# 2.11 Pervious Pavement

Figure 2.11.1 Porous Concrete at Indian Run Park in Dublin, Ohio.

## Description

Pervious pavement systems consist of a permeable pavement surface layer and one or more underlying aggregate layers designed to temporarily store stormwater. Most pervious pavement systems are designed to infiltrate stormwater into the underlying soil, reducing the volume of runoff leaving the site. Where the underlying soil will not permit full infiltration of runoff, outlets and/or underdrains are used to remove excess runoff and discharge it to an appropriate outlet[1].

Research has shown that pervious pavement can be a very effective component of a stormwater management system, mitigating many of the water quality and quantity impacts associated with runoff from impervious pavements. Pervious pavements reduce suspended solids, metals and petroleum hydrocarbons in runoff, and significantly reduce runoff volumes and peak flow rates.

Pervious pavements perform water quality functions by filtering suspended solids and hosting microbial organisms known to biodegrade pollutants. Depending upon the construction of the pavement, soil infiltration, transpiration (vegetated open celled grids), and increased soil adsorption may all contribute to reducing offsite runoff and associated adverse impacts. Additionally pervious pavements provide some moderating of water temperatures compared to traditional pavements.

1 Note that pervious pavements and their drainage strucures must be considered as part of the larger site and stormwater system when meeting local peak discharge requirements.

There are a variety of pervious pavement surfaces available in the commercial marketplace, including pervious concrete, porous asphalt, permeable interlocking concrete pavers, clay pavers, concrete grid pavers, and plastic grid pavers. While the design specifics vary for each product, pervious pavements have the same general structural components detailed in this practice.

There are several examples of pervious pavement installations that are still functioning well after 15 or 20 years (see e.g., Adams, 2003). If designed, constructed, and maintained according to the following guidelines, pervious pavements should have life spans comparable to traditional pavements.

## Condition where practice applies and settings to avoid

Pervious pavement can be used in most settings where traditional pavements are used. It is especially well suited to parking lots, sidewalks, playgrounds and plazas. Pervious pavement can be used in driveways if the homeowner is aware of the stormwater management function and subsequent maintenance requirements of the pavement.

*Areas of Heavy Traffic* - Pervious pavement typically is not suitable for areas that experience high traffic loads or high vehicle weight traffic such as busy roadways or travel lanes in heavily used parking lots. However, pervious pavement is suited for parking lanes on roadways and in parking lots. When it is necessary to use traditional pavement for traffic lanes, runoff can be directed as sheet flow to pervious pavement areas.

*Areas of Potential Groundwater Contamination* – Pervious pavements should not be used in heavy industrial developments, areas with chemical storage, fueling stations or areas with significant risk of spills that might contaminate groundwater. Pervious pavements should not be used for sites located over contaminated soils without placing an impermeable liner between the pavement structure and soils.

*Other Sites to Avoid*

*Unstable slope areas* – pervious pavement should not be used in slip prone areas where concentrated infiltration may exacerbate slope instability

*Steep slopes* - areas with slopes steeper than 10 percent present design challenges that are difficult to overcome

*Sediment sources* - sites with sources of sediment (from vehicles, bare soils, spoil piles, sand storage, etc.) should be separated from pervious pavements with filter strips or other sediment removal practices.

## Anticipated Performance

Pervious pavements are projected to perform well in reducing the annual load of suspended solids, metals and hydrocarbons in runoff, and significantly reduce runoff volumes and peak flow rates. Pervious pavements filter solids in the pavement layer and may completely remove them in the matrix of the sub-pavement layers depending upon the nature of the subgrade and designed drainage of the system. Though this varies with design; filtering, detention, adsorption processes all contribute to some degree in reducing pollutants in contributed flows and offsite runoff. Pervious pavements also buffer water temperatures. Increased infiltration into the subgrade soils contributes to the highest removal of pollutants from site runoff, although some pollutants such as soluble nutrients, chlorides or sodium raise concern for groundwater pollution.

*Table 2.11.1 Anticipated performance of pervious pavements.*

| Category | Subcategory | Full WQv Infiltration | Partial Infiltration | No Infiltration |
|---|---|---|---|---|
| Runoff Water Quality | Suspended Solids* | >90% | 80-90% | 80% |
| | Phosphorus* | Medium | Medium | Medium |
| | Nitrogen/Nitrates* | Low | Low | Low |
| | Heavy Metals | High | High | High |
| | Bacteria | Not clear at this time. Other practices using media filtration do treat bacteria. Using a sand layer may enhance this. | | |
| | Thermal | Pervious pavements with a reservoir storing the WQv or most of that volume are expected to provide good thermal attenuation, but this will vary based on the particular design (i.e. material, the storage volume, outlet configuration etc.) | | |
| | Oil and Grease | High | High | High |
| | Poly Aromatic Hydrocarbon | Reduced compared to runoff from traditional ashalt | | |
| | Chlorides & Sodium** | Not controlled. | | |
| Runoff Volume Reduction | | 85-90% | %WQv-captured * 85% | |
| Recharge | | High | Medium | Not at all. |
| Runoff Time of Concentration | | Improved lag time, but varies with design. | | |
| Peak Flow Attenuation | | Significant peak flow attenuation, but varies with design. | | |

*** There would be an expected improvement with the addition of sand layers and/or vegetative systems.**
**** May be a significant groundwater concern depending upon winter application practices.**

## Planning Considerations

*Preliminary Site Evaluation* - The overall site should be evaluated for potential pervious pavement/infiltration areas early in the design process, as effective pervious pavement design requires consideration of soils, grading, outlets, groundwater, and other site infrastructure.

*Size of Project* – Small projects such as walkways, or driveways with limited traffic may not have associated requirements for treating or storing stormwater. Therefore small scale projects may not need the depth of stone reservoir described in this practice. There are still numerous benefits to applying pervious pavements even with less stone subbase than this practice describes. For small scale practices where local or state regulations do not require treating the water quality volume, manufacturer recommendations should be consulted.

*Soils* - Pervious pavements may be used on any soil type, although soil conditions determine whether an underdrain is needed. Less permeable soils (most Hydrologic Soil Group C or D soils, some HSG B soils) usually require an underdrain, whereas soils with higher permeability (HSG A, and some HSG B soils) often do not. Estimates of soil permeability are available based on soil type, but designers should verify underlying soil permeability rates before proceeding with site and stormwater system design (see discussion below). Special measures may be needed when pervious pavement will overlay high shrink-swell soils in order to limit moisture or to stabilize these soils.

*Subgrade Compaction* - One of the major benefits of pervious pavement is runoff volume reduction from infiltration into underlying soils. Subgrade compaction severely limits the infiltration capacity of the underlying soil. For pervious pavement systems with an infiltration component, the subgrade should not be compacted according to traditional pavements. Structural integrity of pervious pavements is ensured through several mechanisms other than subgrade compaction (see discussion below). If the structural design of the pavement section requires subgrade compaction to achieve the required design strength or to minimize the possibility of pavement failure, then soil permeability should be measured based on the required subgrade design.

*Separation Distances* - Pervious pavements should not be located or used where their installation would: create a significant risk for basement seepage or flooding; interfere with public or private wells, septic or sewage disposal systems; or cause problematic groundwater issues. These issues should be evaluated and potential problems avoided by the designer.

Horizontal Separation Distances

- separation from buildings - pervious pavement systems should be installed at least 10' away from up-gradient building foundations and 100' from down-gradient foundations, unless an acceptable barrier is provided or the building foundation can adequately handle additional water;
- sanitary sewers - care should be taken to minimize infiltration of runoff into sanitary sewers and building laterals;
- septic systems - pervious pavement should be installed no closer than 100' from a septic system or leach bed; when this or any infiltration BMP is located up-gradient, appropriate perimeter drainage should be used to prevent flows from reaching the septic system;
- drinking water wells - pervious pavement should not be located within 25' of a private drinking water well or within the sanitary isolation radius of a public drinking water supply well. (The isolation radius ranges from 50 to 300 feet, and is based on the well's average daily pumpage; see the chart below.) If it is necessary to pave within the sanitary isolation radius, use of an impermeable bottom liner and an underdrain discharging beyond the isolation radius is recommended, especially if the pavement will support motorized vehicles.

| Feature protected by setback | Setback Distance (feet) | |
|---|---|---|
| Building Foundations or basements | At least 10' downgradient or 100' upgradient of foundations | |
| Septic Systems | At least 100' separation | |
| Private Well | At least 25' (See OAC 3701-28-10) | |
| Public Well | 50 – 300 ft minimum depending upon Average Daily Water Demand (based upon sanitary isolation distance found in OAC 3745-9-04) | |
| | Average Daily Pumpage (Q) (gal/day) | Sanitary Isolation Radius (feet) |
| | 0-2500 | 50 |
| | 2501-10,000 | Square root of Q |
| | 10,001 – 50,000 | 50 + Q/200 |
| | Over 50,000 | 300 |
| Source Water Protection Area | See Ohio EPA Source Water Protection Area. Each area may have its own specific requirements. | |

**Table 2.11.2 Horizontal separation distances.**

Vertical Separation Distances - Give special consideration to the following situations:

- Infiltrating pervious pavement systems with recharge layers located over soils with ground water tables that reach within 2 feet of the subgrade infiltration bed.
- Infiltrating pervious pavement systems with recharge layers located over impermeable bedrock within 2 feet of the subgrade infiltration bed.

These situations are likely to result in mounding of stormwater to the level of the infiltration bed for extended periods, especially during the spring. These systems may still help meet watershed management goals - for example, baseflow maintenance and temperature moderation during summer low-flow periods. However, a more thorough mapping and modeling of surface and subsurface hydrology is necessary to prevent unintended consequences. The pavement system configuration and drainage system should be modified to achieve stormwater management goals while minimizing unintended consequences.

Soil surveys can be used as rough guidance during initial planning and site layout to identify areas where shallow water tables or shallow bedrock may be a concern. However, in areas where these concerns are known, a professional geotechnical engineer and/or professional soil scientist should be contracted to take core samples to a depth of 6 ft below the proposed subgrade depth and report: depth to bedrock, any layering of the subgrade representing significant changes in texture or structure, the particle size distribution of the subgrade soil, the particle size distribution of any deeper layers, and depth to water table (ideally the water table will be checked between late March to early May when the water table is highest).

*Groundwater Concerns* – Pervious pavement, as with any infiltrating practice, requires the designer to consider the potential for adversely impacting groundwater. Elevated pollution sources or areas with high risk of toxic spills should not be directed to pervious pavement without appropriate pretreatment.. Examples include maintenance yards where salt storage or distribution takes place, airport areas where deicing occurs, fueling stations and composting facilities.

Development sites that include both relatively clean runoff (e.g., rooftop runoff) and dirtier runoff (e.g., from a maintenance yard or material storage area) should consider separate stormwater management systems appropriate to the specific runoff source. In such a scenario, rooftop runoff or runoff from office parking could be safely directed to an infiltrating BMP without pretreatment, whereas runoff from a maintenance yard should be treated in a separate facility designed to minimize potential negative impacts to groundwater. Such areas should be separated with physical barriers (fence, curb, etc.) to minimize tracking of pollutants into "clean" runoff areas.

*Karst Terrain* - Active karst regions are found in parts of Ohio (Hull, 1999; ODNR, 1999), and complicate development and stormwater system design. The use of permeable pavement or other infiltration BMPs in karst regions may promote the formation of sinkholes. In karst regions, a detailed geotechnical survey should be conducted to the satisfaction of the local approval authority. Permeable pavement designs in karst should exceed the minimum vertical separations recommended above and consider the use of an impermeable bottom liner and an underdrain. Additionally they should not receive runoff from other (external) impervious areas.

*Freeze-Thaw* - Water entrapped in the pavement course during freezing and thawing cycles will result in cracking, scaling and/or deterioration of the pavement (NRMCA, 2004). Therefore, the pavement structure and drainage system should be designed to ensure free drainage of the pavement surface and to prevent ponding into the pavement structure.

*Frost Heave* - Frost heave occurs when underground water accumulates in ice formations or ice "lenses", expanding and pushing the pavement structure upward resulting in uneven pavement (Leming et al., 2007) . Unlike their traditional counterparts, pervious pavements are specifically designed to introduce water below the pavement surface. Therefore, the pavement structure and drainage system should be appropriate for the subgrade soils (Leming et al., 2007; UNH, 2009).

One recommendation is to increase pavement thickness to accommodate the extra load carried by the surface course during spring thaw (Leming et al., 2007). This is reflected in some guidance for specific pavement surfaces (see e.g., ORMCA, 2009).

Frost heave is a serious concern for finer textured soils. Sands and coarser aggregates are much less susceptible to frost heave. One straightforward approach to minimize frost heave is to provide a base aggregate course thickness to minimize the formation of ice in the underlying subgrade. The University of New Hampshire Stormwater Center (UNH, 2009) recommends that the thickness of the pervious pavement structure (i.e., pavement plus subbase thickness) be a minimum of 0.65 x design frost depth for the location. Local maximum frost penetration depth oftentimes can be provided by the local building authority. In the absence of locally available information, the following table can be used.

| Located North of Latitude | Max. Frost Depth (inches) | Min. Recommended Thickness (0.65 x Max Frost Depth in inches) |
|---|---|---|
| 38.3 | 24 | 16 |
| 38.7 | 26 | 17 |
| 39.0 | 28 | 18 |
| 39.3 | 30 | 20 |
| 39.7 | 32 | 21 |
| 40.0 | 34 | 22 |
| 40.3 | 36 | 24 |
| 40.7 | 38 | 25 |
| 41.0 | 40 | 26 |
| 41.3 | 42 | 27 |
| 41.7 | 44 | 29 |
| 42.0 | 46 | 30 |

**Table 2.11.3 Frost depth and minimum recommended pavement system (pavement + sub-base) thickness by latitude (interpolated from Fig. 13 in Floyd, 1978; http://www.ngs.noaa.gov/PUBS_LIB/GeodeticBMs/#figure13)**

*Grading* – The bottom of the infiltration bed should be level or nearly level. Sloping bed bottoms will lead to poor distribution and reduced infiltration. It is recommended pervious pavement slopes be less than 5% to optimize the ponding depth under the pavement surface. If pavement slopes cannot be reduced, infiltration beds may be placed along a slope by benching or terracing the subsurface infiltration beds to promote more uniform infiltration.


**Figure 2.11.2 A level infiltration bed and limited pavement slope will maximize stormwater treatment and storage.**

Figure 2.11.3 Terrace sloping areas to limit the pavement slope (photo credit: Brandon Andreson).

*Runoff from External Areas* - Drainage from traffic lanes or other impervious surfaces (e.g., sidewalks) can be directed to pervious pavement surface as sheet flow. The impervious area contributing runoff should be less than twice the area of pervious pavement receiving the runoff. Roof drains and leaders may connect directly to the subbase reservoir, but should be provided a means of trapping sediment prior to the subbase reservoir. Runoff from pervious areas (lawns or landscaping) or other sediment sources should not be directed onto pervious pavement.

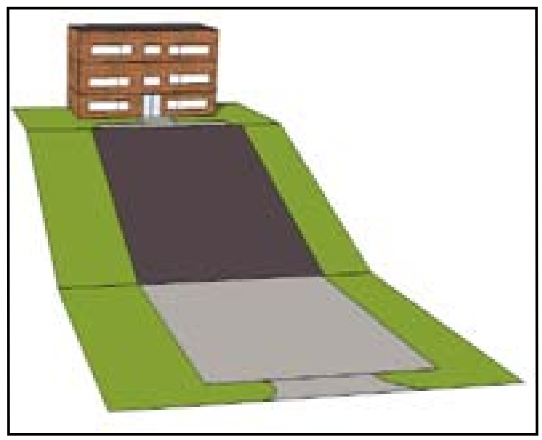

**Figure 2.11.4 Calculate "run-on" from impervious areas, making sure it does not exceed twice the pervious pavement (infiltration bed) area.**

### *Sites to Use or Consider Use of an Impermeable Liner*

A liner should be used for pervious pavement systems for sites:

- all sites over contaminated (or potentially contaminated) soils
- sites with high pollution potential source areas
- sites with slip prone soils
- sites in source water protection areas

A liner may be considered for pervious pavement systems for sites with:

- subgrade soil infiltration rates less than 0.02 in/hr
- depth to bedrock or seasonal high water table less than 2 ft below subgrade infiltration bed
- karst geology

If the site requires a liner, the designer should consider whether a different BMP (e.g., bioretention, constructed wetland, wet swale) may be more appropriate.

Stormwater Detention - Sub-pavement infiltration beds are typically sized to manage the water quality volume and to convey stormwater without allowing ponding into the pavement itself. These sub-pavement aggregate "reservoirs" also may be designed to mitigate the peak discharge of less-frequent, more intense storms (such as the critical storm or 100-yr event). Discharge control typically is provided by an outlet control structure. The specific design of these structures may vary, depending on factors such as rate and storage requirements.

*Construction Sequencing* - The pervious pavement system is most susceptible to failure during construction, and therefore it is important that the construction be undertaken in such a way as to prevent:

- Compaction of underlying soil
- Clogging the subgrade soil or geotextile with sediment and fines
- Tracking of sediment onto pavement
- Drainage of sediment laden waters onto pervious surface or into aggregate base

Pervious pavement will be prone to failure if it is not protected from sources of sediment. For this reason, insure that nearby areas or areas contributing runoff are completely stabilized prior to construction of the pervious pavement system. Sediment on the subgrade infiltration bed will greatly reduce the infiltration capacity of the final practice. Therefore special measures are needed to avoid this situation. Quick succession from excavation to placement of materials during dry weather is ideal for protecting the practice's long term functioning. Planned pavement areas that will be exposed for a period of time while other site construction occurs may be excavated within twelve (12) inches, but no closer than six (6) inches, of the final subgrade elevation. Following construction and site stabilization, sediment should be removed and final grades established when materials can be placed in a timely manner.

*Maintenance* - Pervious pavements have different maintenance requirements than traditional pavements, discussed in some detail below. The use of pervious pavement must be carefully considered in all areas where the pavement potentially could be seal coated or paved over due to lack of awareness by a new owner, such as individual home driveways. In those situations, a system that is not easily altered by the property owner may be more appropriate. Educational signage at pervious pavement installations may promote its prolonged use. Maintenance is critical to the long-term performance of pervious pavement, especially those activities that prevent clogging of the surface pavement and subsequent clogging of the subsurface layers by accumulated sediments and organic matter. The most important activities to protect the long term function of pervious pavement include periodic vacuum sweeping to remove accumulated sediments and organic materials, monitoring of the drainage functions of the pavement and maintenance/cleanup of landscaped areas contiguous to the parking area (CSN, 2010).

*Cost Considerations* - The primary added cost of a pervious pavement/infiltration system lies in the underlying aggregate bed, which is generally deeper than a conventional pavement subbase. However, this additional cost may be offset by a significant reduction in the number of inlets and pipes. Pervious pavement systems may eliminate or reduce the need (and associated costs, space, etc.) for surface detention basins. When all these factors are considered, pervious pavement with infiltration is increasingly competitive with traditional pavement for the pavement and associated stormwater management costs.

*Types of Pervious Pavement*

*Porous Asphalt* - Porous asphalt is very similar to standard bituminous asphalt except the fines have been removed to maintain interconnected void space. Research has led to improvements in porous asphalt through the use of additives and higher-grade binders. Porous asphalt is similar in appearance to standard asphalt and is suitable for use in any climate where standard asphalt is appropriate. Guidance specific to the design, installation and maintenance of porous asphalt is available from the National Asphalt Pavement Association (NAPA, 2008) and the University of New Hampshire Stormwater Center (UNHSC, 2009).

**Figure 2.11.5 Porous Asphalt**

*Pervious Concrete* - Pervious concrete is produced by reducing the fines in the mix to maintain interconnected void space for drainage. Pervious concrete has a coarser appearance than its conventional counterpart but may be colored similar to traditional decorative concrete. In northern climates such as Ohio, pervious concrete should always be underlain by a stone subbase designed for proper drainage and stormwater management, and should generally not be placed directly on a soil subbase. Special care must be taken during the placement of the pervious concrete to avoid overworking the surface and creating an impervious pavement. Guidance on the design, installation and maintenance of pervious concrete is available from the Ohio Ready Mix Concrete Association (ORMCA, 2009). ORMCA also offers installer training and certification for pervious concrete.

**Figure 2.11.6 Pervious Concrete**

*Block or Brick Pavement* - A number of concrete or clay paver products are available, providing either a traditional brick pavement look or more complex designs and configurations. Block or brick pavements maintain drainage through gaps between the pavers filled with small, uniformly-graded gravel. The pavers are bedded on a stone or sand layer that provides uniform support and drainage. Pavers are especially well suited for plazas, patios, small parking areas, parking stalls in larger lots, and streets.

Pervious interlocking concrete pavement (PICP) are one commonly used product that consist of 3 1/8" thick concrete units or pavers with various shapes, patterns, and colors. The size and complexity of the project determines whether PICP may be placed by machine or by hand. Guidance for design, installation and maintenance of concrete pavers is available from the manufacturer and the Interlocking Concrete Pavement Institute (ICPI, 1995).

**Figure 2.11.7 Pervious Interlocking Concrete Pavement**

*Reinforced Turf and Gravel Filled Grids* - Grid-type pervious pavements consist of open-celled concrete or plastic structural units filled with small, uniformly-graded gravel or turf that allows infiltration through the pavement surface. The structural units are underlain by a stone and/or sand drainage system for stormwater management. Reinforced turf applications are excellent for fire access roads, overflow parking, occasional use parking (such as at religious facilities and athletic facilities). Reinforced turf is also an excellent application to reduce the required standard pavement width of paths and driveways that must occasionally provide for emergency vehicle access.

**Figure 2.11.8 Vegetatated Grid System utilitized for fire access.**

**Figure 2.11.9 Vegetated Grid System with established turf grass.**

## Design Criteria - General/Introduction

Pervious pavements typically will be designed to address two types of design criteria:

- Minimum specifications should be met to ensure the long-term structural performance appropriate to the specific use of the pavement (pavement type, location, type of traffic, traffic load, etc.). The pavement should meet all design, construction and maintenance requirements of the local approval authority.
- Secondly, pervious pavement typically will be part of the stormwater management infrastructure of the development site. Therefore, meeting specific design criteria should allow the pervious pavement system to receive credit toward meeting water quality treatment performance requirements of the NPDES Construction General Permit (OEPA, 2008) and/or receive appropriate credit toward meeting local peak discharge requirements.

## Design Criteria - Stormwater Requirements

The Ohio DNR and Ohio EPA mandate is to ensure post-construction stormwater performance over the long-term. This means the pervious pavement system must show equivalent WQ performance to the structural BMPs listed in Table 2 of the NPDES Construction General Permit (Ohio EPA, 2008), or be part of a larger stormwater system that collectively meets those requirements. Pervious pavement can be used to meet the WQv requirement for either new development or re-development.

*Full infiltration of WQv* - Pervious pavement, without prior OEPA approval, may be used to meet the WQv requirements of the Construction General Permit (CGP) as long as the practices designed to fully infiltrate the WQv and follows the design, construction and maintenance protocols outlined in this section.

No infiltration - If the site is not suitable for deep infiltration (e.g., lined system or compacted subgrade), pervious pavement may be considered for WQv on a case-by-case basis with prior approval from OEPA and the local MS4. This scenario will require an appropriately designed outlet control to release runoff over a 24 hour period; however, no additional sediment storage volume (=0.2*WQv) is required. The volume of runoff detained shall drain over 24 hours, releasing no more than one half the volume in the first eight hours. Until further notice, monitoring of system function/performance is likely to be required.

*Partial infiltration of WQv* - If the site is capable of partially infiltrating the WQv, the volume infiltrated may be subtracted from the WQv when determining detention requirements. As for the no infiltration scenario, an appropriately designed outlet will be needed to release runoff over 24 hours, releasing no more than one half the volume in the first eight hours.. This scenario requires prior approval from OEPA and the local MS4.

*Redevelopment Projects* - For redevelopment projects, the area of pervious pavement receives a 1:1 credit toward the 20% reduction in impervious area requirement of the CGP. All areas draining to the pervious pavement receive credit toward the impervious area reduction as long as the storage layer is designed to hold and either infiltrate (within 48 hours) or release (with a drain time of 24 hours, releasing no more than half the WQv in the first 8 hours) the water quality volume AND the pervious pavement system meets all other requirements outlined in this guidance.

*Inspection and Maintenance* - Pervious pavement must be inspected and cleaned regularly to maintain the hydrologic performance of the pavement system. Therefore, Ohio EPA will consider pervious pavement as meeting the requirements of the CGP only if the property owner has a maintenance agreement approved by the local MS4 that includes the minimum practices outlined under the section titled "Maintenance" below.

*Water Quality Calculations -*

Calculate the **total water quality volume** (WQv) using the following equation:

WQv (ac-ft) = Rv * 0.90 * A / 12 (Equation 1)

Where:

Rv = volumetric runoff coefficient

A = area draining into the BMP in acres

The volumetric runoff coefficient, Rv, is calculated using the following equation or alternatively values provided in the Ohio EPA NPDES general permit (OHC00005) for construction activities.

Rv = 0.05 + 0.9 (i) (Equation 2)

Where:

i = watershed imperviousness ratio, the percent imperviousness divided by 100

If the additional contributing drainage area is entirely impervious surfaces (traditional pavements and/or roofs), i = 1 and Rv = 0.95. For the purpose of calculating the WQv, permeable pavement areas are treated like an impervious area.

No additional storage is required for sediment accumulation.

**Converting Storage Volume to Storage Depth** - The sub-pavement volume available for temporary storage of stormwater will typically be filled with aggregate (washed, uniformly-graded stone or gravel). The volume occupied by the aggregate itself is unavailable for water storage. The remaining volume of voids is available for storage of water:

$V_T = V_S + V_V$ (Equation 3)

Where: $V_T$ = Total Volume
$V_S$ = Solids Volume
$V_V$ = Voids Volume

A more common way to communicate about the volume available for water storage is the aggregate porosity, φ, the ratio of void-space volume to the total volume:

$\varphi_{aggregate} = V_V / V_T$

Aggregate porosity can range from 0.30 to 0.40 (Ferguson, 2005). However, some percentage of the voids will be unavailable for additional stormwater storage because of previous wetting and entrapped air resulting in a lower usable or effective porosity. We recommend using an aggregate porosity of φaggregate = 0.30 in the following calculations[2][3].

The aggregate thickness required to meet the WQv objective can be calculated:

$D_{agg}\text{-}WQv = WQv/(A_{reservoir} * \varphi_{aggregate})$

Where: $D_{agg}$-WQv = required aggregate thickness (L)
WQv = water quality volume ($L^3$)
$A_{reservoir}$ = basal area of aggregate reservoir ($L^2$)
$\varphi_{aggregate}$ = aggregate porosity

2 Note that the proosity of the pavement itself typically is substantially lower than the aggregate base; when needed for calculations, porosities for the pavement should be taken from guidance provided by the specific industry association.

3 A number of underground storage chambers have been developed and designed to provide both sturctural support for pavements and temporary stormwater storage. Because the void space within the chambers approaches 100%, these chambers may provide a cost-effective alternative to a sub-pavement reservoir consisting entirely of aggregate. Guidance for both the chambers and the industry association for the desired pavement should be consulted to ensure sturctural performance.

*Drawdown Calculation* - Ideally, the water quality volume will be drained within 48 hours in preparation for the next runoff event. The approach to determine drawdown characteristics is different depending on whether the pervious pavement is an infiltrating or non-infiltrating system.

The entire area under both pervious (e.g., parking lanes or pull-in parking) and traditional pavement (e.g., traffic lanes) may be used as infiltration or storage area as long as the WQv/sub-base gravel layer is fully interconnected and the soil infiltration capacity is adequate throughout the area. A minimum of 33% of the infiltration bed should be covered with pervious pavement.

For non-infiltrating systems, the drawdown calculation should follow the procedure used for surface detention basins with the depth and head adjusted for the porosity of the aggregate. For WQv detention under pervious pavement, a 24 hour drawdown time is recommended, with no more than ½ of the water quality volume draining from the facility in the first 8 hours. The drawdown control device should have a minimum orifice diameter of 1".

For infiltrating systems, the WQv should be infiltrated into the subgrade soil within 48 hours. The design infiltration rate of the subgrade soil will be based on field measurements at the appropriate depth, and be verified during construction (see section on measurement and verification of subgrade infiltration rate). The infiltration rate shall be based on the final, after-compaction subgrade properties, if compaction is required[4].

There are a number of factors - including soil compaction, surface smearing, aggregate “masking”, sedimentation, and air entrapment - that typically mean the actual infiltration rate under real-world, post-construction conditions will be substantially lower than the measured infiltration rate. To increase the likelihood of achieving design performance over the long-term, it is recommended that an infiltration rate equal to one-half the measured infiltration rate of the subgrade be used for the design:

$$f_{design} = 0.5 * f_{measured}$$

Where: $f_{design}$ = design subgrade infiltraion rate (L/T)
$f_{measured}$ = field measured subgrade infiltration rate (L/T)

The following table presents estimates of design infiltration rate that can be used for initial planning considerations until field measurements can be collected[5].

| Soil Texture of Subgrade Soil | Clay Content (%) | Clay + Silt Content (%) | Preliminary $f_{design}$ (in/hr) | Soil Texture of Subgrade Soil | Clay Content (%) | Clay + Silt Content (%) | Preliminary $f_{design}$ (in/hr) |
|---|---|---|---|---|---|---|---|
| Sand | < 8 | < 15 | 3.0 | Sandy Clay Loam | 20 - 35 | <55 | 0.05 |
| Loamy Sand | < 15 | < 30 | 2.0 | Clay Loam | 27 - 40 | 54 - 80 | 0.02 |
| Sandy Loam | < 20 | < 60 | 0.9 | Silty Clay Loam | 27 - 40 | >80 | 0.02 |
| Loam[5] | 7 - 27 | 48 - 80 | 0.2 | Silty Clay | 40 - 60 | >80 | 0.02 |
| Silt Loam[5] | < 27 | 48 - 100 | 0.1 | Sandy Clay | 35 -55 | <55 | <0.01 |
| Silt[5] | <12 | 80 - 92 | 0.1 | Clay | > 40 | >55 | <0.01 |

**Table 2.11.4 Estimated infiltration rate based on soil texture.**

4 If the subgrade will be compacted to meet structural design requirements of the pavement section, the design infiltration rate of the subgrade soil shall be based on measurement of the infiltration rate of the subgrade soil subjected to the compaction requirements.

5 For silt, silt loam and loam subgrade textures, check for the presence of a fragipan, which can severely limit permeability.

For infiltrating systems, the drawdown calculation shall be determined using the following equation. The infiltration area $A_{inf}$ shall be the bottom area of the infiltration bed.

$$T_d = WQv / (f)(A_{inf})$$

Where

$T_d$ = drawdown time (T)

WQv = water quality volume ($L^3$)

f = infiltration rate of subgrade soil (L/T)

$A_{inf}$ = area of infiltration bed ($L^2$)

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### *WQv Sample Problem*

A site in Columbus proposes to install 1 acre of pervious pavement that will also receive sheet flow from 2 acres of traditional asphalt. The subgrade infiltration area is equal to the area of the pervious pavement.  The measured subsurface infiltration rate (fmeasured) of the native soil is 0.5 in/hr. The aggregate base is composed of No. 57 aggregate. Calculate the WQv, the depth of the WQv, the porosity adjusted WQv depth, and the time necessary for the WQv to drain into the native soil.

#### *Calculate the WQv:*

WQv = Rv * P * A

i = 100% impervious = 1.0

Rv = 0.95

P = 0.9 inches

A = 3 acres

WQv = (0.95)(0.9 in)(3 ac) = 2.6 ac-in = 0.22 ac-ft = 9,583 $ft^3$

#### *Calculate the WQv "depth":*

$DWQv = WQv/A_{inf}$ = 2.6 ac-in/1.0 ac = 2.6 inches

#### *Calculate the porosity adjusted WQv depth:*

$\varphi_{aggregate} = 0.30$

$D_{agg}\text{-}WQv = WQv /(A_{inf})(\varphi_{aggregate}) = DWQv /(\varphi_{aggregate})$ = 2.6 in/0.30 = 8.7 inches

#### *Calculate the WQv drain time:*

$f_{design} = 0.5\ f_{measured}$ = 0.5 (0.5 in/hr) = 0.25 in/hr

$T_d = WQv / (A_{inf})(f_{design})$ = 2.6 ac-in/(1.0 ac * 0.25 in/hr) = 10.4 hr

$T_d$ = 8 hr < 48 hr

*Water Quantity (incl. Peak Discharge) Credits* - The peak rate of runoff from a site is radically altered by development. The addition of impervious surfaces, the hardening of pervious areas, and the improved hydraulic efficiency of the drainage network all contribute to greatly increased flow peaks, as well as extended periods of elevated discharge. Pervious pavements have been shown to considerably reduce flow peaks, when compared with traditional pavements, through several mechanisms including subgrade infiltration (also called exfiltration), temporary storage and increased flow path resistance.

**Pervious pavement can be encouraged by appropriately crediting the stormwater management benefits provided. The ways that pervious pavement potentially can receive credit include:**

- infiltration or extended detention of the WQv (described above)
- stormwater utility credit or fee reduction
- critical storm adjustment
- peak discharge attenuation

The ways that pervious pavement may be used to fulfill the WQv requirement are discussed in the previous section. The other three quantity "credits" are discussed here.

*Stormwater Utility Credit* - [Note: All credits are at the discretion of the local stormwater management authority.] All contributing drainage area for which the pervious pavement system fully infiltrates the WQv should receive full credit for runoff volume reduction and water quality purposes, and partial to full credit for peak flow reduction. Pervious pavement systems with partial or no infiltration should be considered for a partial credit because of the combination of water quality benefits, runoff volume reduction, and flow peak reduction.

*Critical Storm Adjustment* - The State of Ohio does not regulate stormwater discharges for large, infrequent rainfall events (e.g., 1-year to 100-year events). However, controlling discharge for these events is an important consideration toward protecting public safety and minimizing damage to property and infrastructure. Many Ohio communities have peak discharge or "flood control" regulations aimed at reducing the impacts of large events. Many of those communities have adopted the Critical Storm criteria for peak discharge control (ODNR, 1980). The following recommendations are designed to encourage consideration of pervious pavement while still protecting the public interest.

For pervious pavement systems, the CN for Critical Storm determination should be based on the abstraction potential, which is a function of infiltration capacity of the underlying soil and the elevation at which underdrains are placed above subgrade. Until more definitive research is developed by NRCS or another research entity, it is recommended that the Critical Storm CN for the pervious pavement system be based on TR-55 guidance (USDA, 1986) for "newly graded areas" or "open space in poor condition" based on the hydrologic soil group (HSG) of the in-situ soil and the measured subgrade infiltration rate upon completion of excavation of the underground reservoir.

| Soil HSG (in/hr) | Measured Infiltration Rate | CN |
|---|---|---|
| A | > 1.0 | 68 |
| B | > 0.02 | 79 |
| C | > 0.05 | 86 |
| D | > 0.02 | 89 |

Table 2.11.5 Recommended Critical Storm CN for $A_{inf}$ for No Underdrains or Underdrains Placed $D_{agg}$-WQv or Higher above Subgrade.

| Soil HSG (in/hr) | CN |
|---|---|
| A | 77 |
| B | 86 |
| C | 91 |
| D | 94 |

Table 2.11.6 Recommended Critical Storm CN for $A_{inf}$ for Underdrains Placed Directly on Subgrade.

*Modeling Stormwater Detention and Peak Discharge Attenuation -* The aggregate subbase “reservoir” can be used as a detention basin to temporarily store stormwater. Outfitted with an appropriate outlet, the aggregate reservoir may be able to meet local peak discharge requirements for the area that drains to the pervious pavement system. Otherwise, the aggregate reservoir and outlet become part of the overall drainage network that needs to be properly “routed” to determine inflow to an end-of-pipe facility.

**The following guidelines will help ensure the pervious pavement system achieves long-term structural and stormwater management goals:**

- Peak discharge requirements are set by local regulations. All stormwater systems that incorporate pervious pavement require review and approval from the local stormwater authority. Preliminary approach, plans and calculations should be discussed as early as possible with the plan reviewer to facilitate communication and avoid delays in review and approval.
- The available storage volume is equal to area*depth*effective porosity of the aggregate layer(s).
- though porosities for washed, uniformly-graded aggregate may approach 0.4, some percentage of the voids will be unavailable for storage because of previous wetting and entrapped air resulting in a lower usable or effective porosity; for consideration of intense design events such as a NRCS type II distribution, use of a conservative effective porosity of 0.3 for clean, uniformly-graded aggregate is merited.
- the porosity of the pavement course typically will be substantially lower than the aggregate base; when needed for calculations/routing, porosities for the pavement should be taken from guidance provided by the specific industry association.
- For infiltrating systems, the modeler should assign a steady discharge (often termed exfiltration rate) equal to the final (or minimum) infiltration rate.
- The aggregate reservoir should be designed to prevent the (routed) 10-yr, 24-hr design event from entering the pavement course.
- The site design should include a secondary, surface drainage network that will pass the 100-yr, 24 hr event without damage to property assuming failure of the pervious pavement system. The model should show flow paths and elevations for the 100-yr, 24-hr design event with the pervious pavement treated as impervious.

*Subgrade Infiltration Capacity -* The hydrologic performance of infiltrating pervious pavement systems requires special attention to the subgrade soil (i.e., soil at the bottom of the aggregate reservoir) and the infiltration bed surface throughout planning, design and construction. The following guidelines will help ensure the pervious pavement system achieves long-term stormwater management goals:

- The bottom surface area of the infiltration bed should not be less than the surface area of the pervious pavement. The designer should consider increasing the infiltration bed surface area by extending the infiltration bed under adjacent traditional pavement. Such an expansion of the infiltration bed may be necessary to achieve the required drawdown time for the WQv.
- The bottom surface area of the infiltration bed should be at least 33% of the sum of the area of the pervious pavement surface plus all contributing impervious surfaces (parking lot, roads, driveways, sidewalks, roofs, etc.), that is Ainf > 0.33*(Aperv-pave + Aimpervious).
- The bottom of the infiltration bed should be level or nearly level. Sloping bed bottoms will lead to poor distribution and reduced infiltration.
- For infiltrating systems, the subgrade should not be compacted as it would be for traditional pavements. If the structural design of the pavement section requires subgrade compaction to achieve a required design strength, then subgrade infiltration should be measured based on the required subgrade design.
- The design infiltration rate of the subgrade soil should be based on field measurements at the appropriate depth and verified during construction (see section on measurement and verification of subgrade infiltration rate).

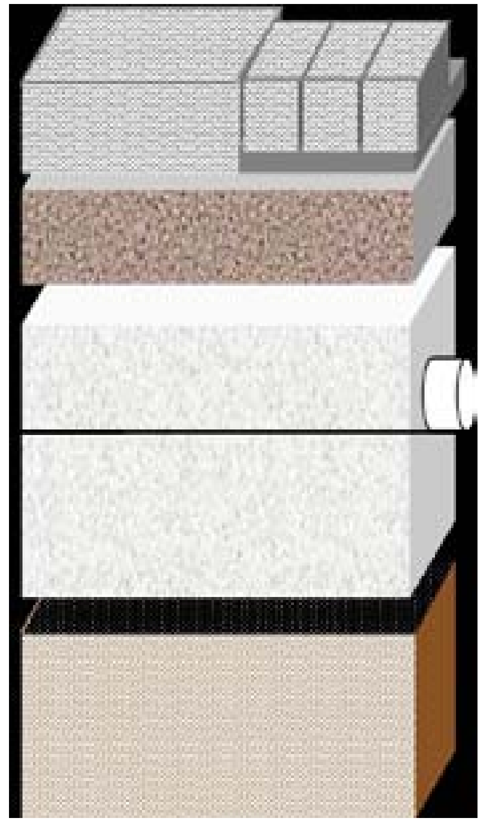
## Design Criteria - Pavement Structure Design

Structural Design – The designer shall refer to the appropriate industry association or manufacturer's specifications for structural design of the pervious pavement system.

Table 2.11.7 Reference appropriate specifications for structural design.

| Pavement Type | Guidance | Website |
|---|---|---|
| Porous Asphalt | Porous Asphalt Pavements for Stormwater Management: Design, Construction and Maintenance Guide. Info Series 131, Revised November, 2008. National Asphalt Pavement Association, Lanham, MD. | www.asphaltpavement.org |
| Pervious Concrete | Specifier's guide for Pervious Concrete Pavement with Detention. Revised October, 2009. Ohio Ready Mixed Concrete Association, Columbus, OH. | http://www.ohioconcrete.org |
| Concrete Pavers | Structural Design of Interlocking Concrete Pavement for Roads and Parking Lots. ICPI Tech Spec Number 8. Interlocking Concrete Pavement Institute, Washington, DC. | http://www.icpi.org |
| Grid Pavements | Concrete Grid Pavements. ICPI Tech Spec Number 8. Interlocking Concrete Pavement Institute, Washington, DC. | http://www.icpi.org |
| Vegetated Grid Pavements | See various manufacturer specifications | |

### Infiltrating Systems:



**Pavement & bedding material** - see industry association guidance.

**Filter/choker course** - minimum 2” of AASHTO #57 if larger aggregate is used for reservoir course or AASHTO #7, #8 or #9 if the reservoir course uses #57.

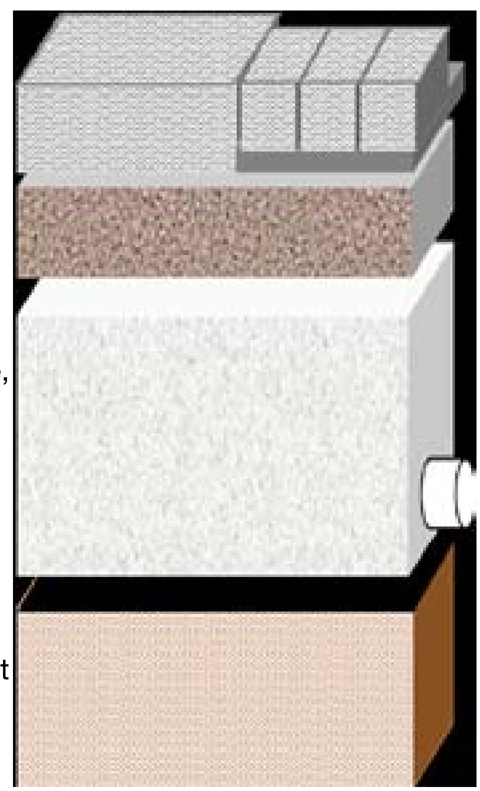
**Underdrains** - 4”-6” dia. PVC placed at top of recharge layer.

**Recharge course** - sized to infiltrate the WQv from the contributing drainage area (minimum 3” depth). Typically AASHTO #57 or larger.

**Permeable geotextile fabric or sand layer equivalent**

**Subgrade** - uncompacted subgrade

### Closed Systems:



**Pavement & bedding material** - see industry association guidance.

**Filter/choker course** - minimum 2” of AASHTO #57 if larger aggregate is used for reservoir course or AASHTO #7, #8 or #9 if the reservoir course uses #57.

**Reservoir course** - clean, uniformly-graded coarse aggregate, typically #57, #4, #3 or #2.

**Underdrains - 4”-6” dia. PVC placed** placed on subgrade.

**Impermeable liner** (if necessary)

**Compacted subgrade** graded with positive slope toward outlet (minimum slope - 1%?)

Figure 2.11.10 Types of materials used in infiltrating and closed pervious pavement systems.

*Subgrade Preparation* - The subgrade shall be designed to carry the desired traffic load. Check the appropriate industry association or manufacturer's specifications for compaction requirements. Design infiltration rates must be adjusted to account for intended and unintended subgrade compaction.

*Subgrade Soil/Aggregate Base Interface* - For open (infiltrating) systems on fine-textured soils a geotextile should be placed between the native soil and the aggregate base[6]. The geotextile limits the migration of fines, limits the settling of aggregate into the underlying soil, and helps to distribute surface loads.

For infiltrating systems, given the soil characteristics of the native soil, alternative materials such as a layer of clean sand may be placed in lieu of a geotextile on top of the native soil layer to provide adequate separation between the native soil and aggregate base in an open system (UNHSC. 2009).

For closed systems, an impermeable liner shall be placed between the native soil and the aggregate base using standard measures to prevent puncture of the geomembrane (e.g., smooth subgrade, sand bedding, geotextile). Prevent lateral flow by bringing the impermeable liner to the surface or by securing the liner to a cut-off or perimeter wall making sure that the outlet pipe and any other penetrations of the liner are adequately sealed. An impermeable liner should be used for pervious pavement systems for:

- all sites over contaminated (or potentially contaminated) soils
- sites with high pollution potential source areas
- sites with slip prone soils
- sites in source water protection areas

A closed system may also be used to prevent saturation of the underlying soil for structural reasons; consult a geotechnical engineering or pavement design engineer to determine whether a closed system is required based on soil conditions.

*Perimeter Barrier:* Some paving materials will be prone to lateral movement unless secured against a perimeter barrier. This may be a cut stone or concrete barrier or a manufactured edge restraint. Concrete barriers at the surface grade or as a raised curb can also serve as a way to secure the impermeable liner in non-infiltrating systems to prevent lateral flow between cells in a sloping situation. Where open graded subbase material will be place against conventional road base material or soils, some type of barrier is probably needed to prevent migration of fines into the permeable pavement subbase and movement of water into the conventional road base.

*Aggregate Bed* - The underlying aggregate bed is typically 8-36 inches deep and is a function of structural requirements, stormwater storage requirements, frost depth considerations, site grading, and anticipated loading. Several sizes of aggregate may be required for pavement bedding, choker courses, or stormwater storage. It is critical the aggregate be uniformly graded, clean washed, and contain a significant void content. A range of aggregate sizes has been used successfully in pervious pavement projects. Choice of aggregate(s) will depend on structural requirements, local availability, and cost. Check the appropriate industry association or manufacturer's specifications for specific aggregate requirements.

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6 UNHSC, 2009. UNHSC Design Specifications for Porous Asphalt Pavement and Infiltration Beds. Revised October, 2009. University of New Hampshire Stormwater Center, Durham, NH. http://www.unh.edu/erg/cstev/pubs_specs_info.htm.

*Underdrains and observation well* - Most pervious pavement systems should be designed with an underdrain system to efficiently drain the system during larger events. To avoid damage to the pavement layer, water within the subsurface stone storage bed should only rise to the level of the pavement surface in extremely rare events based on the risk tolerance of the engineer, owner or MS4 (we recommend a minimum of the 10-yr, 24-hr event). Underdrains should be installed with a minimum slope of 1% and capped at dead ends of drains. For pervious pavement areas of at least 10,000 square feet, at least one observation/cleanout standpipe should be installed near the center of the pavement and shall consist of rigid 4 to 6 inch non-perforated PVC pipe. This should be capped flush with or just below the top of pavement elevation and fitted with a screw or flange type cover. Portions of the underdrain system within 1 foot of the outlet structure should be solid and not perforated.

**Figure 2.11.11 Commonly used stone for choker and reservoir layers (not to scale).**

## Construction

Any non-traditional stormwater practice presents challenges during the construction phase that require extra attention to plan detail (both for the design engineer and the contractor) and benefit from construction oversight by the design engineer or others with intimate knowledge of system design and function. Infiltrating pervious pavement systems increase complexity by striving to maintain infiltration capacity while ensuring structural integrity. For these systems, the design engineer should provide additional detail or requirements that protect or assure design infiltration capacity, and this capacity should be confirmed with field measurements during construction.

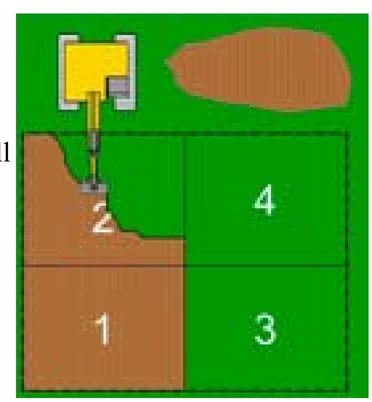
*Acceptable Conditions for Initiating Construction* - Construction of the pervious pavement shall begin only after all the contributing drainage area has been stabilized with vegetation or the planned cover in order to prevent contamination with sediments. Do not construct the pervious pavement practice in rain or snow. Construction of any infiltration BMP should be completed during a window of dry weather - excess compaction or smearing of the subgrade will ensure failure of the stormwater functions of the practice and threaten non-compliance with local or state requirements.

*Erosion, Sediment and Runoff Controls* - Keeping sediment out of this practice is critical. Rigorous installation and maintenance of erosion, sediment and runoff control measures should be provided to divert runoff and to prevent sediment deposition on the pavement surface, the subgrade or within the stone bed. A non-woven geotextile may be folded over the edge of the pavement to reduce the likelihood of sediment deposition. Any construction materials that are contaminated by sediments must be removed and replaced with clean materials (CSN, 2010). Surface sediment should be removed as soon as possible using a vacuum sweeper.

*Clearing and Excavation* - Clear and excavate the area for pavement and base courses in a manner that maintains the infiltrative capacity to the greatest extent possible (Brown, 2010). First insure plans detail staging of work in order to maintain the infiltrative capacity of the subgrade soils. Compaction of the subgrade soils will be increased by working in wet conditions, allowing construction equipment to work or travel across the area and by smearing the final soil surfaces during excavation. Final grade of the bed should be level for infiltrating systems, while closed or lined systems should have positive drainage to the outlet. To protect and maintain subgrade infiltrative capacity (adapted from Brown, 2010):

- Do not all allow excavation in wet conditions or if wet weather is forecasted for the construction period or before the area can be filled. Excavate in dry soil moisture conditions and avoiding excavating immediately after storms without a sufficient drying period.
- Do not allow equipment or haul routes to cross the planned pavement area, especially once excavation has begun.
- Station and operate excavating equipment from outside the planned pavement area or from unexcavated portions of the area using an excavation staging plan (see figure 2.11.12).
- Leaving 6 to 12 inches of undisturbed soil above the subgrade elevation if geotextile and base material placement will be delayed.
- Dig the final 9-12 inches by using the teeth of the excavator bucket to loosen soil so as not to smear the sub grade soil surface. Grading of the bottom (subgrade) surface of the practice with construction equipment should be avoided. Final grading or smoothing of the bottom should be done by hand.
- Avoid allowing water to pond in bottom of cuts.

**Figure 2.11.12 Stage excavation in order to avoid compaction.**



- Areas that have been allowed to trap sediment must have sediment removed and be allowed to dry before final excavation down to the subgrade elevation. Any accumulation of sediments on the finished subgrade should be removed with light equipment and the subgrade surface lightly scarified with hand tools. *Very important note: limit breaking natural soil structure (especially for clayey-silty soils) or risk adversely impacting the infiltrative capacity of the subgrade.
- Finally, before placing geotextile and base aggregate, the final subgrade infiltration rate must be measured for infiltrating systems and reported to the local stormwater authority.

Place geotextile or planned filter material on the uncompacted subgrade and place geotextile up and over the sides of the excavated area. Place geotextiles so that there is a minimum of 16 inches of overlap between subsequent rolls of fabric (see manufacturers recommendation) and a minimum of four feet of material beyond the sides of the excavation. Secure geotextile so that it will not move or wrinkle as aggregate is placed. Some designers may use an alternative filter material such as sand and/or pea gravel between the base aggregate (reservoir layer) and the subgrade soils instead of geotextile (see e.g., UNHSC, 2009). Non-infiltrating designs may compact the subgrade and replace the geotextile with a suitable impermeable lining. Excess fabric (beyond the excavation) should not be trimmed until there is no possibility of sediment entering the pavement area.

Place reservoir course of aggregate and underdrain system. For infiltrating systems, plans will dictate the depth of aggregate to be placed beneath the underdrain system, although this generally exceeds 3 inches. Underdrains should be installed with a minimum slope of 1%. Dead ends of pipe underdrains shall be closed with a suitable cap placed over the end and held firmly in place. For pervious pavement areas of at least 10,000 square feet, at least one observation/cleanout standpipe shall be installed near the center of the pavement and shall consist of rigid 4 to 6 inch non-perforated pvc pipe. This should be capped flush with or below the top of pavement elevation and fitted with a screw or flange type cover. Portions of the underdrain system within 1 foot of the outlet structure should be solid and not perforated.

Moisten and spread 4-12 inch lifts of the washed stone aggregate comprising the reservoir layer. Place and spread lifts of stone without driving on the subgrade and being careful not to damage drainpipes, connections or observation wells. Place at least 4 inches of additional aggregate above the underdrain. The aggregate layer should be lightly compacted, although industry references vary on the degree and number of passes with a roller. The Interlocking Concrete Pavement Institute (ICPI, 2007; LID, ) specifies making 2 passes with a roller in vibratory mode and at least 2 passes in static mode until there is no movement of the stone, while the National Asphalt Pavement Association recommends compacting each lift with a light roller or vibratory plate compactor. Do not crush the aggregate with the roller.

Install filter/choker layer (and bedding layer if used). This course transitions from a larger aggregate size of the subbase to a size that will fill large voids and provide a smooth surface for the pavement layer. Its use depends upon the size of the aggregate course below. For pervious concrete and porous asphalt, AASHTO No. 57 may be used for the reservoir layer and in the layer transitioning to pavement. For interlocking pavers, a smaller size aggregate will be used as a filter layer and also as a bedding layer. These layers should be spread, leveled and compacted to their designed thicknesses.

Install paving materials. Install the planned paving materials in accordance with manufacturer or industry specifications for the particular type of pavement, whether pervious concrete, porous asphalt (Hansen, 2008; Jackson, 2007), interlocking pavers or grid pavers.

## Maintenance

Pervious pavements require maintenance to provide stormwater benefits over a long time period. Because pervious pavements convey water through the pavement and also effectively trap fine materials, the majority of maintenance efforts will be to keep the system permeable (unclogged) and to manage pollutants such as salts that might effect groundwater. Therefore regular inspection will evaluate whether the surface and the bed of the pavement are functioning as intended. In other words, water should continue to move through the pavement, not pond into the pavement layer, and drain from the reservoir layer in sufficient time. Maintenance of the pavement will remove fine materials as they collect in the surface and prevent winter deicing materials from being overused or clogging the system.

Effective management includes educating the property owner, landscapers, maintenance staff, snow removal personnel and general users. In this regard, an operation and maintenance plan, signage, maintenance agreements, and contracts will serve as important points of reference for these audiences. Each document should reflect the appropriate actions to take and those to avoid for the appropriate audience. For example, landscaping personnel that work adjacent to the pavement area should be required to keep landscaping materials, such as soil, mulch or plants off the pavement and to use adequate sediment control and/or stabilization for bare areas. Snow removal, pavement repair and similar contracts should include notes regarding appropriate and inappropriate actions regarding the pervious pavement area. Because pervious pavements will be maintained and managed differently than traditional pavements, signage at pervious pavement installations is recommended. This will promote its prolonged use and prevent conventional pavement management from damaging the system. An example of this includes preventing seal coating of porous asphalt or allowing snow to be stockpiled on a pervious pavement.



**Figure 2.11.13 Examples of signage that might be used to protect pervious pavements.**

An operation and maintenance plan should be prepared by the designer and provided to the owner and the stormwater authority as well as the property manager and maintenance personnel. An operation and maintenance plan for pervious pavement should detail specific actions that must be performed and their timing and/or frequency. It also describes potential damaging actions and measures to take to prevent damage to the pervious pavement. The operation and maintenance plan should also provide detailed information regarding the observation well and the depth or elevations of the underdrain system and outlet, so that the water levels under the pavement can be monitored and compared to the designed function of the system. The operation and maintenance plan should provide the normal drain time (hours) of the pavement.

*Three main strategies dominate pervious pavement operation and maintenance:*

*Prevent clogging of the pavement and regularly remove accumulated fines.* Vacuum sweeping is necessary to remove grit, leaves and other debris collecting at the pavement surface. This should be done two to four times a year. Times that especially will have an accumulation of material include after winter snow melt and after leaf drop in the fall. Vacuums used on paver systems with bedding material should be able to remove sediments and organic matter without removing the bedding aggregate. If bedding aggregate is removed, it should be replaced. Preventing clogging also involves managing adjacent vegetated and landscaped areas. These area should be maintained in healthy vegetation. Soil, mulch and other landscaping materials should never be stored or stockpiled directly on the pavement. Construction equipment should not be driven over or stored on the pavement.

*Snow and Ice Removal.* No sand or cinders should be used on pervious pavements. Instead winter maintenance should focus on timely snow plowing and judicious use of deicing materials. Deicing materials present a problem in any pavement system due to their solubility and history of building up to levels that are toxic to plant and animal life. In pervious pavements, high salt use has an increased potential of reaching groundwater sources, but case studies of pervious pavements have shown a reduced need for deicing material to be applied to pervious pavements due to the effects of a warmer subbase. The operation and maintenance plan should provide guidelines for reduced salt use responsive to the actual ice on the pavement rather than typical rates applied on conventional pavements in the Midwest. Snow should not be stockpiled on the pavement. The operation and maintenance plan should show where snow will be pushed or stockpiled during plowing. The operation and maintenance plan should detail the blade depth that plow operators should use, because in some instances, such as grid pavements, snow plow operators may need to raise the blade slightly to avoid dislodging the surface. In every case, care should be taken with snow plowing to keep from gouging the pavement or dislodging aggregate or pavers.

*Repair pervious pavements appropriately.* Areas may be repaired using the same treatment as the original pervious pavement application or, in the case of porous asphalt or pervious concrete, small areas (not the lowest area on a sloping section) can be replaced with standard (impermeable) pavement. In that case the stone bed of the entire pavement will continue to provide storage and infiltration as designed. In no case should seal coats or new impermeable pavement layers be applied, as is typical in traditional asphalt pavements.

**Inspection Items. The following are suggested items for inspection and are adapted from CSN, 2010:**

- Using the observation well, observe the rate of drawdown in the practice. Measure the water level in the observation well following a storm event exceeding one half inch of rainfall. This should be done immediately after the storm, recording the precipitation amount, the time of the measurement and the water level in the well. Observe and record the water level after 24, 48 and 72 hours. Actual expected performance will depend on the soils and the intended performance of the design. If the subgrade soils were hydrologic soil group D, there may still be water standing in the reservoir layer after 48 or 72 hours. There should not be standing water above the elevation of the underdrain, and this would indicate problems with the outlet or underdrain system being clogged. Assess potential clogging of the subgrade soils and geotextile by comparing the actual drawdown rate to the intended or design performance of the reservoir layer.
- Observe the pavement surface during and after rain for evidence of ponding, deposited sediments, leaves or debris. Address any signs of clogging or accumulated fine material

by performing vacuum maintenance.

- Inspect the structural integrity of the pavement surface for damage such as missing infill material or broken pavers, spalling, rutting, or slumping of the surface. Any adversely affected areas should be repaired as soon as possible.
- Check contributing impervious areas and their associated pretreatment or runoff control structures for sediment buildup and structural damage. Remove sediment as needed.
- Inspect adjacent and contributing drainage area for sources of sediment or areas that may need better stabilization with erosion control.

| Typical Maintenance Activities | Anticipated Schedule |
|---|---|
| Avoid sealing with construction sediments | During construction & long-term |
| Water vegetated grid pavement areas and adjacent vegetated areas to ensure good growth | As necessary during first growing season |
| Avoid sealing or repaving with non-porous materials | Long-term |
| Clean pavement to ensure pavement is free of debris and sediments | As needed (at least twice a year) |
| Check to see that pavement dewaters during large storms and does not pond into surface (check observation well for appropriate water levels) | After large storms |
| Inspect upland and adjacent vegetated areas. Seed & straw bare areas. | As needed |
| Inspect pavement surface for structural integrity and areas in need of repair. Repair as needed. | Annually |

**Table 2.11.7: Typical maintenance activities for permeable pavement (adapted from WMI, 1997)**

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