PP-1. Introduction

Permeable Pavements are alternative paving surfaces that capture and temporarily store the Target Treatment Volume (Tv) by filtering runoff through voids in the pavement surface into an underlying stone reservoir. Filtered runoff may be collected and returned to the conveyance system, or allowed to partially infiltrate into the soil.

Permeable Pavements can be used to:

- Manage the first one inch of rainfall on-site using an Infiltration Design with no underdrain (see **Table PP-1**, Level 2 design)
- Manage the first one inch of rainfall on-site using an Infiltration Sump Design with an underdrain and an infiltration sump (see **Table PP-1**, Level 2 design)
- Partially manage the first one inch of rainfall on-site using a Basic Design with an underdrain (see **Table PP-1**, Level 1 design)
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs; see **Table PP-2**).
- Meet partial or full storage requirements for local stormwater detention standards
- Retrofit existing developed areas, especially highly impervious areas

Permeable Pavements can be blended into the urban environment by replacing almost any paved surface. Designers often limit the application of Permeable Pavement to parking stalls and lower traffic areas such as emergency access roads or non-travel lanes of parking lots. However, new materials and construction techniques have made Permeable Pavements applicable to most applications. Examples illustrated in the photos above include parking lot Concrete Grid Pavers (left) and a Porous Asphalt parking lot (right). The photo on the right illustrates the porosity of the pavement passing water through the pavement section without any runoff.

For the purposes of this section, "Permeable Pavement" refers to **Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, Permeable Interlocking Concrete Pavers** and other products and configurations that are designed for the same purpose (plastic, dirt or grass filled pavers, interlocking pavers, etc.).

Figure PP-1 further illustrates typical Permeable Pavement materials and applications. **Figures PP-2 and PP-3** are schematics of a typical Permeable Pavement sections and profiles. **Tables PP-1 and PP-2** describe two levels of Permeable Pavement design and associated volume reduction and pollutant removal performance rates. **Table PP-3** is a design checklist to help guide the design process for Permeable Pavement practices.

PP-1.1 Planning This Practice

Figure PP-1. Typical Permeable Pavement Materials

Pervious Concrete

Porous Asphalt

Concrete Grid Pavers

Permeable Interlocking Concrete Pavers

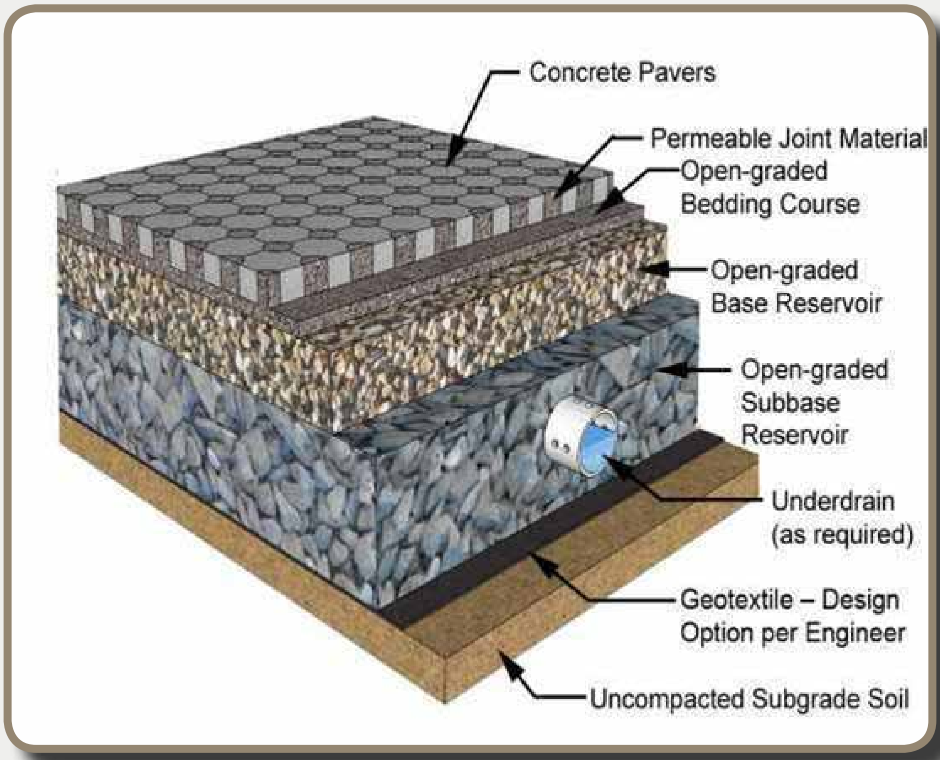
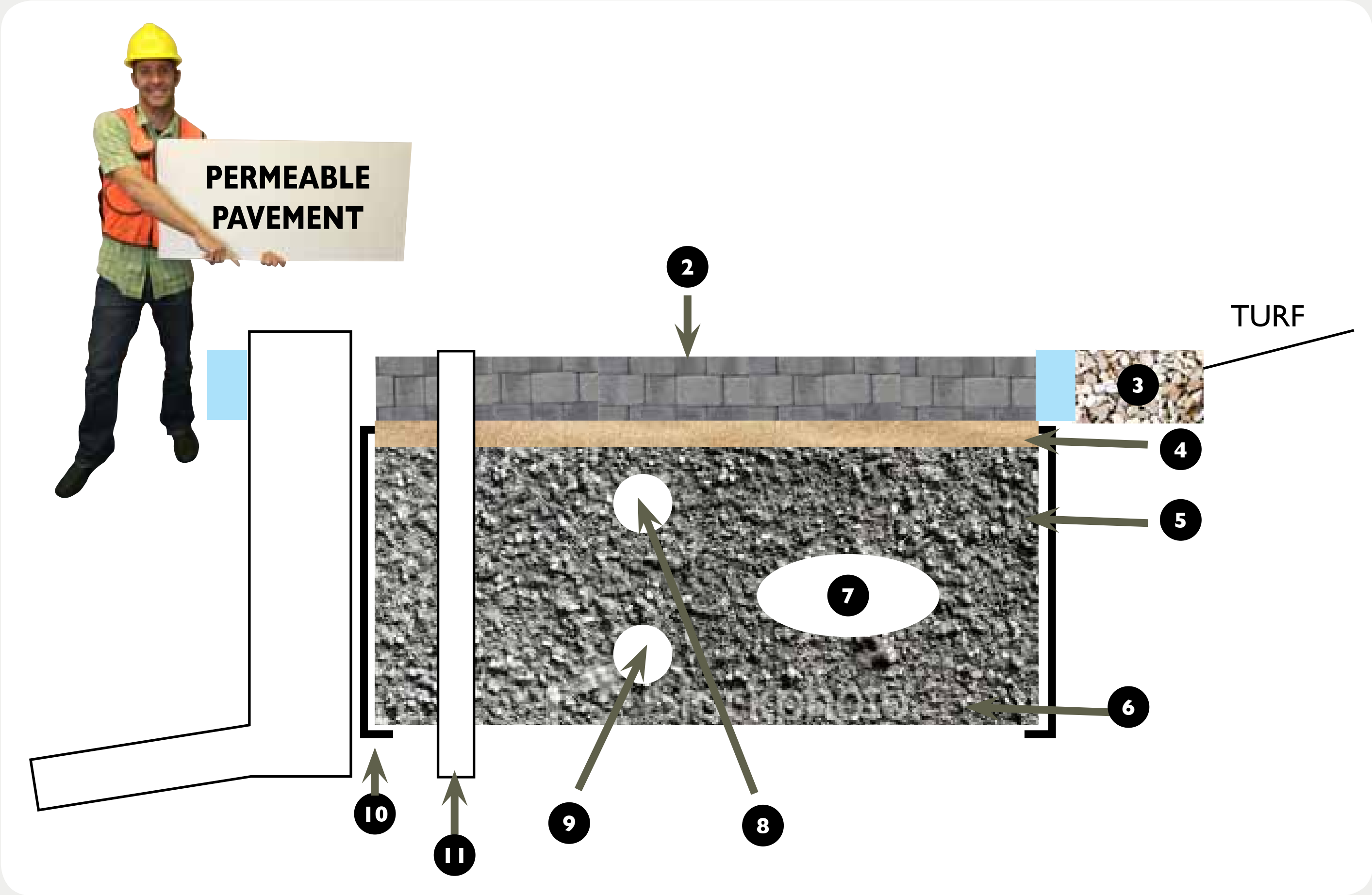


Figure PP-2. Schematic Profile for Typical Permeable Pavement Section (Source: David Smith, ICPI).

Figure PP-3. Schematic for Typical Permeable Pavement



1. **Overflow/storm drain structure** – Section PP-4.4
2. **Pavement type** – Sections PP-1.1 & PP-4
3. **Pretreatment (if needed)** – Section PP-4.5
4. **Bedding layer (as per manufacturer)**
5. **Reservoir layer** – Sections PP-4.1, PP-4.2, PP-4.6
6. **Infiltration sump (reservoir below underdrain)** – Sections PP-4.1 & PP-4.6
7. **Additional storage for larger storms (optional)** – Section PP-4.3
8. **Overdrain (optional)** – Section PP-4.4
9. **Underdrain (Level 1 standard design & Level 2 infiltration sump design)** – Section PP-4.7
10. **Filter fabric (sides only)** – Section PP-4.9
11. **Observation well** – Section PP-4.8

PP-1.2 Permeable Pavement Design Options & Performance

Table PP-1 describes the Level 1 and Level 2 design options for Permeable Pavement and the practice performance in terms of reducing the volume associated with one inch of rainfall on the site. **Table PP-2** summarizes pollutant removal performance values for Level 1 and Level 2 designs. This is for the purpose of calculating site-based pollutant load reductions in the context of TMDLs and/or watershed plans.

Table PP-1. Permeable Pavement Design Levels: Descriptions & Performance

Design Level	Description	Applications	Performance[1]
Level 1	Basic Design - • Underdrain design • Depth of reservoir layer (above underdrain) from Equation PP-1. • No infiltration sump below underdrain pipe(s)	• Sites with poor soils or constructed on fill material; • Constraints such as high bedrock or water table OR confirmed karst, stormwater hotspot, or other applications that require an impermeable liner.	45% volume reduction for the Design Volume of the practice[2]
Level 2	Infiltration Design: • No underdrain • Depth of reservoir layer from Equation PP-1. • Water infiltrates into the underlying soil within 48 hours	• Sites with permeable soils; confirmed infiltration rates ≥ 0.5 in./hr	100% volume reduction for the Design Volume of the practice[2]
Level 2	Infiltration Sump Design: • Underdrain • Depth of reservoir layer (above underdrain) from Equation PP-1. • Sump below underdrain sized to drain within 48 hours (based on confirmed infiltration rate)	• Sites with marginal soils • Sites with permeable soils where an underdrain is preferred	• 100% volume reduction for the part of the Design Volume contained in the sump[3]; • 45% volume reduction for the part of the Design Volume in the reservoir layer (above and including the underdrain)[2]

[1] *Performance achieved toward reducing one inch of rainfall*

[2] *Design Volume includes storage within the stone reservoir below the pavement surface, including the volume of the infiltration sump, if used. The Design Volume can be 100% of that needed to meet the 1-inch performance standard for the contributing drainage area ("Target Treatment Volume") or some proportion of it when used in conjunction with other practices. See* **Section PP-4.1** *for sizing details.*

[3] *Sump depth and volume based on ability to fully drain within 48 hours based on confirmed infiltration rate. See Section PP-4 for design and sizing details.*

Table PP-2. Total Pollutant Load Reduction Performance Values for Level 1 and 2 Design

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN) [1]
1	TSS = 81%	TP = 59% TN = 59%
2	TSS = 91%	TP = 81% TN = 81%

[1] Total Pollutant Load Reduction = combined functions of runoff reduction and pollutant removal. Pollutant removal refers to the change in event mean concentration as it flows through the practice and is subjected to treatment processes, as reported in Hirschman et al. (2008).

PP-1.3. Permeable Pavement Design Checklist

Table PP-3. Permeable Pavement Design Checklist

CHECKLIST

This checklist will help the designer through the necessary design steps for Permeable Pavement.

- ☐ Check feasibility for site – **Section PP-3**
- ☐ Determine applicability of Level 2 Infiltration Design or Infiltration Sump Design, or Level 1 Basic Design based on soils/geotechnical investigation; **Table PP-1**
- ☐ Complete Site Design Spreadsheet to determine the Target Treatment Volume (Tv) plan and confirm required Permeable Pavement Stone Reservoir Sizing, and any additional practices needed, and overall site compliance – Site Compliance Spreadsheet & **Chapter 3** of Manual
- ☐ Check Permeable Pavement sizing guidance and make sure there is an adequate footprint (often split into multiple areas) on the site for Permeable Pavement area(s) – **Sections PP-4.1 & PP-4.2**
- ☐ Check design adaptation appropriate to the site – **Section PP-6**
- ☐ Design Permeable Pavement in accordance with design criteria and typical details – **Sections PP-2 & PP-4**
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence and notes

PP-2. Typical Details

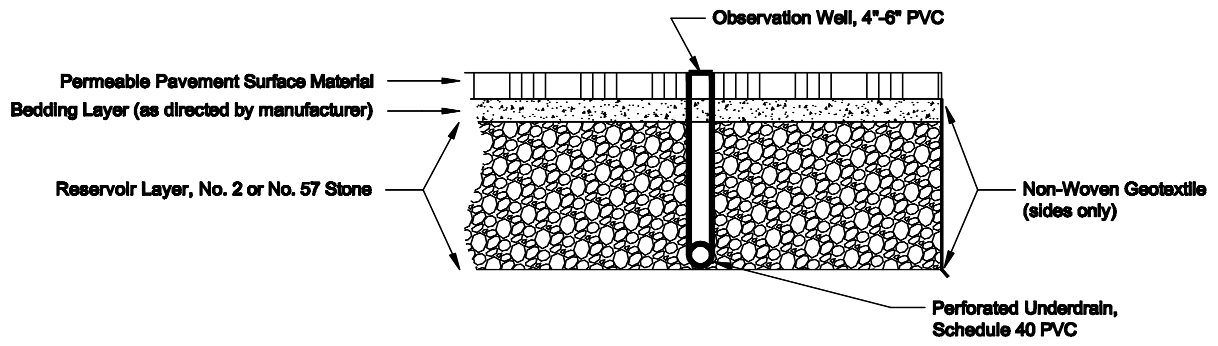


Figure PP-4. Cross Section of a Basic Level 1 Permeable Pavement Design

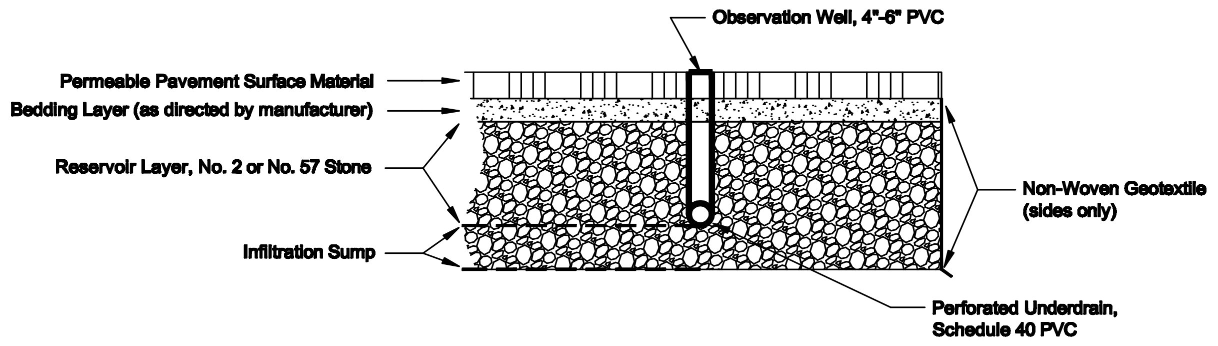


Figure PP-5. Cross Section of Level 2 Permeable Pavement Design with Infiltration Sump

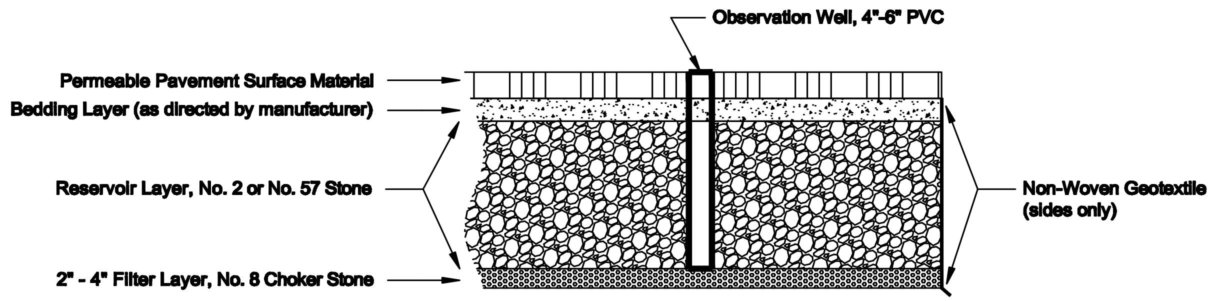


Figure PP-6. Cross Section of Level 2 Permeable Pavement Infiltration Design

4.2.4. Permeable Pavement (PP)

PP-3. Feasibility Criteria and Design Considerations

Since Permeable Pavement has a very high runoff reduction capability, it should be considered as an alternative to conventional pavement on any design. The Basic Design (Level 1) can be applied at most development sites, while the Infiltration Design and Infiltration Sump Design (Level 2) are subject to the same feasibility constraints as Infiltration practices.

Key constraints for Permeable Pavement include the following:

Available Space. A prime advantage of Permeable Pavement is that it does not normally require additional space at a new development or redevelopment site, which can be important for tight sites or areas where land value is high.

Site Topography. Steep pavement surface slopes can reduce the stormwater storage capability of Permeable Pavement and may cause shifting of the pavement surface and base materials. Further, long runs of pavement on a slope will allow runoff to migrate downslope through the reservoir and pool at the lower end of the pavement. Designers should consider using a terraced design for Permeable Pavement in sloped areas, especially when the finished parking grade will be 3 percent or greater.

Pavement Section Bottom Slope. The bottom slope of a Permeable Pavement Infiltration or Infiltration Sump installations should be as flat as possible (i.e., 0% longitudinal and lateral slopes) to enable even distribution and infiltration of stormwater. On sloped sites, internal check dams or berms can be incorporated into the subsurface to encourage infiltration.

If an underdrain design is used, low-grade longitudinal slopes on the bottom and the underdrain (i.e., 0.5%) are required to ensure the system drains, but the designer must account for this grade when establishing the stone reservoir minimum depth. On especially long runs, this may result in the reservoir depth being deeper at the lower end in order to create the required storage volume.

External Drainage Area. The area of pavement draining onto ("run-on") a Permeable Pavement section should be limited to two times the area of Permeable Pavement. The external drainage area should be as close to 100% impervious as possible. Both of these constraints are the result of numerous observations of Permeable Pavements being overloaded with sediment and grit (pavement erosion) increasing the required frequency of maintenance.

Limit the Size of the External Drainage Area for Long-Term Performance & Maintenance

The external drainage area contributing "run-on" to a Permeable Pavement section is limited to two times the area of the Permeable Pavement. For example: a 1 acre section of Permeable Pavement can have up to 2 adjacent acres sheet flowing to the permeable section. Keeping this "run-on" to a minimum, and limiting it to impervious cover has been demonstrated to maximize the performance life and minimize the frequency of maintenance of Permeable Pavement.

Available Hydraulic Head. The elevation difference needed for Permeable Pavement to function properly is generally nominal, although 2 to 4 feet of head from the pavement surface to the underdrain outlet is optimal (this value may vary based on several design factors such as whether an underdrain or an upturned elbow is used).

Water Table. A high groundwater table may cause runoff to pond at the bottom of the Permeable Pavement system. Therefore, a minimum vertical distance of 2 feet must be provided between the bottom of the Permeable Pavement installation (i.e., the bottom invert of the reservoir layer) and the seasonal high water table.

Soils. Soil conditions do not typically constrain the use of Permeable Pavement, although they do determine whether an underdrain is needed. Underdrains are required if the measured permeability of the underlying soils is less than 0.5 in/hr. Designers may choose to incorporate an infiltration sump below the underdrain where underlying soils are marginal (in the range of 0.1 to 0.5 in/hr). In either case, designers must verify soil permeability by using the on-site soil investigation methods provided in Appendix B. Low permeability soils will require an underdrain.

In fill soil locations, geotechnical investigations are required to determine if the use of an impermeable liner and/or underdrain are necessary or if the use of an infiltration sump (see Section PP-4 for Design Criteria) is permissible.

Use of Permeable Pavement on Fill Section

In areas of significant fill, soil slips can result from infiltrating water, including use of an infiltration sump. It is preferable to use this type of design in cut sections. Geotechnical investigations are required if any design that infiltrates water will be used in a fill section. Impermeable liners and underdrains (without a sump) may be necessary, based on the outcome of the investigation (see Section PP-4.10).

Hotspot Land Uses. Permeable Pavements should not be used to treat hotspot runoff. However, Permeable Pavement can still be used to treat "non-hotspot" parts of the site; for instance, employee or visitor parking while vehicular maintenance or other hotspot areas would be treated by a more appropriate practice.

For a list of potential stormwater hotspots, please consult Chapter 5 of the Manual.

High Traffic or High Pollutant Loading Conditions. Permeable Pavement is not intended to treat sites with high sediment or trash/debris loads, since such loads will cause the practice to clog and fail without frequent and intensive maintenance. Sites with a lot of pervious area (e.g., newly established turf and landscaping) can be considered high loading sites and the pervious areas should be diverted away from the Permeable Pavement area if possible. If directing runoff from new pervious areas to the Permeable Pavement is unavoidable, aggressive pretreatment measures should be employed.

High Speed Roads. Permeable Pavement should not be used for high speed roads, although it has been successfully applied for low speed residential streets, parking lanes and roadway shoulders.

Floodplains. Permeable Pavement should be constructed outside the limits of the 100-year floodplain, unless a waiver is obtained from the local authority.

Non-Stormwater Discharge. Permeable Pavement should not receive non-stormwater discharges such as irrigation runoff, air-conditioning condensation discharge, chlorinated wash-water or other such non-stormwater flows.

Setbacks. To avoid the risk of seepage, Permeable Pavement practices should not be hydraulically connected to structure foundations. Setbacks to structures vary based on the size of the Permeable Pavement installation:

- 250 to 1,000 square feet of Permeable Pavement = 5 feet if down-gradient from building; 25 feet* if up-gradient.
- 1,000 to 10,000 square feet of Permeable Pavement = 10 feet if down-gradient from building; 50 feet* if up-gradient.
- More than 10,000 square feet of Permeable Pavement = 25 feet if down-gradient from building; 100 feet* if up-gradient.

* In some cases, the use of an impermeable liner along the sides of the Permeable Pavement practice (extending from the surface to the bottom of the reservoir layer) may be used as an added precaution against seepage, and the setback requirements can be relaxed.

At a minimum, Permeable Pavement Infiltration Design or Infiltration Sump Design applications should be located a minimum horizontal distance of 100 feet from any water supply well and at least 5 feet down-gradient from dry or wet utility lines. These setbacks are general guidelines and may be reduced by the local plan approving authority if precautions are taken.

Proximity to Utilities. Interference with underground utilities should be avoided whenever possible, particularly water and sewer lines. Under no circumstances should utility lines be run through the stone reservoir. Approval from the applicable utility company or agency is required if utility lines will run below or immediately adjacent to a Permeable Pavement installation.

Conflicts with water and sewer laterals (e.g., house connections) on residential driveway applications may be unavoidable, and the construction sequence must be altered, as necessary, to avoid impacts to existing service.

Community Factors. Permeable Pavement can be designed as a safe and aesthetically pleasing practice. Creative mosaic paver designs can be utilized in highly visible pedestrian residential or commercial areas.

Underground Injection Permits. Permeable Pavement is not considered to be Class V wells subject to permits under the Underground Injection Control (UIC) Program (U.S. EPA, 2008). However, in certain cases the designer should confer with West Virginia Department of Environmental Protection (WVDEP) about the possible applicability of a UIC permit. These cases would include Infiltration Designs (or Infiltration Sump Designs) in close proximity to sensitive groundwater areas (e.g., aquifers overlain with thin, porous soils), or designs with a subsurface fluid distribution system (e.g., underdrains that do not discharge to the surface or the storm drain system).

PP-4. Design Criteria

The design of Permeable Pavement includes the selection of the pavement type: **Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, Permeable Interlocking Concrete Pavers,** and other products that are designed to support varying amounts of vehicle or pedestrian traffic. The type of pavement should be selected based on a review of the pavement specifications and properties, and the proposed site conditions, and designed according to the product manufacturer's recommendations.

The critical components of the design related to stormwater quality and runoff volume reduction is the internal or subsurface geometry, including the stone reservoir layer and the designation of an underdrain and/or infiltration sump based on the soil conditions under the proposed pavement (Hunt and Collins, 2008).

The thickness of the stone reservoir layer is determined by both a structural and hydraulic design analysis. The reservoir layer serves to retain stormwater and also supports the design traffic loads for the pavement. The Permeable Pavement structural design is discussed in **Section PP-4.2**, and is critical to the design since it may impact the ability to use an Infiltration Design.

Consider Structural Load Capacity as Part of the Design Process

An additional pavement design element is the structural load capacity of the pavement section. **Section PP-4.2** provides a brief discussion of this design element as it may relate to the subgrade preparation or the selection of pavement material. Designers should investigate this design parameter before applying an Infiltration Design.

PP-4.1. Permeable Pavement Sizing for Water Quality & Volume Reduction

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage within different layers as prescribed in the BMP specification. For Permeable Pavement, Dv will equal Tv if the CDA is only the pavement surface itself and any external drainage area. However, if Permeable Pavement is used in conjunction with downstream runoff reduction practices, the Dv of the Permeable Pavement can be a subset of the overall Tv. In such cases, the sum of the Dvs in the Permeable Pavement plus those of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

Permeable Pavement design for runoff reduction and water quality consists of sizing the stone reservoir for one of the following design configurations:

1. Basic Design (Level 1) where the depth of stone reservoir above and including the underdrain is sized to store the Dv; **the runoff reduction credit is 45% of the Dv.**
2. Infiltration Sump Design (Level 2) where the combined depth of stone reservoir above and including the underdrain and the infiltration sump are sized to store the Dv; **the runoff reduction credit is 100% of the portion of the Dv stored in the sump, and 45% of the portion of the Dv stored above the sump**; or
3. Infiltration Design (Level 2) where the depth of stone reservoir is sized to store the Dv; **the runoff reduction credit is 100% of the Dv** provided.

The Level 1 design is intended for those sites where the infiltration rate of the soil is below the minimum design rate of 0.5"/hr. The Level 2 Infiltration Sump Design is intended for those applications where the soils may be marginal, the pavement structural design will result in a diminished soil infiltration rate, or the pavement section design requires that the stone reservoir be dewatered, but does allow for the full infiltration design (no underdrain). The Infiltration Sump Design provides a 100% runoff reduction credit for the volume of the infiltration sump. The Level 2 Infiltration Design is for applications where the existing soils are adequate and the construction of the Permeable Pavement section is such that the underlying soils can be utilized for infiltration.

Underdrains Can Flow to Downgradient Practices, Such as Infiltration

Some designers are reluctant to design a Permeable Pavement section without an underdrain since the structural requirements will require some compaction of the underlying soils (refer to Section PP-4.2), potentially limiting or even eliminating the infiltrative capacity of the soils. Since this will potentially lead to pavement failure, some designers have elected to convey the runoff from the underdrain to an adjacent infiltration trench (stone reservoir out from under the pavement section). The infiltration trench can be designed to accept surface runoff from the perimeter impervious pavement, as well as subsurface inflow from the underdrain.

The sizing of the stone reservoir consists of establishing the depth of the stone to store the Dv. An additional design step is to consider the storage or conveyance of larger storms (discussed in **Sections PP-4.3 and PP-4.4**). Both of these volume requirements can be established through a storage indication routing program using the underdrain or the infiltration rate to accurately determine the required reservoir depth. Or the designer may use **Equation PP-1** to approximate the depth of the reservoir layer.

Level 1 Underdrain and Infiltration Designs

Equation PP-1 can be used to design the depth of the stone reservoir layer above and including the underdrain for the Basic Design, and the entire stone reservoir layer for the Infiltration Design.

Equation PP-1

$$d_{stone} = \frac{(P \times A_I \times Rv_I) + (P \times A_P)}{\eta_r \times A_P}$$

d_{stone} = Depth of the stone reservoir layer (ft)
P = Rainfall depth (1") for the design Treatment Volume = 0.083 ft.
A_I = Contributing impervious drainage area (ft^2)
Rv_I = Volumetric Runoff Coefficient for impervious cover = 0.95
A_P = Area of permeable pavement (ft^2)
η_r = porosity of reservoir layer (0.4)

Equation PP-1 makes the following design assumptions:

- The contributing drainage area (AI) is entirely impervious. Pervious areas should be diverted to alternate drainage systems. If this is not possible, the pervious areas should be directed to pretreatment as described in **Section PP-4.5** prior to draining to the Permeable Pavement.
- The ratio of the area of impervious pavement contributing runoff to the Permeable Pavement area shall be no greater than 2;
- The surface area of the Permeable Pavement is equal to that of the stone reservoir.
- The porosity (ηr) for No. 57 stone = 0.4. Designers should verify the acceptance of a different value if an alternate stone designation is used.
- The pavement section surface and reservoir bottom are level. Since this is not likely, the designer should ensure that the depth of the stone reservoir from **Equation PP-1** is the minimum dimension at the upper end of the pavement and the depth gradually increases along the slope of the section. The designer can incorporate baffles into the stone reservoir design if needed.

Minimum Depth of Stone Reservoir

In the absence of a minimum design factor based on the structural design of the pavement, the depth of the stone reservoir layer (dstone) should be a minimum of six (6) inches above the underdrain or the choker stone layer on Infiltration Designs.

Level 2 Infiltration Sump Design

The Infiltration Sump Design includes the use of the infiltration sump beneath the underdrain. The intent is to allow for infiltration into the underlying soils even if the soil infiltration rate is marginal (< 0.5''/hr). The depth of the sump is therefore sized according to confirmed design infiltration rate of the underlying soils and their ability to drain the sump within 48 hours using **Equation PP-2**.

Equation PP-2

$$d_{IS} = \frac{{}^{1}\!/_{2}\, i \times t_d}{12}$$

Where:

d_{IS} = Maximum depth of the stone infiltration sump (ft)
i = field-verified infiltration rate for the sub-grade soils (inches/hr)
t_d = design drain time of sump = 48 hours

Table PP-4. Maximum Depth of Infiltration Sump corresponding to Infiltration Rates

Field Verified Infiltration rate (i) (in./hr.)	**Design Drawdown Time (t_d), (hrs.)**	**Depth of Infiltration Sump[1] (d_{IS}) (in.)**
0.5[2]	48	12
0.25	48	6
0.1	48	2.4[3]

[1]Depth of sump is the total depth with gravel. Effective depth of water storage = dIS x ☐ (0.4)
[2]Field verified infiltration rate of 0.5 in./hr. allows Infiltration Design.
[3] Due to construction tolerances and the practical measure of gravel placement, designers should assume a minimum dIS of 4 in.

Once the depth of the infiltration sump is determined, the corresponding depth of the stone reservoir above the sump (Reservoir Layer in **Figure PP-5**) can be calculated by subtracting the depth of the infiltration sump (Infiltration Sump in **Figure PP-5**) from the total required depth of stone calculated with **Equation PP-1** as provided in **Equation PP-3**:

Equation PP-3

$$d_{res} = d_{stone} - d_{IS}$$

Where:

d_{res} = Depth of the stone reservoir above the sump (ft) (Reservoir Layer in **Figure 4**)

d_{stone} = Depth of the stone reservoir layer from **Equation 4.1**

d_{IS} = Depth of the stone infiltration sump (ft) from **Equation 4.2** (Infiltration Sump in **Figure 4**)

PP-4.2. Structural Design

If Permeable Pavement will be used in a parking lot or other setting that involves vehicles, the pavement surface must be able to support the maximum anticipated traffic load. The structural design process will vary according to the type of pavement selected, and the manufacturer's specific design recommendations. In general, traffic load is supported by the thickness of the Permeable Pavement and reservoir layer along with the underlying soil strength. On most new development and redevelopment sites, the structural support requirements will require a greater depth of stone reservoir than the design Tv.

The structural design of Permeable Pavements generally involves the consideration of four main site elements:

- Total traffic;
- In-situ soil strength;
- Environmental elements; and
- Surface materials, bedding and reservoir layer design.

The resulting structural requirements may include, but are not limited to, the thickness of the pavement, filter, and reservoir layers. Designers should note that if the underlying soils have a low California Bearing Ratio (i.e, less than 4%), they may need to be compacted to at least 95% of the Standard Proctor Density, which generally limits their use for infiltration. Other options include the use of geotextiles or geogrids placed under the stone reservoir or infiltration sump to better distribute the traffic loads to an uncompacted fill.

Designers should determine structural design requirements by consulting transportation design guidance sources, such as the following:

- Guide for Design of Pavement Structures (AASHTO, 1993); and,
- Supplement to the Guide for Design of Pavement Structures (AASHTO, 1998).

Permeable Pavement Structural Design – The structural design process for supporting vehicles varies according to the type of pavement selected. ASTM test methods for characterizing compressive or flexural strengths of pervious concrete are currently being developed. These tests are needed to model fatigue under loads. As an interim step, fatigue equations published by the American Concrete Pavement Association (ACPA 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.

General guidelines for pervious concrete surface thickness are published by the National Ready Mix Concrete Association and the Portland Cement Association (Leming 2007).

Porous asphalt (Hansen 2008) and permeable interlocking pavements (Smith 2010) use flexible pavement design methods adopted from the 1993 AASHTO ***Guide for Design of Pavement Structures*** (AASHTO 1993). In addition, manufacturer's specific recommendations should be consulted.

Concrete grids only see intermittent traffic and generally only require a minimum 8 inch thick compacted, dense-graded base. The minimum open-graded base and subbase thicknesses under permeable interlocking concrete grid pavement can generally be used for water storage

There has been little research or full-scale testing of the structural behavior of open-graded bases used under permeable pavements to better characterize the 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 lb 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
- 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 the lowest anticipated soil strength or stiffness values used for design. Structural design for vehicular applications assumes the following:

- Minimum soil CBR of 4% (96-hour soaked per ASTM D 1883 or AASHTO T 193); or
- Minimum R-value = 9 per ASTM D 2844 or AASHTO T-190; or
- Minimum Mr of 6,500 psi (45 MPa) per AASHTO T-307

Soil compaction required to achieve this criteria 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.

PP-4.3. Permeable Pavement Sizing for Larger Storms (Local Detention Criteria)

Permeable Pavement can also be designed to address, in whole or in part, the detention storage needed to comply with channel protection and/or flood control requirements. The designer can model various combinations of storage within the stone aggregate layer, expected infiltration, additional storage in the form of chambers or perforated storage pipes in the upper elevations of the stone reservoir, and any outlet structures used as part of the design. Routing calculations with a stage-storage-discharge relationship can be used to provide a more accurate representation of the Permeable Pavement's influence on the required design storms (2-year, 10-year, etc.).

It should be noted that all site designs should include provisions for safe conveyance of larger flows, either contained within properly sized pipe or channel systems or as overland flood routing to a receiving waterbody, so as to minimize public safety risks and property damage. While some large storm detention credit can be realized by oversizing runoff reduction practices such as Permeable Pavement (which may reduce the size or footprint of downstream detention structures), the downstream drainage system and flood routing should be designed conservatively and be based on the expected peak rate of discharge without any downsizing credited to runoff reduction.

PP-4.4. Conveyance and Overflow

Permeable Pavement designs should include methods to convey larger storms (e.g., 2-yr, 10-yr) to the storm drain system or receiving water body. The following is a list of methods that can be used to accomplish this:

- Place an overdrain, a perforated pipe laid horizontally near the top of the reservoir layer, to pass excess flows after water has filled the base.
- Increase the thickness of the top of the reservoir layer by as much as 6 inches to increase storage (i.e., create freeboard). The design computations used to size the reservoir layer do not include freeboard.
- 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 the management or detention of large storms.
- Set the storm drain inlets flush 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.

PP-4.5. Pretreatment

The best pretreatment technique for Permeable Pavement is to limit the CDA to pavement. Traffic will carry particulate pollutants onto the pavement section, and the pavement itself is subject to wear and over time will create its own particulate load. However, the most common cause of pavement clogging is the presence of landscaped or turf areas in the CDA. Turf areas will take 1 to 2 growing seasons to fully vegetate and lock soil in place. Large intense rain events will mobilize sediment onto the pavement.

Landscaped areas and lawn cutting operations will potentially mobilize high concentrations of organic particulates that can contribute to pavement clogging as well. Additional pretreatment may be appropriate if the pavement receives run-on from these types of areas. For example, a gravel or sod filter strip can be placed adjacent to pervious (landscaped) areas to trap coarse sediment particles before they reach the pavement surface.

PP-4.6. Permeable Pavement Design Elements

The three major components of Permeable Pavement section are the pavement itself, the reservoir layer, the infiltration sump, and the filter layer.

Permeable Pavement

Several different brands of pavement materials are available in each of the categories of Permeable Pavements: Pervious Concrete, Porous Asphalt, Concrete Grid Pavers, and Permeable Interlocking Concrete Pavers. Designers should periodically request updates from the different manufacturers as these materials have undergone many manufacturing and installation improvements over the years. Further, manufacturers will typically provide detailed design assistance in order to optimize the performance of the product.

Reservoir layer

The reservoir layer consists of the stone underneath the pavement section and above the bottom filter layer and underlying soils.

- The stone reservoir below the Permeable Pavement surface should be composed of clean, washed stone aggregate and sized for both the storm event to be treated and the structural requirements of the expected traffic loading.
- The stone reservoir may consist of clean washed No. 57 stone, although No. 2 stone is preferred because it provides additional structural stability.
- The bottom of the reservoir layer should be completely flat when using an Infiltration Design so that runoff will be able to infiltrate evenly through the entire surface. The use of terracing and check dams is permissible.

- If a Basic Design is used, low-grade longitudinal slopes on the bottom and the underdrain (i.e., 0.5%) are required to ensure the system drains, but the designer must account for this grade when establishing the stone reservoir minimum depth. On especially long runs, this may result in the reservoir depth being deeper at the lower end in order to create the required storage volume.

Infiltration Sump

The infiltration sump consists of the same stone material as the reservoir layer. The depth of this layer is sized so that the Design Volume of the sump can infiltrate into the subsoil in a 48 hour period. The bottom of infiltration sump must be at least 2 feet above the seasonally high water table. The inclusion of an infiltration sump is not permitted for designs with an impermeable liner. In fill soil locations, geotechnical investigations are required to determine if the use of an infiltration sump is permissible.

PP-4.7. Underdrains

Most Permeable Pavement designs will include an underdrain (see Section PP-3). Underdrains placed at the bottom of the stone reservoir provide drainage out of the system when a Level 1 Basic Design is used. A perforated pipe placed at the top of the stone reservoir can keep detained stormwater from flooding the Permeable Pavement when runoff exceeds the capacity of the stone reservoir and bottom underdrain or infiltration. Underdrains should be used in accordance with the following:

- Minimum 0.5% slope
- Located 20 feet or less from the next pipe when using multiple pipes
- Perforated schedule 40 PVC pipe (corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center
- Encased in a layer of clean, washed No.57 stone
- Include an adjustable outlet control design such as an orifice and weir wall housed within an adjacent manhole or other structure that is easily accessed for maintenance and inspections
- Outlet control design should ensure that the stone reservoir drains slowly (recommended > 24 hours); however, it must completely drain within 48 hours.
- Level 2 Infiltration Designs can be fitted with an underdrain(s) and capped at the downstream structure as an option for future use if maintenance observations indicate a reduction in the soil permeability.
- Underdrain cleanouts should be provided if the pavement surface area exceeds 1,000 ft2.

PP-4.8. Observation Wells

All Permeable Pavement practices should include observation wells. The observation well is used to observe the rate of drawdown within the reservoir layer following a storm event and to facilitate periodic inspection and maintenance. The observation wells should consist of a well-anchored, perforated 4 to 6 inch (diameter) PVC pipe that is tied into any Ts or Ys in the underdrain system. The well should extend vertically to the bottom of the reservoir layer and extend upward to be flush with the surface (or just under pavers) with a lockable cap.

PP-4.9. Filter Fabric (optional)

Filter fabric is another option to protect the bottom of the reservoir layer from intrusion by underlying soils, although some practitioners recommend avoiding the use of filter fabric beneath Permeable Pavements since it may become a future plane of clogging within the system. Designers should evaluate the paving application and refer to AASHTO M288-06 for an appropriate fabric specification. AASHTO M288-06 covers six geotextile applications: Subsurface Drainage, Separation, Stabilization, Permanent Erosion Control, Sediment Control and Paving Fabrics. However, AASHTO M288-06 is not a design guideline. It is the engineer's responsibility to choose a geotextile for the application that takes into consideration site-specific soil and water conditions. Fabrics for use under permeable pavement should at a minimum meet criterion for Survivability Classes (1) and (2).

PP-4.10. Impermeable Liner

This material should be used where deemed necessary by a geotechnical investigation, such as in fill applications, karst, adjacent to building foundations, etc. Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile.

PP-4.11. Signage

Permeable Pavement applications should include signage in highly visible locations, especially near entrances to identify the pavement as being permeable and having very specific limitations on potential operation and maintenance activities. Specific activities common to most parking lots should be clearly identified as being prohibited, such as winter sanding, seal coating, etc.

4.2.4. Permeable Pavement (PP)

PP-5. Materials Specifications

Permeable Pavement material specifications vary according to the specific pavement product selected. A general comparison of different Permeable Pavements is provided in **Table PP-5** below, but designers should consult manufacturer's technical specifications for specific criteria and guidance. **Table PP-6** describes general material specifications for the component structures installed beneath the Permeable Pavement. Note that the size of stone materials used in the reservoir and filter layers may differ depending on the type of surface material.

Table PP-5. Different Permeable Pavement Specifications

Material	Specification	Notes
Permeable Interlocking Concrete Pavers (PICP)	Surface open area: 5% to 15%. Thickness: 3.125 inches for vehicles. Compressive strength: 55 Mpa. Open void fill media: aggregate	Must conform to ASTM C936 specifications. Reservoir layer required to support the structural load.
Concrete Grid Pavers	Open void content: 20% to 50%. Thickness: 3.5 inches. Compressive strength: 35 Mpa. Open void fill media: aggregate, topsoil and grass, coarse sand.	Must conform to ASTM C1319 specifications. Reservoir layer required to support the structural load.
Plastic Reinforced Grid Pavers	Void content: depends on fill material. Compressive strength: varies, depending on fill material. Open void fill media: aggregate, topsoil and grass, coarse sand.	Reservoir layer required to support the structural load.

Material	Specification	Notes
Pervious Concrete (PC)	Void content: 15% to 25 %. Thickness: typically 4 to 8 inches. Compressive strength: 2.8 to 28 Mpa. Open void fill media: None	May not require a reservoir layer to support the structural load, but a layer may be included to increase the storage or infiltration.
Porous Asphalt (PA)	Void content: 15% to 20 %. Thickness: typically 3 to 7 in. (depending on traffic load). Open void fill media: None.	Reservoir layer required to support the structural load.

Table PP-6. Material Specifications for Underneath the Pavement Surface

Material	Specification	Notes
Bedding Layer	PICP: 2 in. depth of No. 8 stone over 3 to 4 inches of No. 57 stone PC: None PA: 2 in. depth of No. 8 stone	ASTM D448 size No. 8 stone (e.g., 3/8 to 3/16 inch in size). Should be double-washed and clean and free of all fines.
Reservoir Layer	PCIP: No. 2, 3, or 4 stone subbase PC: No. 57 stone PA: No. 2 stone	ASTM D448 size No. 57 stone (e.g. 1- 1/2 to 1/2 inch in size); No. 2 Stone (e.g. 3 inch to 3/4 inch in size). Depth is based on the pavement structural and hydraulic requirements. Should be double-washed and clean and free of all fines.
Underdrain	Use 4 to 6 inch diameter perforated PVC pipe (or equivalent corrugated HDPE may be used for smaller load-bearing applications), with 3/8-inch perforations at 6 inches on center. Perforated pipe installed for the full length of the Permeable Pavement cell, and non-perforated pipe, as needed, is used to connect with the storm drain system. Ts and Ys installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the Ts and Ys.	
Infiltration Sump (optional)	An aggregate storage layer below the underdrain invert. The depth of the reservoir layer above the invert of the underdrain must be at least 12 inches. The material specifications are the same as reservoir layer	

Material	Specification	Notes
Non-woven Geotextile (optional)	AASHTO M288-06 Paving Fabrics Survivability Classes (1) and (2)	
Impermeable Liner (optional)	Use a thirty mil (minimum) PVC Geomembrane liner covered by 8 to 12 oz./sq. yd. non-woven geotextile. Note: This is used only in fill soils as determined by a geotechnical investigation.	
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 just beneath PICP.	

4.2.4. Permeable Pavement (PP)

PP-6. Design Adaptations

PP-6.1. Karst Terrain

Permeable Pavement Level 2 Infiltration and Infiltration Sump Designs are not recommended in any area with a moderate or high risk of sinkhole formation. Level 1 Basic Designs that meet separation distance requirements should work well. A geotechnical investigation and recommendations should be reviewed to consider whether an impermeable bottom liner is necessary. In general, small-scale applications of Permeable Pavement (drainage areas not exceeding one-half acre) are preferred in karst areas in order to prevent possible sinkhole formation.

PP-6.2. Steep Slopes

Permeable Pavement can be used on sites with steep slopes; provided the paved areas are terraced and maintain maximum slopes. A geotechnical evaluation should also evaluate the need for impermeable liner on the sides of the stone reservoir to minimize saturation of soils adjacent to steep slopes.

PP-6.3. Cold Climate and Winter Performance

The prevalence of sanding and salting operations create additional hazards for Permeable Pavement installations. Since the pavement itself is the pretreatment mechanism for the stone reservoir and infiltration design, precautions such as signage near the entrances to the pavement should specifically warn against applying sand or other grit to the pavement.

Research at the University of New Hampshire Stormwater Center (UNHSC) indicates that Permeable Pavement has a higher frictional resistance than standard pavements and therefore requires less sand and/or salt to maintain braking distance and safety. Further, the internal thermal convection of subsurface ground temperatures serves to warm the Permeable Pavement section faster than regular pavement, thereby minimizing the need to apply chemicals or salt to accelerate melting. (Roseen et al. 2006.)

Finally, UNHSC research on Permeable Pavement's durability in cold weather is ongoing with positive results. Properly constructed Permeable Pavements structural durability is comparable to traditional pavement materials (Roseen and Ballestero,2008.). Design variations may include extending the stone reservoir to below the frost line.

PP-6.4. Stormwater Retrofitting

Permeable Pavement is a versatile retrofitting practice that can be applied in any situation where the existing pavement may require repair or replacement. Considerations include determining if there is enough hydraulic head available to tie underdrains into an existing drainage structure or to daylight. Many retrofit practices cannot meet the full sizing requirements outlined in Section PP-4.1, so it is important to define retrofit objectives and the desired design volume necessary to meet TMDL or watershed restoration goals.

For more information on retrofitting, see the Center for Watershed Protection's manual, Urban Stormwater Retrofit Practices (Schueler et al., 2007).

4.2.4. Permeable Pavement (PP)

PP-7. Construction & Installation

PP-7.1. Erosion and Sediment Controls

The following erosion and sediment control guidelines must be followed during construction:

- Permeable Pavement areas should be clearly marked on all construction documents and grading plans.
- Any area of the site intended ultimately to be a Permeable Pavement area should remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment.
- If adjacent pervious (turf or landscaped areas) are designed to drain to Permeable Pavement, the Permeable Pavement areas should be fully protected from sediment intrusion by silt fence.
- During and immediately after construction of the Permeable Pavement, care should be taken to avoid tracking sediments onto any Permeable Pavement surface to avoid clogging.
- Any area of the site intended ultimately to be a Permeable Pavement area should generally not be used as the site of a temporary sediment basin. Where locating a sediment basin on an area intended for Permeable Pavement is unavoidable, the invert of the sediment basin must be a minimum of 2 feet above the final design elevation of the bottom of the aggregate reservoir course. All sediment deposits in the excavated area should be carefully removed prior to installing the sub-base, base and surface materials.

PP-7.2. Permeable Pavement Installation

The following is a typical construction sequence to properly install Permeable Pavement, which may need to be modified depending on the specific variant of Permeable Pavement that is being installed.

Step 1. Construction of the Permeable Pavement shall only begin after the entire CDA has been stabilized. The proposed site should be checked for existing utilities prior to any excavation. Do not install the system in rain or snow, and do not install frozen aggregate materials.

Step 2. As noted above, temporary erosion and sediment controls are needed during installation to divert stormwater away from the Permeable Pavement area until it is completed. Special protection measures such as erosion control fabrics may be needed to protect vulnerable side slopes from erosion during the excavation process. The proposed Permeable Pavement area must be kept free from sediment during the entire construction process. Construction materials contaminated by sediments must be removed and replaced with clean materials.

Step 3. Where possible, excavators or backhoes should work from the sides to excavate the reservoir layer to its appropriate design depth and dimensions. For small pavement applications, excavating equipment should have arms with adequate extension so they do not have to work inside the footprint of the Permeable Pavement area (to avoid compaction). Contractors can utilize a cell construction approach, whereby the proposed Permeable Pavement area is split into 500 to 1000 sq. ft. temporary cells with a 10 to 15 foot earth bridge in between, so cells can be excavated from the side. Excavated material should be placed away from the open excavation so as to not jeopardize the stability of the side walls.

Step 4. The native soils along the bottom of the Permeable Pavement system should be scarified or tilled to a depth of 3 to 4 inches prior to the placement of stone. In large scale paving applications with weak soils, the soil subgrade may need to be compacted to 95% of the Standard Proctor Density to achieve the desired load-bearing capacity. (NOTE: This effectively eliminates the infiltration function of the installation, and it must be addressed during hydrologic design).

Step 5. Filter fabric should be placed as required by the design. This is typically only on the sides of the reservoir layer. Filter fabric should never be placed below the reservoir stone layer. In some cases, an impermable layer, as described in Section PP-4.10 Permeable Pavement Design Criteria may be warranted. Impermeable liner material should be installed in accordance with the manufacturer's instructions with regard to seams, overlap, sides, etc.

Step 6. Provide a minimum of 2 inches of aggregate above and below the underdrains. The underdrains should slope down toward the outlet at a grade of 0.5% or steeper. The up-gradient end of underdrains in the reservoir layer should be capped. Where an underdrain pipe is connected to a structure, there shall be no perforations within 1 foot of the structure. Ensure there are no perforations in clean-outs and observation wells within 1 foot of the surface.

Step 7. Moisten and spread 6-inch lifts of the appropriate clean, washed stone aggregate (usually No. 2 or No. 57 stone). Place at least 4 inches of additional aggregate above the underdrain, and then compact it using a vibratory roller in static mode until there is no visible movement of the aggregate. Do not crush the aggregate with the roller.

Step 8. Install the desired depth of the bedding layer, depending on the type of pavement, as follows:

- **Pervious Concrete:** No bedding layer is used.
- **Porous Asphalt:** The bedding layer for Porous Asphalt pavement consists of 1 to 2 inches of clean, washed ASTM D 448 No.57 stone.
- **Permeable Interlocking Concrete Pavers:** The bedding layer for open-jointed pavement blocks should consist of 2 inches of washed ASTM D 448 No.8 stone.

Step 9. Paving materials shall be installed in accordance with manufacturer or industry specifications for the particular type of pavement.

- **Installation of Porous Asphalt.** The following has been excerpted from various documents, most notably Jackson (2007).
  - o nstall Porous Asphalt pavement similarly to regular asphalt pavement. The pavement should be laid in a single lift over the filter course. The laying temperature should be between 230oF and 260oF, with a minimum air temperature of 50oF, to ensure the surface does not stiffen before compaction.
  - o Complete compaction of the surface course when the surface is cool enough to resist a 10-ton roller. One or two passes of the roller are required for proper compaction. More rolling could cause a reduction in the porosity of the pavement.
  - o The mixing plant must provide certification of the aggregate mix, abrasion loss factor, and asphalt content in the mix. Test the asphalt mix for its resistance to stripping by water using ASTM 1664. If the estimated coating area is not above 95%, additional anti-stripping agents must be added to the mix.
  - o Transport the mix to the site in a clean vehicle with smooth dump beds sprayed with a non-petroleum release agent. The mix shall be covered during transportation to control cooling.
  - o Test the full permeability of the pavement surface by application of clean water at a rate of at least five gallons per minute over the entire surface. All water must infiltrate directly, without puddle formation or surface runoff.
  - o Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine the facility is draining properly.

- **Installation of Pervious Concrete.** The basic installation sequence for Pervious Concrete is outlined by the American Concrete Institute (2008). It is strongly recommended that concrete installers successfully complete a recognized Pervious Concrete installers training program, such as the Pervious Concrete Contractor Certification Program offered by the National Ready Mixed Concrete Association (NRMCA). The basic installation procedure is as follows:
  - Drive the concrete truck as close to the project site as possible.
  - Water the underlying aggregate (reservoir layer) before the concrete is placed, so the aggregate does not draw moisture from the freshly laid Pervious Concrete.
  - After the concrete is placed, approximately 3/8 to 1/2 inch is struck off, using a vibratory screed. This is to allow for compaction of the concrete pavement.
  - Compact the pavement with a steel pipe roller. Care should be taken to ensure over-compaction does not occur.
  - Cut joints for the concrete to a depth of 1/4 inch.
  - The curing process is very important for Pervious Concrete. Cover the pavement with plastic sheeting within 20 minutes of the strike-off, and keep it covered for at least seven (7) days. Do not allow traffic on the pavement during this time period.
  - Remove the plastic sheeting only after the proper curing time. Inspect the facility 18 to 30 hours after a significant rainfall (greater than 1/2 inch) or artificial flooding, to determine the facility is draining properly.

- **Installation of Interlocking Pavers.** The basic installation process is described in greater detail by Smith (Smith 2011). Permeable paver job foremen should successfully complete the PICP Installer Technician Course training program offered by the Interlocking Concrete Pavement Institute. The following installation method also applies to clay paving units. Contact manufacturers of composite units for installation specifications.
  - Moisten, place and level the No. 2 stone subbase and compact it in minimum 12 inch thick lifts with four passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode with the final two passes in static mode. The filter aggregate should be moist to facilitate movement into the reservoir course.
  - Place edge restraints before the base layer, bedding and pavers are installed. Permeable interlocking pavement systems require edge restraints to prevent vehicle loads from moving the pavers. Edge restraints may be standard concrete curbs or curb and gutters.
  - Moisten, place and level the No. 57 base stone in a single lift (4 inches thick). Compact it into the reservoir course beneath with at least four (4) passes of a 10-ton steel drum static roller until there is no visible movement. The first two passes are in vibratory mode, with the final two passes in static mode.
  - Place and screed the bedding course material (typically No. 8 stone, 2 inches thick).
  - Pavers may be placed by hand or with mechanical installers.
  - Fill gaps at the edge of the paved areas with cut pavers or edge units. When cut pavers are needed, cut the pavers with a paver splitter or masonry saw. Cut pavers no smaller than one-third (1/3) of the full unit size if subject to tires.
  - Fill the joints and openings with stone. Joint openings must be filled with No. 8, 89 or 9 stone per the paver manufacturer's recommendation. Sweep and remove excess stones from the paver surface.
  - Compact and seat the pavers into the bedding course with a minimum low-amplitude 5,000 lbf, 75- to 95 Hz plate compactor. Do not compact within 6 feet of the unrestrained edges of the pavers.
  - Thoroughly sweep the surface after construction to remove all excess aggregate.
  - Inspect the area for settlement. Any paving units that settle must be reset and inspected.
  - The contractor should return to the site within 6 months to top up the paver joints with stones.

PP-7.3. Construction Inspection

Inspections before, during and after construction are needed to ensure Permeable Pavement is built in accordance with these specifications. Use detailed inspection checklists that require sign-offs by qualified individuals at critical stages of construction, to ensure the contractor's interpretation of the plan is consistent with the designer's intent. An example construction phase inspection checklist for Permeable Pavement practices can be found in **Appendix A**.

Some common pitfalls can be avoided by careful construction supervision that focuses on the following key aspects of Permeable Pavement installation:

- Store materials in a protected area to keep them free from mud, dirt, and other foreign materials.
- The CDA should be stabilized prior to directing water to the Permeable Pavement area.
- Check the aggregate material to confirm it is clean and washed, meets specifications and is installed to the correct depth.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Make sure the Permeable Pavement surface is even, runoff evenly spreads across it, and the storage bed drains within 48 hours.
- Ensure caps are placed on the upstream (but not the downstream) ends of the underdrains.
- Inspect the pretreatment structures (if applicable) to make sure they are properly installed and working effectively.
- Once the final construction inspection has been completed, log the GPS coordinates for each facility and submit them for entry into the local BMP maintenance tracking database.

It may be advisable to divert the runoff from the first few runoff-producing storms away from larger Permeable Pavement applications, particularly when up-gradient conventional asphalt areas drain to the Permeable Pavement. This can help reduce the input of fine particles often produced shortly after conventional asphalt is laid down.

4.2.4. Permeable Pavement (PP)

PP-8. Maintenance Criteria

PP-8.1. Maintenance Considerations

Maintenance is a crucial element to ensure the long-term performance of Permeable Pavement. The most frequently cited maintenance problem is surface clogging caused by organic matter and sediment. Periodic street sweeping will remove accumulated sediment and help prevent clogging; however, it is also critical to ensure that surrounding land areas remain stabilized.

The following tasks must be avoided on ALL Permeable Pavements:

- sanding
- re-sealing
- re-surfacing
- power washing
- storage of snow piles containing sand
- storage of mulch or soil materials
- construction staging on unprotected pavement

It is difficult to prescribe the specific types or frequency of maintenance tasks that are needed to maintain the hydrologic function of Permeable Pavement systems over time. The frequency of maintenance will depend largely on the pavement use, traffic loads, and the surrounding land use.

One preventative maintenance task for large-scale applications involves vacuum sweeping on a frequency consistent with the use and loadings encountered in the parking lot. Many consider an annual, dry-weather sweeping in the spring months to be important. **The contract for sweeping should specify that a vacuum sweeper be used that does not use water spray, since spraying may lead to subsurface clogging**.

Recommended maintenance tasks are outlined in **Table PP-7**.

Table PP-7. Recommended maintenance tasks for Permeable Pavement practices.

Maintenance Tasks	Frequency[1]
• For the first 6 months following construction, the practice and CDA should be inspected at least twice after storm events that exceed 1/2 inch of rainfall. Conduct any needed repairs or stabilization.	After installation
• Mow grass in grid paver applications	At least 1 time every 1-2 months during the growing season
• Stabilize the CDA to prevent erosion • Remove any soil or sediment deposited on pavement. • Replace or repair any necessary pavement surface areas that are degenerating or spalling	As needed
• Vacuum pavement with a standard street sweeper to prevent clogging	2-4 times per year (depending on use)
• Conduct a maintenance inspection • Spot weeding of grass applications	Annually
• Remove any accumulated sediment in pre-treatment cells and inflow points	Once every 2 to 3 years
• Conduct maintenance using a regenerative street sweeper • Replace any necessary joint material	If clogged

[1] *Required frequency of maintenance will depend on pavement use, traffic loads, and surrounding land use.*

PP-8.2. Winter Maintenance

Winter maintenance on Permeable Pavements is similar to standard pavements, with a few additional considerations:

- Large snow storage piles should be located in adjacent grassy areas so that sediments and pollutants in snowmelt are partially treated before they reach the Permeable Pavement.
- Sand or cinders should not be applied for winter traction over Permeable Pavement or areas of standard (impervious) pavement that drain toward Permeable Pavement, since it will quickly clog the system. If applied, the materials must be removed by vacuuming in the spring.
- When plowing plastic reinforced grid pavements, snow plow blades should be lifted 1/2 inch to 1 inch above the pavement surface to prevent damage to the paving blocks or turf. Porous Asphalt, Pervious Concrete and Permeable Interlocking Concrete Pavers can be plowed similar to traditional pavements, using similar equipment and settings.
- Owners should be judicious when using chloride products for deicing over all Permeable Pavements designed for infiltration, since the salts will most assuredly be transmitted into the groundwater. Salt can be applied but environmentally sensitive deicers are recommended. Permeable Pavement applications will generally require less salt application than traditional pavements.

Maintenance agreements must be executed between the owner and the local authority. The agreements will specify the property owner's primary maintenance responsibilities and authorize local agency staff to access the property for inspection or corrective action in the event that proper maintenance is not preformed.

All Permeable Pavement areas must be covered by a drainage easement to allow inspection and maintenance by local authority staff.

When Permeable Pavements are installed on private residential lots, homeowners will need to (1) be educated about their routine maintenance needs, (2) understand the long-term maintenance plan, and (3) be subject to a maintenance agreement as described above.

It is highly recommended that a spring maintenance inspection and cleanup be conducted at each Permeable Pavement site, particularly at large-scale applications. Example maintenance inspection checklists for Permeable Pavements can be found in **Appendix A**.

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