



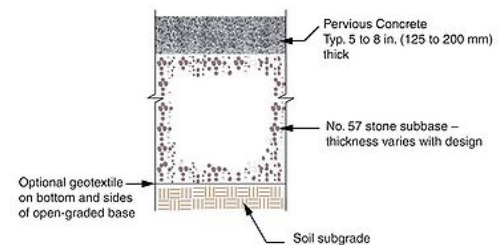
Design criteria for permeable pavement

Green Infrastructure: Permeable pavement can be an important tool for retention and detention of stormwater runoff. Permeable pavement may provide additional benefits, including reducing the need for de-icing chemicals, and providing a durable and aesthetically pleasing surface.



This section provides information on design considerations, criteria and specifications for permeable pavement. Base/subbase thickness is determined for water storage using hydrologic sizing and/or dynamic modeling over time. Base/subbases thickness for supporting traffic is determined using structural design methods. The thicker of the two resulting designs is employed.

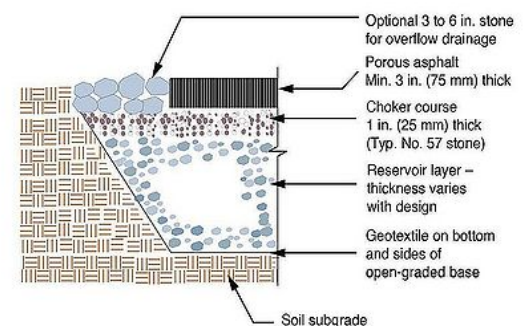
Pervious Concrete



Schematic illustrating typical pervious concrete cross section and basic components of a pervious concrete system.

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Schematic illustrating typical porous asphalt cross section and basic components of a pervious concrete system.

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Design phase maintenance considerations

Implicit in the design guidance is the fact that many design elements of infiltration and filtration systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include

- limiting drainage area;
- providing easy site access (*REQUIRED*); and
- providing pretreatment (*REQUIRED*).

For more information on design information for individual infiltration and filtration practices, link here (http://stormwater.pca.state.mn.us/index.php/Category:Design_criteria).

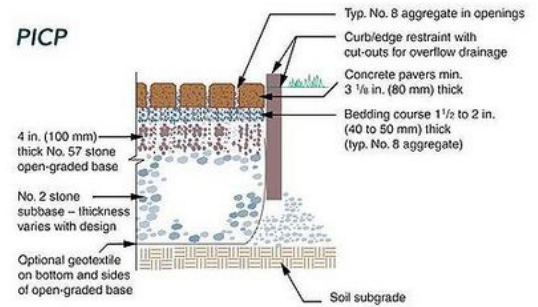
Hydrologic design considerations

Permeable pavement is subject to the following design considerations, including benefits and constraints.

- Available space – A significant advantage of permeable pavement is its ability to combine detention/infiltration and pavement, thereby reducing or eliminating land required for detention facilities. This is especially important in urban areas with high land prices and highly developed sites with little or no space for stormwater detention.
- Soils – Soil conditions and infiltration rates determine the use of an underdrain. (NRCS (<http://www.nrcs.usd.gov/wps/portal/nrcs/main/national/home>) Hydrologic Soil Group (HSG) C or D soils usually require an underdrain, whereas HSG A and B soils often do not.) Designers should evaluate existing soil properties during initial site layout with the goal of configuring permeable pavement that conserves and protects soils with the highest infiltration rates. In particular, areas of HSG A or B soils shown on soil surveys should be considered as primary locations for all types of infiltration practices.

Soil surveys and HSG classifications provide a general estimate of the soil's infiltration rate. Soil infiltration rates can also be estimated from soil classifications per ASTM (<http://www.astm.org/Standard/index.shtml>) D2487. However, it is best to determine rates using on-site infiltration testing per ASTM D3385 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer, D5093 Standard Test Method for Field Measurement of Infiltration Rate Using Double-Ring Infiltrometer with Sealed-Inner Ring or other available methods. The median rate determined from in-situ measurements should be reduced by a factor of 2.5 and this reduced value used in design calculations. This reduction accounts for incidental compaction during construction and sedimentation of the subgrade over time.

Information: The safety factor of 2.5 is greater than a factor of 2 recommended in most guidance for permeable pavement (see [1] (<http://www.vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec7PERMEABLEPAVEMENT.html>), [2] (http://www.rwra.org/wp-content/uploads/2011/09/Stormwater-Fact-Sheets-Minimum-Standard_s.pdf), [3] (http://doec.dc.gov/sites/default/files/dc/sites/ddoe/publication/attachments/Ch3.4PermeablePavement_0.pdf), [4] (http://www.cambridgepavers.com/dfiles/PermPvtManual7_27.pdf), [5] (http://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.7.pdf)). This manual utilizes recommended soil infiltration rates for hydrologic soil groups (see [6] (http://stormwater.pca.state.mn.us/index.php/Design_infiltration_rates)). These are not as conservative as



Schematic illustrating typical permeable interlocking concrete pavement cross section and basic components of a pervious concrete system.

infiltration rates based on the Unified Soil Classification System (<https://www.pca.state.mn.us/sites/default/files/p-g-en3-12d.pdf>), particularly for finer textured soils. We therefore recommended the more conservative value of 2.5

In most cases, permeable pavement should not be situated above fill soils. Designs in compacted fill soils may require an impermeable liner and an underdrain. Permeable pavements should only be placed on fill soils when laboratory tests indicate the compacted fill will be stable when saturated and that slope stability of deep fills has been verified by a geotechnical engineer.

- Geotextiles - In the absence of full-depth concrete curbs or impermeable liners, geotextiles are recommended on the (vertical) sides of permeable pavements to separate the reservoir layers from the adjacent soil subgrade. Horizontally placed geotextiles between the aggregate base and soil subgrade are at the option of the designer. Geotextile use should be carefully evaluated and selection should be guided by AASHTO M-288 Geotextile for Highway Applications (AASHTO 2010). Specific selection guidance is provided under the Subsurface Drainage section. Class II geotextiles are generally used.
- Contributing drainage area – Permeable pavements sometimes capture runoff from adjacent areas, pavements, and roofs. Runoff from permeable areas is not recommended due to potential clogging of the permeable pavement. The at-grade contributing drainage area into permeable pavement should generally not exceed twice the surface area of the permeable pavement. This guideline helps reduce the rate of surface sedimentation. The 2:1 ratio can be increased to no greater than 5:1 if at least one of these conditions exists:
 - permeable pavement is receiving runoff from roofs as it tends to be very low in sediment; or
 - runoff from adjacent impervious surfaces remains unburdened with sediment due to effective pre-treatment prior to entering the permeable pavement.

For more information on contributing area, see Contributing drainage area to stormwater BMPs.

Caution: Permeable pavement and contributing impervious pavements are assumed to receive regular vacuuming to reduce and control sediment loads and surface clogging potential.

- Soil subgrade slope – The slope of the soil subgrade should be as flat as possible (i.e., less than 1 percent longitudinal slope) to enable even distribution and infiltration of stormwater. Lateral slopes should be less than 1 percent. Steep slopes can reduce the stormwater storage capacity of permeable pavement. Designers should consider using a terraced subgrade design for permeable pavement in sloped areas, especially when the subgrade slope exceeds 3 percent.
- Soil subgrade compaction – This should be avoided wherever possible to maximize infiltration. In some situations, compaction may be needed for supporting vehicular loads. In such cases, compaction density and subsequent soil infiltration should be assessed in a test pit(s) on the site to determine an acceptable soil density and its contribution to soil strength and infiltration. The measured infiltration rate for use in hydrologic calculations may be reduced by the designer to compensate for long-term sedimentation on the soil subgrade.
- Excavation methods - Excavation should be conducted in a manner that minimizes soil subgrade compaction. Tracked rather than wheeled equipment is recommended working from the sides of the excavation. For larger projects, excavation can create cells and berms where equipment removes soil from one area or cell while positioned on higher soil around each cell (see Construction specifications for permeable pavement). Other techniques include ripping or loosening soils compacted by construction equipment. This can be done with the teeth on excavation equipment buckets. Compaction of the aggregate base into these areas is especially important since scarified soil can settle and be reflected on the surface.
- Surface slope – Surface slopes for all permeable pavement types should be at least 1 percent to provide an alternate means for drainage should the surface become completely clogged due to lack of maintenance. Designs should provide an alternate means for stormwater to enter the aggregate reservoir if the pavement surface should ever become clogged, or for extreme storm events. For pervious concrete and porous asphalt

without curbs, this can be a 2 foot wide stone edge connected to the reservoir. For curbed pavements, inlets may be used.

- Overflow structures – Permeable pavements are not designed to store and infiltrate all stormwater from all storms. Therefore, an outlet or outlets are required to prevent water from rising into and over the surface. One type of outlet control would be a catch basin with an internal weir and low-flow orifice. The catch basin can also handle runoff from the surface should it become clogged.
- Minimum depth to seasonal high water table – A high groundwater table may cause seepage into the bottom of permeable pavement and prevent complete drainage. Also, soil acts as a filter for pollutants between the bottom of the pavement base and the water table. Therefore, a minimum vertical separation of 3 feet is required between the bottom of the permeable pavement reservoir layer and the seasonal high groundwater table. For systems with impermeable liners, a minimum of one foot clearance is Highly recommended between the liner and the seasonal high water table.
- Setbacks – To avoid harmful seepage, permeable pavement should not be hydraulically connected to building foundations unless an impermeable liner is placed against the foundation or basement wall. Even under these circumstances, great care should be taken to avoid creating a wet basement problem. If there is no liner, the permeable pavement base should be 10 feet or greater from structures (EPA recommends a minimum setback from building foundations of 10 feet down-gradient and 100 feet up-gradient. See EPA factsheet “Storm Water Technology Fact Sheet: Porous Pavement,” EPA 832-F-99-023 (<http://www.cleanwatermn.org/Documents/MS4%20toolkit%20files/Good%20Housekeeping/Porous%20Pavement/porouspa.pdf>)). Again, it is the designer’s responsibility to avoid creating a wet basement problem. Likewise, permeable pavement bases should be hydraulically separated from adjacent road bases.

Permeable pavements without underdrains infiltrate stormwater and should follow requirements for wellhead protection (EPA recommends a minimum setback of 100 feet from water supply wells). Underground utility lines are best located away from permeable pavement bases. However, if they need to penetrate the base, consideration should be given to waterproofing (depending on the utility) or possible encasement using low-strength flowable concrete fill. Setbacks can be reduced at the discretion of the local authority for designs that use underdrains and/or liners.

- Informed Owner – The property owner should clearly understand the unique maintenance responsibilities inherent with permeable pavement, particularly for parking lot applications. The owner should be capable of performing routine and long-term actions (e.g., vacuuming) to maintain the pavement’s hydrologic functions, and avoid future practices (e.g., winter sanding, seal coating or repaving) that diminish or eliminate them. For porous asphalt a diluted emulsion fog can be used as needed. Maintenance agreements, covenants, maintenance easements or performance bonds are encouraged between the local authority and the property owner.

Green Infrastructure: Permeable pavement can be used at highly developed urban sites that have little or no space retention.

Caution: The required setback distance to a municipal water supply well is 50 feet, but it is recommended that permeable pavements be a minimum horizontal distance of 100 feet from any municipal water supply well

Warning: A minimum vertical separation of 3 feet is required between the bottom of the permeable pavement reservoir layer and the seasonal high groundwater table (saturated soil) or the top of bedrock (i.e. there must be a minimum of 3 feet of undisturbed soil beneath the infiltration practice and the seasonally high water table or top of bedrock).

- Limitations – There are several limitations for use of permeable pavement, as summarized below.
 - Permeable pavements should not be used in high pollutant loading sites. High pollutant loading sites are those that receive constant sediment or trash and/or debris. Places where fuels and chemicals are stored or handled can be potential stormwater hotspots and permeable pavement should not be constructed in these places. Likewise, areas subject to wind borne dust and sediment should not use

permeable pavement unless the pavement can be vacuumed regularly. The following limitations should be considered before utilizing permeable pavements in any design.

- Permeable pavement is suitable for pedestrian-only areas, low-volume roads, low speed areas, overflow parking areas, residential driveways, alleys, and parking stalls. These can be residential collector roads or other applications with similar traffic loads.
- Permeable pavement can be prone to clogging from sand and fine sediments that fill void spaces and the joints between pavers. As a result, it should be used carefully where frequent winter sanding is necessary because the sand may clog the surface of the material. Periodic maintenance is critical, and surfaces should be cleaned with a vacuum sweeper at least two times a year.
- Fuel may leak from vehicles and toxic chemicals may leach from asphalt and/or binder surface. Porous pavement systems are not designed to treat these pollutants.

Design criteria

Base/subbase thickness is determined for support traffic using structural design methods and for water storage using hydrologic sizing and/or dynamic modeling over time. The thicker of the two resulting designs is used.

Structural design

The structural design process for supporting vehicles varies according to the type of pavement selected. The pervious concrete industry is in the process of developing ASTM test methods for characterizing compressive or flexural strengths of pervious concrete. These tests are needed to model fatigue under loads. As an interim step, fatigue equations published by the American Concrete Pavement Association (ACPA (<http://www.pavement.com/>) 2010) assume such inputs to be comparable in nature (but not magnitude) to those used for conventional concrete pavements. The ACPA design method should be consulted for further information as well as pervious concrete industry software. General guidelines for pervious concrete surface thickness are published by the National Ready Mix Concrete Association NRMCA (<http://www.nrmca.org/>) and the Portland Cement Association (Leming (http://www.rmc-foundation.org/images/PCRC%20Files/Hydrological%20&%20Environmental%20Design/PC_DesignManual.pdf) 2007).

Porous asphalt (Hansen 2008) and permeable interlocking pavements (Smith 2011) use flexible pavement design methods adopted from the 1993 AASHTO *Guide for Design of Pavement Structures* (AASHTO 1993). In addition, MnDOT design methods, approved mechanistic principles, and manufacturer's specific recommendations should be consulted.

There has been limited research on full-scale testing of the structural behavior of open-graded bases used under permeable pavements to better characterizing relationships between loads and deformation. Therefore, conservative values (i.e., AASHTO layer coefficients) should be assumed for open-graded base and subbase aggregates in permeable pavement design.

Regardless of type of permeable pavement, structural design methods consider the following in determining surface and base thicknesses to support vehicular traffic:

- pavement life and total anticipated traffic loads expressed as 18,000 pounds equivalent single axle loads or ESALs (This method of assessing loads accounts for the additional pavement wear caused by trucks.);
- soil strength expressed as the soaked California Bearing Ratio (CBR), R-value or resilient modulus (Mr);
- strength of the surfacing, base and subbase materials; and
- environmental factors including freezing climates and extended saturation of the soil subgrade.

Soil stability under traffic should be carefully reviewed for each application by a qualified geotechnical or civil engineer and lowest anticipated soil strength or stiffness values under saturated conditions used for design. Structural design for vehicular applications should generally be on soil subgrades with a CBR (96-hour soaked per

ASTM D 1883 or AASHTO T 193) of 4 percent, or a minimum R-value = 9 per ASTM D 2844 or AASHTO T-190, or a minimum Mr of 6,500 pounds per square inch (45 Mega Pascals) per AASHTO T-307. Soils with lower strengths typically require thickened permeable bases or those using cement or asphalt stabilized open-graded aggregates per Mn/DOT Pavement Manual (<http://www.dot.state.mn.us/materials/pvmtdesign/>), Section 3-3.01.02 Treated Base.

Soil compaction required to achieve these soil strengths will reduce the infiltration rate of the soil. Therefore, the permeability or infiltration rate of soil should be assessed at the density required to achieve one of these values. If soils under vehicular traffic have lower strengths than those noted above, or are expansive when wet, there are several options, including

- underdrains;
- thickened base/subbase layer(s);
- cement or asphalt stabilized base layers; and
- lime or cement stabilized (with design consideration given to practically no infiltration in such cases).

These options are typically used in combination. Pedestrian applications can be placed on lower strength soils than those noted.

Pedestrian applications can be placed on lower strength soils than those noted.

Outflow rate and volume through underdrains

If the depth of the base/subbase for the full infiltration system is excessive, because, as an example, the design subgrade soil infiltration rate is not adequate to remove the water from the design storm within the designated period of time, then the design should include underdrains. The following procedure is for sizing the base/subbase for partial infiltration designs (i.e. contains underdrains).

The outflow rate from underdrain(s) can be approximated by

$$q_u = km$$

where

q_u = outflow through underdrain, feet/hour

k = Coefficient of permeability for each 6 inch diameter underdrain, feet/hour

m = underdrain pipe slope, feet/feet

This equation is based on Darcy's Law, which summarizes several properties that groundwater exhibits while flowing in aquifers. Although the hydraulic conductivity (measure of the ease with which water can move through pore spaces of a material) of the aggregate subbase is very high (approximately 17,000 feet per day or 8,500 inches per hour), the discharge rate through underdrains is limited by the cross sectional area of the pipe. As the storage volume above/around the underdrain(s) decreases (i.e., the hydraulic head or water pressure decreases), the base/subbase and in turn the underdrain(s) will drain increasingly slower. To account for this change in flow conditions within the subbase and underdrain(s) over time, a very conservative coefficient of permeability (k) of 100 feet per day per pipe can be used to approximate the average underdrain outflow rate.

Once the outflow rate through each underdrain has been approximated, the depth of the base/subbase needed to store the design storm can be determined by

$$d_p = ((0.95 * RP) - (i/2)t_f) / n$$

where

0.95 is the runoff coefficient for impermeable surfaces;

d_p = the depth of the reservoir layer (feet);

$R = A_c/A_p$ The ratio of the contributing drainage area (A_c , including the permeable paving surface), to the permeable pavement surface area (A_p);

t_f = the time to fill the reservoir layer (day) – typically 2 hours or 0.083 day;

P = the rainfall depth for the design storm (feet);

i = field-verified infiltration rate (ft/day); and

n = porosity (cubic feet/cubic feet)

To estimate the number of underdrain pipes (N), take the dimension of the parking lot in the direction the pipes are to be placed and divide by the desired spacing between pipes – round down to the nearest whole number.

With full infiltration systems, the maximum allowable drain time (t_d) needs to be calculated to make sure the stored water within the base/subbase does not take too long to infiltrate into the soil subgrade.

$$td = (d_p n) / (0.5i)$$

The total storage in the permeable pavement system, V_s , is given by

$$V_s = A_p(d_p n + 0.5it_f)$$

where

A_p is the surface area of the permeable pavement (ft²).

When calculating the storage volume for compliance with the Construction Stormwater Permit, only the instantaneous storage volume is considered

$$V_s = A_p(d_p n)$$

Permeable pavement can also be designed to augment detention storage needed for channel protection and/or flood control. The designer can model various approaches by factoring in storage within the base/subbase, expected infiltration and any outlet structures used as part of the design.

Once runoff passes through the surface of the permeable pavement system, designers should calculate outflow pathways to handle subsurface flows. Subsurface flows can be regulated using underdrains, the volume of storage in the reservoir layer, the bed slope of the reservoir layer, and/or a control structure at the outlet.

Design for nutrient and TSS reductions

Permeable pavements can be designed to reduce nutrient loadings to the ground or surface waters. The design needs to be specifically designed to capture phosphorus. The permeable pavement system can also be designed to capture nitrogen, although it is important to note that nitrogen and phosphorus each require specific designs to facilitate their removal from stormwater. The following paragraphs describe the design characteristics necessary for the removal of phosphorus and nitrogen.

A study by (Bean, 2007a) showed higher nitrate concentrations in the exfiltrate compared to the infiltrate. Nitrogen reduction capabilities of permeable pavement can be enhanced in partial infiltration designs that detain water in the base/subbase for over 24 hours. This time is required to ensure complete de-nitrification occurs.

PICP can use specially coated aggregates in the joints and bedding and all systems can use them in the base to reduce phosphorous. Coated aggregates (sometimes called “engineered aggregates”) have an effective life of seven to ten years and target the removal of dissolved phosphorous, according to manufacturer’s literature.

A filter layer made of sand or fine aggregate placed under or sandwiched within permeable pavement bases are occasionally used as a means to reduce nutrients. This layer can be enhanced with iron filings for phosphorous reduction (Erickson 2010). Their effectiveness, initial cost, reduction in flow rates, and maintenance costs should be weighed against other design options for nutrient reductions. Sand filters will incur additional construction expense and this can be reduced by placing sand filters under the subbase at the down slope end of a permeable pavement. The disadvantage of sand filters is that they will eventually require removal and restoration if continued phosphorous reduction credit is desired. Concentrating their location in the down slope areas of the site can help reduce future maintenance costs and site disruptions.

A second approach useful for nutrient and TSS reduction can occur on sloping sites by creating intermittent berms in the soil subgrade. These enable settlement of suspended solids and encourage de-nitrification if appropriately designed. A third alternative is using a “treatment train” approach where a permeable pavement initially filters runoff and the remaining water outflows to bioswales or rain gardens adjacent to the pavement for additional processing and nutrient reduction. There may be additional BMPs used to remove nutrients as the water moves through the watershed.

Soil infiltration rate testing

Prior to infiltration testing, soil borings should be taken with an auger to assess the consistency of the soil type and horizons. Guidance for conducting infiltration tests and for determining the number of borings can be found here (http://stormwater.pca.state.mn.us/index.php/Design_criteria_for_bioretention#Determine_site_infiltration_rates_.28for_facilities_with_infiltration_and.2For_recharge.29).

Conveyance and overflow

Permeable pavement designs should include methods to convey larger storms (e.g., 2-year, 10-year) to the storm drain system. The following is a list of methods that accomplish this.

- Place a perforated pipe horizontally near the top of the reservoir layer to pass excess flows after water has filled the base. The placement and/or design should be such that the incoming runoff is not captured (e.g., placing the perforations on the underside only). Pipe placement should be away from wheel loads to prevent damage.
- Increase the thickness of the top of the reservoir layer.
- Create underground detention within the reservoir layer of the permeable pavement system. Reservoir storage may be augmented by corrugated metal pipes, plastic or concrete arch structures, etc.
- Route excess flows to another detention or conveyance system that is designed for management of extreme event flows.
- Set the storm drain inlets level with the elevation of the permeable pavement surface to effectively convey excess stormwater runoff past the system. The design should also make allowances for relief of unacceptable ponding depths during larger rainfall events.

Reservoir layer

The reservoir below the permeable pavement surface should be composed of clean, washed crushed stone aggregate and thickness sized for both the storm event to be stored and the structural requirements of the expected traffic loading. The recommended minimum void ratio should be 40 percent per ASTM (<http://www.astm.org/>) C29. Reservoir base layers for pervious concrete are typically washed AASHTO No. 57 stone and those for porous asphalt are AASHTO (<http://www.transportation.org/Pages/default.aspx>) No. 2, 3, or 5. PICP uses AASHTO No. 2, 3, or 4 stone.

If exposed to vehicular loads, all crushed stone should be Minnesota Department of Transportation (MnDOT) Class A or B coarse aggregate, minimum 80 percent crushed, typically granite, basalt, gneiss, trap rock, diabase, gabbro, or similar material. The maximum Los Angeles Rattler Loss (<http://www.dot.state.mn.us/materials/manuals/laboratory/1210.pdf>) should be 35 percent per AASHTO T-96 and no greater loss than 10 percent per AASHTO T-104 Magnesium Sulfate Soundness Test on the non-igneous portions and as modified by the MnDOT Laboratory Manual (<http://www.dot.state.mn.us/materials/labmanual.html>) (MNDOT 2005). Limestone aggregates not meeting these requirements are not recommended in vehicular applications. Class C and D aggregates may be used in areas subject only to pedestrian traffic.

Underdrains

Underdrains install quickly when placed on or in the soil subgrade, surrounded by stone base materials. The outflow portion at the end is not perforated and is raised to a designed height that allows for some water detention prior to outflow. Placement at this elevation also protects the pipe with aggregate during base compaction. For permeable pavement bases/subbases using 2 or 3 inch maximum size aggregates, underdrain pipes with them should be surrounded with at least 4 inches of ASTM No. 57 (maximum 1 inch size aggregate) to protect the pipes during compaction. An underdrain(s) can also be installed and capped at a downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.

Maintenance

Proper maintenance of permeable pavement is crucial for ensuring its longevity and functionality. Some portions of the maintenance plan require planning during the design stages. These items are noted below.

- Observation Well – Typically this consists of a well-anchored, six-inch diameter perforated PVC pipe that extends vertically to the bottom of the reservoir layer. This is installed at the down slope end of the permeable pavement. The observation well should be fitted with a lockable cap installed flush with the ground surface (or under the pavers) to facilitate periodic inspection and maintenance. The observation well enables visual monitoring of drawdown within the reservoir layer after a storm.
- Overhead Landscaping – Some communities require a certain percentage of parking lots to be landscaped. Large-scale permeable pavement should be carefully planned to integrate landscaping in a manner that maximizes runoff treatment and minimizes risk of sediment, mulch, grass clippings, crushed leaves, nuts, and fruits inadvertently clogging the surface. Prior to construction, owners should commit to a vacuuming plan that includes vacuuming frequency and equipment needs. The vacuuming frequency typically depends on the time of year. In the spring, tree buds and seeds necessitate frequent vacuuming. In the fall, tree leaves and acorns necessitate frequent vacuuming. In the summer, vacuuming frequency depends on permeable pavement exposure to organic material from trees and nearby vegetated areas. Vacuum equipment and methods for sediment removal are provided in the section addressing operation and maintenance.

Major design elements

The following design elements apply to permeable pavement.

Minimum separation distance

Warning: It is *REQUIRED* that infiltration practices be designed with a minimum vertical distance of 3 feet between the bottom of the infiltration practice and the seasonally high water table or bedrock layer. See also Step 8 under the Design procedures section.

Local authorities may require greater separation depths.

It is *HIGHLY RECOMMENDED* that infiltration practices not be hydraulically connected to structure foundations or pavement, to avoid seepage and frost heave concerns, respectively. If groundwater contamination is a concern, it is *RECOMMENDED* that groundwater mapping be conducted to determine possible connections to adjacent groundwater wells.

Setback distances

Warning: The minimum setback distance from a stormwater infiltration system to a public water-supply well is 100 feet for wells classified as sensitive and 50 feet for all other public supply wells, as *REQUIRED* by the Minnesota Department of Health. See MDH isolation distances (<http://www.health.state.mn.us/divs/eh/wells/construction/isolate.html>) (pollutant or contaminant that may drain into the soil)

Caution: The minimum setbacks in the table below are *HIGHLY RECOMMENDED* for the design and location of infiltration practices. It will be necessary to consult local ordinances for further guidance on siting infiltration practices.

Required and recommended minimum vertical and horizontal separation distances. This represents the minimum distance from the infiltration practice to the structure of concern. If the structure is above-ground, the distance is measured from the edge of the BMP to the structure. If the structure is underground, the vertical separation distance represents the distance from the point of infiltration through the bottom of the system to the structure, while the horizontal separation (often called setback) distance is the shortest distance from the edge of the system to the structure.

Link to this table

	Structure	Distance (feet)	Requirement or recommendation	Note(s)
Vertical	Saturated soil (https://stormwater.pca.state.mn.us/index.php?title=Shallow_groundwater)	3	Requirement ¹	
	Bedrock (https://stormwater.pca.state.mn.us/index.php?title=Shallow_soils_and_shallow_depth_to_bedrock)	3	Requirement ¹	
Horizontal	Public supply well	100 for sensitive wells; 50 for others	Requirement	
	Building/structure/property line ²	10	Recommended	
	Surface water	none unless local requirements exist		If nearby stream is impaired for chloride, see [7] (http://stormwater.pca.state.mn.us/index.php/Stormwater_infiltration_and_setback_%28separation%29_distances#Surface_waters)
	Septic system	35	Recommended	
	Contaminated soil/groundwater (https://stormwater.pca.state.mn.us/index.php?title=Stormwater_infiltration_and_contaminated_soils_and_groundwater)			No specific distance. Infiltration must not mobilize contaminants.
	Slope	200	Recommended	from toe of slope $\geq 20\%$

Structure	Distance (feet)	Requirement or recommendation	Note(s)
Karst	1000 up-gradient 100 down-gradient	Requirement ¹	Active karst

¹ Required under the Construction Stormwater General Permit

² Minimum with slopes directed away from the building

Karst: It is *HIGHLY RECOMMENDED* that infiltration practices not be used in active karst formations without adequate geotechnical testing.

Wellhead Protection Areas: It is *HIGHLY RECOMMENDED* to review the Minnesota Department of Health guidance (<http://www.health.state.mn.us/divs/eh/water/swp/stormwater.pdf>) on stormwater infiltration in Wellhead Protection Areas.

Pretreatment

Warning: It is *REQUIRED* that some form of pretreatment, such as a plunge pool, sump pit, filter strip, sedimentation basin, grass channel, or a combination of these practices be installed upstream of the infiltration practice.

It is *HIGHLY RECOMMENDED* that the following pretreatment sizing guidelines be followed:

- Before entering an infiltration practice, stormwater should first enter a pretreatment practice sized to treat a minimum volume of 25 percent of the V_{wq} .
- If the infiltration rate of the native soils exceeds 2 inches per hour a pretreatment practice capable of treating a minimum volume of 50 percent of the V_{wq} should be installed.
- If the infiltration rate of the native soils exceeds 5 inches per hour a pretreatment practice capable of treating a minimum volume of 100 percent of the V_{wq} should be installed.

It is *HIGHLY RECOMMENDED* that pretreatment practices be designed such that exit velocities from the pretreatment systems are non-erosive (less than 3 feet per second) and flows are evenly distributed across the width of the practice (e.g., by using a level spreader).

Depth

The depth of an infiltration practice is a function of the maximum drawdown time and the design infiltration rate.

Warning: The *REQUIRED* drawdown time for infiltration practices is 48 hours or less, and so the depth of the practice should be determined accordingly.

Warning: Groundwater Protection: It is *REQUIRED* that runoff from potential stormwater hotspots (PSHs) not be infiltrated unless adequate pretreatment has been provided. Infiltration of runoff from confirmed hotspot areas, industrial areas with exposed significant materials, or vehicle fueling and maintenance areas is *PROHIBITED*.

Materials specifications

Permeable pavement material specifications vary according to the specific pavement product selected. The following table describes general material specifications for the components installed beneath the permeable pavement. Note that the size of stone materials used in the reservoir and filter layers differ depending whether the system is pervious concrete, porous asphalt or permeable interlocking concrete pavement.

Summary of specifications for materials under the pavement surface. For more information, see the footnote ⁽¹⁾. Reference or links to any specific commercial product, process, or service by trade name, trademark, service mark, manufacturer, or otherwise does not constitute or imply endorsement, recommendation, or favoring by the Minnesota Pollution Control Agency.

Link to this table

Material	Specification	Notes
Bedding/choker layer	<ul style="list-style-type: none"> ▪ Pervious concrete: None ▪ Porous asphalt: 1 inch of AASHTO No. 57 stone ▪ PICP: 2 inches of AASHTO (http://www.transportation.org/Pages/default.aspx) No. 8 stone (MnDOT 3127FA-3 (http://www.dot.state.mn.us/pre-letting/spec/2005/3101-3491.pdf)) 	Washed free of fines
Reservoir Layer	<ul style="list-style-type: none"> ▪ Pervious concrete: AASHTO No. 57 stone or per hydraulic design ▪ Porous asphalt: AASHTO No. 2, 3, or 5 stone ▪ PICP: 4 inches of AASHTO No. 57 base and AASHTO No. 2, 3 or 4 stone subbase 	Stone layer thickness based on the pavement structural and hydraulic requirements. Stonewashed and free of fines. Recommended minimum void ratio = 0.4.
Underdrain (optional)	Use 4 to 6 inch diameter perforated PVC (AASHTO M-252) pipe or corrugated polyethylene pipe. Perforated pipe installed for the full length of the permeable pavement cell, and non-perforated pipe, as needed, connected to storm drainage system.	
Filter Layer (optional)	Sand filter layer is separated from base above and native soils with geotextile. Sand layer typically ASTM (http://www.astm.org/) C33 gradation, 6 to 12 inches thick.	The Filter Layer is REQUIRED if using the permeable pavement system to meet permit requirements. The sand layer may require a choker layer on surface to provide transition to base layer stone.
Geotextile (optional)	Comply with AASHTO M-288 <i>Standard Specification for Geotextile Specification for Highway Applications</i> , drainage and separation applications, Class I or II. Porous asphalt industry recommends non-woven geotextile.	
Impermeable Liner	Use a minimum 30mil PVC liner covered by 12 ounce/square yard non-woven geotextile. EPDM and HDPE liner material is also acceptable.	
Observation Well	Use a perforated 4 to 6 inch vertical PVC pipe (AASHTO M-252) with a lockable cap, installed flush with the surface (or under pavers).	

¹for additional information on materials referenced in this table (e.g. stone dimensions), see the following links:

- stone size 1 (<http://laurel aggregates.com/stone-types>), 2 (see Table 1) (<ftp://ftp.dot.state.fl.us/lts/CO/Specifications/SpecBook/2010Book/901.pdf>)
- definitions of aggregates 1 (<ftp://ftp.dot.state.fl.us/lts/CO/Specifications/SpecBook/2010Book/901.pdf>)
- information on geotextiles 1 (<ftp://ftp.wfl.fhwa.dot.gov/geotech/Geotech%20FP-12/207,%20714%20-%20Geosynthetics/AASHTO%20M-288%20spec%20%28DAN%29.pdf>), 2 (http://www.tencate.com/amer/Images/TN_aashto0608_tcm29-16706.pdf)
- liners 1 (http://stormwater.pca.state.mn.us/index.php/Liners_for_stormwater_management)

A general comparison of different permeable pavements is provided in the following table. Designers should consult industry association and manufacturer's technical specifications for specific criteria and guidance.

This table shows summarizes specifications for permeable pavement.

Link to this table.

Material	Specification	Notes
Permeable Pavers	Surface open area: typically 5% to 15%; minimum thickness: 3 inches for vehicles; minimum compressive strength: 8,000 psi	Concrete pavers conform to ASTM C936 and clay pavers C1272. Reservoir layer required to support the structural load.
Pervious Concrete	<ul style="list-style-type: none"> ▪ Void content: 15% to 35 % ▪ Thickness: typically 5 to 8 inches 	May not require a reservoir layer to support loads, but a layer is required for storage/infiltration. In no case should plain steel rebar or mesh be used in pervious concrete as this invites corrosion.
Porous Asphalt	<ul style="list-style-type: none"> ▪ Void content: 16% to 20 % ▪ Thickness: minimum 2.5 inch surface 	Reservoir layer contributes to structural load support.

Other design considerations

There are additional design considerations for permeable pavement, including use of permeable pavement in karst terrain and winter considerations.

Karst terrain

A detailed geotechnical investigation may be required for any kind of stormwater design in karst terrain. Permeable pavements, as with other infiltration practices, are not recommended at sites with known karst features as they can cause the formation of sinkholes and can provide a direct link for stormwater to access groundwater without providing any treatment.

Winter considerations

Plowed snow piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach all permeable pavements. Sand is not recommended for winter traction over permeable pavements. If sand is applied, it must be removed with vacuum cleaning in the spring. Traction can be accomplished on PICP using jointing stone materials, some of which will find its way into the joints by springtime. A significant winter advantage of permeable pavements is that they require less deicing materials than their impervious counterparts. Use of deicing material on permeable pavement is therefore not recommended.

Signage

Permeable pavements can be used as opportunities for public education with signs explaining how they work. Infiltration demonstrations also help show how the pavements work. Signs provide a reminder to maintenance crews of their presence and list maintenance do's and don'ts specific to the permeable pavement type.

Design checklists

Design checklists have not been developed for the Minnesota Stormwater Manual. We anticipate developing these in 2018. Below are links to checklists developed by other organizations.

- Iowa Stormwater Education Partnership, Permeable Paver Design Review Checklist (http://www.iowastormwater.org/documents/filelibrary/files/rainscaping_iowa/checklists/Permeable_Pavement_72516_1D67FA1EB1EBE.pdf)
- Cartegraph, Permeable Pavement Design Review checklist (<https://www.slideshare.net/Cartegraph/permeable-pavement-check-list>)

Related articles

- Overview for permeable pavement
- Types of permeable pavement
- Design criteria for permeable pavement
- Construction specifications for permeable pavement
- Assessing the performance of permeable pavement
- Operation and maintenance of permeable pavement
- Calculating credits for permeable pavement
- Case studies for permeable pavement
- Green Infrastructure benefits of permeable pavement
- Summary of permit requirements for infiltration
- Permeable pavement photo gallery
- Additional considerations for permeable pavement
- Links for permeable pavement
- References for permeable pavement
- Fact sheets for permeable pavement
- Requirements, recommendations and information for using permeable pavement BMPs in the MIDS calculator

Permeable pavement main page (https://stormwater.pca.state.mn.us/index.php?title=Permeable_pavement)

Retrieved from "https://stormwater.pca.state.mn.us/index.php?title=Design_criteria_for_permeable_pavement&oldid=42694"

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