indicate limited infiltration capacity or specific structural requirements.

USCS Soil Classification

USCS soil classification is used to give the designer a general idea of the permeability of different soil types (see chart) but does not replace site soil testing. (Chart source: Smith, 2000)

USCS Soil Classification	Typical ranges for coefficient of permeability, k, in/hr (approx. m/s)	Relative permeability when compacted and saturated	Shearing strength when compacted	Compressibility	Typical CBR range
GW: well-graded gravels	1.3 to 137 (10^{-5} to 10^{-3})	Pervious	Excellent	Negligible	30–80
GP: poorly graded gravels	6.8 to 137 (5×10^{-5} to 10^{-3})	Very pervious	Good	Negligible	20–60
GM: silty gravels	1.3×10^{-4} to 13.5 (10^{-8} to 10^{-4})	Semipervious to impervious	Good	Negligible	20–60
GC: clayey gravels	1.3×10^{-4} to 1.3×10^{-2} (10^{-8} to 10^{-6})	Impervious	Good to fair	Very low	20–40
SW: well-graded sands	0.7 to 68 (5×10^{-6} to 5×10^{-4})	Pervious	Excellent	Negligible	10–40
SP: poorly graded sands	0.07 to 0.7 (5×10^{-7} to 5×10^{-6})	Pervious to semipervious	Good	Very low	10–40
SM: silty sands	1.3×10^{-4} to 0.7 (10^{-9} to 5×10^{-6})	Semipervious to impervious	Good	Low	10–40
SC: clayey sands	1.3×10^{-5} to 0.7 (10^{-9} to 5×10^{-6})	Impervious	Good to fair	Low	5–20
ML: inorganic silts of low plasticity	1.3×10^{-5} to 0.07 (10^{-9} to 5×10^{-7})	Impervious	Fair	Medium	2–15
CL: inorganic clays of low plasticity	1.3×10^{-5} to 1.3×10^{-3} (10^{-9} to 10^{-8})	Impervious	Fair	Medium	2–5
OL: organic silts of low plasticity	1.3×10^{-5} to 1.3×10^{-2} (10^{-9} to 10^{-6})	Impervious	Poor	Medium	2–5
MH: inorganic silts of high plasticity	1.3×10^{-6} to 1.3×10^{-5} (10^{-10} to 10^{-9})	Very impervious	Fair to poor	High	2–10
CH: inorganic clays of high plasticity	1.3×10^{-7} to 1.3×10^{-5} (10^{-11} to 10^{-9})	Very impervious	Poor	High	2–5
OH: organic clays of high plasticity	Not appropriate under permeable interlocking concrete pavement				
PT: peat, mulch, soils with high organic content	Not appropriate under permeable interlocking concrete pavement				

Infiltration Rate

For PICP with full exfiltration, an infiltration rate of at least 0.5″ per hour is recommended. This figure may vary depending on local authorities having jurisdiction. Sands and gravels as listed in the USCS classification system—specifically GW, GP, GM, GC, and SW soils—are suitable.

Within the NRCS classification system, PICP systems are suitable for group A or B soils. Group D or most group C soils, or soils with a high (>30%) clay content, can still be compatible with the PICP system when an underdrain is provided in the form of a perforated pipe.

In colder climates, the lowest recommended design infiltration rate will vary from the standard.

NRCS Soil Classification	
Group	Infiltration Rate
A	0.30″–0.50″ per hour
B	0.15″–0.30″ per hour
C	0.05″–0.15″ per hour
D	0″–0.05″ per hour

There are a variety of field tests for determining infiltration capacity of a soil. On-site infiltration tests are recommended over laboratory tests. Tests should not be conducted in the rain, within 24 hours of significant rainfall events (>0.5″), or when the temperature is below freezing. The type of infiltration rate test is often determined by local jurisdictional authorities and should always be done at the elevation of the bottom of the base course.

Design Storm, Drainage Area, and Contributing Area

Data gathered includes the design storm data and drainage area information. The design storm is a rainfall event of specified size and return frequency (i.e., a storm that has the likelihood of occurring once every 2, 5, 10, 50, or 100 years) that is used to calculate the runoff volume and peak discharge rate. Selection of the design storm will determine the amount of rainfall that must be considered for a given area. With a permeable surface, the intensity of the storm isn't as much a determining factor as the duration, since permeable paver infiltration rates are capable of capturing more than 100″ (2540 mm) per hour. The most frequent storms leave under an inch of rain. For small watersheds, the 2- and 10-year storms are used. The 2-year storm is often used as the design load for water quality purposes, while the 10-year storm has been traditionally used for the design of water collection systems. The larger 20-year, 50-year, and 100-year storms are often used when designing water management systems for larger areas for flood control. Local authorities will usually determine the required design storm.

The total drainage area, which includes not only the PICP area but also any adjacent contributing areas and their permeability, must also be determined. Some municipalities restrict the ratio of the contributing impermeable area to the permeable paver surface area to no greater than 3:1.

Combination of the three items, design storm, drainage area, and contributing area, will provide the volume of runoff or peak flow to be captured, exfiltrated, or released using the design storm.

Traffic and Soil Strength

The design traffic loading, if applicable, must be determined to design enough strength into the base and subbase, which provide the majority of the resistance to loading. Traffic loads are often expressed in ESALs, equivalent single axle loads.

The California bearing ratio (CBR) is the mechanical strength or density of a subgrade or base course. The unit is usually used for road building. The test is performed by measuring the pressure required to penetrate a soil sample with a plunger of standard area. The minimum CBR value for vehicular traffic is 5%.

Most vehicular applications will require compaction, and this must be taken into account in the design infiltration rate of the soil since any compaction will also affect the infiltration rate of the soil. Infiltration tests must be done on the compacted soils. Pedestrian and landscaping applications usually do not require compaction of the soil.

Review Question

What should be the first step in beginning to design a PICP system to meet a design goal?

Answer

When beginning the design of a PICP system, the first step is to gather preliminary site data through research or testing.

PICP Components and Installation

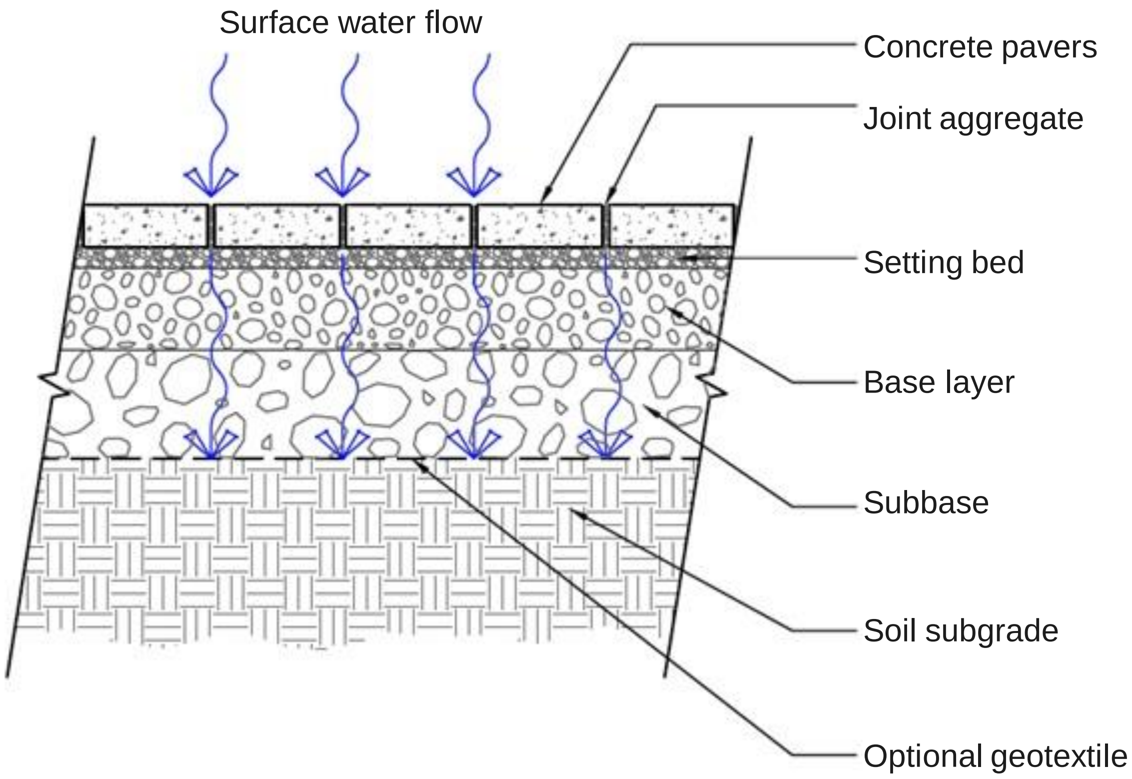
PICP Components

PICP is typically built over a number of layers of open-graded aggregate bases consisting of hard, crushed stone, though a variety of aggregate materials including dense-graded may be used depending on project parameters.

The open-graded aggregate that forms these layers should have a narrow range of particle sizes with little or no fines.

The open voids between the particles should provide 30–40% porosity and remain well drained. A 40% porosity or void space means that the volume of the base will need to be 2.5 times the volume of the water to be stored.

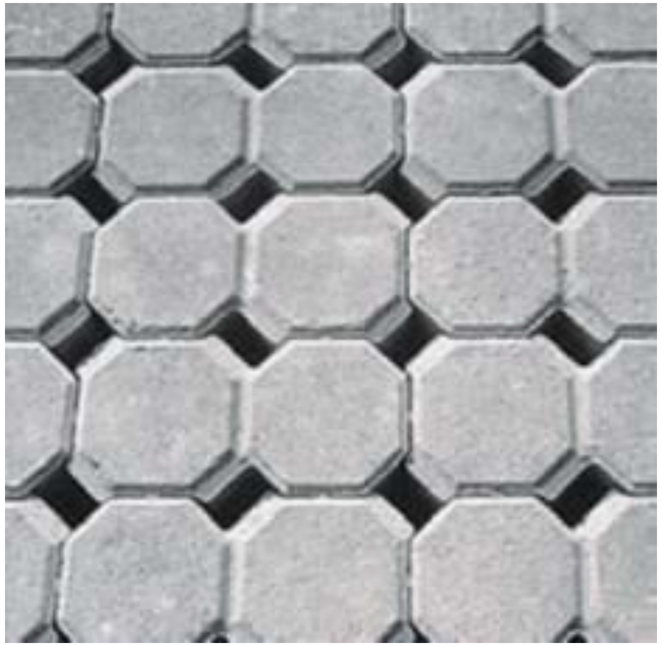
PICP System

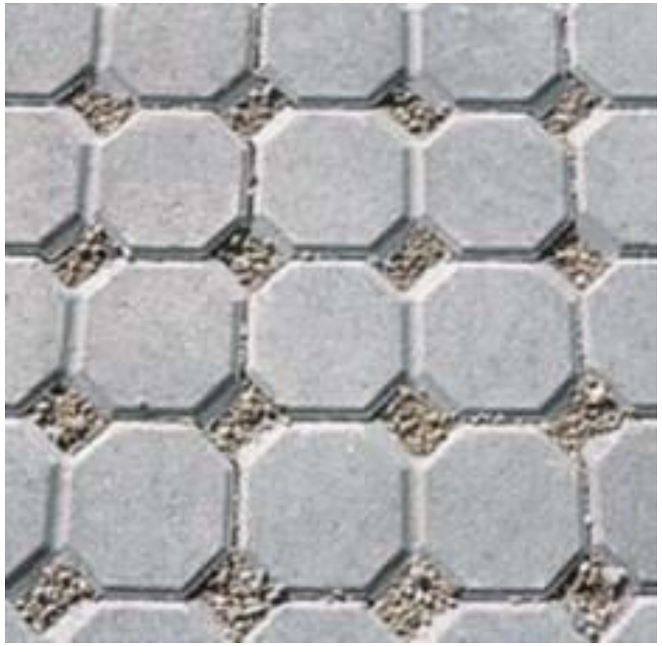


PICP Components

Joint Aggregate: ASTM No. 8 or 9

As the initial filtering layer, the ¼″ (2–5 mm) crushed, angular chip stone captures approximately 80% of debris in the first 1″ (25.4 mm) to 2″ (50.8 mm). The secondary function of the joint aggregate is to increase the positive interlock between the paver units that is essential to the structural stability of the PICP. The joint aggregate must always remain filled to the lip of the PICP units to reduce unnecessary clogging.





PICP Components

Setting Bed Aggregate: ASTM No. 8 or No. 9

Typical open-graded setting bed specifications are for ASTM No. 8 or ASTM No. 9 stone. This aggregate will make the setting bed adequately level and meet filter criteria over a No. 57 base. Using this angular chip stone provides a smooth leveling course for placing pavers and additional structural interlocking of the PICP.

Unlike sand, the setting bed aggregate allows for rapid water infiltration with over 500″ (12,700 mm) per hour through the 40% void space. Sand must be avoided as a setting bed in a PICP application.

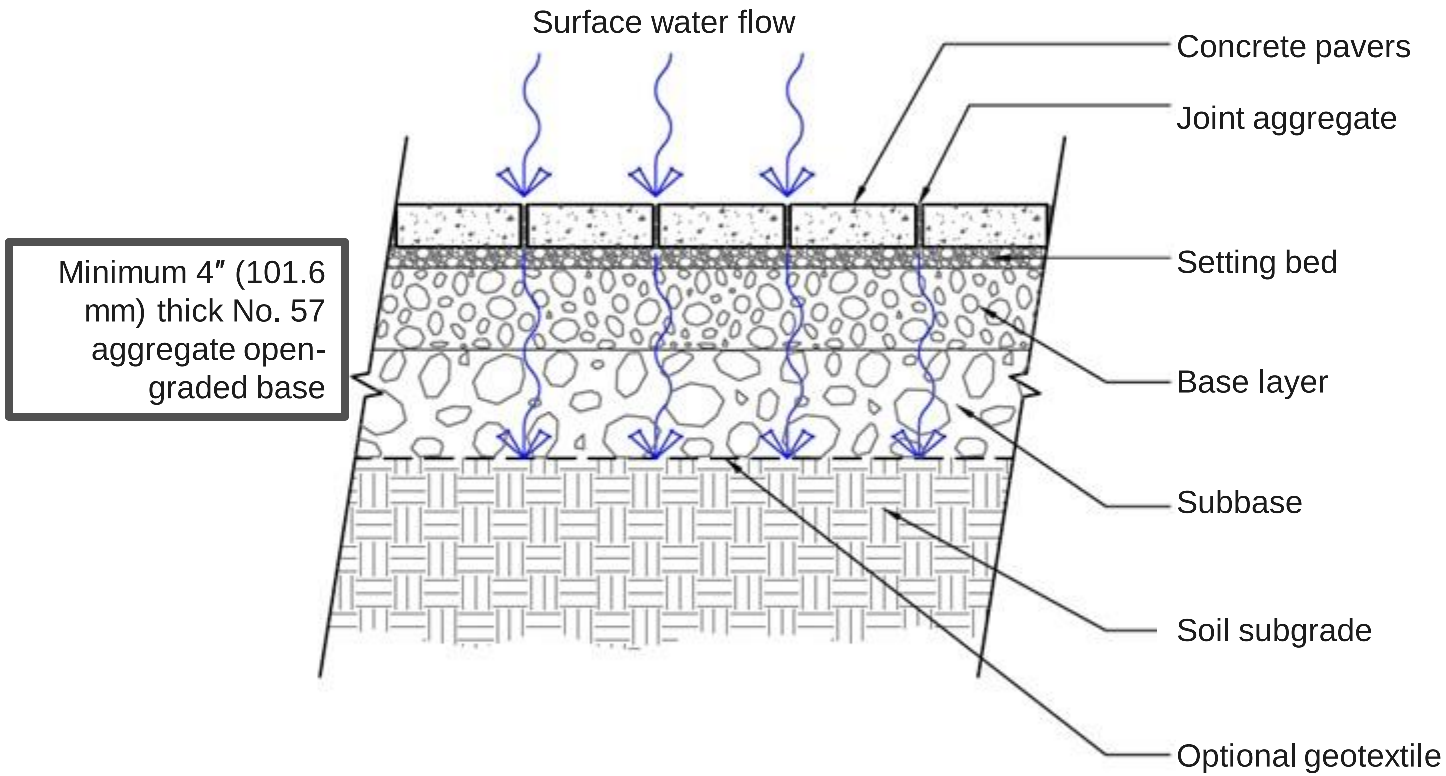
PICP Components

Base Layer Aggregate: ASTM No. 57

The ASTM No. 57 base aggregate, with a minimum thickness of 4″ (101.6 mm), serves as a transition material between the ASTM No. 8 or 9 setting bed and the ASTM No. 2 subbase aggregate. This layer adds structural thickness over the subgrade, provides stable particle-to-particle interlock, stores and transmits water, and acts as a tree rooting zone (“structural soil”). Base layer aggregate design is subject to change based on soil and use/application.

The infiltration rate of the ASTM No. 57 layer is over 500″ (12,700 mm) per hour.

PICP System



PICP Components

Subbase Layer Aggregate: ASTM No. 2

Subsoil conditions will dictate the necessity of this larger ASTM No. 2, crushed, angular, open-graded subbase aggregate. Installation of such material will provide increased structural stability on sites with poor soil conditions. (In some conditions, ASTM No. 57 can be supported without migration so that ASTM No. 2 is not necessary.)

Subbase aggregate thickness must be designed to sufficiently support anticipated loads as well as to accommodate stormwater temporarily detained in the 40% void space of the material. ASTM No. 2 aggregate also has an infiltration rate of over 500″ (12,700 mm) per hour.

Mechanical screeding of aggregate

PICP Components

Edge Restraint

PICP containment is vitally important to the success of its interlocking properties. Lack or failure of an edge restraint will negatively impact the integrity of the pavement surface.

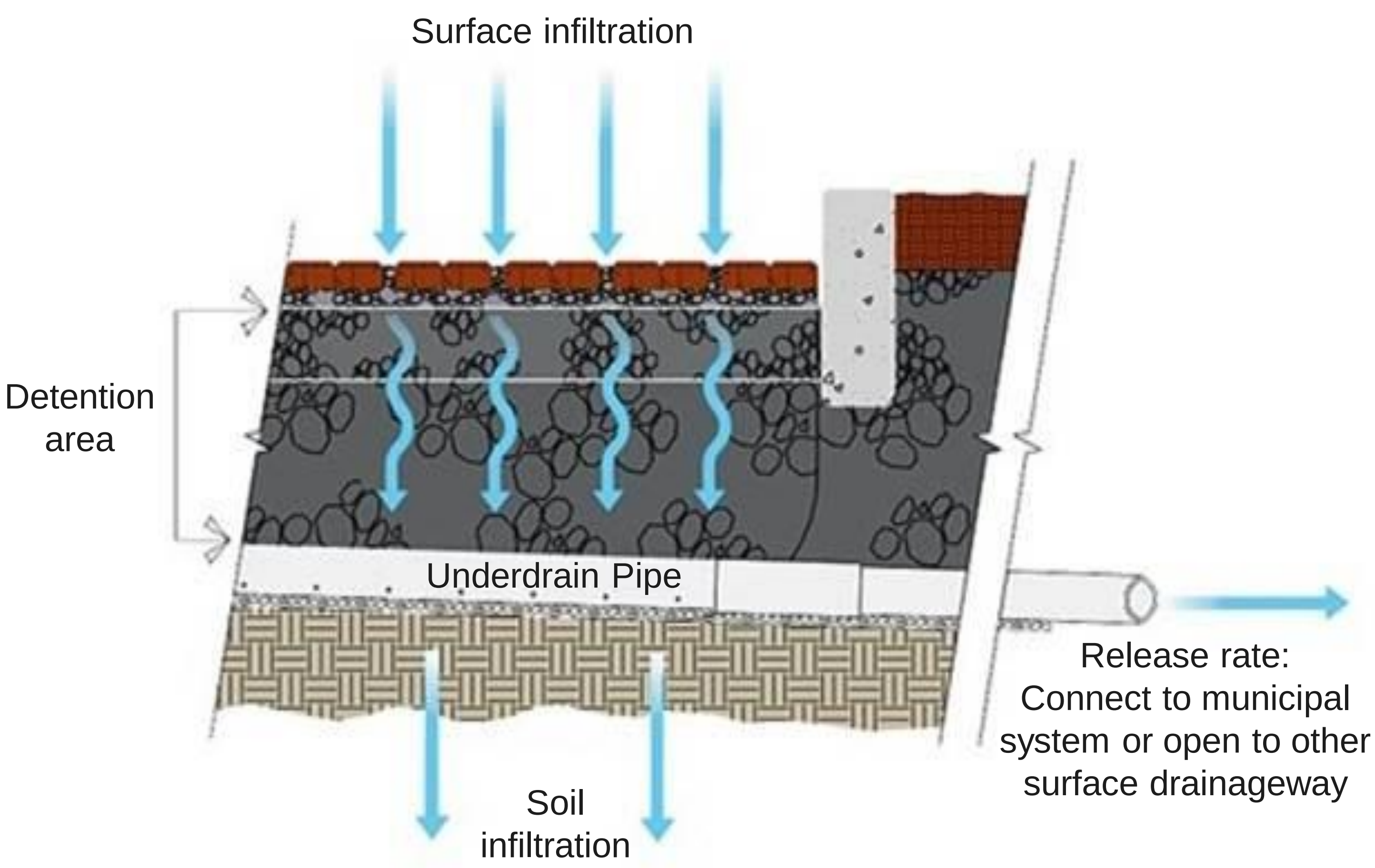
Recommended edge restraints for PICP on open-graded bases are cast-in-place and precast concrete curbs. They should be a minimum of 6″ (150 mm) wide and 12″ (300 mm) deep. Consideration should be given to providing a stable footer or concrete haunch under the curbs. Plastic edge restraints that utilize spikes are not recommended for commercial and municipal applications.

PICP Components

Underdrain Pipe

In PICP systems, use of the underdrain pipe is based on several factors, such as the permeability of the subsoil, detention requirements, and stormwater release rates.

With highly permeable subsoils with infiltration rates over 0.5″ (12.7 mm) per hour, underdrain pipe could be eliminated. Underdrain pipe size is inconsequential, provided the flow rate is greater than the release rate.



PICP Components

Geotextile Fabric

Geotextile fabric between the soil subgrade and the ASTM No. 2 subbase is optional and based on subsoil characteristics. If such fabric is required, it is placed between the subsoil and ASTM No. 57 base aggregate or ASTM No. 2 subbase aggregate only. Geotextile fabric is not recommended between aggregate material layers.

The geotextile fabric type must be determined by soil conditions specific for each project. Geotextile fabrics should be considered for clay soils where vertical migration of fines may occur.

Selecting the Base and Subbase Porosity/Particle Size

The materials selected for the base and subbase will provide an active storage area for runoff; therefore, their capacity to both infiltrate and store rainwater runoff needs to be evaluated. Choice of the aggregate base is a compromise between stiffness for stability and void space for water storage. An open-graded aggregate is chosen for the base for the reason that this aggregate contains little or no mineral filler, and the void spaces in the compacted aggregate are relatively large. This is as opposed to a dense, well-graded aggregate, which is an aggregate of near maximum density; it has a wide range of particle sizes with few void spaces. Dense, well-graded aggregate is typically used in road building.

Void:
Difference between the total volume and the volume occupied only by the aggregate particles.

The amount of void space (or air space) is a function of the aggregate gradation, particle shape and texture, and the amount of compaction of the material.

As the open-graded aggregate has a low fines content, the load-carrying capabilities within the aggregate are achieved by point-to-point contact between aggregate particles. It is therefore necessary that the aggregate be of an angular nature to maximize the frictional contact between aggregate particles. Sands and gravels with rounded particles are not suitable for this type of construction. The No. 2, No. 57, and No. 8 subbase typically have a void space ratio of between 39% and 41%. A conservative design approach is to assume a void space ratio of 35%. Using the conservative approach, the base would need to be roughly three times the volume of water to be stored. Void space data can be supplied by the quarry or through testing.

Base and Subbase Depth

If the pavement is to be used for any kind of vehicular loading, the base must be first designed to meet these structural needs before water quality or storage requirements are met. For all structural design, the use of a civil engineer is essential.

If the structural depth is greater than the hydrologic depth, then the structural depth should be used. All stone materials should be crushed for the highest interlock and stability during construction and load-spreading capacity during service. The bedding layer should choke into the base and the base into the subbase, thereby creating a stable structure for traffic.

Base Thickness (all thicknesses are after compaction)			
Pavement Use	Subbase ASTM No. 2	Base ASTM No. 57	Minimum Total
Heavy-Duty Industrial	14.00	6	22
Municipal Street	12.00	6	18
Light-Duty Parking Lot	8.00	6	14
Residential Driveway	n/a	12	12
Nonvehicular Sidewalk	n/a	10	10

Storage Time and Runoff Coefficient

Storage time is the length of time it takes for the water to exfiltrate the system. Shorter storage times ensure the soil is not saturated for any great length of time. A saturated soil can be a weaker soil. Therefore, shorter storage times may be beneficial for PICPs meant to support traffic. Design storage time is often provided by the local authority.

A runoff coefficient is used to measure the percentage of water that runs off different surface types. For example, bituminous asphalt has a runoff coefficient (C value) of 0.85. This means that during a rainfall, 85% of the water will run off the surface.* In comparison, turf has a C value of 0.15 or 15%.

The runoff coefficient of permeable paving, with up to a 5% slope, is actually 0 unless the rainfall intensity exceeds the surface infiltration rate or the entire open-graded base reaches capacity. With a properly designed permeable paver system, capacity will rarely be reached. However, to achieve maximum surface infiltration, maintenance of the joints may be necessary.

**Design and Construction of Sanitary and Storm Sewers*, p. 333. ASCE, 1969.

Elimination of Sediment in the Base

PICP has a 40-year functional life span; however, the surface infiltration rate will drop over time due to clogging of the openings with sediment and fines. It is of great importance to keep the aggregates free of sediment until their use in the system. The best situation is if they arrive on the site and are used immediately. If this is not possible, they should be stored on a hard surface or on geotextiles until use.

Also, once installed, the PICP system should not receive runoff until all sources of sediment or fines in the catchment area are covered. If the cover is to be grassed or planted areas, this may require temporary measures such as erosion control techniques. This is the reason some engineers discourage significant amounts of contributing drainage area as it can cause problems with siltation and erosion.

The lifetime infiltration rate should be taken into account when designing a PICP system. A conservative projected lifetime surface infiltration rate is 15% of the initial rate. If the initial rate is 100″ per hour, then the lifetime (worst case) infiltration rate is 15″ per hour. This rate can still accommodate just about all rainstorms.

Removal of Sediment

Vacuum type street cleaning once or twice a year has proven to be most effective in removing sediment and restoring infiltration rates. Streets must be dry for cleaning, and joint aggregate should be replenished if necessary at the time of the cleaning.

Installation

Both the rectangular and L-shaped pavers can be mechanically installed, significantly reducing installation cost. Installation rates of up to 12,000 square feet per day have been documented.

Mechanical installer.

Mechanical joint filler.

Applications

PICP is ideal for urban applications in sidewalks, parking lots, parks, and outdoor seating areas. It is often used in driveways and parking bays on roadways.

Applications

PICP provides added aesthetic appeal to residential driveways and suburban layby/public seating areas.

Applications

Pervious pavers can be used in areas receiving heavy-duty loading.

Applications

PICP is ideal for urban applications in street tree-planting areas and will improve tree viability by allowing for an expanded root zone.

Pervious paving around tree

Impervious paving: tree may survive 7 years

Applications

Although pervious paving is not suitable for high-speed roads, in 2007 the town of Warrenville, Illinois, used pervious pavers to resurface this local road.

Applications

Reasons for choosing a pervious paver surface included easing ponding issues, reduction of water runoff, improved durability over asphalt, and its attractive appearance.

Residents comment favorably on not only the environmental benefits of the system, but also on its charming appearance and traffic-calming effects.

Review Question

What is the functional life span of PICP?

Answer

PICP has a 40-year functional life span; however, the surface infiltration rate will drop over time due to clogging of the openings with sediment and fines.

PICP and Sustainable Design

LEED v4 Sustainable Sites Credits

In LEED v4, the latest version of the LEED rating system, the stormwater design credit has been modified and moved to a new credit called **Rainwater Management** within the Sustainable Sites category. There are two options for meeting the requirements of this credit.

Option 1 means managing the site runoff for the 95th or 98th percentile of regional or local rainfall events for non-zero lot line buildings. For zero lot line buildings, manage the site runoff for 85th percentile rainfall events.

Option 2 allows the designer to manage on-site the annual increase in runoff volume from the natural land cover condition to the postdeveloped condition.

Permeable pavement is able to contribute to the design of a system that manages runoff.

LEED v4 Sustainable Sites Credits

The new LEED v4 credit titled **Heat Island Reduction** is a combination of LEED 2009 Heat Island Effect—Non-roof and Heat Island Effect—Roof with some updates. In v4, the contributing non-roof portion of the site must use paving materials with a three-year aged solar reflectance (SR) value of at least 0.28. If three-year aged value information is not available, use materials with an initial SR of at least 0.33 at installation. Also, use an open-grid pavement system (at least 50% unbound).

An open-grid pavement system is one that consists of loose substrates supported by a grid of a more structurally sound grid or webbing. Pervious concrete and porous asphalt are not considered open-grid as they are bounded materials. Unbounded, loose substrates do not transfer and store heat like bound and compacted materials do.

To earn credit, the following criteria must be met:

$$\frac{\text{Area of Non-roof Measures}}{0.5} + \frac{\text{Area of High-Reflectance Roof}}{0.75} + \frac{\text{Area of Vegetated Roof}}{0.75} \geq \text{Total Site Paving Area} + \text{Total Roof Area}$$

Alternatively, an SRI and SR weighted average approach may be used to calculate compliance.

LEED v4 Materials and Resources Credits

The LEED v4 Materials and Resources credits have changed substantially. Many of the credits from 2009 are now included in three new credits:

- Building Product Disclosure and Optimization—Environmental Product Declarations
- Building Product Disclosure and Optimization—Sourcing of Raw Materials
- Building Product Disclosure and Optimization—Material Ingredients

These new credits recognize the selection of products for which the environmental impacts are well-known.

For the credit **Building Product Disclosure and Optimization—Environmental Product Declarations**, products with a cradle to gate, life cycle analysis conforming to ISO 14044 or environmental product declarations that conform to ISO standards contribute towards earning a point. Also, third-party certified products that demonstrate impact reduction below the industry average for a number of environmental impact categories will also contribute towards earning a point.

LEED v4 Materials and Resources Credits

The **Building Product Disclosure and Optimization—Sourcing of Raw Materials** credit addresses transparency in raw material sourcing and selecting materials that have been appropriately sourced.

It rewards products from manufacturers who have provided information on land use practices, extraction locations, labor practices, etc. To that end, this credit looks for:

- products sourced from manufacturers with self-declared reports from raw material supplies:
  - valued as one half of a product, or
- products that have a third-party verified corporate sustainability report (CSR), which includes environmental impacts of extraction operations and activities associated with the manufacturer's product and the product's supply chain
  - valued as one product.

LEED v4 Materials and Resources Credits

Finally, the **Building Product Disclosure and Optimization—Material Ingredients** credit encourages the use of products and materials for which life cycle information is available and that have environmentally, economically, and socially preferable life cycle impacts. It has three options that look for products that have documented material ingredient reporting, material ingredient optimization, and/or product manufacturer supply chain optimization.

Option 1: Material Ingredient Reporting

This option looks for products with a demonstrated chemical inventory through:

- a publicly available inventory of all ingredients identified by name and Chemical Abstract Service Registration Number (CASRN)
- a product that has a published, complete Health Product Declaration® with full disclosure of known hazards
- a product that is *Cradle to Cradle Certified*™ at the v2 Basic level or *Cradle to Cradle Certified*™ at the v3 Bronze level, or
- a USGBC approved program.

LEED v4 Materials and Resources Credits

Option 2: Material Ingredient Optimization

This credit looks for products that document their material ingredient optimization using one of the paths below:

- GreenScreen v1.2 Benchmark
- *Cradle to Cradle Certified*™
  - At the v2 Gold level: 100% of cost
  - At the v2 Platinum level: 150% of cost
  - At the v3 Silver level: 100% of cost
  - At the v3 Gold or Platinum level: 150% of cost
- International Alternative Compliance Path – REACH Optimization
- USGBC approved program

LEED v4 Materials and Resources Credits

Option 3: Product Manufacturer Supply Chain Optimization

This option requires products that:

- are sourced from product manufacturers who engage in validated and robust safety, health, hazard, and risk programs that at a minimum document at least 99% (by weight) of the ingredients used to make the building product or building material, and
- are sourced from product manufacturers with independent third-party verification of, broadly, the health, safety, and environmental impacts of chemical ingredients along the supply chain.

If Options 2 and 3 are achieved, products sourced (extracted, manufactured, purchased) within 100 miles (160 km) of the project site are valued at 200% of their base contributing cost.

More information can be found at www.usgbc.org. (Accessed Jan. 2021.)

LCA of Surfacing Materials

A life cycle analysis (LCA) considers the environmental effects of a product’s inputs and outputs throughout its entire life cycle from resource through use and end-of-life.

Shown here are the LCA findings of the British Green Guide to Specification (BREEAM 2002) of the various exterior surfacing materials.

Environmental Impact of Exterior Surfacing Materials **A: Low impact** **B: Moderate impact** **C: High impact** **Paving Type**	**Summary Rating**	**Climate Change**	**Fossil Fuel Depletion**	**Ozone Depletion**	**Human Toxicity to Air & Water**	**Waste Disposal**	**Water Extraction**	**Acid Deposition**	**Ecotoxicity**	**Eutrophication**	**Summer Smog**	**Minerals Extraction**	**Typical Replacement Interval, yr**	**Recycled Content**	**Recyclability**	**Recycled Currently**	**Energy Saved by Recycling**	**Initial Cost**
Asphalt	C	C	C	A	C	C	A	C	C	C	C	A	20	C	B	B	A	Low
Clay Pavers	B	B	B	A	A	B	A	A	A	A	C	A	40	C	A	A	A	Medium
Concrete Pavers/PICP	A	A	A	A	A	B	A	A	A	A	B	A	40	A	A	A	A	Medium
Concrete Paving Slabs	A	A	A	A	A	B	A	A	A	A	A	A	40	C	A	A	A	Medium
Concrete Grid Pavers	A	A	A	A	A	B	C	A	A	B	C	A	30	C	A	A	A	Medium
Cast-in-Place Concrete	C	C	A	A	B	C	B	B	A	C	B	C	60	C	A	A	A	Low
Granite Pavers	B	A	A	A	A	B	A	A	A	A	A	B	60	C	A	A	A	High
Stone Slabs	A	A	A	C	A	A	A	A	A	A	A	A	60	C	A	A	A	High
Gravel	B	A	A	A	A	C	B	A	A	A	A	C	10	C	B	B	C	Low

Chart Source: ICPI Tech SPEC No. 16, 2007

EPA BMPs

The EPA takes the approach that the control of stormwater and protection of the natural environment must work in concert. To that end, they have created six minimum control measures that include both structural and nonstructural best management practices (BMPs).

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 pavement. Nonstructural practices are preventative actions that involve management and source controls. For more information on the EPA Stormwater Phase II management plan, see https://www.epa.gov/npdes/stormwater-phase-ii-final-rule-fact-sheet-series. (Accessed Jan. 2021.)

In Canada, regional districts and municipalities are currently developing comprehensive local stormwater standards. Toronto is one of the areas that has published guidelines for improved stormwater management with their Wet Weather Flow Master Plan. (https://www.toronto.ca/311/knowledgebase/kb/docs/articles/toronto-water/water-infrastructure-management/stormwater-management/wet-weather-flow-master-plan-wwfmp.html, accessed Jan. 2021.)

★ Please remember the **test password STORMWATER**. You will be required to enter it in order to proceed with the online test.

EPA BMPs

The BMPs encourage a system approach (using a series of BMPs) to stormwater management. This may include the use of PICP along with infiltration trenches or grassed swales.

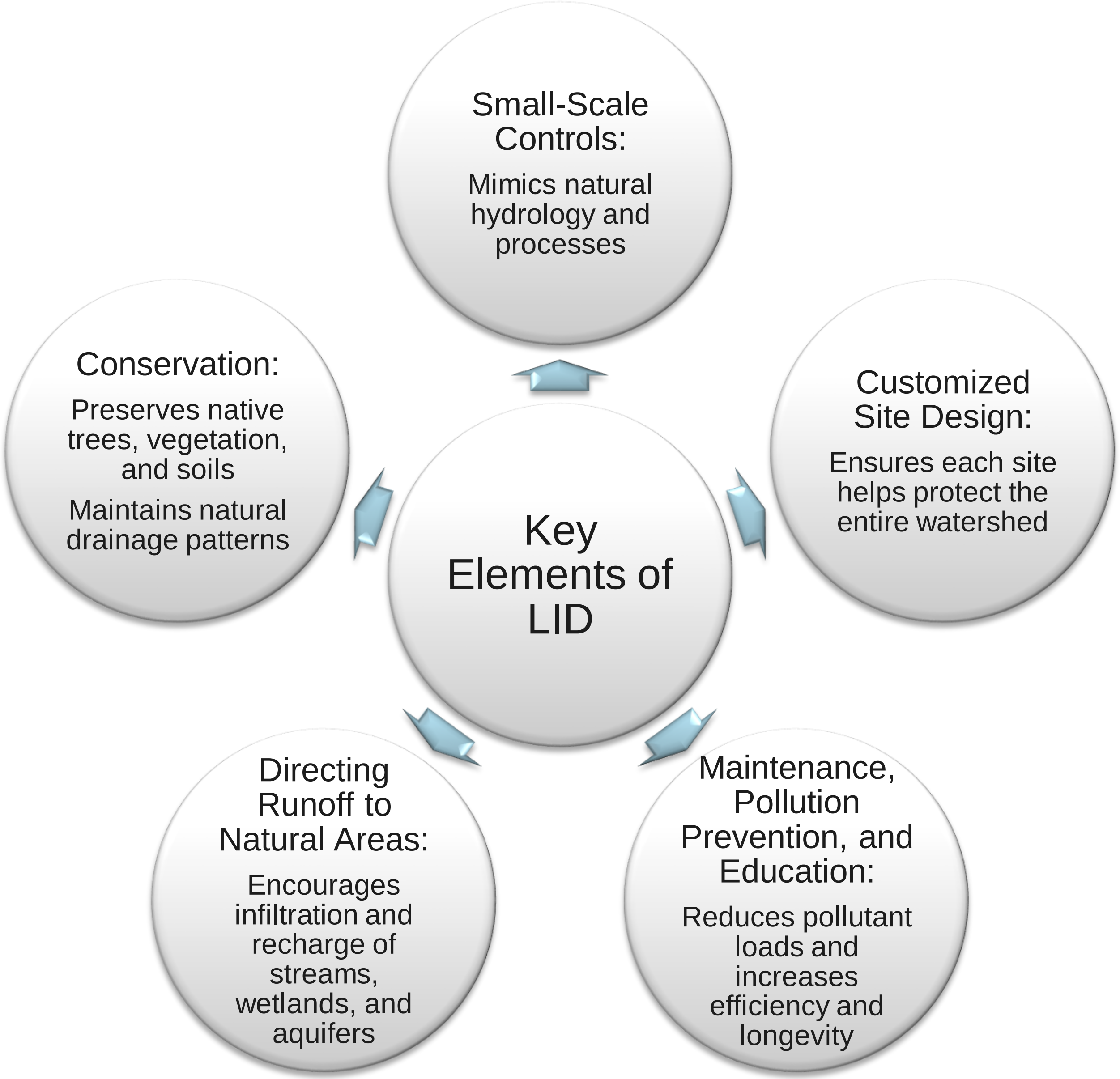
The focus is on preventing pollutants from entering stormwater. In this way a municipality will not find itself dealing with the more expensive and difficult process of restoring polluted water bodies in addition to dealing with stormwater quantities.

A raised inlet (to force infiltration) and vegetated swale work in concert with PICP.

Low-Impact Development

Low-impact development (LID) is currently being used by many cities, counties, states, and private-sector developers to help protect and restore water quality.

LID objectives include the reduction of impervious cover to reduce runoff volume, the preservation of natural landscape features, and the maximization of infiltration opportunities.



Review Question

What are the two options for meeting the requirements of the LEED Rainwater Management credit in the Sustainable Sites category?

Answer

Option 1 means managing the site runoff for the 95th or 98th percentile of regional or local rainfall events for non-zero lot line buildings. For zero lot line buildings, manage the site runoff for 85th percentile rainfall events.

Option 2 allows the designer to manage on-site the annual increase in runoff volume from the natural land cover condition to the postdeveloped condition.

Summary, Glossary, and Resources

Summary

Permeable interlocking concrete pavement has the ability to create solid, strong surfaces for pedestrians and a range of vehicular uses and infiltrate all stormwater from the vast majority of storms in the US and Canada. PICP may contribute to LEED and LID and scores well on the BREEAM life cycle analysis. The lighter colors of the concrete paver have SRIs much lower than asphalt and will lessen the impact of the heat island effect. This product, available in a wide range of colors and styles, allows the designer the aesthetic freedom to create hard surfacing for a wide range of applications, from parks and outdoor seating areas to roadways and parking lots.

Many municipalities in the US have stormwater management regulations that reduce amounts of stormwater runoff, thereby reducing pollutant discharge and protecting downstream water bodies with the goal of maintaining a site’s existing natural hydrologic function and reducing the overall hydrological impact of development.

PICP is ideally suited to address this goal. In most cases, both hydrologic and structural factors must be considered when designing with permeable pavers—the permeability of the surface layer of the system, the interlocking pavement, and the base layer consisting of the crushed stone, filters, and drainage pipes.

Although this type of design should be performed by a licensed, experienced civil or hydraulic engineer, we’ve reviewed some of the inputs, outputs, and limitations required for the design of a permeable interlocking concrete system.

Glossary

Best Management Practices (BMPs): Schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants to waters of the United States. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Bioretention: Vegetated depressions that collect runoff and facilitate its infiltration into the ground.

Cation: A positively charged atom or group of atoms in soil particles that, through exchange with ions of metals in stormwater runoff, enable those metals to attach themselves to soil particles.

Detention Pond or Structure: The temporary storage of stormwater runoff in an area with the objective of decreasing peak discharge rates and providing a settling basin for pollutants.

Dry Wells: Gravel- or stone-filled pits that are located to catch water from downspouts or paved areas.

Exfiltration: The downward movement of water through an open-graded, crushed stone base into the soil beneath.

Glossary

Filter Strips: Bands of dense vegetation planted immediately downstream of a runoff source designed to filter runoff before entering a receiving structure or water body.

Grassed Swales: Shallow channels lined with grass and used to convey and store runoff.

Infiltration: The movement of water into or through a surface or medium.

Infiltration Trenches: Trenches filled with porous media such a bioretention materials, sand, or aggregate to collect runoff and exfiltrate it to the ground.

Retention Pond: A body of water that collects runoff and stays full permanently. Runoff flowing into the pond that exceeds its capacity is released into a storm sewer, stream, lake, or river.

Total Phosphorus (TP): A measure of all the forms of phosphorus, dissolved or particulate, that are found in a sample.

Total Suspended Solids (TSS): A measure of the filterable solids present in a sample.

Resources

Bean, Eban Z., William F. Hunt, et al. "Study on the Surface Infiltration Rate of Permeable Pavements." World Water and Environmental Resources Congress, 2004, https://ascelibrary.org/doi/abs/10.1061/40737%282004%2972. Accessed Jan. 2021.

Burak, Rob. "Achieving LEED® Credits with Segmental Concrete Pavements, Part 1 and Part 2." *Interlocking Concrete Pavement Magazine*. ICPI, May 2006, https://www.uni-groupusa.org/PDF/06_Aug_Eng_View_LEEDS-part_2.pdf. Accessed Jan. 2021.

Burak, Rob. "Construction of Bases for Permeable Interlocking Concrete Pavements – Part I." Interlocking Concrete Pavement Magazine. ICPI, August 2007, https://wgpaver.com/wp-content/uploads/2012/05/PICP_Base_Construction1.pdf. Accessed Jan. 2021.

Clausen, John C. *Jordan Cove Watershed Project, Section 319*. Dept. of Natural Resources Management and Engineering, College of Agriculture and Natural Resources, Univ. of Connecticut, 2007, http://www.jordancove.uconn.edu/jordan_cove/publications/final_report.pdf. Accessed Jan. 2021.

Debo, T. N. and A. J. Reese. *Municipal Stormwater Management*. CRC Press, 1995.

EPA. "Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices." US EPA, December 2007, https://www.epa.gov/sites/production/files/2015-10/documents/2008_01_02_nps_lid_costs07uments_reducingstormwatercosts-2.pdf. Accessed Jan. 2021.

EPA. "Stormwater Phase II Final Rule: Small MS4 Stormwater Program Overview." US EPA, December 2005, http://www.epa.gov/npdes/pubs/fact2-0.pdf. Accessed Jan. 2021.

"A Guide to Stormwater Best Management Practices." City of Chicago, 2003, http://www.cityofchicago.org/dam/city/depts/doe/general/NaturalResourcesAndWaterConservation_PDFs/Water/guideToStormwaterBMP.pdf. Accessed Jan. 2021.

Resources

Hydraulic Design Manual. Texas Department of Transportation, last updated July 2016, http://onlinemanuals.txdot.gov/txdotmanuals/hyd/manual_introduction.htm. Accessed Jan. 2021.

“Hydrological Design of Pervious Concrete.” Pervious Pavement Design. National Ready Mixed Concrete Association, n.d., http://perviouspavement.org/design/hydrologicaldesign.html#part3. Accessed Jan. 2021.

Joint Committee of the ASCE and the Water Pollution Control Federation. *Design and Construction of Sanitary and Storm Sewers*. ASCE, 1969.

Murphy, Sheila. “General Information on Phosphorus.” *Boulder Community Network*. City of Boulder/USGS Water Quality Monitoring, April 2007, http://bcn.boulder.co.us/basin/data/NEW/info/TP.html. Accessed Jan. 2021.

Patchett, James M. and Gerould S. Wilhelm. “The Ecology and Culture of Water.” Conservation Research Institute, revised March 2008, https://conservationresearchinstitute.org/files/ecologyandcultureofwater.pdf. Accessed Jan. 2021.

Smith, David R. “Permeable Interlocking Concrete Pavements.” 3rd edition. ICPI, 2006, http://www.idealconcreteblock.com/tl_files/pages/designers/know-green/PICP_Manual_3rd_edition.pdf. Accessed Jan. 2021.

“Sprawl, Congestion, and Farmland.” *NumbersUSA*. NumbersUSA Action, n.d., https://www.numbersusa.com/problems/sprawl-congestion-and-farmland. Accessed Jan. 2021.

US Army Corps of Engineers. “Unified Facilities Criteria: Low Impact Development.” US Dept. of Defense, June 2015, https://www.wbdg.org/FFC/DOD/UFC/ufc_3_210_10_2015_c1.pdf. Accessed Jan. 2021.

“Warrenville Leads the Way in Environmental Roadway Construction.” City of Warrenville Press Release, January 8, 2008.

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