IOWA STORM WATER MANAGEMENT MANUAL

8 PERMEABLE PAVEMENT SYSTEMS

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IOWA DEPARTMENT OF NATURAL RESOURCES

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8 PERMEABLE PAVEMENT SYSTEMS

SUMMARY

Permeable pavement provides the structural support of conventional pavement, while allowing stormwater to drain through voids within the pavement into an underlying storage aggregate and the soil below to reduce surface stormwater runoff. Common permeable pavement surfaces suitable for Iowa include **permeable pavers (PP)** (see Figure C8-SU-1), **pervious concrete (PC)**, and **porous asphalt (PA),** or open grid pavers. For all permeable pavement types, stormwater flows through the porous surface then drains into the storage aggregate, where it is stored until it percolates into the soil or is gradually released to a suitable outlet such as a channel, waterway, stormwater detention area, or downstream storm network. The information and sections to follow outline design, construction, and maintenance best practices for the three permeable pavement surfaces, as well as their key advantages.

FIGURE C8-SU-1: Example of permeable pavement system in West Union, Iowa.

DESIGN CHECKLIST

1. Check site feasibility
2. Calculate design volume
3. Calculate necessary footprint and consider using multiple sites
4. Design permeable pavement system using design criteria and typical details
5. Submit plans for review by a local authority

GENERAL SITE CONSTRAINTS

High debris loading: Not suitable for high sediment or trash/debris loading (e.g., areas receiving traffic from gravel or dirt roads).

Water table depth: **Minimum 2 foot** separation from top of subgrade to seasonal high water table. Anything less than a 2 foot separation requires an impermeable liner.

Setbacks from:

- Private well: ≥ 100 feet
- Septic system tank/leach field: ≥ 100 feet
- Surface waters: ≥ 100 feet *(requires special considerations)*
- Public water supply well: ≥ 1,000 feet

Soil: When infiltration capacity is less than 1 inch/hour, typically Hydrologic Soil Group (HSG) C or D, an underdrain is required.

Limitations: Not suitable for high speed traffic.

MAINTENANCE AND BEST PRACTICES

Prevent sediment run-on from drainage area.

Conduct regular inspections:

- Surface pavement structural integrity
- Evidence of surface clogging due to sediment build-up, organic debris, staining, and ponding
- Sediment build-up at inlets, pretreatment cells, and/or any flow control structures
- Standing water in observation well(s)

Vacuum in spring and fall, and as needed.

Prevent application of winter sand with signage and education. Use alternative de-icing products that do not harm the environment.

PERMEABLE PAVEMENT SYSTEMS

KEY ADVANTAGES

- Can be used in place of traditional paved surfaces.
- Can fit into spaces of almost any size and be integrated into many different site layouts.
- Reduces ponding and icing that can be associated with traditional paving surfaces.
- Provides other benefits such as better conditions for trees, and reduces heat island effect.
- Water quality and quantity benefits

TYPES OF PERMEABLE PAVEMENT SYSTEMS

Permeable Pavers (PP)

Pervious Concrete (PC)

Porous Asphalt (PA)

Alternative Systems

KEY SYSTEM SELECTION FACTORS

- Performance
- Necessary structural loading
- Individual system key advantages and key limitations
- Budget
- Constructibility
- Desired aesthetic

HELPFUL **TIP**

If PP gets clogged due to inadequate maintenance, repairs are typically easier to make than with PA and PC.

DEFINITIONS

CLEAN WASHED AGGREGATE: Stone material that has been machine cleaned to ensure there is no stone dust or other residues, clay, dirt, or organic material present.

BEDDING AGGREGATE: The layer of aggregate located above the filter aggregate which helps level the permeable pavement and provides a uniform surface.

8.1 DESIGN

8.1.1 Applications

Types of Permeable Pavement

This section details attributes of typical permeable pavement systems. A comparison of these systems is shown in Table C8-S1-1 on page 5. The design and application of these systems is driven by the site characteristics and their intended use. A breakdown of the advantages and limitations of the individual systems is provided on the following pages. Hydraulic and structural performance of the system throughout its lifecycle must be accounted for in the design of the system.

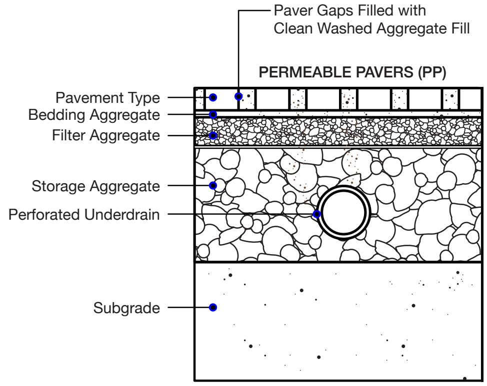


FIGURE C8-S1-1: Diagram of a typical Permeable Pavement System

PERMEABLE PAVERS (PP)

PP are a type of system that provides drainage through gaps between the pavers filled with clean washed aggregate (see Figure C8-S1-2). Pavers are placed on layers of aggregate consisting of a bedding aggregate, filter aggregate, and storage aggregate that provides uniform support and drainage. However, there are some paver systems that do not require the placement of the aggregate fill between the voids of the pavers (see Figure C8-S1-2).

FIGURE C8-S1-2: Permeable paver examples

KEY ADVANTAGES

- Water quality and quantity benefits
- Can be used in place of traditional paved surfaces
- Can fit into spaces of almost any size and be integrated into many different site layouts
- Reduces ponding and icing that can be associated with traditional pavement surfaces
- Provides multiple benefits such as better conditions for trees, reduced heat island effect, and reduced vehicular glare compared to standard asphalt
- Pavers can be removed and replaced as needed
- Aesthetically pleasing

KEY LIMITATIONS

- Without proper maintenance it will become clogged by sediment, compromising its effectiveness
- Permeable pavement installation upfront costs can be higher than conventional pavements. However, overall costs may be comparable or lower when considering the cost savings associated with storm pipes, intakes, and other stormwater management infrastructure

ALTERNATIVE SYSTEM

Made with a structurally sound grid or webbing, open grid, open void, or grass pavers may be considered for areas of light use, partial shade, and if irrigation is present and snow removal is not required.

These areas also require a specific plant materials palette in order to have a high level of success. Appropriate uses may include small residential areas or driveways and some large scale areas. They are not appropriate on areas where traffic is heavy and frequently used. Evaluate each site for traffic use. Consideration of spring thaws and heavy rains should be addressed during design.

FIGURE C8-S1-3 Open Void Pavers example.

PERVIOUS CONCRETE (PC)

PC is produced by reducing the fines in a conventional concrete mix to maintain interconnected void space for drainage, which causes a coarser appearance than standard concrete (see Figure C8-S1-4).

KEY ADVANTAGES

- Water quality and quantity benefits
- Technical support and a contractor certification program is managed by independent organizations like the American Concrete Institute (ACI) and National Ready Mixed Concrete Association NRMCA)
- Can fit into spaces of almost any size and be integrated into many different site layouts
- Reduces ponding and icing that can be associated with traditional pavement surfaces

KEY LIMITATIONS

- Mixing and installation must be done correctly, or PC will not function properly and can lead to surface wear and appearance deterioration
- Requires maintenance with specialized equipment to maintain performance a few times a year, but varies based upon the completion of monthly routine maintenance
- May degrade more rapidly if located in areas with frequent vehicular turning
- May be difficult to restore permeability after a significant loss of initial permeability without removal and installation of a new course
- High rate of failure if not properly maintained
- Spot repairs to surfaces are much more difficult than for permeable pavers

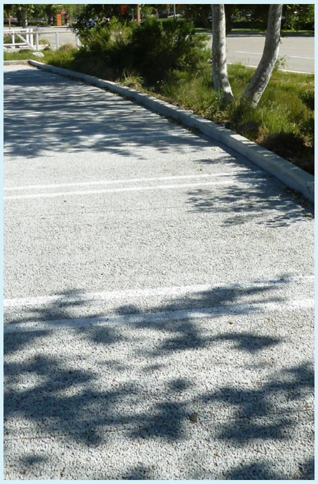


FIGURE C8-S1-4: Pervious concrete examples.

THE VOID SPACE OF POROUS ASPHALT IS APPROXIMATELY **15-18%**, AS OPPOSED TO **2-3%** FOR CONVENTIONAL ASPHALT.

DEFINITIONS

DESIGN PERMEABILITY: The rate at which a specified depth of water moves through the system.

POROUS ASPHALT (PA)

PA is similar to standard asphalt, however fines are removed to maintain interconnected void space (see Figure C8-S1-5).

KEY ADVANTAGES

- Water quality and quantity benefits
- There are many industry representatives and associations that provide guidance on admixture designs, and proper installation
- Can fit into spaces of almost any size and be integrated into many different site layouts
- Reduces ponding and icing that can be associated with traditional pavement surfaces
- Utilizes standard installation equipment

KEY LIMITATIONS

- May have a lower bearing capacity than PC
- Use of asphalt sealants or overlays would eliminate permeability
- Requires proper mixing and installation for optimal performance
- Spot repairs to the surface are much more difficult than for PP
- Requires maintenance with specialized equipment to maintain performance a few times a year, but varies based upon the completion of monthly routine maintenance

FIGURE C8-S1-5: Porous asphalt section in parking lot and closeup.

COMPARATIVE PROPERTIES OF 3 MAJOR PERMEABLE PAVEMENT TYPES			
DESIGN FACTOR	PERMEABLE PAVERS (PP)	PERVIOUSCONCRETE(PC)	POROUS ASPHALT (PA)
Scale of Application	Micro, small, and large	Small and large	Small and large
Pavement Thickness	3 inches	5 to 8 inches	3 to 4 inches
Bedding Aggregate	2 inches of No. 8 aggregate	None	2 inches of No. 8 aggregate
Filter Aggregate	4 inches minimum depth of No. 57 aggregate	Filter aggregate is optional	4 inches minimum depth of No. 57 aggregate
Storage Aggregate	8 inches minimum depth, 6 inch minimum for pedestrian uses (No. 2 aggregate)	8 inches minimum depth, 6 inch minimum for pedestrian uses (No. 2 aggregate)	8 inches minimum depth, 6 inch minimum for pedestrian uses (No. 2 aggregate)
Construction Properties	No cure period; manual or mechanical installation of premanufactured units, over 5000 square feet per day per machine	Cast in place; seven day cure, must be covered. Most labor intensive option.	Cast in place; 24 hour cure
Min. Batch Size	No minimum	500 square feet	500 square feet
Longevity	25-30 years	5-20 years	5-20 years
Overflow	Surface overflow or stormwater intake	Surface overflow or stormwater intake	Surface overflow or stormwater intake
Temperature Reduction	Cooling in the storage aggregate	Cooling in the storage aggregate	Cooling in the storage aggregate
Colors/Texture	Wide range of colors, textures, and patterns	Limited range of colors and textures	Black or dark gray color
Surface Clogging	Vacuum and replace permeable aggregate jointing materials	Replace paved areas or install stormwater intake. If the area can not be removed for a reasonable cost, stormwater intake may be installed to ensure lower spots drain correctly.	Replace paved areas or install stormwater intake. If the area can not be removed for a reasonable cost, stormwater intake may be installed to ensure lower spots drain correctly.

TABLE C8-S1-1

DEFINITIONS

INFILTRATION AND PERCOLATION: These two related but different processes describe the movement of water through soil.

Infiltration is the downward entry of water into the soil or rock surface *(SSSA, 1975)*

Percolation is the flow of water through soil and porous or fractured rock.

Exfiltration A type of percolation, exfiltration is the loss of water from a drainage system due to percolation or absorption into the subsoil.

Infiltration rate is the rate at which a soil absorbs falling rain or melting snow (*ASCE, 1985).*

Percolation rate, the rate at which soil water moves down through the soil or permeable rock.

Source: https://www.fema.gov/media-library-data/20130726-1731-25045-9495/dl_perc.pdf

UNDERDRAIN: A perforated drain placed in the storage aggregate used to convey water to the bottom of the watershed once it has moved through the profile.

CONTRIBUTING DRAINAGE AREA: The total surface area where the water from rain, snowmelt, or irrigation, which is not absorbed into the ground flows over the ground surface and contributes to the permeable pavement system.

DEBRIS: Loose material or sediment, vegetative material, cigarette butts, litter, trash, etc.

WATER TABLE: The level below which the ground is saturated with water.

NOTE

The specific soil characteristics of the site should be investigated prior to planning any infiltration practices. Areas such as Karst Terrain and the Loess Hills may require special considerations to support the installation of these practices.

8.1.2 Major Design Criteria

Same Footprint

A key advantage of permeable pavement systems is that they provide stormwater management without additional storage area. Within a limited existing footprint, these systems don't require any more space than traditional pavement, which is important for small sites or areas with high land prices.

Soils

Soil conditions can constrain the use of permeable pavement. They can also determine whether an underdrain or liner is needed. Low permeability soils HSG C or D require an underdrain, whereas HSG A and B soils may not. Permeable pavement should never be situated above fill soils unless designed with an impermeable liner and underdrain and confirmed by a geotechnical report.

A minimum percolation rate of 1 inch per hour is required for permeable pavement areas to be designed without underdrains. Soil percolation rates can be estimated from USDA-NRCS soil data, but they must be confirmed by an on-site percolation measurement. Designers should evaluate existing soil properties during initial site layout, and configure the site to conserve and protect the soils with the greatest recharge and percolation rates. If it is found that unsuitable fill soils are present, a permeable pavement installation may not be feasible, unless the soils are removed and replaced with suitable soils. While underdrains are not required on extremely sandy sites, they should be considered as a system back up.

Karst Terrain

Karst terrain is characterized by the presence of easily dissolved bedrock, such as limestone and dolomite, near the ground surface. Karst areas are typically identified by sinkholes, springs, and losing streams where some surface flow is lost to groundwater via voids from dissolved carbonate rocks. Since pollutants move rapidly through open fractures in the surface and caves to aquifers, springs, and streams, the ground and surface water are less likely to be filtered by soils making these areas very susceptible to contamination.

Karst terrain is found in much of Northeast Iowa and throughout other parts of the state, including Floyd and Linn Counties and other localized areas, and can complicate both stormwater design and land development. A geotechnical investigation may be required for any kind of stormwater design in karst terrain. The Iowa DNR has developed a statewide map of karst terrain that can be found on their website.

Design Guidelines for Karst Terrain:

- ✓ The use of permeable pavement designs at sites with known karst features is not recommended as conditions may cause the formation of sinkholes (especially for large scale pavement applications).
- ✓ Micro-scale and small-scale permeable pavement installations are acceptable if they possess an impermeable bottom liner and an underdrain.
- ✓ Storage aggregate should provide extra chemical buffering capacity by being carbonate in nature.
- ✓ PP may be used if a impermeable liner is used and the karst is not too close to the top of the surface.

Drainage Area (CDA)

Any drainage area contributing runoff to permeable pavement should generally not exceed three times the surface area of the permeable pavement. Some field experience has shown that an up-gradient drainage area (even if it is impervious) can contribute debris to the permeable pavement and lead to clogging. Therefore, careful sediment source control and/or a pre-treatment strip or sump should be considered to control sediment run-on to the permeable pavement section. Note: See margin note.

Pavement Slope

The surface of the permeable pavement should have a slope of ≤ 8%. Terraces, baffles, and/or check dam systems shall be incorporated under sloping pavement surfaces to provide continuous volume along the length of the slope (see Section 8.1.4).

Water Table

A minimum vertical separation distance of 2 feet must be provided between the top of subgrade and seasonal high water table to prevent ponding and contamination of groundwater. If this is not possible, install an underdrain and an impermeable liner. Checking the soil survey and conducting site visits may identify hydric soils on site which indicates a high water table that will need to be addressed.

Design Storm

At a minimum, permeable pavement must be designed to treat the runoff and provide safe conveyance of the Water Quality (WQv) storm event. The water quality volume must be able to pass through the surface of the system. Designers must also consider providing safe conveyance of larger storm events, without excessive ponding or damage to property and/or structures. Refer to Part C: Design Alternatives for Larger Storms (p. 16) for design options for these systems.

Setbacks

To avoid harmful seepage, permeable pavement should not be hydraulically connected to structure foundations. Setbacks to structures vary based on the scale of the permeable pavement installation.

At a minimum, small and large-scale pavement applications should be located a minimum horizontal distance of:

≥10 FT
from a building foundation
Setback may be less if waterproofing is used

≥100 FT
from a private well, septic system tank/leach field, and surface waters

≥1,000 FT
from public water supply well, or from an up gradient point source with pollutant generating activities *(vehicle fueling, hazardous material loading/unloading, and trans load facilities).*

Run-on

Permeable pavement can be designed to receive runoff from adjacent impervious surfaces such as roofs and conventional pavement. Evaluate the drainage area to determine if the area contributing run-on is appropriate for the permeable pavement system. Care should be taken to not direct runoff from uncontrolled areas such as mulch piles, gravel parking lots, soil stockpiles, and hotspot areas as this will lead to premature clogging of the permeable pavement system. There are some instances when draining uncontrolled areas to pavement is unavoidable, such as parking lot islands. When directing flow from uncontrolled areas, consideration should be given to potential clogging or damage to the system (e.g., grass versus mulched areas). Maintenance planning for specific conditions will help prevent clogging of the system.

NOTE

Drainage Area to Permeable Pavement Ratio: A 3:1 ratio should be used for more intensive land uses such as roadways, parking areas, and surfaces that generate higher pollutant loads, and a 5:1 ratio for less intensive land uses such as driveways, patios, and areas for pedestrian use.

DEFINITIONS

DESIGN STORM: A storm whose magnitude, rate, and intensity do not exceed the design load for a storm drainage system or flood protection project.

SETBACKS: The distance from a structure or other feature to the edge of the system.

RUN-ON: Surface flow that drains from an adjoining area onto permeable pavement areas.

UNCONTROLLED AREAS: An area of land draining directly to the permeable pavement system that may convey sediment, debris, etc., when it rains and has not been filtered prior to reaching the permeable pavement system.

HELPFUL **TIP**

Underground utilities can be installed under permeable pavers.

HELPFUL **TIP**

Grading in dry conditions helps to prevent rutting and compaction of subgrade. Dewater when necessary.

DEFINITIONS

SUBGRADE: The bottom of the excavated soil area.

OBSERVATION WELL: Observation wells are placed in pavements in order to monitor water levels and isolate pollutant sources. See page 32 for more details.

TESTING OF THE SUBSOIL RESULTING IN A LOW CALIFORNIA BEARING RATIO **(CBR ≤ 4%)** MAY REQUIRE COMPACTION TO REACH A MINIMUM OF **95%** OF THE STANDARD PROCTOR DENSITY TEST

NOTE

Subgrade compaction may be required based on the geotechnical recommendations of each site. Care should be taken to properly scarify to restore site permeability.

Installation

Permeable pavement systems should not be installed until the upslope and adjoining areas are stabilized. If installed before an area is stabilized, effective erosion and sediment control measures must be installed and maintained. After installation, barriers must be installed to prevent construction traffic from driving onto the pavement.

For PP: Follow manufacturer recommendations and industry standards to ensure lasting effectiveness. Some of the manufacturer requirements that must be considered include designing the bedding course and specifying jointing materials. Any manufacturer requirements should be implemented in addition to, not instead of, the design requirements in this manual.

For PC and PA: Use the appropriate and most current mix designs. For all permeable pavement practices, design and installation should be done by certified and experienced professionals.

APPROPRIATE

- ✓ Well maintained landscape and lawn areas
- ✓ Sidewalks and boulevard areas
- ✓ Urban streetscapes
- ✓ Uncontrolled landscape areas

NOT APPROPRIATE

- ✗ Gravel parking lots or where gravel is present
- ✗ Woodland areas with high levels of tree debris
- ✗ Environmentally sensitive areas such as junkyards, waste areas, unkept landscape areas, trash piles, etc.

Subgrade

Care should be taken to minimize the impact to the subgrade during construction. If this is not feasible, the surface of the subgrade can be scarified, ripped, or trenched to maintain the preconstruction subgrade percolation rate. There may be special situations that require compaction of subgrade to support the pavement structure.

The subgrade for permeable pavement must be dry when graded. The aggregate base and permeable course should be completed as soon as possible to reduce the chance of compaction of the subgrade. Permeable pavement areas must be marked on all construction documents and grading plans. They should show that all permeable pavement areas will remain outside the limit of disturbance during construction to prevent soil compaction by heavy equipment--unless the area has been determined to have a low California Bearing Ratio (CBR) and will require compaction during the permeable pavement construction phase. In areas that will be impacted during construction, the existing material should be left in place during construction to a depth of 2' above the bottom of the aggregate storage layer. Upon completion of construction activities the area can then be excavated to plan grade. This will prevent further compaction by heavy equipment. After the area is excavated to grade, the impacted area should be scarified to restore permeability of the subgrade. Consult a geotechnical professional regarding the suitability of the soil subgrade.

Underdrain Flushing

Flat terrain may affect proper drainage of permeable pavement designs, so underdrains should have a positive slope so they may be flushed out and free flowing.

Observation Well

Recommended for large-scale pavement projects, observation wells provide access for monitoring percolation performance, water accumulation, and water quality data in the aggregate base.

Measure effectiveness by observing the drawdown rate following a storm event in excess of 1.25 inches in depth.

Edge Restraints

Edge restraints must be provided around the perimeter of permeable pavement systems, with the exception of PC, as well as anywhere permeable pavement (of any type) is adjacent to existing asphalt or concrete that is in poor condition. This is done in order to keep the permeable pavement system from settling and moving both horizontally and laterally during heavy use or freeze and thaw cycles. See 8.1.4 for more information and figures of edge restraints.

Maintenance

The property owner should understand the unique maintenance responsibilities inherent with permeable pavement systems. The owner should have a maintenance plan and budget that includes routine and long-term actions (e.g., vacuuming) to maintain the pavement's hydrologic functions and avoid future practices that diminish or eliminate the effectiveness of the system (e.g., winter sanding, seal coating, or repaving).

High Loading Situations

Permeable pavement is not intended to treat sites with high sediment or trash/debris loads as they will cause the practice to clog and fail prematurely.

Hot Spots

Permeable pavement can be used on hotspot locations but care should be taken to not locate them directly adjacent to the source. Care should be taken to install and maintain liners and shutoff systems in installations near fueling stations and gas pumps so that a spill or event that may contaminate runoff from the contributing drainage area can be controlled. Designers should evaluate each site on a case-by-case basis to determine if the benefits outweigh the risks involved in using permeable pavement in hotspot locations. Permeable pavement should not be used in hotspot locations where there is a high water table, areas prone to flooding, or other environmentally sensitive areas. Signed and sealed design drawings, specifications, and calculations prepared by a licensed professional should be part of each project and reviewed by a qualified professional with experience in this field.

NOTE

HOT SPOTS MAY INCLUDE:

- Commercial nurseries
- Auto recycle facilities
- Fueling stations
- Storage areas
- Industrial rooftops
- Marinas
- Outdoor container storage of liquids
- Outdoor loading and unloading facilities
- Public works storage areas
- Vehicle service and maintenance areas
- Vehicle and equipment washing facilities
- Hazardous materials generators (if containers are exposed to rainfall)
- Steam cleaning facilities

DEFINITIONS

EDGE RESTRAINTS: An essential component of permeable paver systems. Restraints hold the pavers tightly together, providing consistent interlock.

HOTSPOTS: Areas that have the potential to produce relatively high levels of stormwater pollutants.

NOTE

For sites where proximity to a hotspot is an issue, an impermeable liner is strongly recommended.

DEFINITIONS

FLOODPLAINS: According to FEMA, a floodplain is "any land area susceptible to being inundated by floodwaters from any source."

High Speed Roads

Permeable pavement systems should not be used for roads with speed limits higher than 40 miles per hour, however they have been successfully applied on low speed residential streets, parking lanes, and roadway shoulders.

Floodplains

Permeable pavement systems should be constructed outside the limits of a 100-year floodplain, unless a waiver is obtained from a local jurisdiction. If installing inside of a 100-year floodplain, owners should be aware that if the area were to flood, the surface must be vacuumed after the waters subside. PP systems are not recommended for installation in flood prone areas.

Groundwater

The depth of permeable pavement systems should be constructed at least 2 feet above the seasonal water table. This separation provides a factor of safety to prevent temporary groundwater below the system from penetrating into the pervious pavement subbase aggregate.

8.1.3 Calculations

Design Protocol and Equations

This section provides the procedure and equations necessary to design a permeable pavement system. Calculating the structural depth and hydraulic storage depth is necessary since the larger of the two will dictate the design. This procedure is intended to serve as a reference for the design example that follows and for designers throughout the design process.

Part A: Structural Depth Calculations

The structural depth of sub-pavement aggregate should be calculated by a licensed engineer. The design process and necessary equations to calculate the structural depth are not covered in this manual since it is covered within other well established references found in the reference section at the back of this chapter. As a general rule, the structural depth should be calculated before the hydraulic storage depth, since the structural depth may dictate the design.

It is important that designers are aware that the structural depth varies according to the type of pavement selected, the specific use (sidewalks, high traffic versus low traffic, etc.), the in-situ soil strength, environmental factors, and the manufacturer's specific recommendations. Be aware of how compaction will impact percolation through the subsoil and provide design features (i.e. underdrains) as necessary.

Part B: Hydraulic Storage Calculations

The hydraulic storage calculation includes seven steps to size the aggregate layer beneath the permeable pavement. This includes the hydraulic storage depth, which is the depth of the storage aggregate layer that provides adequate void storage capacity to collect the design storm volume. For purposes of this section, the water quality storm event is the minimum volume to use for the design.

Be sure to confirm with local jurisdictions prior to finalizing the design as to what type of storm event the system should be designed to accommodate. If the system is to be designed for events larger than the water quality event, the process is similar but the required volumes will be calculated based on the design storm rainfall depth. If the permeable pavement systems are to be utilized for detention purposes, utilize the procedures detailed in Chapter 3, Section 9.

NOTE

This chapter utilizes the Unified Sizing Criteria found in Chapter 2 and the NRCS TR-55 Methodology found in Chapter 3, Sections 5 and 6.

DEFINITIONS

STRUCTURAL DEPTH: The necessary depth of the storage aggregate layer in order to ensure the structural integrity of the permeable pavement system.

MAXIMUM ALLOWABLE DEPTH (d_{max}): The maximum depth of the storage aggregate layer where all the stored runoff is able to exfiltrate into the subsoil or be released through underdrain within 72 hours.

DRAINAGE AREA (DA): The area of the site in acres that contributes to runoff to practices

NOTE

Use WinSLAMM as an option to check for long-term performance as a verification option.

- 30-year simulation with expected maintenance selected (bi-annual recommended in WI)
- Maintain 10 inches per hour at the end of the simulation period

DEFINITIONS

Q_{IN}: Peak flow to entire practice area in cubic feet per second.

A_{PP}: Surface area of permeable paver system in square feet.

Qwq: Peak runoff volume in watershed inches based on the Water Quality Volume (WQv)

q_{wq}: Peak Flow Rate for the Water Quality Volume (WQv) in cubic feet per second

VOLUMETRIC RUNOFF COEFFICIENT (R_v): Coefficient used to compute the required WQv (measured in cubic feet) treatment volume

IMPERVIOUS AREA PERCENTAGE (I): The impervious area divided by the total project area and converted to a whole number (i.e. 70% = 70 for use in the equation).

NOTE

Directly connected runoff to a subsurface chamber should have pretreatment or be clean of sediment loads.

1. Compute WQv treatment volume
2. Compute peak runoff rates
3. Determine storage volume level
4. Verify pavement surface size
5. Design storage aggregate depths
6. Verify volume of storage
7. Subdrain system design

Step 1: Compute the required WQv treatment volume.

The **Water Quality Volume (WQv)** is the volume of runoff generated by the water quality storm event, which in Iowa is 1.25 inches. The Short Cut Method (see Chapter 2, section 1) is to be used for this calculation. See Chapter 3, Section 6 for detailed equations and instructions.

$$R_v=0.05+0.009(I)$$

EQUATION C8-S1-1

$$WQ_v=(43{,}560\ SF/acre)[(P)(R_v)(DA)]/12$$

Where:

- P = 1.25 inches (WQv storm event depth)
- R_v = from equation C8-S1-1
- DA = drainage area (in acres)
- WQv will be in units of cubic feet

EQUATION C8-S1-2

Step 2: Compute peak runoff rates.

- Compute WQv peak flow rate (q_{wq}) with adjusted CNs (to size the pavement surface in Step 4 - see Chapter 3 Section 6 of the Stormwater Manual to determine the adjusted CN value associated with WQv and Rv. Use TR-55 to calculate q_{wq} in cubic feet per second and Qwq in watershed inches.)
- Compute larger storm runoff (>2" rainfall in 24 hours) with standard CNs (to size detention practices in Part C - using TR-55 and the same steps as mentioned above.)

Step 3: Determine storage volume level

Identify if the pavement system is going to be used to manage water quantity (large storm detention) as well as quality.

IS THE PAVEMENT SYSTEM USED TO MANAGE WATER QUANTITY

YES

How is runoff from larger storms introduced into the storage layers?

1. Enlarge permeable pavement area?
2. Direct connection in subsurface chambers (see left)?

NO

How do overflows from larger storms bypass the system?

1. System overflow?
2. Storm Inlets?

Step 4: Verify pavement surface size

Check the size of permeable pavement surface.

- The required peak flow rate from a Water Quality Volume (WQv) event from Step 2 must be able to pass through the surface of the pavement system. For long-term performance and maintenance purposes, assume 10 inches/hour is the necessary minimum design infiltration rate of the pavement surface.

- If larger storms are introduced to the system, a combination of pavement surface infiltration rates, and intake structures may need to be evaluated to bypass the flow rates to the storage aggregate layer or underground storage chambers.
- Infiltration rate design check: 10 inches per hour.

A_{PP} = (Q X 3,600 SEC/HR X 12 IN/FT)/10 IN/HR

Where:

- A_{PP} is the minimum area of practice in square feet
- Q is the peak flow rate of runoff for the design storm in cubic feet per second

EQUATION C8-S1-3

Step 5: Design storage aggregate depths

Calculate the Dimensions of the Storage Aggregate Layer: The storage aggregate layer must be sized to provide a volume equal to or greater than the volume of runoff generated from the design storm event, discussed in Step 1 above. The design of the Storage Aggregate Layer is determined by reviewing multiple factors:

- ✓ Pavement system (pavers, asphalt, concrete)
- ✓ Filter aggregate (material, thickness)
- ✓ Storage aggregate (material thickness)
  - Subsurface chamber systems
  - Subsurface concrete storage systems
  - Rainwater recapture systems

MINIMUM DEPTH REQUIRED (FILTER AND STORAGE AGG) = WQ_V / (A_{PP} X 0.35)

Where:

- WQ_V = from Equation C8-S1-2 or other design volume
- A_{PP} = from Equation C8-S1-3

EQUATION C8-S1-4

In part A, the structural depth of the sub-pavement aggregate was determined. This is the minimum aggregate depth that may govern the design. Calculate the void volume within the stone based on the stone porosity percentages (see right), the depth of the stone, and the area of the permeable pavement. The #8 bedding aggregate in between and directly beneath the pavers should not be counted in the storage volume calculation. Be sure to account for surface and subsurface slopes as discussed in Section 8.1.4 below as part of calculation of the storage volume.

Equation C8-S1-4 calculates the minimum depth for a flat excavated area or the lower end of the installation. The calculation will need to be adjusted for sites with slopes and baffles as follows.

The available volume for water storage within the aggregate uphill of a slope baffle (aka – check dam, weir, etc.) can be calculated by multiplying the porosity of the aggregate (typically 0.35) by the volume of the triangular wedge whose level top is at the height of the top of the baffle. Baffles constructed with a peaked shape (such as an aggregate windrow perpendicular to the slope, covered with geotextile or geomembrane) can be assumed to be "vertical" for the sake of simple calculation without significant error, so long as they're less than a couple feet high and the side slopes are as vertical as possible. The width of the system is the dimension of the excavated aggregate chamber perpendicular to the slope (assuming it's a constant width).

NOTE

STONE POROSITY PERCENTAGES

Use 35% void space for ASTM #2 and #57

ADJUSTED CN VALUES

Adjusted CN values are used for storms with < 2" rainfall in 24 hours

3:1 RATIO

Use a 3:1 ratio of contributing drainage area to permeable pavement area for more intensive land uses such as roadways, parking areas, and surfaces that generate higher pollutant loads, and a 5:1 ratio for less intensive land uses such as driveways, patios, and areas for pedestrian use.

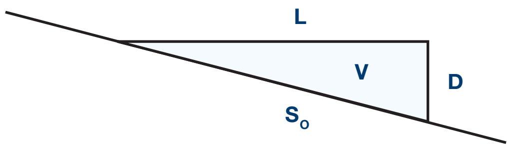
Often the most convenient dimensions available during design are the system width, baffle height, and slope of the bottom of the practice, so the following equation was developed for determining the volume when the length of the ponded area is unknown. Note that the slope of the bottom of the practice (the excavated pit which will receive the rock aggregate) may be different than the slope of the pavement surface. The pavement surface may affect the baffle layout and height, but it is immaterial in the volume calculation.

$$V = 50 \times p \times W \times (D^2/S_O)$$

Where:

- V=Volume of water stored uphill of a baffle on a sloped surface (cu ft^3)
- ρ=porosity of aggregate (assume 0.35)
- W=width of the aggregate perpendicular to the slope (ft)
- D=height of the baffle (ft)
- S_o=slope of the excavated bottom of the aggregate chamber (%) (10% is “10”,not “0.10”)

EQUATION C8-S1-5



The bottom of the practice must be 2 feet above the seasonal groundwater elevation to provide some factor of safety from a potential fluctuation in groundwater from inundating the stone and taking away from the ability to store water when it rains. Less than a 2 foot separation requires an impermeable liner.

For larger storm events, the sub-pavement aggregate thickness or area of the pervious pavement may need to increase. Subsurface chambers may also be necessary to accommodate the required storage volume if it cannot fit within the stone void volume. See Part C below for more information.

Step 6: Verify volume of storage

The design storage volume must be equal to or exceed the WQv to be sized properly. Designing the permeable paver storage area for the Channel Protection Volume (CPv) per Chapter 3, Section 6-C, is an additional target to consider during the design process. The Overbank Flood Protection Volume (Qp) may need to be evaluated as well per Chapter 3, Section 14. The depth of the aggregate and the pavement area may need to be adjusted accordingly.

NOTE

Designing for the Channel Protection Volume (CPv) is a target criteria, something that should be provided if feasible. This standard will better mimic natural site hydrology for small storm events with temporary storage volume and not exceeding allowable release rates.

DESIGN STORAGE VOLUME ≥ REQUIRED WATER QUALITY TREATMENT VOLUME (WQv)

EQUATION C8-S1-6

For larger storm events, the runoff volume may be managed within the storage aggregate and subsurface chambers but may also be achievable through the use of other practices or in combination with subsurface chambers to increase available storage.

Verify the design storage volume provided is greater than or equal to the required Water Quality Volume and/or the larger storm detention volume.

Step 7: Subdrain system design
Determine the infiltration rates of the existing soils below the practice. It is recommended that site infiltration rates based on field measurements be divided by 2 to provide a safety factor that accounts for a decrease in infiltration rates over time. See Table C8-S1-2 for typical infiltration rates for soil types and textures. (Note: Obtain infiltration rate testing results of soils below the practice. A geotechnical engineer can be consulted if needed to verify the infiltration rates.):

THEORETICAL INFILTRATION RATES			
HYDROLOGIC SOIL GROUP	INFILTRATION RATE (INCHES/HOUR)	SOIL TEXTURES	CORRESPONDING UNIFIED SOIL CLASSIFICATION
A	1.63*	gravel sandy gravel silty gravel	GW - well graded gravels, sandy gravels GP - gap-graded or uniform gravels, sandy gravels GM - silty gravels, silty sandy gravels SW - well-graded gravelly sands
	0.8	sand loamy sand sandy loam	SP - gap graded or uniform sands, gravelly sands
B	0.45		SM - silty sands, silty gravelly sands
	0.3	loam silt loam	MH - micaceous silts, diatomaceous silts, volcanic ash
C	0.2	sandy clay loam	ML - silts, very fine sands, silty or clayey fine sands
D	0.06	clay loam silty clay loam sandy clay silty clay clay	GC - clayey gravels, clayey sandy gravels SC - clayey sands, clayey gravelly sands CL - low plasticity clays, sandy or silty clays OL - organic silts and clays of low plasticity CH - highly plastic clays and sandy clays OH - organic silts and clays of high plasticity

TABLE C8-S1-2

NOTE

Site specific infiltration rates can be determined to verify if proper infiltration is available on your project site, and used as a part of the permeable pavement design.

TABLE C8-S1-2 NOTES

HSG A soils have two infiltration rates that are a function of soil texture

This table is per the Minnesota Stormwater Manual.

Sources: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates.

*Wisconsin Department of Natural Resources Conservation Practice Standard: Site Evaluation for Stormwater Infiltration.

Determine the existing soils characteristics:

Full Exfiltration: A subdrain may not be needed if the post construction subsoil infiltration rate is 1 inch/hr or greater and can convey the storage volume in 24 to 48 hours. However, a subdrain should still be considered as a fail safe if an outlet is available.

Partial/No Exfiltration: A subdrain is necessary within the aggregate if the existing subsoil infiltration rate is less than 1 in/hr. The subdrain is sized to convey the flow from the design storm that is not exfiltrated through the soil. If the subdrain is draining too quickly, the subdrain may need to be routed to an outlet control prior to exiting the practice. The outlet control structure can utilize a properly sized orifice and/or weir to slow the drainage rate of the aggregate. See Chapter 3, Section 12 for more information on outlet control sizing and calculations.

Size the subdrain pipe based on the flow rate that is unable to exfiltrate into the existing soil. Require 10% of the system to be within 1 foot of the proposed subdrain. (E.g. - 1 subdrain per 20 feet on center of practice width)

Part C: Design Alternatives for Larger Storms

Each system is designed to accommodate a specific storm size and duration. During the design process, designers must also evaluate and provide a system to store or bypass larger storm events. There are various options that can be designed to handle these larger storms: increased pavement area, increased subsurface storage, and surface intakes for emergency overflow. For storm events larger than the 5-year, 24-hour storm, designers must provide conveyance for stormwater, either through surface flow or traditional stormwater intakes and pipe networks. The flow rate generated for each larger storm event should be compared to the infiltration rate of the permeable pavement section to verify it can be conveyed to the subsurface drainage system.

For larger storm detention verification, calculate allowable release rate, required storage and an outlet control design that maintains the allowable release rate.

- Refer to Detention Modeling Chapters
- Check velocities at outlets and provide stabilizations as necessary to prevent channel and/or embankment erosion.
- Overflow and bypass discussion may be necessary as part of very large storm events and offsite bypass flows routed through the proposed site area.

Increase Pavement Area: To compensate for a larger storm, increasing the pavement area is usually considered when area is available and if increasing depth is cost prohibitive. This additional pavement area will provide additional storage volume.

Increasing the pavement area will affect parts of the pavement design. This solution will not affect the subsoil, the engineering fabric selection, or the wearing surface design. It will impact the sizing of the bypass system and the system outlet or overflow design. Be sure to consider the increased area into these calculations in Part B: Hydraulic Storage Depth Calculations.

Increase Subsurface Storage: Another way to store runoff from larger storms than the WQv is by increasing the size of the storage aggregate layer which can be done two ways. One way is to increase the depth of the storage aggregate layer. This is effective when the calculated diameter of the underdrain exceeds the depth of the storage aggregate layer and/or when the design can accommodate a deeper stone section. Increasing the depth will affect parts of the pavement design. This solution will not affect the subsoil, the engineering fabric selection, or the wearing surface design. It will affect the sizing of the bypass system and possibly the system outlet or overflow design. Consider the increased subsurface depth in the calculations in Part B: Hydraulic Storage Depth Calculations. Another option to increase the subsurface storage is by expanding the aggregate beyond the permeable pavement footprint, but no more than 10% of the required volume. For both options, the infiltration rate of the permeable pavement material will need to be compared to the larger storm flows to verify the larger storm flows can access the increased subsurface storage without ponding at the surface, otherwise these options are not feasible.

Surface Intakes for emergency overflow: The third option for handling a larger storm event is installation of surface intakes. Surface intakes can be installed and/or retrofitted to collect the excess runoff. Surface intakes may discharge to the existing storm sewer or to another downstream system. The capacity of the existing sewer or downstream practice should be considered during sizing. The surface intakes need to be designed so the small storm events do not bypass the permeable pavement system entirely. If surface intakes already exist in the location of the system, then surface intakes provide a feasible and economical way to handle larger storms.

The addition of surface intakes will affect the sizing of the bypass system and the system outlet or overflow design. Make sure to consider the underdrain size and location during the calculations in Part B.

Design Example

This design example is focused on the design of a permeable pavement system that meets the water quality treatment requirements for the site. This example demonstrates the procedural steps and calculations for sizing the storage aggregate layer given the design scenario.

DESIGN SCENARIO

The Waterwidget Manufacturing Company in Marshalltown, Iowa would like to replace their existing impervious main parking lot with a pervious paver system. Design the thickness of the storage aggregate layer of the pavement system for the given area to meet the water quality treatment requirements.

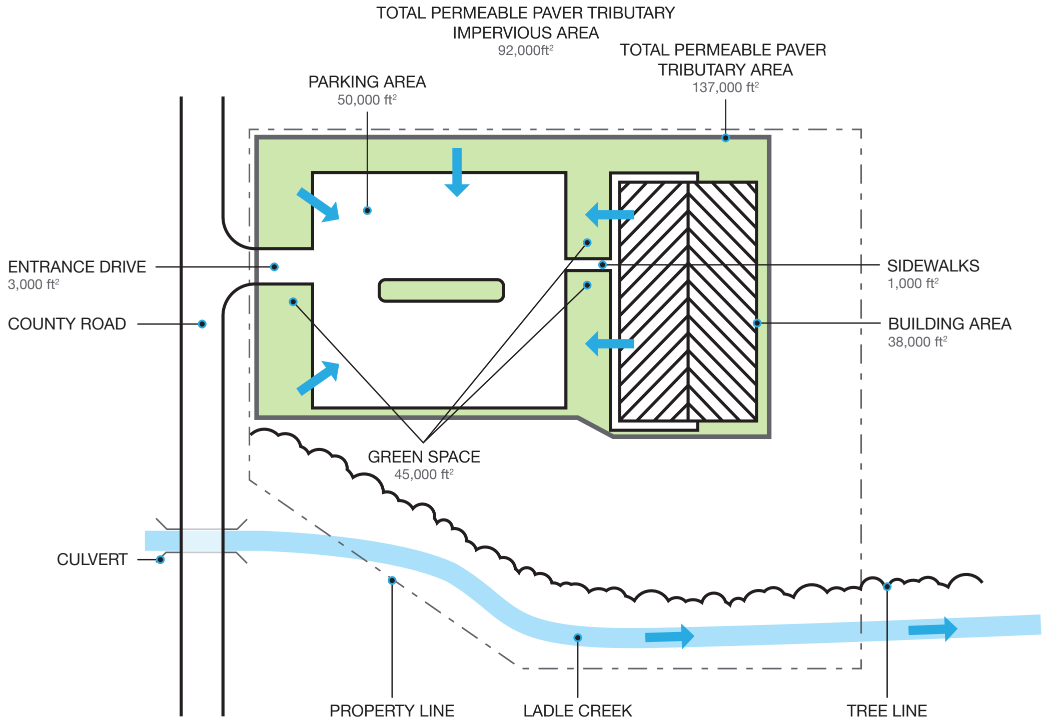


FIGURE C8-S1-7

Propsed Site Structures and Development

Total Permeable Paver Drainage Area:

137,000 SQUARE FEET x (1 ACRE/43,560 SQ FT) = 3.15 ACRES

IMPERVIOUS SURFACE AREA	
Building	38,000 square feet = 0.87 acres
Parking Lot	50,000 square feet = 1.15 acres
Entrance Drive	3,000 square feet = 0.07 acres
Sidewalk	1,000 square feet = 0.02 acres
TOTAL	92,000 square feet = 2.11 acres

SITE CONDITONS

The natural lot is considered to be a meadow in good condition. One quarter of the site is a Hydrologic Soil Group B and the remainder is Hydrologic Soil Group C.

Land slope is ±2-3% to the south to Ladle Creek.

Soil textures at the site are loam and silt loam.

Soil borings at the site indicate soils in the north portion of the site are SP (poorly graded sands) and transitions to SM (silty sand) and SC (clayey sands) in the direction of the creek.

Borings indicate depth to seasonal high water table at approximately 8 feet.

Two tests with a double-ring infiltrometer at the proposed location of parking area indicated infiltration rates at 0.88 inches per hour (north) and 0.48 inches per hour (south) with an average infiltration rate of 0.68 inches per hour. The safety factor of 2 is applied to give the design infiltration rate of 0.34 inches per hour. Site is not within the 100-year FEMA floodplain.

Vehicle loading on parking lot is estimated at 250,000 ESALs over a 20-year life-cycle.

SITE DATA SUMMARY

Criteria	Value
Total Drainage Area	3.15 Acres
Impervious Area	2.11 Acres
% Impervious Area	2.11/3.15 = 67.0%
Soils	HSG B (Silty) ≈ 25% HSG C (Clayey) ≈ 75%
Tributary Area to Paver Area Ratio	87,000/50,000 = 1.74 which is less than 3:1.

TABLE C8-S1-3

HYDROLOGIC SITE DATA FOR EXISTING AND PROPOSED CONDITIONS

	Natural	Post-development
CN	68[1]	87[3]
T_c (minutes)	16.8[2]	6.2[4]

** See Chapter 3, Section 6 for detailed calculations of CN and Tc.*

TABLE C8-S1-4

DESIGN STORM DEPTHS PER GIVEN INTERVALS AND A 24 HOUR EVENT

Return interval (Years)	Depth (Inches)
1	2.67
2	3.08
5	3.81
10	4.46
100	7.12

TABLE C8-S1-5 FROM TABLE C3-S2-3 FOR SECTION 5-CENTRAL IOWA FOR A 24 HOUR STORM EVENT.

SITE SPECIFIC DATA SUMMARY

Criteria	Value
Soil (NRCS texture)	Sands, Silty Sands, Clayey Sands
Soils (USCS)	SP, SM, SC
Existing Infiltration Rate	0.34 in/hr
Ground Elevation at BMP	1,020 feet
Seasonally High Water Table	1,012 feet
Steam Invert	1,006 feet
Soil Slopes	2.0-4.0%

TABLE C8-S1-6

DEFINITIONS

CN: Runoff curve number

T_c: Time of concentration

(see Section 3, Chapter 6 for detailed calculations of CN and Tc.)

TABLE C8-S1-4 NOTES

1
(0.80 acres x 58 + 2.35 acres x 71) / 3.15 acres = 68; CN = 68; meadow cover used per Table C3-S5-4.

2
100’ at 2% with short grass and 800’ at 1.5% slope, unpaved.

3
(0.80 acres x 61 + 0.24 acres x 74 +2.11acres x 98) / 3.15 = 87; CN=87;

Good Condition grass cover and impervious surface used per Table C3-S5-2. Assumes 0.8 acres is open space HSG B soils and 0.24 acres is part of HSG C soils area.

4
55’ at 2% in short grass to pavers.

Footnote 1 & 3 are calculations for composite curve number (CN)

Footnote 2 & 4 are calculations for time of concentration (Tc)

DEFINITIONS

VOLUMETRIC RUNOFF COEFFICIENT (Rv): Coefficient used to compute the required WQv treatment volume

IMPERVIOUS AREA PERCENTAGE (I): The impervious area divided by the total project area and converted to a whole number (i.e. 70% - 70 is used in the equation)

DRAINAGE AREA (DA): The area of the site in acres.

R_v: Runoff Volume Coefficient

Qwq: Peak runoff volume in watershed inches based on the Water Quality Volume (WQv)

q_{wq}: Peak Flow Rate for the Water Quality Volume (WQv)

PRELIMINARY SITE ASSESSMENT

- ✓ Loam and silt loam soils at this site meets both criteria for SP/SM/SC soils. Soil gradation indicated 58% sand, 12% clay, and 18% silt and a soaked CBR of 15.
- ✓ **Slopes ≤ 8% and in non-fill soils:** Slope is 2-4%; not fill soils.
- ✓ **Not in karst topography:** Not in karst.
- ✓ **Not near hotspots:** Not located near hotspots.
- ✓ **Located a minimum of 100 feet horizontally from any water supply well:** No water supply wells nearby.
- ✓ **A setback at least 10 feet from structures:** 240 feet straight-line distance between the parking lot and the tree line.
- ✓ **Minimum vertical separation distance of 2 feet from the seasonally high water table:** Elevation of seasonally high water table: 1012 feet. Elevation of BMP location: 1,020 feet. Elevation of parking lot: 1,020 feet. Maximum depth of storage aggregate layer according to the water table depth is 1,020 feet - 1,012 feet - 2 feet = 6 feet. The depth of the storage aggregate layer must be less than 6 feet.
- ✓ **Infiltration rate (f) ≤ 1 inch per hour use underdrain:** Site f (0.34 inches per hour) is less than 1 inch per hour, therefore a full exfiltration is unlikely and an underdrain is recommended.

The example below follows the design calculations procedure described on page 12:

Part A: Structural Depth Calculations
The licensed engineer assumed typical thickness of the pavers, bedding aggregate layer, and a filter aggregate layer. The engineer followed the structural guidelines found in the Iowa SUDAS Design Manual for Permeable Interlocking Pavers and used the tables found in the ASCE Structural Design of Interlocking Concrete Pavement for Municipal Streets and Roadways, then recommended a storage aggregate layer thickness of 16 to 18 inches.

Part B: Hydraulic Storage Calculations
For this example, the depth will be designed to hold the Water Quality Volume (WQv), and the Channel Protection Volume (Cpv), but larger storms are considered.

The design goal is to convey all surface runoff from the site into the permeable paver system before being discharged into the Ladle Creek. The minimum design will be for WQv and the Cpv, but larger storms (e.g. the 5-year and 10-year) requirements will need to be checked.

Necessary information includes:

- Catchment area, Ac = 137,000 square feet
- Pavement area, Ap = 50,000 square feet
- Porosity = 0.35 for ASTM #2 and #57 Storage Aggregate
- Percent impervious area = 67%

Step 1 Compute Runoff Volumes - Compute Water Quality Volume (WQv) and Peak Discharge (Q_{wq}): Use Equation C2-S1-1 and C2-S1-2 from Chapter 2, Section 1 for the Short Cut Method. (For a full explanation of calculations, see Chapter 3, Section 6.)

$$R_v = 0.05 + 0.009(67) = 0.65$$

EQUATION C8-S1-9

$$WQ_v = (43{,}560 \text{ SF/AC})[1.25 \text{ IN} \times .65 \times 3.15 \text{ AC}] / 12 \text{ IN} = 9{,}291 \text{ CU FT}$$

EQUATION C8-S1-10

Step 2: Compute peak runoff rates
Compute Q_{wq} and q_{wq} using TR-55 with a CN = 95, T_c = 0.10 hour (proposed Tc from C8-S1-4), and 1.25 inches, for the water quality storm event. The curve number (CN) is calculated using equation C3-S6-3, the previously calculated Rv above in C8-S1-9 and 1.25 inches for the water quality storm event.

TR-55 RESULTS:

q_{wq} = 3.78 CFS

Q_{WQ} = 0.70 IN

Compute larger storm runoff volumes and peak flows: Use TR-55 to compute the natural and post- development runoff depths and peak runoff rates for the 1 to 100 year, 24 hour duration storms. See Table C8-SI-7 for TR-55 results.

PRE AND POST DEVELOPMENT RUNOFF DEPTHS AND RATES FOR P1 TO P100

CONDITION	CN	P1		P5	
		Q (CF)	q (CFS)	Q (CF)	q (CFS)
Natural	68	4,620	1.39	12,384	3.84
Post-developed	87	16,477	7.02	27,980	11.78

CONDITION	CN	P10		P100	
		Q (CF)	q (CFS)	Q (CF)	q (CFS)
Natural	68	17,163	5.48	40,021	13.18
Post-developed	87	34,841	14.53	63,873	25.81

TABLE C8-S1-7

Note: Post-development flows are inflows to the BMP.

Step 3: Determine Volume Storage Types
For this example, the pavement system is used to manage the water quality volume (WQv) and the channel protection volume (Cpv), but larger storms are also considered including the overbank flood protection volume since the site discharges directly to an open channel. Storm inlets are not considered.

Step 4: Verify the pavement surface size.
The proposed permeable pavement area is 50,000 square feet, so there is enough pavement area to pass the peak water quality volume flow rate through the pavement section.

$$A_{PP} = (Q \text{ X } 3600 \text{ SEC/HR X12 IN/FT})/(10 \text{ IN/HR})$$

Where:

- A_{PP} is the minimum area of practice in square feet
- Q is the peak flow rate of runoff for the design storm in cubic feet per second

EXAMPLE:

$$A_{PP} \text{ (SQ FT)} = (3.78 \text{ CFS X } 3600 \text{ SEC/HR X } 12 \text{ IN/FT})/(10 \text{ IN/HR})$$

$$A_{PP} = 16{,}330 \text{ SQ FT}$$

Note: With the difference in square footage (50,000 available and 16,330 required), a designer could consider as they continue through the design process, to reduce the permeable paver footprint depending on other design calculations and considerations, thus saving costs on the system but still meeting the design requirements. The remaining parking lot could be traditional pavement, however, the permeable portion should be situated such that the entire paved area drains to it.

Step 5: Design Storage Aggregate Depth
Per the structural depth calculations in Part A, the minimum pavement depth is 16 inches. This places the bottom elevation of the pavement section at 1018.67 which is greater than 2 feet higher than the seasonal groundwater table.

Calculate the Available Storage within the storage and filter aggregate for 50,000 square feet of permeable pavement area with a porosity of 35% void space:

$$50{,}000 \text{ SF x 16IN (1 FT/12 IN) x } 35\% = 23{,}333 \text{ CF OF AVAILABLE STORAGE}$$

Step 6: Verify Volume of Storage
The design storage volume of 23,333 cf exceeds the water quality volume of 9,291 cubic feet. Estimate if the design storage volume exceeds the channel protection volume.

Stormwater practices designed for the Water Quality volume (“WQv”) are typically designed such that the volume available for storing water in the practice meets or moderately exceeds the calculated WQv, using Equation C3-S6-1 and C3-S6-2. Therefore, the calculation of the “design volume” can be calculated by basic geometry (volume equals area times depth times the decimal “porosity” of the media). Some consideration should be given to the rates at which water enters and leaves the practice so that the entrance does not erode, and so that water does not escape too quickly nor remain too long (typical target retention time is 12 to 48 hours depending on the practice), however these rates are not considered in the geometric volume determination.

Conversely, practices for detaining the runoff from large storm events are typically designed for the net volume that is the difference between the incoming runoff rate, and the outgoing release rate (designed to be just less than the maximum allowable by the local jurisdiction, often the "5-year pre-development runoff rate"). The calculation of this volume is a calculus problem known as "routing", which is tedious and iterative to solve by hand – most designers use software.

Designing a practice for the Channel Protection volume ("CPv") is the point of divergence for these two calculation methods. Practices larger than the CPv are typically always designed with routing because they would be wastefully oversized if designed for the total volume of the runoff (the water slowly leaving the practice over the time of detention reduces the required volume considerably). Practices designed for the CPv can be designed for the total volume of runoff from the design storm (the 1-yr event), or for the "routed volume" as determined by appropriate methods (see Chapter 3, Section 9). The magnitude of difference between these methods is relatively small for smaller practices (less than ~1-2 acres drainage area). Designers should bear in mind that regardless of the volume method used, the total release rate from the practice is still critical for CPv practices, and should be designed to meet local requirements.

The WQv formulas (C3-S6-1 and C3-S6-2) are only appropriate for rainfall totals less than 2" in 24 hours, so calculation of the total geometric volume (maximum design volume) for CPv practices is performed with the TR-55 "Curve Number" method:

$$S = 1000/CN - 10$$

Where:

- S = portion of the rainfall that doesn't become runoff because it gets stuck to plants, soaks into soil, etc.
- CN = the composite "Curve Number" for the contributing drainage area (see Table C3-S5-3)

EQUATION C3-S5-4

$$Q = (P - 0.2\ S)^2/(P+0.8\ S)$$

Where:

- Q = the depth of the runoff (inches; total volume of runoff is this depth times the area of the watershed, see below)
- P = total rainfall depth for the design storm event (inches; the 1-yr, 24-hour event for CPv design)
- S = defined above

EQUATION C3-S5-3

Total volume of runoff:

$$V = Q \times A \times (1\ FT)/(12\ IN) \times (43560\ FT^2)/1\ AC)$$

Where:

- V = total volume of runoff from the design storm over the whole watershed (cubic feet)
- Q = defined above (inches)
- A = area of the contributing watershed (acres)

DEFINITIONS

V_S: Storage volume

V_R: Runoff volume

Q_a: Runoff in watershed inches

EXAMPLE:

CN = 87

P = 2.67 IN

A = 3.15 AC

$$S = (1000/87) - 10$$
$$S = 1.494$$

$$Q = (2.67 - 0.2(1.494))^2 / (2.67+0.8(1.494))$$
$$Q = 1.45 \text{ INCHES}$$

$$V = 1.45 \text{ IN} \times 3.15 \text{ AC} \times (1 \text{ FT}/12 \text{ IN}) \times (43560 \text{ FT}^2/1 \text{ AC})$$
$$V=16,580 \text{ FT}^3$$

Therefore 16,580 cubic feet is the volume of runoff from this watershed and this storm event; this is the maximum required design volume for a practice intended to treat the CPv runoff. The design volume could however be reduced by conducting routing calculations. The estimation method presented in Chapter 3-Section 6, Part C produces an estimated 10,867 ft3 required (see below), however this would need to be confirmed with routing software for the specific outlet design.

Routed Volume Estimation Method: Use the TR-55 results in C2-S1-C and C3-S6-E to compute the estimated routed volume for the post development 1-year 24 hour design storm. Use the unit peak discharge, q_u, to find the ratio of outflow to inflow (q_o/q_i) from Figure C3-S6-1 (as described in Chapter 3, Section 6).

NOTE: the equations below are an ESTIMATION procedure and NOT final storage volume. Routing must be done to confirm the volume and check the release rate.

$$q_u = 990.9 \text{ CSM/IN}$$

FROM FIGURE C3-S6-1, $q_o/q_i = 0.02$

$$(V_s/V_r) = 0.683 - 1.43(0.02) + 1.64(0.02)^2 - 0.804(0.02)^3 = 0.66$$

$$V_r \text{ (OR } Q_a) = Q_{P1a} = 1.44 \text{ IN}$$

$$C_{pv} = (V_s/V_r)(Q_{P1a})DA$$
$$= (0.66)(1.44 \text{ in})(1 \text{ FT}/12 \text{ IN})3.15\text{AC}(43,560 \text{ SF}/1 \text{ AC})$$
$$= 10,867 \text{ CF}$$

DEFINITIONS

q_u : Unit peak discharge in cubic feet per second per square mile of drainage area per inch (csm/in)

q_o/q_i: Discharge Ratio. This is the ratio of outflow to inflow

The storage volume provided is in excess of estimated channel protection volume. The additional volume can be utilized as part of the larger storm volume requirements if possible. The channel protection volume and larger storm volume should be calculated using a stage storage model that includes a detailed outlet control structure design. Please refer to Chapter 3 for more information.

Step 7: Subdrain System Design

Since the existing soils infiltration rate is less than 1 inch per hour, a subdrain will be required within the stone base of the pavement section. The subdrain is typically placed 2 inches above the bottom of the aggregate storage area at the uphill end while the subdrain may be at the bottom or below the aggregate at the downhill end. The designed storage volume in cubic feet needs to drain out completely within 48 hours. The design flow rate can be determined from the following equation: NOTE: this equation determines the average discharge rate required and provides a good starting point for the design. The final design should be checked for stage-discharge performance via the pipe manufacturer's specific performance data, and the orifice discharge calculation methods provided in section 9.04.

Q = (DESIGN VOLUME IN CU FT/48 HOURS) x (1 HOUR/3,600 SEC)

Solve for Q = Average subdrain flow rate in cubic feet per second (cfs)

In this example we are designing for the CPv of 16,580 cu ft.

Q = (16,580 CU FT/48 HOURS) x (1 HOUR/3,600 SEC) = 0.096 CFS

After solving for Q, use typical engineering methods to size the subdrain pipe system.

Determine the amount of pipe needed so that 10% of the system is within 1 foot of the proposed subdrain. This can be achieved by placing 1 subdrain per 20 feet on center across the pavement width, therefore, to determine the total collection pipe length needed, divide the practice width by 20 and multiply that by the practice length. For example, assume the 50,000 sq ft parking lot is 220 feet wide and 227.3 feet long. Therefore:

220 FT WIDE/20 FT PER COLLECTION PIPE = 11 COLLECTION PIPES

11 PIPES x 227.3 FEET LONG = 2,500 FEET OF SUBDRAIN COLLECTION PIPES

Another way to determine the pipe amount is the following equation:

SUBDRAIN COLLECTION PIPE LENGTH (FT) = (PERMEABLE PAVEMENT SURFACE AREA (SQ FT) x 10%)/ (1 FT X 2)

For this example we have a 50,000 sq ft permeable pavement parking lot.

SUBDRAIN COLLECTION PIPE LENGTH (FT) = (50,000 SQ FT X 10% /1 FT X 2) = (5,000 SQ FT/2 FT) = 2,500 FT

If a larger sized subdrain is installed to accommodate cleanout and inspection, an outlet control structure should use a properly sized orifice to slow the drainage to the required release rate.

Other considerations:

Placing the subdrain higher in the aggregate storage layer. To use this alternative design method, the subgrade soils below the aggregate storage area must be tested and a report generated to ensure the water stored in the aggregate below the pipe will infiltrate into the subgrade within the required time.

The subdrain for this design is a 6 inch diameter perforated PVC with a flowline depth of 8 inches above the bottom of the aggregate storage. This allows for 4 inches of aggregate cover over the top of the piping and drainage beneath to infiltrate into the subsurface soils.

The water quality volume requires 6.4 inches of depth and will be captured completely below the underdrain. In this scenario, the water quality volume will not pass through the subdrain and will infiltrate into the ground.

9,291 CF/23,333 CF X16 IN = 6.4 IN

DRAWDOWN CHECK (<48 HRS):
6.4 IN/ 0.34 IN/HR = 18.8 HRS

The aggregate storage provided will more than meet the WQv and the Cpv requirements below the underdrain.

The existing infiltration rate can drain the channel protection volume in 11.7 hours based on the calculations below.

0.34 IN/HR (1 FT/12 IN) 50,000 SF = 1,416.67 CF/HR

DEFINITIONS

HYDRAULIC STORAGE DEPTH: The depth of storage aggregate subbase which holds the filtered runoff prior to being exfiltrated into the subsoil or conveyed to an existing storm sewer through an underdrain

f = 0.34 inches/hour (design infiltration rate)

16,580 CF/1,416.67 CF/HR = 11.7 HOURS

Part C: Design for Larger Storms
For storm events larger than the 10-year, 24-hour storm, designers must provide conveyance for stormwater, either through surface flow or traditional stormwater intakes and pipe networks.

The total storage capacity of the aggregate base is 23,333 cubic feet and can be used for larger storm detention if beneficial. Flow rates for storms larger than the 10-year event will require further review to determine if the difference can be routed overland. The site drains directly to Ladle Creek so the flow rate not captured by the permeable pavement must be conveyed safely to the creek.

Velocities of the subdrain piping daylighting to the creek and the additional overland flow to creek need to be evaluated to determine the proper stabilization at the downstream end of the piping and along the overland flow route.

NOTE

Minimum subdrain size for cleanout is 6 inches

Minimum subdrain size for camera is 8 inches

DEFINITIONS

SOIL BORING TESTS: Performed by a geotechnical engineer by drilling holes and collecting soil cores in order to determine some, or all of the following:

• Ability of the soil to support structures on the surface with or without additional assistance from footings, piers, and other aids.

• Permeability/porosity of the soil to determine whether it will percolate sufficiently for permeable pavement system.

8.1.4 Design Elements

Soil Infiltration and Percolation Rate Testing

Soil infiltration testing determines the speed at which water enters into the soil. This information allows designers to incorporate the infiltration rate into design calculations. Representative number of soil borings should be taken throughout the proposed practice area to identify the underlying soil properties at the depth where percolation is designed to occur. Borings will provide information needed to identify the depth to the water table, bedrock, and/or karst.

Pretreatment and Drainage

Pretreatment is difficult to achieve with a permeable pavement system. The designer should be aware of the upgradient landuses and pollutant loading that could increase clogging in the system. Erosion and sediment control and other pretreatment practices can be used to prevent untimely clogging, as they trap sediment particles before reaching the permeable pavement surface. Properly designed permeable pavement systems can receive flow from impervious areas including travel lanes in parking lots, sidewalks, and roof drains.

FIGURE C8-S1-8: Draining pervious areas adjacent to permeable pavement

Types of Surface Pavement

Selection of the surface pavement type should be based on a review of existing conditions and project needs and designed according to the product manufacturer's recommendations.

Subbase Storage Aggregate

The storage below the permeable pavement surface should be sized for the storm event to be treated and the structural requirements of the expected traffic loading (see Section 8.1.3 Design Calculations). The storage aggregate should consist of clean washed aggregate with preference given to sizes that provide additional storage and structural stability. Ideally, the bottom layer should have a slope of less than 1% for runoff to be able to percolate evenly through the entire surface. Optimal storage capacity within the storage aggregate can be achieved when a flat subgrade is provided. The subgrade design can use baffles or terraces (see Figure C8-S1-9) to store and treat stormwater at different elevations. See Detail 6A on page 42 and 6B on page 43 for a schematic of how baffles can be configured in the subgrade. A separate subsurface (subgrade) grading plan should be included in the plan set, especially for sites with baffles and terraces.

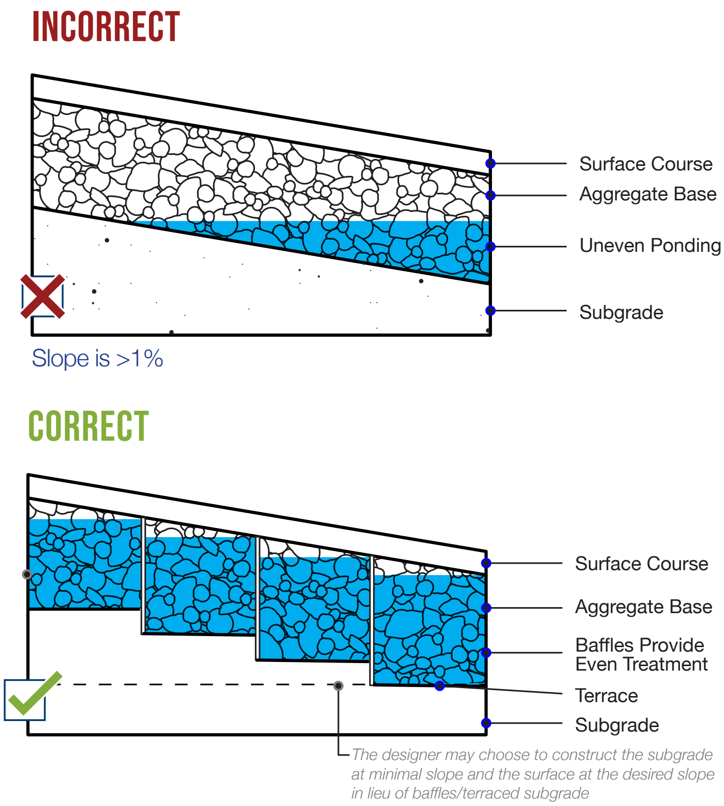


FIGURE C8-S1-9: Incorrect and correct preparation of subbase for stormwater quality volume

When using baffles, the designer should select a "low permeability" non-woven geotextile for the baffles that has a published flow rate (per ASTM D4491 - "Water Flow Rate" in gallons per minute per square foot) capable of restricting, but safely passing the design storage volume within the desired time frame (typically 24 to 48 hours). The area, pursuant to the "per square foot" element of the published rate, would be the face area of the baffle (perpendicular to flow). The designer should also consider if the baffle will be constructed of a single piece of fabric, or a double layer, as in the case of a triangular mound of aggregate covered on both sides with fabric. In the case of double fabric the total flow rate would be halved as the two layers would double the resistance to flow. A fabric with a slightly higher flow rate than the design rate should be selected to compensate for some initial surface fouling by fine particles. Design calculations for flow through the practice should be provided to reviewers for final design acceptance.

HELPFUL **TIP**

Spread drainage out evenly so it is not directed to a single point in the system.

DEFINITION

BAFFLE: A wall used at each step down of a terraced subgrade to control the water elevation in the aggregate base of a permeable pavement. This causes water to attenuate in each terrace up to the top of the baffle before spilling over into the next terrace where the next baffle wall controls the elevation of the water. A baffle can also be used independently of a terrace.

TERRACE: A stepped subgrade while there is a sloped elevation change at the surface. This allows for uniform aggregate storage beneath the sloped surface.

Underdrains

Underdrains are always recommended for permeable pavement systems, even when permeable soils are present to provide a failsafe to the practice. Underdrains are typically placed 2 inches above the subgrade. In some applications, treatment and volume objectives could dictate other options for underdrain placement within the storage aggregate.

Underdrains should be placed within the storage aggregate and encased in clean, washed aggregate. Underdrains can be used to convey water to downstream practices for further treatment. They 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.

ADDITIONAL UNDERDRAIN GUIDANCE:

- ☑ Underdrains should be installed with a positive slope.
- ☑ See SUDAS Section 4040 for underdrain guidance
- ☑ Encased in a layer of clean, washed aggregate
- ☑ If an adjustable outlet control design (e.g., orifice and weir wall) is included, it should be located within an adjacent manhole or other structure that is accessible for inspections and maintenance
- ☑ Design the outlet control so the storage aggregate drains slowly and completely in 48 hours.
- ☑ Paver systems 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.
- ☑ Minimum underdrain size for cleanout is 6 inches and for camera inspection is 8 inches

PLACEMENT OF UNDERDRAINS

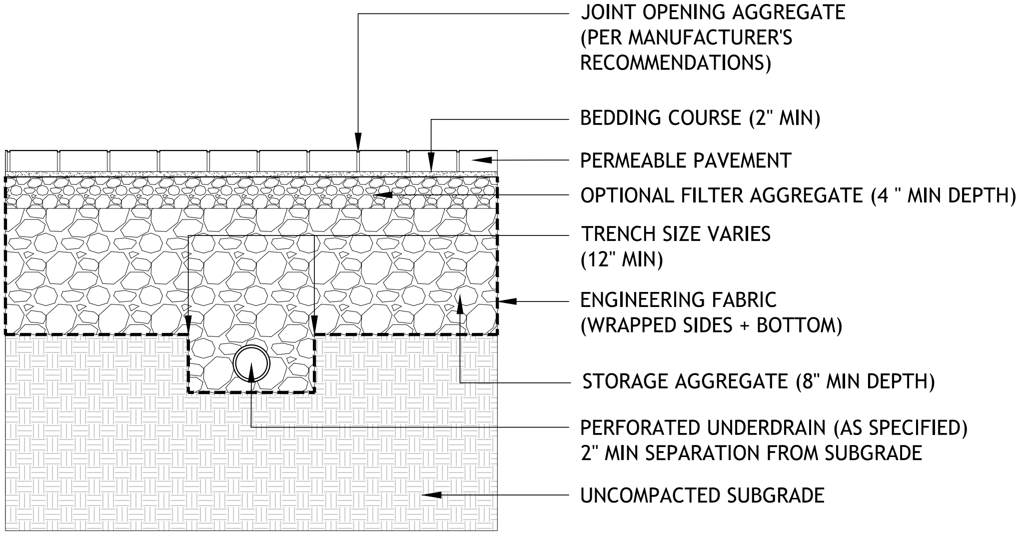


FIGURE C8-S1-10: Diagram of permeable pavement with a trench

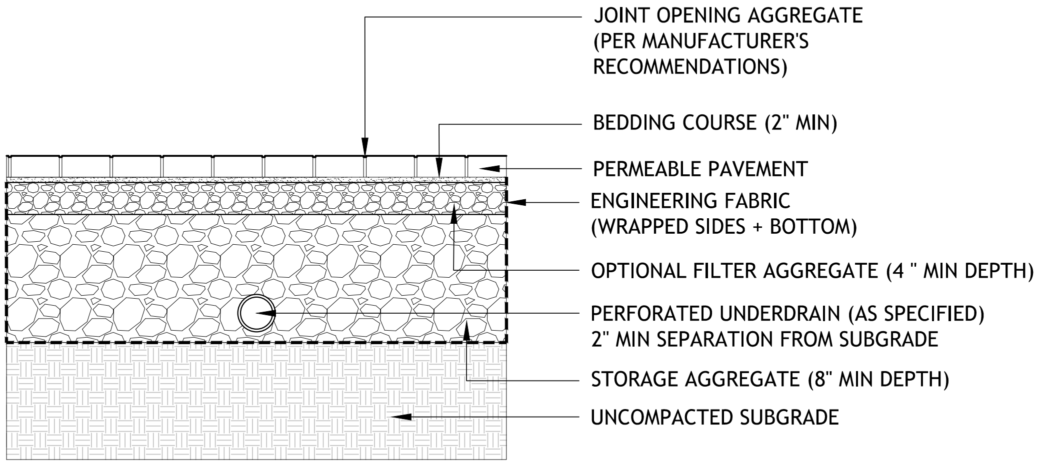


FIGURE C8-S1-11: Diagram of permeable pavement without a trench

NOTE

An underdrain trench may be needed in the following situations:

Heavy clay soils

Percolation not possible

Liner is used

Shallow rock base

Outlet elevation

OBSERVATION WELLS ARE **STRONGLY RECOMMENDED** FOR ALL PERMEABLE PAVEMENT APPLICATIONS, NO MATTER THE SIZE, IN ORDER TO BE ABLE TO TEST AND MONITOR WATER QUALITY AND MOVEMENT.

FIGURE C8-S1-12: Various types of observation wells

Internal Geometry and Extended Detention

Where soils are suitable, the depth of storage aggregate should be based on the measured percolation rate. The depth should be designed to drain completely between 48 and 72 hours.

Elevated Underdrain on Soils with High Percolation Rates: An elevated underdrain can be installed to increase the storage volume below the underdrain invert to promote greater runoff reduction for permeable pavement located on soils with high percolation rates (see Chapter 8.1.3 Design Calculations for sizing storage aggregate base).

Extended Detention: Design permeable pavement so the Water Quality Volume (WQv) is detained in the storage aggregate for at least 48 hours but not to exceed 72 hours, before being discharged through subsoil and/or an underdrain, if necessary.

Conservative Percolation Rates: Decreasing the measured percolation rate by a factor of safety of two will allow designers to approximate long-term reduction in percolation rates. Installation of underdrains and overflow conveyance will offset reduction in percolation rates.

Conveyance and Overflow

The following methods can be used so permeable pavement is able to convey large storm events to the storm drain system.

- Install stormwater intakes with rim of the intake flush with the permeable pavement system. As ponding develops on the surface of the system it will flow into the intake and be passed through the system either via storage chamber or piping.
- Create additional capacity by increasing the thickness of the storage aggregate.
- Underground detention is provided and calculated within the storage aggregate layer.
- Storage area may include various prefabricated underground detention products available.
- Locate a perforated pipe horizontally near the top of the storage aggregate to pass excess flows after water has filled the base. The design should ensure that incoming runoff is not captured by placing the perforations on the underside only.

Observation Wells

Observation wells are recommended and are used to measure and monitor performance of the permeable pavement system. Observations of the water depth throughout the estimated ponding time provide an indication of how well the water is percolating. Observation wells consist of a rigid 3 to 6 inch perforated PVC pipe, with a cap installed at the surface of the system (see Figure C8-S1-13). The key to correct capping is knowing the traffic that will be experienced on the surface. Observation wells can also be used for water quality monitoring and sampling. See Figure C8-S1-12 for examples of different types of observation wells.

FIGURE C8-S1-13: Installation of observation wells and clean-out

Placement

If the surface and subgrade are flat, the observation well should be placed near the center of the pavement (see Figure C8-S1-14). If the subgrade is terraced, one observation well should be placed at the lower end of each terrace.

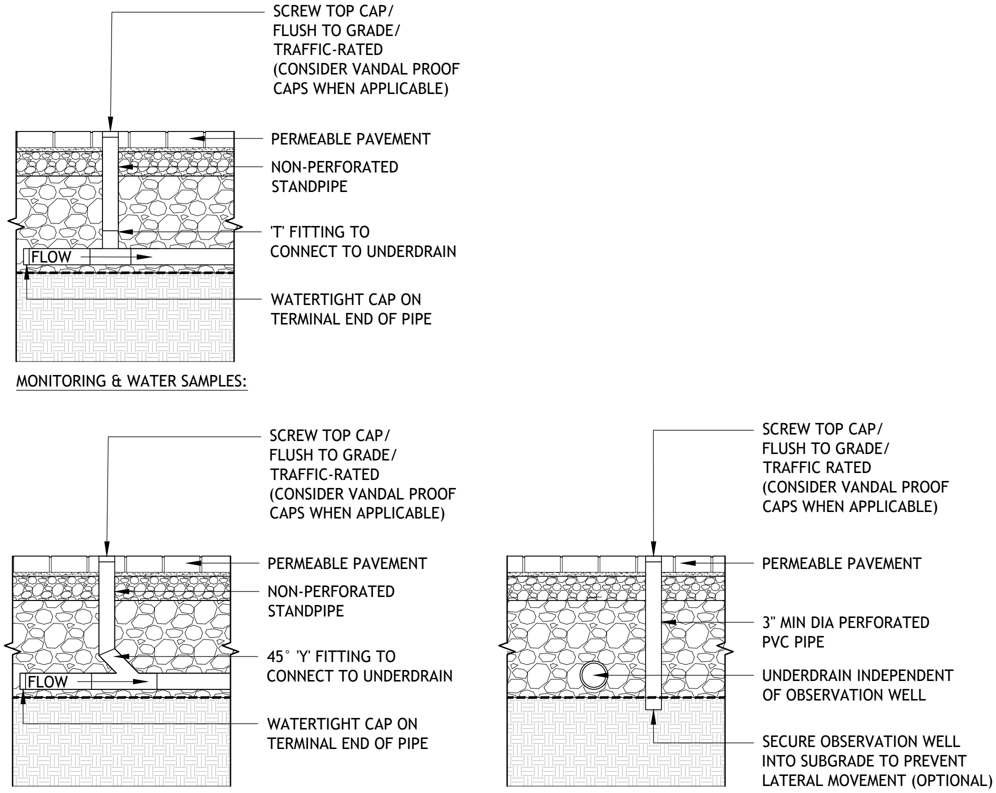


FIGURE C8-S1-14: An observation well/clean-out allows for monitoring and system maintenance. A Y-connection is better for clean-out.

Engineering Fabric

Engineering fabric should be used per the Iowa DOT 4196.01 (AASHTO M288-06) for subsurface drainage applications. The engineer is responsible for choosing the right geotextile for the application that takes into consideration site-specific soil and water conditions. Designers should evaluate the paving application and refer to AASHTO M288-06 for an appropriate fabric specification. While not a design guideline, AASHTO M288-6 provides guidance on geotextiles. Fabrics for use under permeable pavement should at a minimum meet criterion for Survivability Classes (1) and (2). The Iowa DOT has specific information about engineering fabric that can be found at https://www.iowadot.gov/erl/current/GS/content/4196.htm. Engineering fabric may not be required based on geotechnical report findings and site conditions.

Storage Aggregate Protection

Permeable engineering fabric is recommended to protect the excavated sides and bottom of the storage aggregate to prevent soil piping.

Impermeable Liner

Impermeable liners should be used when geotechnical investigations identify a need. The need may be the result of infill applications, hot spots, karst, adjacent to building foundations, or other purposes. Place engineering fabric on each side of permeable liner to prevent damage to the liner. Extra care should be taken when placing stones to prevent puncturing.

Curb/Edge Restraints and Intersection of Permeable and Impermeable Pavements

Edge restraints are a required element to prevent PP and PA from moving over time. They provide structural durability of a permeable pavement system. Lack of edge restraints causes movement so the joints open and unit pavers can get damaged. Concrete edge restraints that are cast-in place or precast curbs are recommended.

IOWA DOT SECTION 4196

4196 provides specifications and information on several types of engineering fabric for use in various applications. Selection of the appropriate engineering fabric is critical to the long-term success of the permeable pavement system. Industry standards typically recommend the use of non-woven engineering fabric for permeable pavement systems.

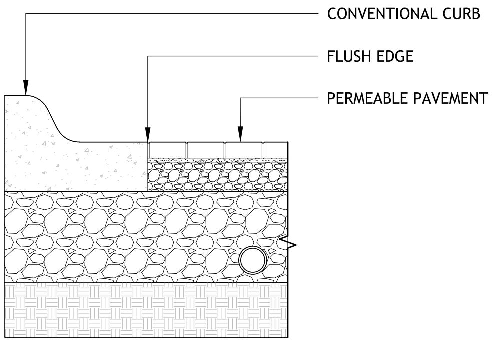


FIGURE C8-S1-15: Perimeter edge restraints for Conventional Curb

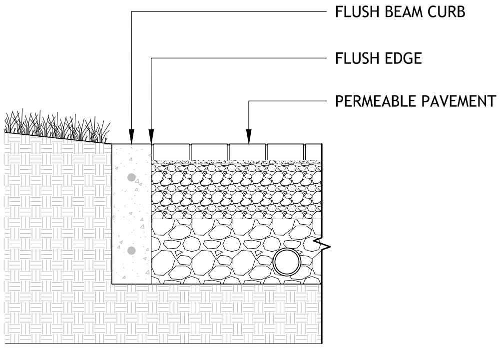


FIGURE C8-S1-16: Perimeter edge restraints for flush beam curb

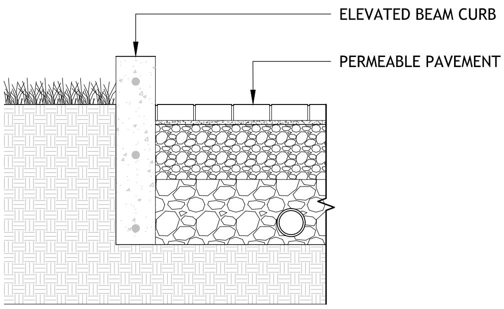


FIGURE C8-S1-17: Elevated beam curb

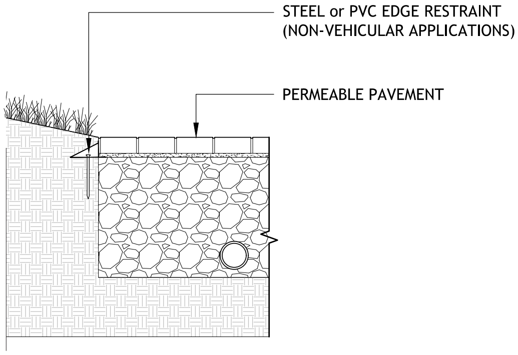


FIGURE C8-S1-18: Steel or plastic edge restraint with 12 inch landscape spike

Due to their lack of structural stability, flexible plastic or metal edging supported with spikes is not recommended for vehicular use (see Figure C8-S1-18). PC systems provide adequate structural edge support and do not require perimeter edge restraints. In addition to concrete edge restraints, it is important to consider the boundary between permeable and conventional pavement. The design will differ depending on whether the permeable pavement is adjacent to conventional asphalt (see Figure C8-S1-19) or conventional concrete (see Figure C8-S1-20). For best results, edge restraints should extend to the bottom of the storage aggregate to prevent long term heaving.

An engineering fabric barrier should be used to contain stormwater under the permeable pavement and protect the subgrade under the conventional concrete at intersections between permeable pavement and conventional concrete. Place them so seams are located between the pavement surfaces for maintenance purposes.

A concrete curb extending to the bottom of the storage aggregate should be provided to protect the subgrade under the conventional asphalt at intersections between permeable pavement and conventional asphalt. The concrete curb provides a larger separation between the pavement courses, which will be useful when resurfacing conventional asphalt. Figures C8-S1-19-21 show different designs for pavement transition.

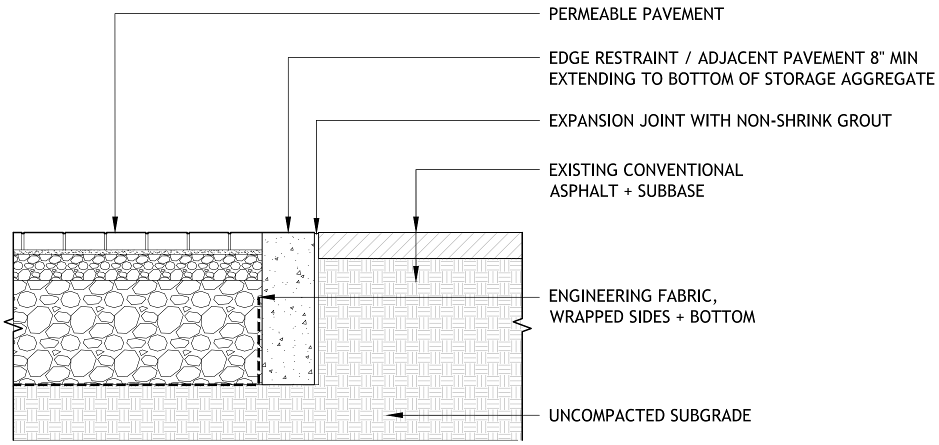


FIGURE C8-S1-19: Transition to existing asphalt

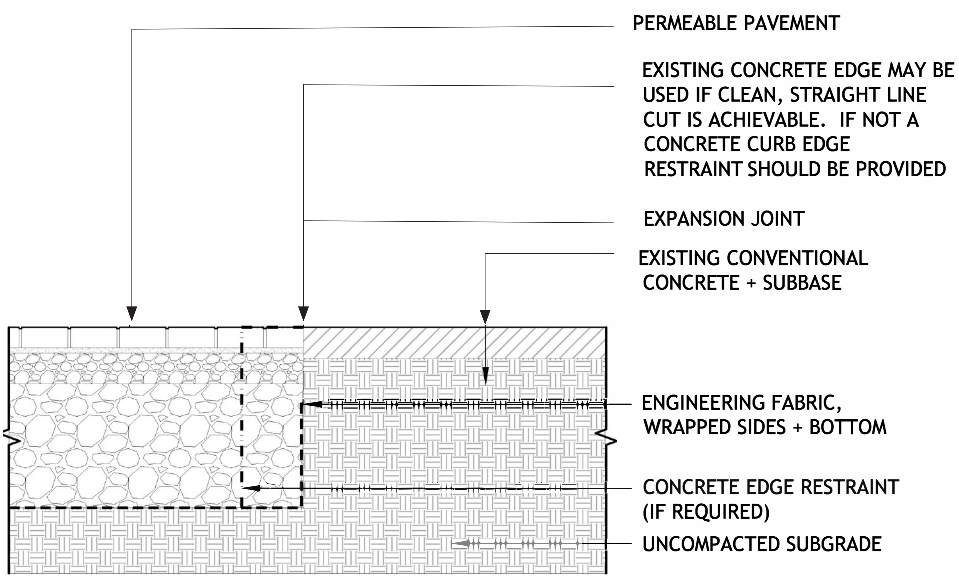


FIGURE C8-S1-20: Transition to existing concrete

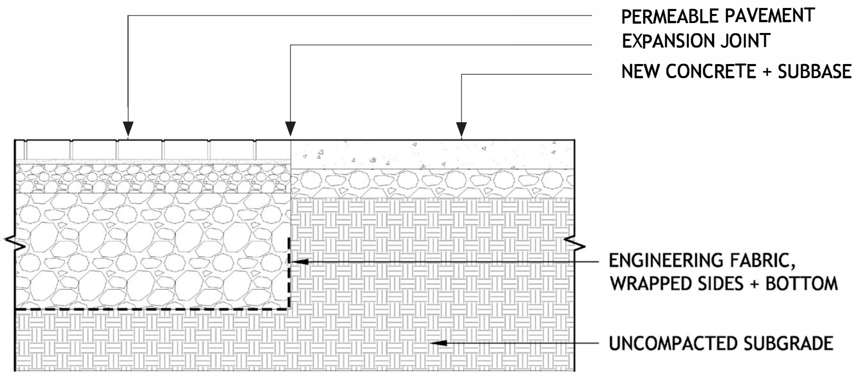


FIGURE C8-S1-21: Transition to new concrete

NOTE

Ensure the aggregate is compacted along the edge against the existing surface or new expansion restraint to prevent settling of the permeable pavement system.

TABLE C8-S1-8 NOTES

All aggregate is to be cleaned prior to installation.

Signage

Signage can be a valuable educational tool to educate the public, promote proper maintenance of the permeable pavement system, and prevent the use of traditional pavement maintenance methods that may damage the system.

Material Specifications

Material specifications vary according to the selected permeable pavement system (see Table C8-S1-8). Table C8-S1-9 lists specifications for different material applications.

MATERIAL SPECIFICATION NOTES			
MATERIAL	**PP**	**PC**	**PA**
Bedding Aggregate	2 inches of No. 8 aggregate	None	2 inches of No. 8 aggregate
	Iowa DOT Gradation No. 21/ASTM D448 Gradation No. 8. Should be double-washed and clean and free of all fines.		
Filter Aggregate	4 inches minimum depth of No. 57 aggregate	Filter aggregate is optional	4 inches minimum depth of No. 57 aggregate
Storage Aggregate	8 inch minimum Iowa DOT No. 13 aggregate / ASTM No. 2 aggregate	8 inch minimum ASTM No. 57 aggregate	8 inch minimum ASTM No. 2 aggregate
Underdrain	Use a minimum of 6 inch diameter underdrains (see SUDAS Section 4040). 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 or other suitable outlet options. Tees and wyes should be installed as needed, depending on the underdrain configuration. Extend cleanout pipes to the surface with vented caps at the tees and wyes.		
Underdrain Trench *(optional)*	A storage aggregate below the underdrain invert. The depth of the storage aggregate above the invert of the underdrain must be at least 12 inches. The material specifications are the same as for storage aggregate.		

TABLE C8-S1-8

CHARACTERISTICS OF PAVEMENT SURFACES			
SPECIFICATION	**PP**	**PC**	**PA**
Thickness	3 inches	5-8 inches	3-4 inches
Open Void Fill Media	Clean, washed aggregate	None	None
NOTES	Must conform to ASTM C936 specifications. Storage aggregate required to support the structural load.	May not require a storage aggregate to support the structural load, but a layer may be included to increase the storage or infiltration	Storage aggregate required to support the structural load.

TABLE C8-S1-9

Stormwater Retrofits

Existing impervious surfaces can be replaced with permeable pavements to achieve improved runoff conditions in most cases. Removal of the old pavement and subgrade and the installation of the underlying reservoir layer are required before placing permeable pavement. Avoid compaction of subgrade soils for the greatest water quality treatment. If this is not possible, then compacted subgrade soils should be loosened or removed to obtain the highest percolation rate possible.

Inspection and Maintenance Access Component

Safe and easy inspection and maintenance access to all major components within permeable pavement is critical to ensuring long-term performance. Inspection and maintenance access structures provide access to subsurface structures within a permeable pavement. Access points provide access to the subsurface systems, both for inspections and routine maintenance, and for pumping water out of subsurface systems in cases of failure or severe damage.

- Manholes provide access for maintenance personnel and camera inspection equipment to perform maintenance and inspections.
- Cleanouts provide access for hoses and vacuum equipment, as well as for any installed underdrains.
- Observation wells provide access to the bottom of subsurface systems for performance inspections and monitoring.
- Access structures may also serve additional functions, such as joining subsurface pipes.

Steep Slopes

Pavement Surface Slope

Several acceptable methods are appropriate for the placement of permeable pavements on a slope and should be determined by site conditions and design professional.

Surface Slope: Alternative methods for stormwater to enter into the storage aggregate may be required in instances of steep surface slopes. This can be achieved with the use of curb or area intakes in low points of the pavement profile.

Steep Slopes: The stormwater storage capability of permeable pavement can be reduced when there is a steep subgrade slope. This may cause shifting of the pavement surface and base materials. Therefore, a terraced design is recommended for permeable pavement in sloped areas of 4% or greater. Designs should ensure the pavement slope does not lead to flow occurring out of the storage aggregate onto lower portions of the pavement surface.

Soil subgrade slope: The slope of the soil subgrade should be as flat as possible and less than a 1% longitudinal slope to enable even distribution and percolation of stormwater. Lateral slopes should be flat. Steep slopes will reduce the stormwater storage capacity of permeable pavement, therefore designers should consider using a terraced subgrade design for permeable pavement in sloped areas with baffles. See Figure C8-S1-9 on page 29.

HELPFUL **TIP**

Designers should consider using a terraced subgrade for permeable pavement in sloped areas, **especially when the pavement surface slope is 4% or greater.**

FIGURE NOTES

Design Note: *Several acceptable methods are appropriate for the placement of permeable pavements on a slope and should be determined by site conditions and design professional.*

Baffle Spacing Note: *Maximum spacing should be to match top of downstream to match toe of upstream. Closer spacing could be used to increase volume used for storage.*

Storage Note: *Storage volume is a function of the baffle spacing and is specific to the designed spacing, subgrade slope, and baffle height. The designer needs to consider these and show in the storage calculations.*

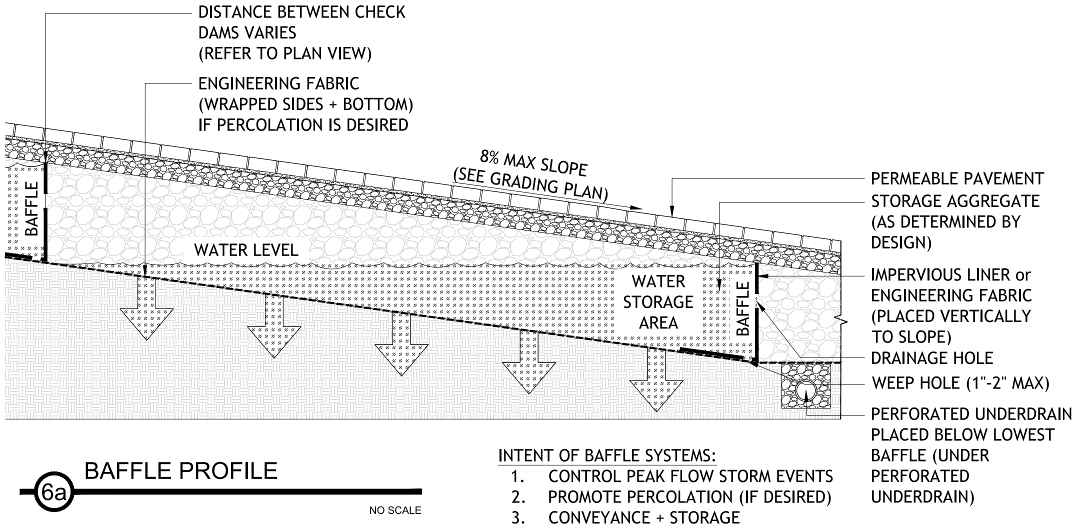


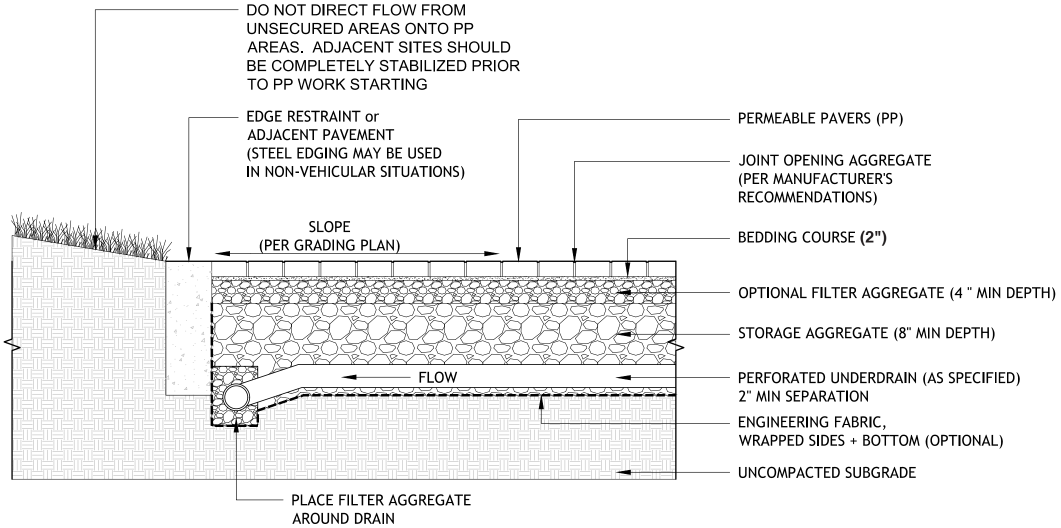
FIGURE C8-S2-8: Baffle Profile

INTENT OF BAFFLE SYSTEMS

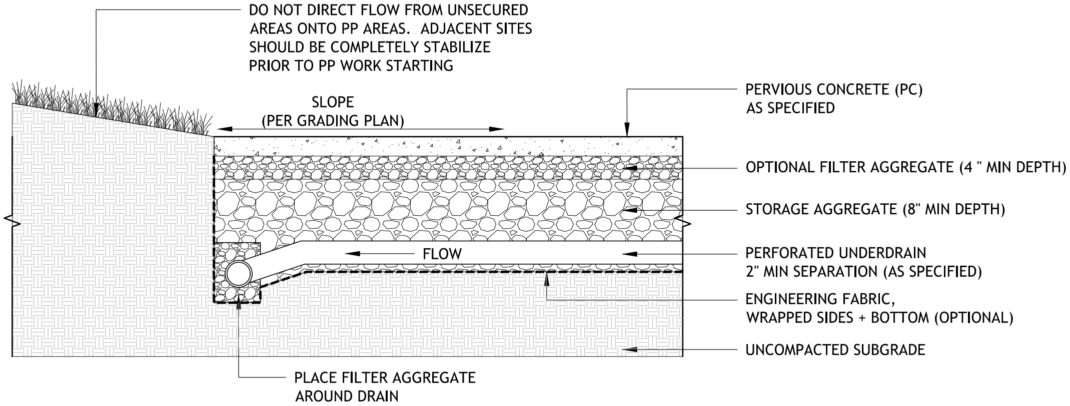
- ✓ Maximize usage of storage aggregate
- ✓ Control flow velocity along subgrade to subsoil interface
- ✓ Decrease peak flow rates through detention
- ✓ Promote percolation into subsoil

8.1.5 Typical Details

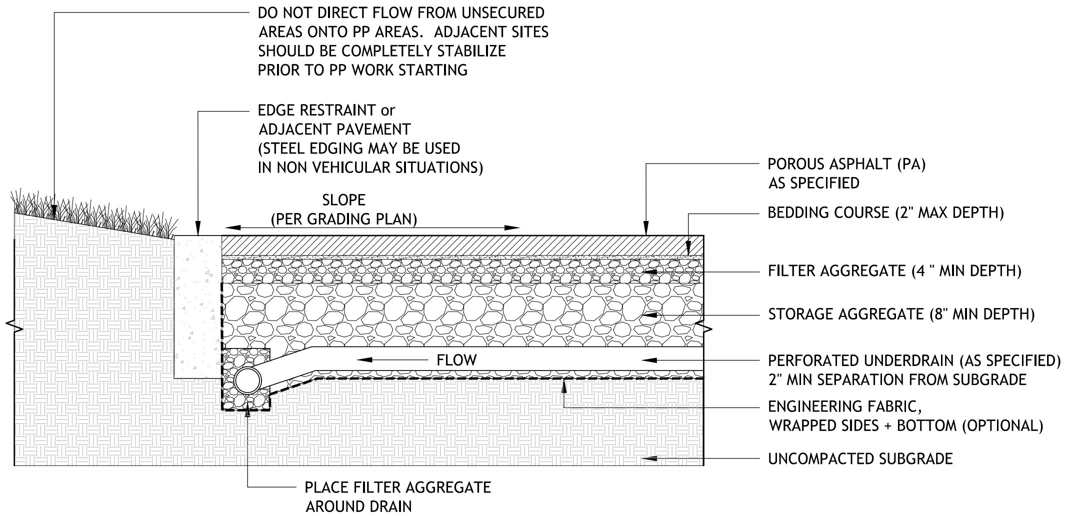
These typical details are a basis for design, however in-situ soils and site conditions should be considered for each design application.



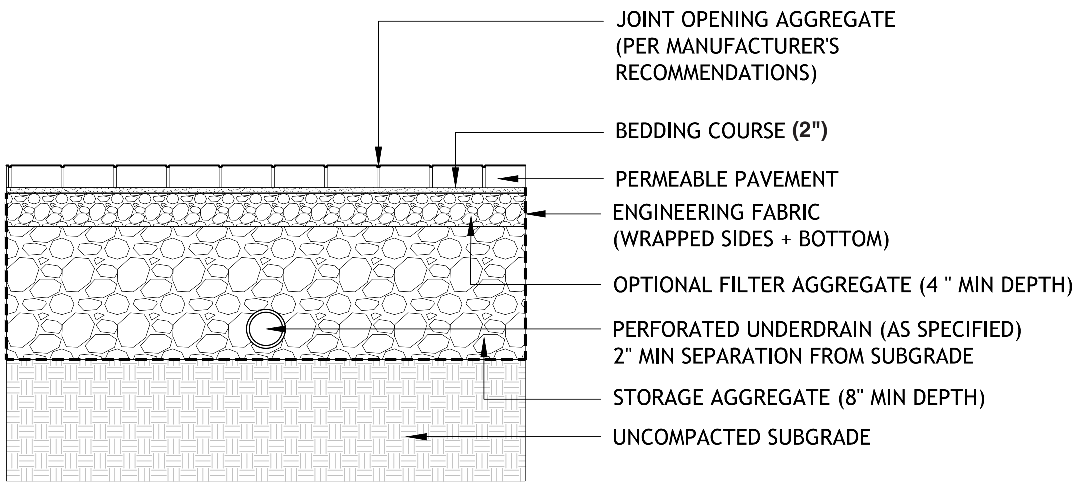
1 PERMEABLE PAVERS (PP)



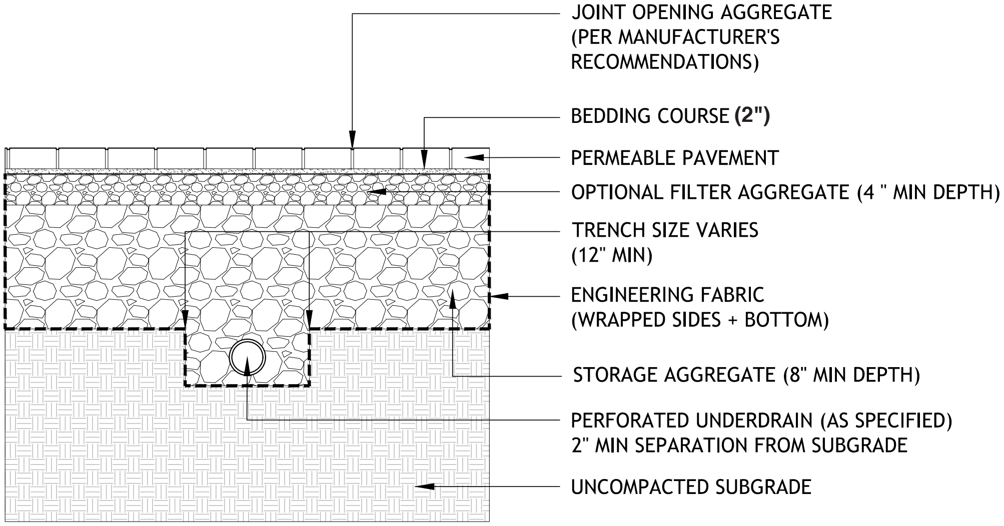
2 PERVIOUS CONCRETE PAVEMENT (PC)



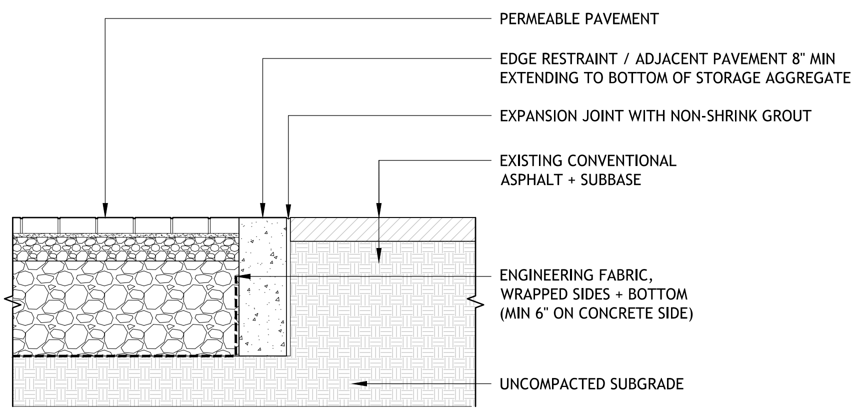
3 POROUS ASPHALT PAVEMENT (PA)



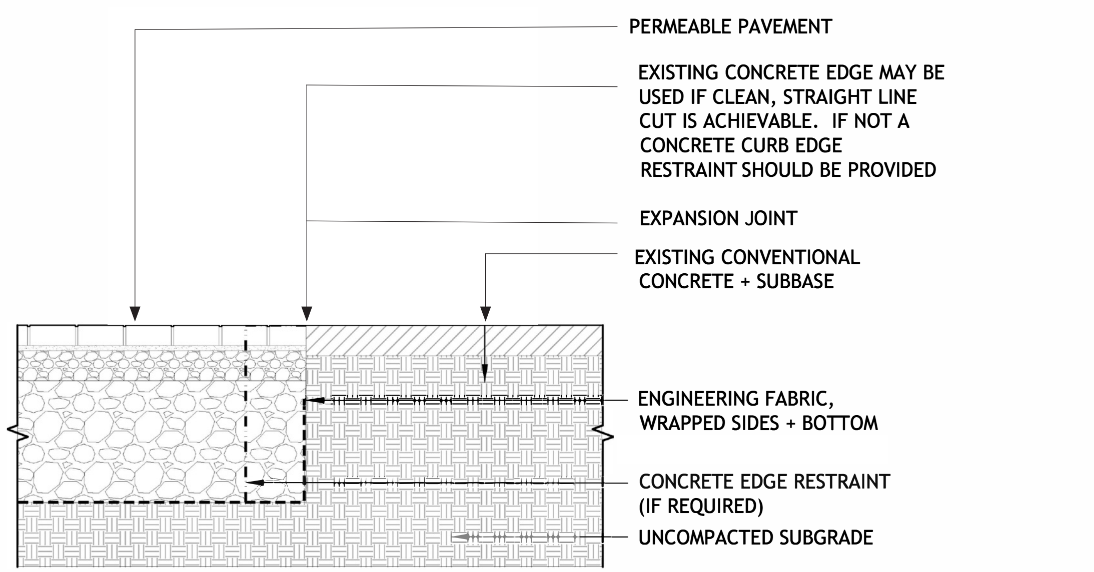
4A PERMEABLE PAVEMENT WITHOUT TRENCH



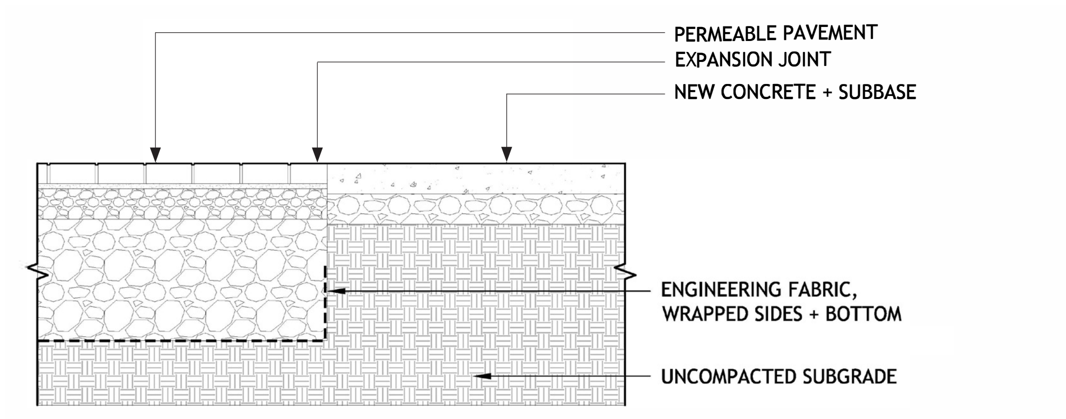
4B PERMEABLE PAVEMENT WITH TRENCH



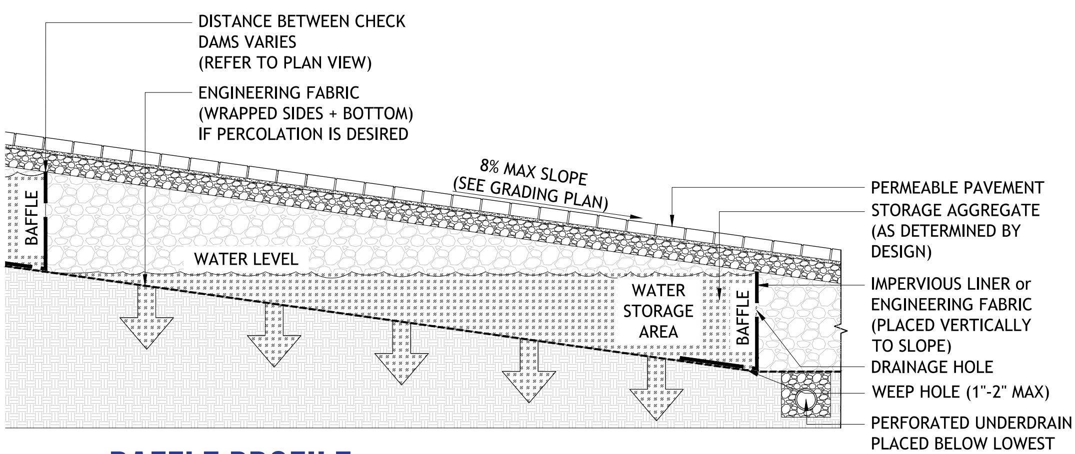
5A TRANSITION TO EXISTING ASPHALT



5B TRANSITION TO EXISTING CONCRETE



5C TRANSITION TO NEW CONCRETE



6A BAFFLE PROFILE

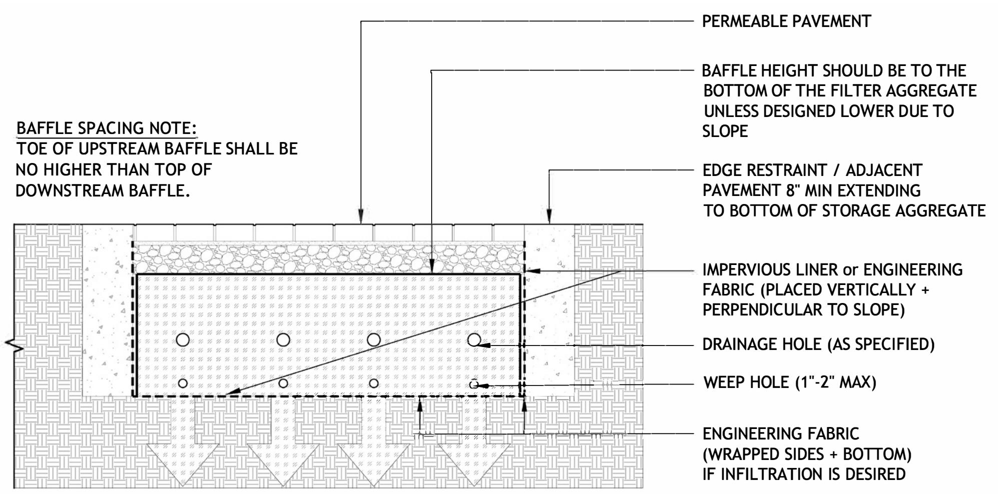
FIGURE NOTES

Design Note: *Several acceptable methods are appropriate for the placement of permeable pavement on a slope and should be determined by site conditions and the design professional. It is also understood that percolation may not be desired if site conditions dictate (i.e., Karst topography, hot spots, etc.).*

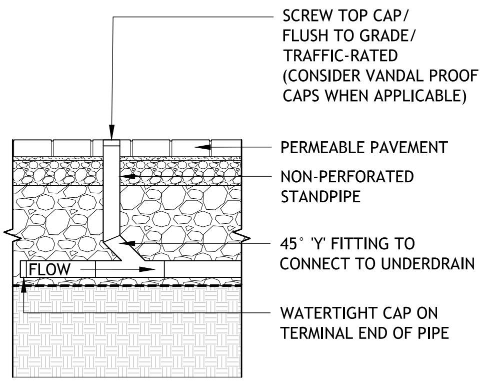
Baffle Spacing Note: *Maximum spacing should be to match top of downstream to toe of upstream.*

NOTE

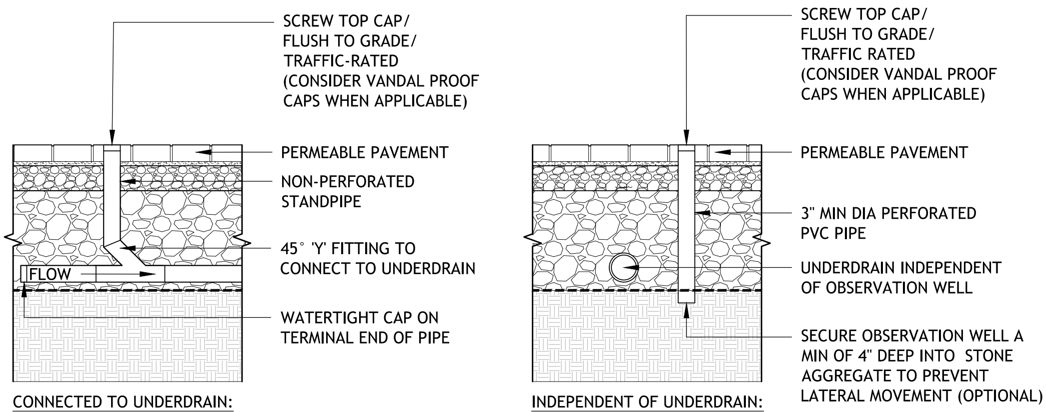
Designer needs to consider the need for drainage holes and weep holes to ensure water drains



6B BAFFLE SECTION



7A MONITORING AND SAMPLE WELL



A MINIMUM OF ONE OBSERVATION WELL SHALL BE PROVIDED AT THE LOW POINT IN THE SYSTEM UNLESS THE SUBGRADE IS TERRACED. IN THAT CASE, THERE SHALL BE ONE WELL FOR EACH TERRACE.

7B OBSERVATION WELL

WARNING

Permeable Pavement is a post construction practice and should be completed at the end of construction when the site is completely stabilized. Not doing so may cause the system to fail and significantly increase construction cost. Construction materials should be stored off of the planned permeable pavement surface areas.

8.2 CONSTRUCTION

8.2.1 Erosion and Sediment Control Measures

Proper installation is vital to the effective operation and long-term success of a permeable pavement system. Specific erosion and sediment control protocols should be installed prior to excavation of rock chamber. This includes the following:

- Erosion and sediment control practices should be used to protect permeable pavement areas, until contributing drainage area is stabilized.
- Permeable pavement areas must be protected from disturbance during construction to prevent soil compaction by heavy equipment (unless the area has been determined to have a low California Bearing Ratio (CBR) and will require compaction during the permeable pavement construction phase). Where this is unavoidable, the impacted area should not be excavated below 2 feet above the final design elevation of the bottom of the aggregate storage course so further compaction by heavy equipment can be avoided.
- Avoid tracking sediments onto any permeable pavement surface during construction to avoid clogging.
- All planned permeable pavement areas should not be used as a temporary sediment basin.
- Remove all sediment deposits in the excavated area prior to installing the subbase, base, and surface materials.

Landscaping

Typical landscaping features should be planned to maximize runoff treatment and minimize the risk of clogging pavement surface due to sediment, mulch, grass clippings, and/or leaves.

FIGURE C8-S2-1: Erosion + Sediment Control Measures

8.2.2 Permeable Pavement Construction Sequence

A preconstruction meeting should include all interested parties, as it is an excellent and important opportunity to discuss the unique construction considerations of permeable pavement systems. A meeting checklist is located in the left margin. When contractors understand how subgrade compaction can prevent percolation and result in failure of the system, they can be better prepared to manage the construction process for long-term system performance. This educational component is necessary since avoiding compaction is a specification that is in direct contrast to a typical pavement construction project. Oversight by the design professional will also help prevent the potential compaction of the subsoil and ensure the sequence is followed correctly to maximize the effectiveness of the system.

1. Verify Acceptable Conditions
2. Install Erosion and Sediment Control Measures
3. Excavate and Prepare
4. Test Percolation Rate
5. Place Engineering Fabric
6. Place Basins, Wells, and Underdrains
7. Place Aggregate Base
8. Install Bedding and Pavement Courses
9. Protect the Pavement
10. Train Staff

***Construction Step 1:** Verify Acceptable Conditions for Construction*

Construction of permeable pavement may begin once the following conditions are verified:

- ☑ Divert uncontrolled areas such as gravel lots, unstable landscape areas, and stockpiles away from PP.
- ☑ Stabilize the contributing drainage area.
- ☑ Stabilize areas of the site adjacent to the permeable pavement with vegetation, mulch, straw, seed, sod, fiber blankets, or other appropriate cover in order to prevent erosion and possible contamination with sediments.
- ☑ Establish construction access to other portions of the site so construction traffic does not pass through the site during installation. Install barriers or fences as needed.
- ☑ Confirm a forecast with a window of dry weather to prevent excess compaction or smearing of the soil subgrade while it is exposed.
- ☑ Permeable pavement areas are clearly marked on the site.

***Construction Step 2:** Install Erosion and Sediment Control Measures*

Edge restraints and barriers between permeable and impervious pavement shall be installed per design (see figure C8-S2-2). Before moving on to Construction Step 3, be certain that the design and installation are consistent.

FIGURE C8-S2-2

***Construction Step 3:** Excavate and Prepare Surface*

Protect and maintain subgrade percolation rates while clearing and excavating the area for pavement and base courses. Protection can be accomplished with the following practices:

- Verify dry subgrade conditions and avoid excavating immediately after rain events without a sufficient drying period.
- Implement an excavation staging plan to ensure equipment does not cross the pavement area after excavation has started. Operate excavation equipment from unexcavated portions of the area or outside the pavement area.
- Use equipment with tracks instead of tires to minimize soil compaction when it is unavoidable to have equipment on the subgrade surface.

PRECONSTRUCTION MEETING CHECKLIST

- ☑ Site Walk Through: Review erosion and sediment control plan, and Stormwater Pollution Prevention Plan (SWPPP).
- ☑ Construction Sequence: Identify where in the project construction sequence the permeable pavement will be built and identify measures to be taken to minimize construction impacts.
- ☑ Site Locations: Identify aggregate material storage locations and access routes.
- ☑ Mock up Location (a small area for set up and approval prior to building the entire practice)
- ☑ Materials Testing
- ☑ Keep Materials Clean
- ☑ Reporting
- ☑ Compaction Plan

DISCUSSION OF INSTALLATION PRACTICES

- ☑ Baffles
- ☑ Observation wells
- ☑ Aggregate compaction
- ☑ Run-on control
- ☑ Impervious area drains to permeable pavement

HELPFUL **TIP**

Where possible, excavate soil from the sides of the pavement area to minimize subgrade compaction from equipment.

Confirm the slope of the subgrade does not exceed 1% before proceeding. Excavate soil from the sides of the pavement area to minimize subgrade compaction from equipment. Subsoil decompaction under permeable pavement systems designed for vehicular loading is not recommended. If an engineer determines decompaction is needed, the process should be monitored and the subgrade tested by geotechnical methods before placing the fabric and rock. Some light recompaction may be needed according to a geotech report to prevent differential settling of the pavement surface. Decompaction of the subsoil under a permeable pavement system with pedestrian use also needs to follow an engineer's recommendation or a geotech report to ensure the pavement surface does not settle and continues to meet ADA requirements.

Construction Step 4: *Test the Subgrade Soil Percolation Rate (Percolation Systems Only)*

A qualified professional shall conduct a direct measurement of the soil's percolation rate immediately after excavation and before the aggregate is placed. If the 72-hour drawdown time is no longer attained because the soil percolation rate has diminished, then it may be necessary to rip or trench the subgrade according to a geotech report or engineer's recommendation.

Construction Step 5: *Place Engineering Fabric and Impermeable Liner (If Applicable)*

Place aggregate and engineering fabric immediately following excavation. Follow the manufacturer's recommendations when using engineering fabric or impermeable liner for the appropriate overlap between rolls of material. Secure engineering fabric or impermeable liner to prevent it from moving or wrinkling when placing aggregate. The engineering fabric or impermeable liner should wrap the sides of the pavement section to prevent migration of material laterally.

FIGURE C8-S2-4: Engineering fabric

Construction Step 6: *Place Catch Basins, Observation Well(s), Underdrain System, and Cleanouts*

Place the catch basins and observation wells per the design plans and verify correct elevations. Place underdrains first if there is an upturned elbow design used (see Figure C8-S2-5). In such case, verify the following:

- ☑ Elevations of the underdrains and upturned elbows are correct.
- ☑ Dead ends of pipe underdrains are closed with a suitable cap placed over the end and held firmly in place.

FIGURE C8-S2-5: Laying of underdrain systems

***Construction Step 7:** Place and Compact Aggregate Base*

Verify that all aggregates are free of fines and meet design specifications. Collect material tickets for documentation. Any aggregates that are delivered and not immediately placed should be located on an impervious surface or geotextile to prevent it from receiving sediment.

Remove any accumulation of sediments on the finished soil subgrade using light, tracked equipment before placing the aggregate base. If rainfall occurs on the excavated subgrade surface before placement of the aggregate base, the resulting surface crust must be excavated to at least an additional 2 inch depth, raked, or scarified to break up the crust. Remove any accumulated sediments and check placement at sites with an impermeable liner or engineering fabric. Verify the plans and specifications are followed for slopes and elevations on the soil subgrade and finished elevation of base after compaction of materials. Spread aggregate with a front-end loader or with an excavator from a pile deposited near the edge of the excavated area, or adjacent to it. Moisten and spread the washed aggregate without driving on the soil subgrade. Take steps to not damage underdrains and their fittings, catch basins, or observation wells during compaction. Follow compaction recommendations by the permeable pavement manufacturer or from industry guidelines. Be sure to adequately compact areas including corners, areas around utility structures and observation wells, and transition areas to other pavements. Prevent creating additional fines that may clog the soil subgrade by avoiding any crushing of aggregates. Proper aggregate placing techniques are shown in Figure C1-S2-6.

***Construction Step 8:** Install Bedding and Pavement Courses*

The permeable pavement surface will determine the bedding and pavement course installation procedures. PP requires a 4 inch thick filter course over the base, then transition to a 2 inch thick bedding layer that provides a smooth surface for the pavers. Follow the manufacturer or industry guide specifications for the bedding course. Successful performance of the pavers and aggregate jointing materials between them is dependent on the proper bedding materials and installation.

For PC, use the appropriate and most current mix designs (See Section 8.5 Example Specifications for mix designs). For all permeable pavement practices, design and installation should be done by certified and experienced professionals. PC installation is accomplished using either the One-Step or the Two-Step method. The Two-Step method is more commonly used and it separates the steps of strike-off from pervious concrete compaction. In this method, the pervious concrete typically requires a more traditional, stiffer mix. The One-Step method uses a counter-rotating roller screed to simultaneously strike-off and compact the pervious concrete. This method requires PC with a more flowable mix so that the screed can more effectively compact the mixture. Dense-paste pervious concrete mixtures are required for both methods. These mixes reduce the viscosity of the cement paste so that it will stick to, and not run off, the aggregates. The mixes provide better cohesion that increases strength and durability.

FIGURE C8-S2-6: Aggregate Placement and Compaction

CONTRACTOR TIP

Baffles can be efficiently constructed during the placement of the aggregate base. Care should be taken to review construction sequencing with jurisdictional governing entity and designer.

NOTE

Keep all sediment and debris from entering the rock layers. Contaminated rock must be removed and replaced.

Compaction of rock layers need to be done in lifts. Refer to engineers specifications and manufacturer recommendations.

HELPFUL **TIP**

Follow specifications and manufacturer's installation instructions.

CONTRACTOR **TIP**

PP: Use a contractor that holds a PP Specialist Certificate from the Interlocking Concrete Pavement Institute. A list of contractors can be obtained from the Interlocking Concrete Pavement Institute.

PA: Use a contractor qualified per Iowa Asphalt Paving Institute (IAPA). In addition, be certain that the contractor follows the Design, Construction, and Maintenance Guide for Porous Asphalt (by the National Asphalt Pavement Association) in conjunction with Iowa's DOT Pavement standards.

Construction Step 9: *Protect the Pavement Through Project Completion*

Install the permeable pavement at the end of the site construction timeline. If that is not possible, protect the permeable pavement until project completion. This can be achieved by routing construction traffic around the site and installing barriers or fences as needed. Methods to protect the pavement include installation of erosion and sediment control measures, mats, plastic sheeting, and barriers. Maintenance practices such as street sweeping and vacuuming may be required during and after construction. Vacuuming is preferred as it is more effective at removing sediment than sweeping.

FIGURE C8-S2-7: Installing bedding and pavement courses

Construction Step 10: *Staff Training and Transferring Operating Manuals and Guidelines to Ownership*

Conduct a site visit and training session with designers, funding agencies, city staff, and other applicable partners to explain what is needed to maintain the long term success of the system and practices. Topics to include:

- Describe how the systems works and key design elements.
- Define maintenance procedures and schedules.
- Explain the importance of educating the public on benefits of the system with signage and field days.
- Train staff and owners on how to inspect the system for maintenance and signs of failure.
- Schedule yearly training for new staff.
- Review permeable pavement maintenance requirements.
- Demonstrate how the observation wells are used for testing and inspection.
- Provide product information, manuals, drawings, and specifications.

8.2.3 Construction Supervision and Inspection

Supervision before, during, and after construction by a qualified professional is recommended to ensure permeable pavement is built and maintained in accordance with these specifications.

Inspection checklists that require sign-off by qualified individuals should be used at critical stages of construction to ensure the contractor's interpretation of the plan is consistent with the designer's intent.

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 contributing drainage area should be stabilized prior to directing water to the permeable pavement area.
- Inspect chamber before placement of material
- Check the aggregate material to confirm it is clean and washed, meets specifications, and is installed to the correct depth. Aggregate loads that do not meet the specifications or do not appear to be sufficiently washed may be rejected.
- Check elevations (e.g., the invert of the underdrain, inverts for the inflow and outflow points, etc.) and the surface slope.
- Confirm permeable pavement surface is even, runoff evenly spreads across it, and the storage drains within 48-72 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 construction is complete, it may be beneficial to log the GPS coordinates for use on future projects or upload the information to a state-wide tracking system.
- Verify that sediment and other contaminants are not entering project site.
- Confirm aggregate is compacted in lifts according to specifications and all areas are compacted.
- Ensure baffles are installed correctly, if applicable.
- Obtain inspector confirmation of the areas to be vacuumed before the project is released.
- Ensure designed impervious surfaces drain towards permeable pavement.

When possible, divert the runoff from the first few runoff-producing storms away from larger permeable pavement applications, particularly when up-gradient conventional pavement areas drain to the permeable pavement. This practice can help reduce the input of fine particles often produced shortly after conventional pavement is placed.

NOTE

Below are some additional conditions to consider in order to establish a successful system:

Verify Correct Installation and Materials

- Hire knowledgeable, contractors experienced in installing permeable pavers.
- Review and approve all subbase, base and joint aggregate materials.
- Do not allow sand and dense-graded aggregates in the subbase materials.

Prevent Construction Damage

- Limit subgrade soil compaction when infiltration is necessary.
- Restrict vehicles with muddy tires from driving over newly placed pavers.
- Do not mix aggregate materials.

Adjacent Construction Considerations

Preventing pavement clogging from construction projects requires contractors to follow certain protocol.

- Prevent mud and sediment deposits from construction vehicle tires by routing construction traffic away from permeable pavement. This will also prevent pavement load capacity exceedances due to heavy construction equipment.
- Install and inspect erosion and sediment controls.
- Inspect for indications of run-on from bare soil and landscaped areas. If run-on is identified, regrading and stabilization with vegetation is needed.
- Schedule maintenance surface cleaning with a regenerative sweeper or vacuum truck during and after construction.
- Remove and replace contaminated rock.

8.2.4 Record Drawing Certification

An as-built check list and inspection should be completed following the installation of a permeable pavement system by a qualified stormwater professional in the State of Iowa or their designee. The record drawing certification verifies that the system was installed as designed and shall also include the following:

- Ensure the pavement is installed per the plans and specifications.
- Stabilize surrounding drainage areas to prevent sediment from clogging the pavement.
- Ensure the surface is not damaged and is free from fines, sediment, and vegetation.
- Soil around the pavement is stabilized with vegetation.
- Prepare record drawings to include any changes to the underdrains, observation well locations, terrace layouts, aggregate depth or storage structures, any revised calculations, etc.
- Test the pavement surface permeability using a simple infiltration test or other appropriate test.
- Ensure impervious surfaces drain to permeable pavement.

Any deficiencies found during the record drawing certification inspection shall be promptly addressed and corrected.

8.3 MAINTENANCE + INSPECTION

8.3.1 Required Maintenance Tasks

Regular maintenance will provide long term stormwater benefits for permeable pavement systems. Preventing surface clogging is a primary maintenance objective for permeable pavements. Protecting groundwater quality from pollutants is another important goal for maintenance. Including inspections in the maintenance schedule will establish whether the pavement surface and storage are working properly, and whether maintenance is needed.

PP, PC, and PA surface cleaning should be scheduled twice per year, and when inspections dictate or surface puddles are present. Regular surface cleaning of the entire area will help prolong the need to restore infiltration. Equipment and mobilization is the primary expense for maintenance and typically includes mechanical sweepers, regenerative air cleaners, and vacuum street cleaners. Pavement use, traffic loads, and land use must be considered when prescribing specific types or frequency of maintenance tasks to maintain the hydrologic function of the systems.

Mechanical Sweepers
Mechanical sweepers are a common and useful choice for permeable pavement and use brushes to lift and remove debris for disposal. They can penetrate PP but not other types of permeable pavement.

FIGURE C8-S3-1: Mechanical sweeper sweeping PP

FIGURE C8-S3-2: Regenerative air cleaner cleaning PP

Regenerative Air Sweepers
Regenerative air sweepers are a common type of street sweeper in the U.S. Regenerative air sweepers use both pressurized air and vacuum air to move material off the surface and into a collection chamber.

Vacuum Street Cleaners
Vacuum street cleaners can be used on all pavement types and are considered the most expensive of the three options and least commonly used. A strong vacuum lifts particulates from the surface of the pavement as well as below. Depending on the equipment strength, their strong suction capability can restore infiltration to clogged permeable pavements.

MAINTENANCE **TIP**

All permeable pavements (PP, PC, + PA) shall be cleaned on a regular basis and be monitored for system performance. Refer to recommended maintenance activities chart for specific actions, dates, and frequency.

THE FOLLOWING TASKS MUST BE AVOIDED ON **ALL** PERMEABLE PAVEMENTS

- Sanding
- Re-sealing
- Re-surfacing
- Power washing or cleaning of equipment vehicles
- Storage of snow piles containing sand
- Storage of mulch or soil materials
- Construction staging on unprotected pavement

MAINTENANCE **TIP**

Use caution when power washing PA and PC, and consider vacuuming simultaneously so debris is both lifted and removed from the surface.

There are **2** service types for maintaining the integrity of a permeable paver system.

1 PREVENTATIVE

Removes most miscellaneous debris before being trapped in the joint aggregate material causing clogging. This usually does not require removal of any joint material to restore infiltration.

2 RESTORATIVE

Occurs after miscellaneous debris has been captured and lodged in the joint aggregate. Requires some removal or complete removal of the joint material to renew infiltration.

INSPECTION

REGULAR INSPECTION IS AN ESSENTIAL PART OF PERMEABLE PAVEMENT MAINTENANCE. During inspection, the pavement surface is examined for accumulated dust, sediment, and debris A simple test to verify whether the pavement is infiltrating properly is to empty a bucket or large bottle of water on the pavement and examine how long it takes for water to soak through the pavement and the water mark that remains.

Pavements that require several seconds to minutes for the water to stop flowing are clogged to some degree. During the site visit, the inspector can scout for weed growth and trash deposition. If the permeable pavement is underdrained, the underdrain outlet should be checked to verify it is not blocked.

Maintenance Equipment

Maintenance equipment requirements will vary according to project size, age, and product type.

Project Type 1

For smaller pedestrian type areas such as sidewalks, driveways, plazas, patios or similar.

PREVENTATIVE

Hand-Held Bristle Broom
- Available at any hardware store
- Sweep as needed to keep the surface clear of debris

Leaf Blower
- Electric or gas powered
- Minimum air speed of 120 mph
- Joint aggregate material will remain in place while removing debris from paver surface

Rotary Brush cost varies depending on attachment vehicle
- Poly bristles only
- Flips debris from joint
- Will require slight refilling of the joint aggregate material

RESTORATIVE

Wet/Dry Shop Vacuum
- Minimum 4 HP (peak) motor with 130 cubic feet per minute suction
- Will remove some joint aggregate material
- Replenish removed joint aggregate material to lip of paver

Riding Litter Vacuum
- Tenant ATLV 4300
- 48 inch wide vacuum head
- 110 gallon capacity
- Can also be used as a preventative technique
- Will evacuate most debris from joint except for aggregate material

Power Washer
- Capable of spraying 1,400 to 1,800 psi
- Spray at a 30 degree angle approximately 18 to 24 inches from the surface
- Will evacuate joint material
- Replenish removed joint aggregate material to lip of paver

Project Type 2

For larger vehicular areas such as roads, parking lots, alleys, plazas, or similar that can support vehicles.

PREVENTATIVE

Rotary Brush cost varies depending on attachment vehicle
- Poly bristles only
- Flips debris from joint
- Will require slight refilling of the joint aggregate material

Broom Sweepers
- Typical street sweeper type
- Rotating curb brushes with center pickup
- Poly bristles only
- Do not utilize water to clean the surface as this can have detrimental effects on the cleaning
- Best for seasonal cleaning

Regenerative Air Sweepers
- Light duty suction cleaning
- Utilizes stream of air blowing horizontally across surface and vacuuming
- No rotating brushes

RESTORATIVE

Vacuum Sweepers

Vacall Dynamic Multi-Purpose Vacuum
- Elgin Whirlwind, for example
- Heavy duty cleaning
- Minimum suction of 14,000 cubic feet per minute
- Complete evacuation of joint aggregate material
- Replenish removed joint aggregate material to lip of paver

Power Washer
- Capable of spraying 1,400 to 1,800 psi
- Spray at a 30 degree angle approximately 18 to 24 inches from the surface
- Will evacuate joint material
- Replenish removed joint aggregate material to lip of paver

MAINTENANCE CONSIDERATIONS

AS NEEDED

Prevent contamination from routine landscape maintenance such as grass clippings from mowing, hedge trimming, mulching plant beds, etc., by implementing the following joint opening cleaning procedures immediately after contamination occurs:

- Hand broom debris from the paver surface.
- Blow debris from the paver surface with a blower device, collect and dispose.
- Mechanically sweep paver surface.
- Edge Maintenance. The perimeter 2’-5’ of the system that receives flow will require additional maintenance to remove debris that has been deposited onto the pavement.

MONTHLY

Observe any collection areas for debris, dirt, topsoil, mulch, etc., after seasonal events such as snowfall, rain storms, and investigate if clogging is occurring. Immediately restore infiltration using the following cleaning options:

- Break up any crust covering the joint aggregate material with hand broom for smaller areas or with a rotary sweeper for larger areas. Remove debris material.
- When necessary, restore infiltration using wet/dry shop vacuum for small areas or vacuum truck for larger areas by removing debris from joint aggregate material.
- Replenish joint aggregate material to lip of paver.

YEARLY

Establish a seasonal maintenance schedule that includes the following:

- Complete restoration of the joint aggregate material.
- Vacuum entire permeable paving surface with appropriate preventative vacuum devices.
- Replenish joint aggregate material to lip of paver.

SEASONAL MAINTENANCE SCHEDULE

***After the Snow Melt:** March 1 through April 15*

- Broom, blow, rotary brush or sweep entire surface.
- Clean and vacuum debris from paver surface in location of snow stockpile area.
- Replenish joint aggregate material after cleaning.
- Vacuum surface or power wash problem areas and refill joint material.

***Late Spring:** April 1 through May 15*

- Broom, blow, rotary brush, or sweep flowers from trees and shrubs.
- Vacuum surface.
- Collect any additional debris from areas mulched or planted with annual flowers.
- Replenish joint aggregate material as necessary.

***Late Summer:** July 15 through August 30*

- Broom, blow, rotary brush, or sweep lawn and shrub clippings or dropped fruit.
- Vacuum surface.
- Collect any additional debris from summer activities such as charcoal coals inadvertently dumped on the permeable surface, beach sand, etc.
- Replenish joint aggregate material as necessary.

***Late Fall:** October 15 through November 30*

- Broom, blow, rotary brush, or sweep plant leaves.
- Vacuum surface.
- Replenish joint aggregate material as necessary.

10+ YRS

Plan long term maintenance to rejuvenate infiltration rates:

- Replenish joint with cleaned or new aggregate material to lip of paver.

MAINTENANCE TIP

Note that the permeable pavement (2'-5') receiving flow will require additional maintenance to prevent debris from flowing onto the pavement.

NOTE

Regarding refilling joint materials:

- Once, between 3 and 6 months after initial installation.
- Repeat as needed.

Avoid Stockpiling of Materials such as:

- Topsoil
- Mulch

NOTE: A maintenance checklist is provided in the resources section of this chapter

Maintenance Communication

Communication with maintenance staff is essential for determining locations and required management practices for keeping pavement unclogged.

MAINTENANCE STAFF **MUST**

- Clean the surface with portable blowers frequently, especially during the fall and spring to remove leaves and pollen before they irreversibly reduce the pavement's surface permeability.
- Place tarps to collect any spillage from soil, mulch, sand, or other materials transported over the pavement.
- Immediately remove any material deposited onto the permeable pavement during maintenance activities. Remove large materials by hand. Remove smaller organic material using a hand-held blower machine. Care should be taken to not blow the chips out of the pavers.
- Remove weeds growing in the joints of PPs by spraying them with a systemic herbicide such as glyphosate and returning within a week to pull by hand. A small torch can be used to remove weeds. Use caution to not damage the surface of the pavers.
- Establish an inspection schedule to include reviewing observation wells, surface condition, and percolation testing.
- Cover stockpiles of soil, mulch, sand, or other materials near the permeable pavement.
- Bag grass clippings or direct them away from the permeable pavement.

MAINTENANCE STAFF **MUST NOT:**

- Stockpile soil, sand, mulch, or other materials on the permeable pavement.
- Wash vehicles parked on the permeable pavement.
- Blow materials onto the permeable pavement from adjacent areas.
- Apply sand during winter storms.

Repairs

Following regular inspections, any repairs and maintenance needs should be scheduled, conducted, and verified. Any required repair of drainage structures should be done promptly to ensure continued proper functioning of the system. While uncommon, potholes may occur through settling if a soft spot in the subgrade is not removed during construction. Repairs must use the same method used during construction in order to allow for permeability. Using conventional pavement patching will not allow the system to function properly.

8.3.2 Signage Recommendations

Requiring signage at installation sites helps to promote proper maintenance and management practices to those who will use and care for it. Signage must identify the location and purpose of the system since it requires different maintenance needs than traditional pavements. Identifying activities that should and should not occur on the site will help prevent unnecessary uses and maintenance practices that could result in damages and repairs. An educational component of the signage may also list the benefits the system brings from improved stormwater management.

FIGURE C8-S3-3: Example of permeable pavement sign

MAINTENANCE **TIP**

Signage at permeable pavement installations is recommended because it is maintained differently than conventional pavement.

MAINTENANCE **TIPS**

DO NOT use magnesium chloride as it will damage pavers and concrete

DO NOT use sand as it will cause clogging

DO NOT use fertilizers that contain ammonium nitrate and ammonium sulfate due to their ability to damage the integrity of concrete

FOLLOW manufacturer's recommendations for use and heed all warnings and cautions

NEVER seal coat permeable pavements under any circumstances.

8.3.3 Winter Maintenance

Snow Melt

A benefit of permeable pavement is its effectiveness in infiltrating small amounts of snow and ice melt into the aggregate base rather than allowing it to pool on the surface of traditional pavements where it will refreeze. Heat in the base and soil can act as a heat sink, allowing water to drain before it freezes. Actual performance depends on location, exposure to sunlight, and system design depth.

FIGURE C8-S3-4: Rubber tipped snowplow blade.

Sand

Sand should never be used on or near permeable pavement to prevent surface clogging. Clogging will occur if sand or cinders are used on nearby impervious surfaces that drain toward permeable pavement.

Plowing

Snow plowing is Acceptable on PP, PC, and PA. Plow blades can be covered with a rubber strip to reduce scraping of the surface. A rotary broom can also be used as an alternative.

Snow Storage

Plowed snow should be placed in adjacent grassy areas to allow sediment and pollutants to separate from the snowmelt.

Salt

If at all possible, salts should not be used on permeable pavement systems as they can infiltrate through the aggregate base to the subgrade and pollute groundwater.

Chemical

Environmentally sensitive salt deicers can be applied to permeable pavements which require less application than traditional pavements. If deicers must be used for safety, a careful application of deicing salts may be considered. The three primary types of deicing salts, sodium, calcium and potassium chloride, are described below.

Sodium Chloride: This rock salt is commonly used and is effective when used at temperatures above 16 degrees Fahrenheit. It can damage adjacent grass, plants, and metal and should be applied sparingly and with caution.

Calcium Chloride: This small, round, pellet salt is effective at temperatures as low as 0 degrees Fahrenheit. Heavy concentrations can damage concrete. It is considered to be less damaging to grass than sodium chloride. It can irritate skin.

Potassium Chloride: Potassium chloride is a deicing salt available in some markets. It will not hurt skin or damage plants. However, it melts ice only when the air temperature is above 15° F.

Use of either calcium chloride or potassium chloride may cause deterioration unless the concrete has a high replacement of fly ash or slag (33% Class C/ 25% Class F). Additional options such as beet brine are also commercially available. Maintenance staff should contact manufacturers and associations for recommendations prior to application of these products on a PP system.

8 ACKNOWLEDGMENTS

Chapter 8 Permeable Pavement Systems of the Iowa Stormwater Management Manual is intended to inform the design, construction, and maintenance of permeable pavement systems within the State of Iowa. Many resources and manuals were consulted throughout the development of this chapter. Some of these resources include:

- Philadelphia Stormwater Manual
- California Stormwater Manual
- Permeable Pavements in Cold Climates Research through the Minnesota Department of Transportation
- North Carolina Stormwater BMP Manual
- Maryland Stormwater Manual
- Nashville, Tennessee Permeable Pavement Report
- New Jersey Stormwater Best Management Practices Manual
- Tennessee Permanent Stormwater Management and Design Guidance Manual

Any omission of resources and examples is unintentional and should be brought to the attention of the Iowa Department of Natural Resources. The numerous hours or work and professional interest in the development of this chapter by all parties is greatly appreciated.

8 REFERENCES

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GLOSSARY

A

Asphalt Sealant
A protective coating applied to asphalt which is used to prevent cracking and infiltration.

American Association of State Highway and Transportation Officials (AASHTO)
A standards setting body which publishes specifications, test protocols, and guidelines that are used in highway design and construction.

Anti-Stripping Agent
A chemical that increases the adhesion between an asphalt binder and the aggregate. It is used to reduce the surface tension of the binder.

B

Baffle
A device used to restrain the flow of a fluid, gas, or loose material in a particular direction.

Best Management Practice (BMP)
Any treatment practice for urban lands that reduces pollution from stormwater. BMPs can be either a physical structure or a management practice.

Bioretention
A water quality process where an engineered subgrade and vegetation is used to remove pollutants from stormwater runoff.

C

Concrete Grid Pavers (CGP)
Pavers with large openings filled with gravel, sand, soil, or turf.

California Bearing Ratio (CBR)
The California bearing ratio (CBR) is a penetration test for evaluation of the mechanical strength of natural ground, subgrades and base courses beneath new carriageway construction. The basic site test is performed by measuring the pressure required to penetrate soil or aggregate with a plunger of standard area. The measured pressure is then divided by the pressure required to achieve an equal penetration on a standard crushed rock material.

D

Design Permeability
The intended amount of time in which a system permits the entire volume of water into or through its pore spaces.

Detention Basin
An excavated area designed to detain water for a specified amount of time and released at a specific rate, to tributaries of rivers, streams, lakes, or bays to protect erosion.

Detention Time
See Residence Time.

Drawdown Time
The amount of time required to dewater the design volume to the bottom of the subgrade from the infiltrating permeable pavement system.

E

Edge Restraint
Pavement that provides structural longevity to the system by restricting paver movement over time.

Erosion
A natural process by either physical processes, such as water or wind, or chemical means that moves soil or rock deposits.

Exfiltration
The loss of water from a drainage system due to percolation or absorption into the subsoil.

F

Fill
Any material used to raise the surface of an area to a desired level prior to or during earth-moving operations. Usually made of soil and/or rock, concrete, or brick.

Filter Material/Media/Medium
Any granular material selected to allow liquid to pass through it but which retains particles.

Filter Strip
A long narrow area of vegetation used to retard sheet flow thus allowing the settlement and/or filtration of sediment from the water.

Filtration
A treatment process that removes pollutants by straining, sedimentation, and similar practices.

Frost Heave
The process in which water in the soil freezes and expands, causing upward movement of the soil.

G

Geotechnical Site Investigation
Surface exploration and subsurface exploration of a site.

Groundwater Contamination
The presence of unwanted chemical compounds in groundwater.

I

Impervious Surfaces
Hard surfaces that do not allow infiltration; not pervious.

In-situ Soil
Soil in the natural or original position.

Infiltration
The process by which water (surface water, rainfall, or runoff) enters the soil. The rate of infiltration is typically expressed in inches per hour.

Infiltration Basin
A basin used to manage stormwater runoff, prevent flooding and downstream erosion, and improve water quality in an adjacent water body.

Infiltration Rate
Velocity or speed at which water enters into the soil.

M

Mix Design
The process of selecting suitable ingredients of concrete and determining their relative proportions to produce concrete with a specific minimum strength and durability, as economically as possible.

N

Nonwoven Geotextile Fabric
A felt-like material made to aid percolation of water and separation of materials. It consists of staple fibers or continuous filaments bonded by mechanically entangling the fibers with barbed needles.

Nutrients
Substances such as nitrogen and phosphorus that are required for growth of all biological organisms.

O

Observation Well
A well that is used to observe changes in groundwater levels over a period, or more specifically during a storm event. It is used to monitor performance of the permeable pavement system.

Orifice
An opening.

P

Permeable Pavement
A modified form of asphalt, concrete, or pavers with a top layer that is porous to water due to voids within the mix design.

Permeable Pavers (PP)
A type of unit paver system that drains water through gaps between the pavers filled with small gravel, or through the paver itself. They typically have a small amount of pervious space between them.

Pervious Asphalt (PA)
A permeable pavement material consisting of asphalt binder in which the fine materials are left out of the mix. The pervious asphalt thus contains voids that allow water to pass through.

Pervious Concrete (PC)
A permeable pavement material consisting of concrete in which the fine materials are left out of the mix. The concrete pavement thus contains voids that allow water to pass through.

Plastic Turf Reinforcing Grid (PTRG)
Flexible plastic interlocking units that allow infiltration through large gaps filled with gravel or turf.

Porosity
The ratio, expressed as a percentage of the void spaces in an aggregate.

Proctor Density Test
A laboratory method of experimentally determining the optimal moisture content at which a given soil type will become most dense and achieve its maximum dry density.

R

Residence Time
The average time it takes water to travel through a treatment system such as permeable pavers. Residence time can also be called detention time.

S

Sediment
Soil, rock, or biological material particles formed by weathering, decomposition, and erosion.

Storage Area
A holding place; in permeable pavement, it is the underground gravel layer where excess stormwater is stored.

Stormwater
Water that originates during rain events, often associated with urban areas. Also called runoff.

Stormwater Conveyance System
Means by which stormwater is transported.

Stormwater Hotspots
Areas which produce higher concentrations of pollutants than normally found in urban runoff.

Stormwater Treatment Practice
A type of best management practice that is structural and reduces pollution in the water that runs through it.

U

Underdrain
A perforated pipe in the bottom of a best treatment practice, such as bioretention or permeable pavement, designed to collect water that does not infiltrate native soils.

W

Watershed
A unit of land that drains to a single pour point. Boundaries are determined by water flowing from high elevations to the pour point. The pour point is the point of exit from the watershed or where the water would flow out of the watershed if it were turned on end.

FOR REVIEWER USE ONLY

☐ Design appears to comply with the standards in the Iowa Stormwater Management Manual

☐ Design does not appear to comply with the standards in the Iowa Stormwater Management Manual

Comments: ____________________________

Name of Reviewer: ____________________________

Date: ____________________________

Signature: ____________________________

PERMEABLE PAVER DESIGN REVIEW CHECKLIST

Applicant: ______________________________ **Date:** ______________________

Submitted By: ___________________________ **Project Location:** _____________

1 Drainage Area (DA) shedding to Permeable Pavement (including permeable pavement area): **SF** _______ and **AC** _______ (Attach map of DA with arrows showing how water flows to pavers)

2 Percent of DA shedding to the Permeable Pavement that is Impervious: _________ %

3 **WQv** __________**CF** (show calculations below or attach, See Equation C8-S1-2):

4 Ratio of drainage area shedding to the permeable pavement to surface of permeable pavement area: _________________ : ___________________

Drainage Area (Sq. Ft.) : Surface of Permeable Pavement (Sq. Ft.)

5 Surface Area of Permeable Pavement: ______ **Square feet** (show calculations for minimum surface area needed A_{pp}) See Equation C8-S1-3.

6 Minimum depth of rock storage area _________Ft. (Show calculations below or attached. See Equation C8-S1-4).

7 Pore space in aggregate storage area: _____________ Cu. Ft.

(Length ________ feet **x** width _______feet **x** depth _______ feet of aggregate storage area **x** 35%).

Does storage volume equal or exceed WQv? EQUAL ☐ EXCEED ☐

8 Describe the type of pavement such as type of paver, manufacturer, etc.: ____________________

9 Describe soils investigation findings such as texture, degree of compaction, percolation potentials, depth to water table, contamination, etc.: ____________________

10 Describe the aggregate used (depth of layer / quantities / size / Iowa Gradation Classification):

a. ____________________

b. ____________________

c. ____________________

11 Provide calculations of aggregate quantities or attach a copy of the calculations.:_______________

12 If permeable pavement is less than 10 feet from a foundation or karst area, describe water proofing methods: _______________

13 What is the maximum slope of the finished surface of the permeable pavement?:_____________%

14 What is the slope of the bottom of the rock base?: _______________%

15 If the bottom of the rock base is greater than 1% slope, describe how slope at the bottom of the rock base will be modified to maximize storage (i.e. fabric checks, earth berms, etc.). If fabric checks are used, describe the material and flow through rate. Show calcuations below or attached for volume of water stored uphill of baffle on a sloped surface (See Equation C8-S1-5). _______________

16 Size of perforated drain tile: _______________

17 Depth of tile from surface of the pavement: _______________

18 How many inches is the tile above the bottom of the rock base?: _______________

19 Describe the outlet for the perforated drain tile.: _______________

20 Describe overflow (i.e. what provisions are provided should the system plug - where would water flow, how would it be conveyed): _______________

21 Describe erosion and sediment control measures used to protect permeable pavement if active construction will be taking place in the drainage area after installation.:_______________

22 Attach a map of the drainage area.

23 Attach a plan, profile, and cross sectional drawing (see Fillable Forms).

PERMEABLE PAVER MAINTENANCE REQUIREMENTS

ACTIVITY	SCHEDULE	RESPONSIBLE PERSONS
Ensure the vacuum equipment is available to perform annual maintenance.	Minimum of twice in year in spring and fall	
Clean the permeable pavers by using vacuum truck to vacuum the surface and joints between the paver blocks to keep them free of debris	Minimum of twice a year in spring and fall	
Inspect the permeable paver system to ensure the area is free of excessive debris, organic matter, or sediment	Spring and fall each year	
Inspect surface of permeable paver system for any deterioration, settlement, lifting, or cracking of blocks. Repair any settling/ raising blocks and replace deteriorating or cracked blocks. If pavers lift or settle, take up pavers, add or remove base course to level, compact, and re-lay pavers.	Spring and fall each year	
Inspect the permeable paver system for vegetative growth in-between paver blocks. Vegetation growth is indication of excess particulate matter buildup and vacuuming is most likely needed.	Monthly	
Inspect outlet of the subdrain to ensure it is not obstructed, free flowing.	Monthly	
After a rainfall of at least an inch inspect permeable pavers to ensure there is no standing water	As needed	
Replace permeable joint material when less than 3 mm of surface.	As needed	
Prevent anyone from stockpiling building or construction materials (i.e. soil, rocks, wood) directly on paver system. If materials have to be stockpiled place a tarp or another solid material underneath materials to protect pavement.	In perpetuity	
Only apply de-icing agents during winter months, never apply sand	In perpetuity	

I certify the ________________________ commits to the specific work elements in this plan for the duration of 10 years from date of the practice certified as completed.

Signature: ____

Title: ____

Date: ____

SYSTEM MAINTENANCE CHECKLIST

Project Location: ______________________________ **Year:** ____________________________

AS NEEDED

Prevent contamination from routine landscape maintenance such as grass clippings from mowing, hedge trimming, mulching plant beds, etc., by implementing one or more of the following joint opening cleaning procedures immediately after contamination occurs:

- Hand broom debris from the paver surface.
- Blow debris from the paver surface with backpack blower-type device, collect and dispose.
- Mechanically sweep paver surface.

MONTHLY

Observe any collection areas of debris, dirt, topsoil, mulch, etc., after events such as snowfall, rain storms, leaves, etc., and investigate if clogging is occurring. Immediately restore infiltration using the following cleaning options:

- Break up any crust covering the joint aggregate material with hand broom for smaller areas or mechanically with a rotary sweeper for larger areas. Remove debris material.
- When necessary, restore infiltration using wet/dry shop vacuum for small areas or vacuum truck for larger areas by removing debris from joint aggregate material.
- Replenish joint aggregate material to lip of paver.

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Break up crust												
Vacuum												
Replenish Joint												

YEARLY

Establish a seasonal maintenance schedule that includes the following:

- Complete restoration of the joint aggregate material.
- Vacuum entire permeable paving surface with appropriate vacuum device.
- Replenish joint aggregate material to lip of paver.

☐ Complete restoration of joint aggregate material Date: ____________________________

☐ Vacuum Entire Surface Date: ____________________________

☐ Replenish Joint Aggregate Material Date: ____________________________

NOTES AND COMMENTS:

NOTES AND COMMENTS:

SEASONAL MAINTENANCE

After the Snow Melt: *March 1 through April 15*

- [ ] Broom, blow, rotary brush, sweep, or vacuum entire surface
- [ ] Clean and vacuum debris from paver surface in location of snow stockpile area
- [ ] Replenish joint aggregate material after cleaning
- [ ] Vacuum surface or power wash problem areas and refill joint material

Late Spring: *April 1 through May 15*

- [ ] Broom, blow, rotary brush, sweep, and vacuum debris from flowers, trees and shrubs
- [ ] Vacuum surface
- [ ] Collect any additional debris from areas mulched or planted with annual flowers
- [ ] Replenish joint aggregate material as necessary

Late Summer: *July 15 through August 30*

- [ ] Broom, blow, rotary brush, sweep, or vacuum lawn and shrub clippings or tree fruits
- [ ] Vacuum surface
- [ ] Collect any additional debris from summer activities such as charcoal coals inadvertently dumped on the permeable surface, beach sand, etc.
- [ ] Replenish joint aggregate material as necessary

Late Fall: *October 15 through November 30*

- [ ] Broom, blow, rotary brush, sweep, or vacuum plant leaves
- [ ] Vacuum surface
- [ ] Replenish joint aggregate material as necessary

10+ YRS

Plan long term maintenance to rejuvenate infiltration rates:

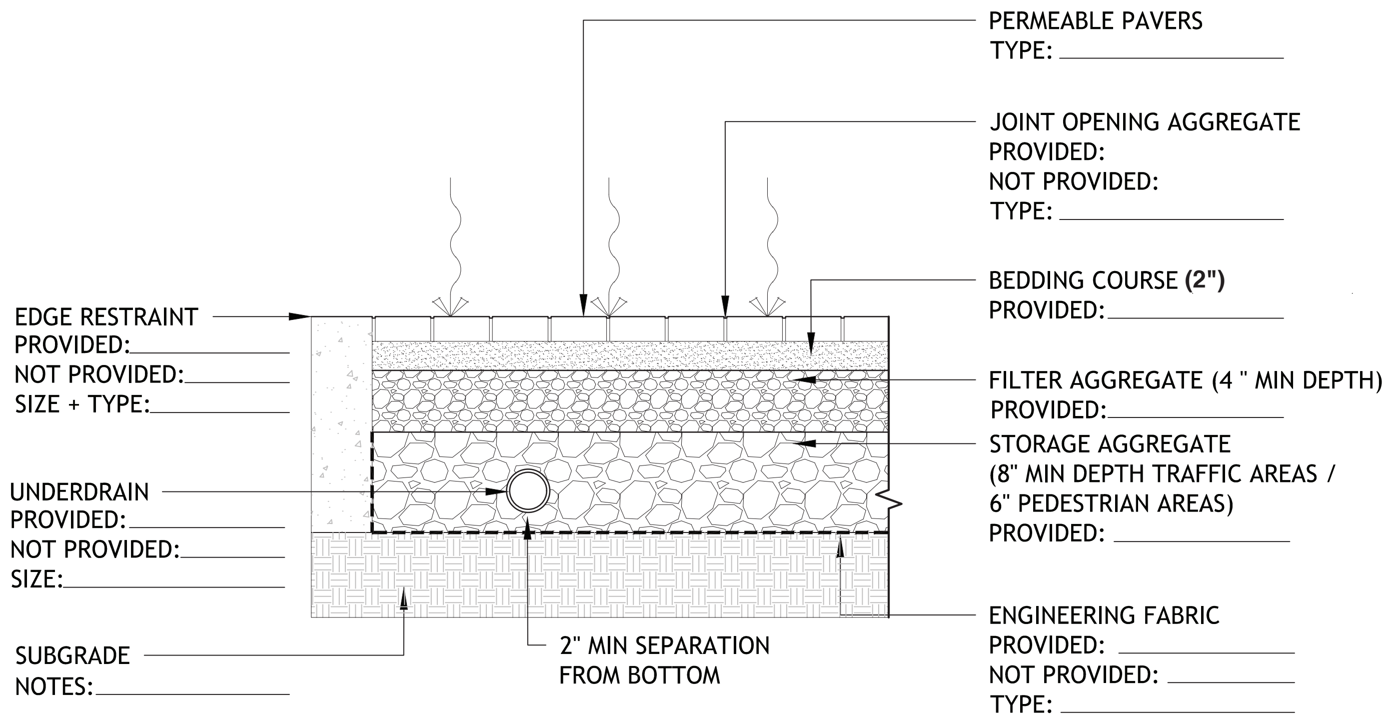
- Replenish joint with cleaned or new aggregate material to lip of paver.

- [ ] Replenish Joint with Cleaned or New Aggregate Date:______________________________

PERMEABLE PAVER SYSTEM SPECIFICATIONS

Applicant: ______________________ **Date:** ______________________

Submitted By: ______________________ **Project Location:** ______________________



PP **PERMEABLE PAVERS**

Additional Notes and Comments:

FOR REVIEWER USE ONLY

Name of Reviewer:

____

____

- ☐ Design appears to comply with the standards in the Iowa Stormwater Management Manual
- ☐ Design does not appear to comply with the standards in the Iowa Stormwater Management Manual

Date:

____

Signature:

____

FOR REVIEWER USE ONLY

Name of Reviewer:

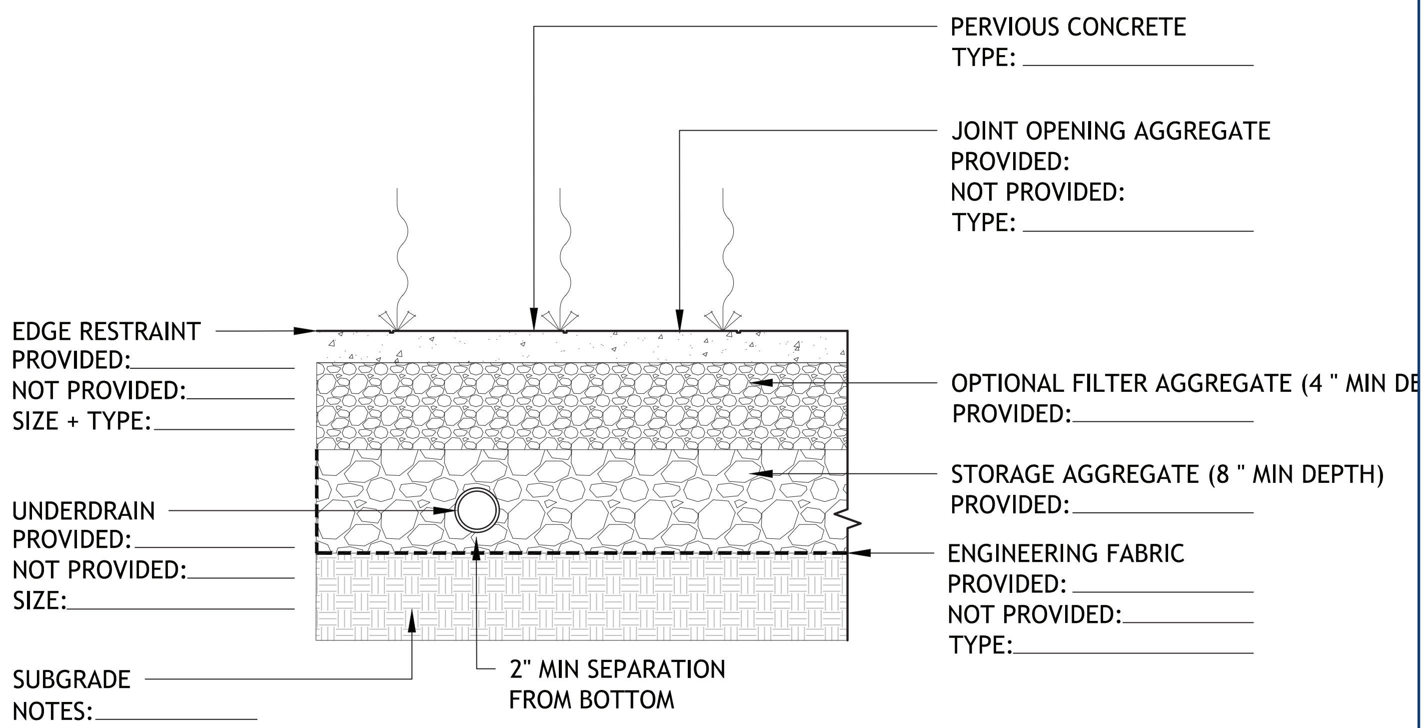
____

____

PERVIOUS CONCRETE SYSTEM SPECIFICATIONS

Applicant: ______________________ **Date:** ______________________

Submitted By: ______________________ **Project Location:** ______________________



PC PERVIOUS CONCRETE

- [ ] Design appears to comply with the standards in the Iowa Stormwater Management Manual
- [ ] Design does not appear to comply with the standards in the Iowa Stormwater Management Manual

Date:

____

Signature:

____

Additional Notes and Comments:

POROUS ASPHALT SYSTEM SPECIFICATIONS

Applicant: ______________________ **Date:** ______________________

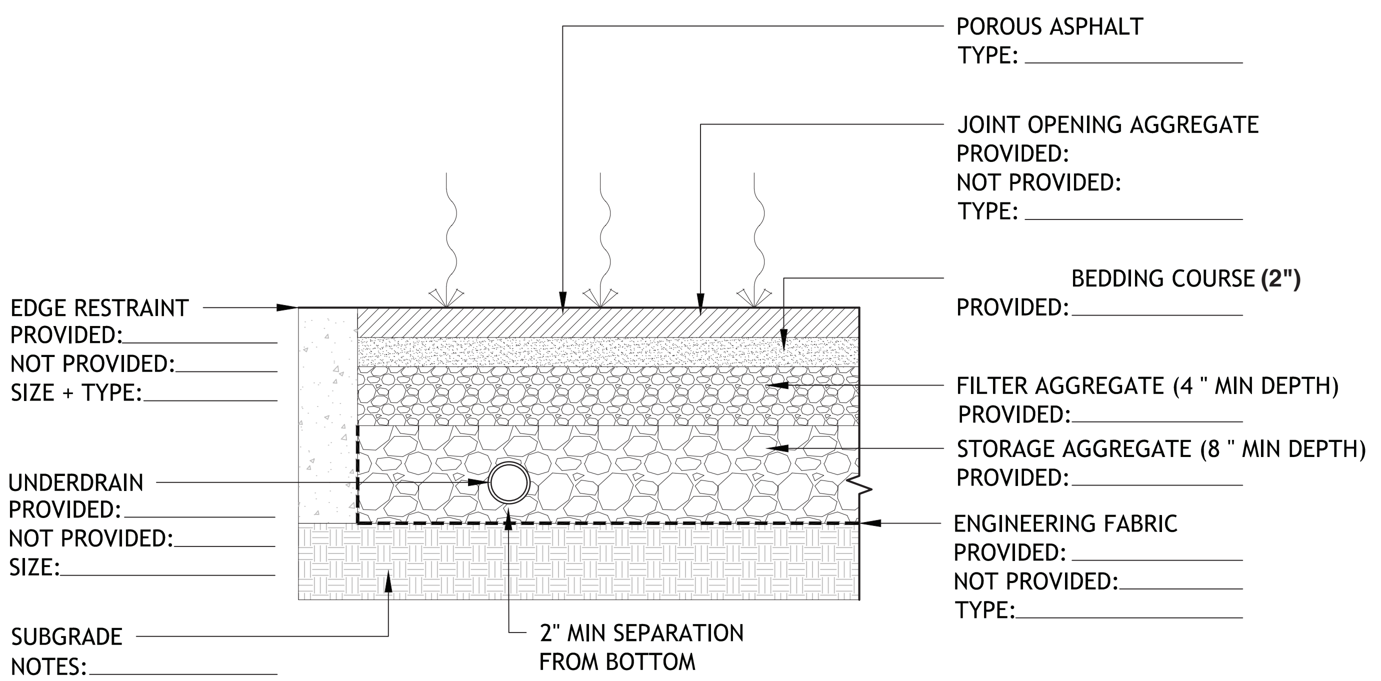
Submitted By: ______________________ **Project Location:** ______________________

FOR REVIEWER USE ONLY

Name of Reviewer:

____

____



PA

POROUS ASPHALT

Additional Notes and Comments:

☐ Design appears to comply with the standards in the Iowa Stormwater Management Manual

☐ Design does not appear to comply with the standards in the Iowa Stormwater Management Manual

Date:

____

Signature:

____