

# PERMEABLE PAVEMENT DESIGN AND CONSTRUCTION WHAT HAVE WE LEARNED RECENTLY?

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## ABSTRACT

Permeable pavements have been gaining popularity throughout North America. Permeable pavements typically consist of pervious concrete, porous asphalt or permeable interlocking concrete block paving units over an open grade base/subbase layer(s). Permeable pavements are designed to infiltrate stormwater, reduce peak flows, filter and clean contaminants in the water stream and promote groundwater recharge. They have become an integral part of low impact design and best management practices for stormwater management. In order to be effective, permeable pavements must be designed to provide sufficient structural capacity to accommodate the anticipated vehicle loadings as well as deal with stormwater flowing into and out of the permeable pavement. While there have been many well designed and constructed permeable pavements, this is a relatively new technology and there have been some “issues” with their performance. This paper describes some of the basics of best practices, design, construction and maintenance considerations for permeable pavement design and construction and focuses on best practices of permeable pavement design and construction in North America.

Keywords: Permeable pavement, permeable interlocking concrete pavement, permeable pavement structural/hydrologic design, case studies, pavement performance, maintenance.

## INTRODUCTION

Permeable pavement technologies are an important aspect in sustainable design. Environmental responsibility through green initiatives is being embraced in the transportation industry from grass roots community groups to federal governments. One such tool in the sustainable infrastructure design arsenal is the use of permeable pavement systems.

Traditional pavement surfaces are virtually impermeable and are used in conjunction with ditches and storm drains to channelize precipitation towards storm water management facilities. Permeable pavements provide a different approach. Rather than channelizing precipitation along the surface of the pavement, the water is allowed to infiltrate and flow through the pavement surface where it can be stored and slowly allowed to return into the local groundwater system. Permeable pavements provide runoff reduction and make a significant contribution to on-site trapping, removing and treating stormwater pollutants. National and provincial/state legislation in Canada and the U.S. and other countries regulating runoff has provided increased incentive for use of these pavements by public agencies.

Permeable pavements in some form have been around for centuries, and in the literature since the early 1970s [Ferguson 2005]. Early permeable pavements included a variety of systems that typically retained earth and grass in cells constructed of stone, concrete or plastic materials. While this increased the permeability and permitted some rainwater to enter the pavement, they did not provide substantial structural capacity.

More recently, permeable pavement systems have been designed to accommodate more frequent and heavier loading than those of turf systems. These have included porous asphalt concrete, pervious concrete, and permeable interlocking concrete paver surfaced pavements. Their application has expanded to include walkways, trails, driveways, large commercial parking areas, and roadways.

## PERMEABLE PAVEMENT SYSTEMS

Permeable pavement systems consist of a surface with joints and/or openings that will freely allow water to infiltrate the system. The openings allow water from storm events to flow freely through the surface into an open-graded base/subbase where it is collected and stored before it leaves the pavement structure. For low-infiltration rate soils, perforated drain pipes are often placed in the subbase or subgrade to drain excess water, thereby functioning as a detention facility that provides treatment for removal of stormwater pollutants and allows some infiltration. For sites that do not allow for any infiltration, permeable pavement is designed with an impermeable liner that prevents water from entering the soil subgrade; water is detained, treated, and exits via underdrains.

Research has demonstrated that permeable pavements are an effective method for reducing stormwater runoff and pollutants from urbanized areas and can function well with minimal maintenance [Hunt 2009]. Design pollutant removal efficiencies are on the order of 85 percent for total suspended solids (TSS), 35 percent for phosphorus and 30 percent for nitrogen. Permeable pavements has also been shown to work well in cold climates, showing early snow melting qualities with minimal maintenance [Drake 2012].

Like all permeable pavements, the surface will accept sediment thereby decreasing its infiltration rate with time. The rate of decrease depends on sources of deposited sediment typically from ordinary use and unexpected soil erosion from adjacent surfaces. Such reductions from normal use still render a surface that can infiltrate most rain events. Demonstration projects have been completed around North American showing that permeable pavement sedimentation can be addressed through the use of regular vacuum sweeping [Kevern 2011].

General configurations of permeable pavements based on subgrade infiltration are shown in Figure 1. Each of these would be further detailed to achieve the specific goals for an individual installation. These details would include items such as: surface type, curbing and other support features, use of geotextile for layer separation or water filtration, outlet pipe location, downstream water volume and quality treatment, etc.

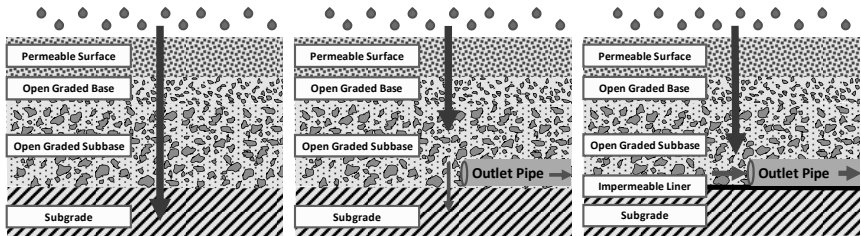


Figure 1a. Full Infiltration

Figure 1b. Partial Infiltration

Figure 1c. No Infiltration

Figure 1a shows a full infiltration design. All stormwater is infiltrated into the subgrade below the pavement. This system does not require any additional stormwater features such as catchbasins, outlet pipes, stormwater management ponds, etc. This system is typically only used in areas where the subgrade materials have high infiltration rates.

Figure 1b, shows a partial infiltration design. Water is encouraged to infiltrate the subgrade; however, excess water from higher intensity storms is removed from the pavement structure using outlet pipes to ensure that that the pavement system does not

overflow. The outlet pipe under the permeable pavement is typically placed at the bottom of the subbase layer or in a shallow trench near the top of the subgrade layer to prevent it from being damaged during construction. In a partial infiltration design, the elevation of the downstream end of the pipe outlet controls the surface discharge elevation and can be set by the designer based on how much infiltration is allowable and desired for site conditions.

Figure 1c, shows a no infiltration design. This type of system is used for low permeability subgrade where infiltration rates are minimal. They are also used for applications where infiltration would be undesirable, such as:

- Water harvesting applications where water is stored for subsequent use;
- “Brownfield” sites where it is not desirable to have water flowing through contaminated subgrades;
- Areas where the subgrade is susceptible to frost heaving or swelling due to moisture content variations; or
- Where subgrade exposure to saturated conditions would result in a reduction in subgrade strength requiring a very thick pavement structure to accommodate traffic loading.

The three primary permeable pavement surface types as designated by their industry associations include porous asphalt, pervious concrete and permeable interlocking concrete pavement. These surface layers are typically underlain by open graded aggregate layer(s). These aggregate layers provide structural capacity to accommodate the traffic loading and act as a reservoir to store and release stormwater as required by the designer. As a design variation to increase load carrying capacity, the pavement industry in the United Kingdom has published a guide to the design and construction of permeable pavements that includes a layer of asphalt concrete beneath the permeable surface [Interpave 2012]. To maintain permeability, holes are drilled in the asphalt concrete and filled with open graded aggregate. The asphalt concrete layer provides additional strength and stability to the permeable surface while the aggregate filled holes provide positive drainage to the underlying aggregate base/subbase.

## **STRUCTURAL AND HYDROLOGICAL DESIGN**

The design of permeable pavements requires the consideration of both structural and hydrological components as shown in Figure 2. The structural design of the pavement is completed to determine the thickness of the various pavement components that are necessary to support the intended design traffic while protecting the subgrade from permanent deformation. The hydrological design determines the key design elements necessary to infiltrate rainwater and surface runoff into the pavement hold and/or detain and filter the water to achieve the stormwater management objectives. An

optimal pavement design is one that is just strong enough to accommodate the design traffic and has the minimum hydrological features to provide water quantity and quality management.

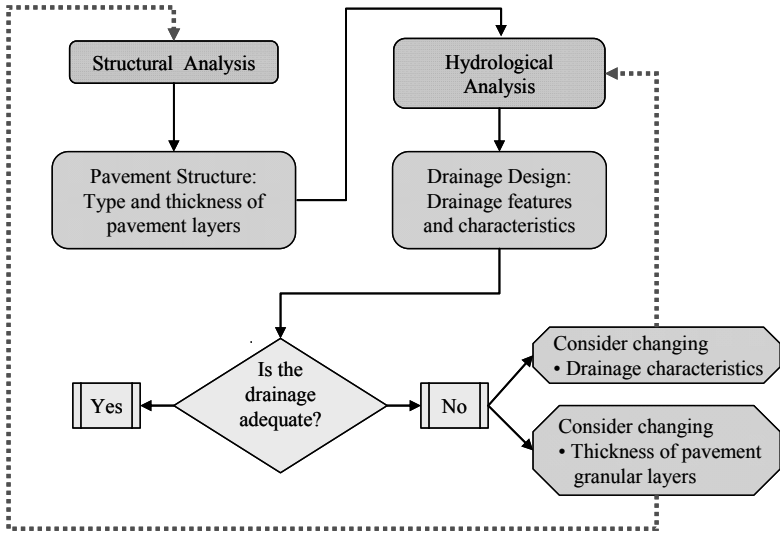


Figure 2. Structural and hydrological design flowchart [Swan 2009].

The most common structural analysis procedure for porous asphalt and permeable interlocking concrete pavement follows the requirements of the American Association of State Highway and Transportation Officials (AASHTO) Guide for the Design of Pavement Structures [AASHTO 1993, Smith 2010]. Pervious concrete structural design is based on the StreetPave system as modified by the American Concrete Paving Association (ACPA) [ACPA 2012].

There are numerous stormwater models that could be used to complete the hydrological design for permeable shoulder pavements. Depending on the hydrologic design goals, appropriate models may include:

**Simple volumetric runoff estimation methods.** These models generate an estimated runoff volume for a specified design storm depth, but do not assign a hydrograph “shape” to this runoff volume. Examples include the NRCS Curve Number method [NRCS 1986], the volumetric runoff coefficient method, and others.

**Event-based hydrograph estimation methods.** These models generate an estimated runoff hydrograph for a specified design storm. Examples include the Watershed Hydrology Program (WinTR-20), Small Watershed Hydrology (WinTR-55), Santa Barbara Unit Hydrograph (SBUH), HEC-1 Flood Hydrograph Package, HydroCAD Stormwater Modelling (HydroCAD), and others.

**Continuous simulation modelling programs.** These models generate long term runoff hydrographs from multiple storms based on a continuous rainfall record and other hydrologic inputs; many also have the capability to route the hydrograph through stormwater management facilities that conduct continuous analysis of transient inflows, outflows, and storage levels. Examples include the USEPA Stormwater Management Model (SWMM), the Hydrologic Engineering Center Hydrologic Modelling System (HEC-HMS), Source Loading and Management Model for Windows (WinSLAMM), Integrated Design Evaluation and Assessment of Loadings (IDEAL), others.

In general, the hydrological analysis assesses if the design runoff volumes or hydrographs can be infiltrated, stored and released by the pavement structure provided. The quantity of water in the pavement system is described as a water balance [NRCS 1986].

The design of underdrain and outlet structures is a function of the hydrologic design goals for the project. Some agency specifications require detention of stormwater for a certain time (i.e., a minimum drawdown time, e.g., 72 hours) to ensure adequate retention time for treatment. For flow control purposes, outlet configurations should be designed to meet the specific flow control objectives of the project. For example, for control of the 10 year peak runoff flowrate to match pre-development peaks, a relatively large outlet may be appropriate to provide “peak shaving” (i.e., functioning similar to a peak flow control detention facility). In contrast, to provide flow duration control from 50 percent of the pre-development 2-year peak to the 10 year peak, a very small low-flow outlet control may be needed, with supplemental outlets at higher elevations to effectively manage flows and durations to pre-development levels across a broad range of storm events.

## PERMEABLE PAVEMENT SUITABILITY

To determine the suitability of a project for permeable pavement, the key factors specific to the project should be considered. Based on their importance in overall decision making, these factors can be divided into primary, secondary, and other considerations which may impact the decision to use permeable pavements for a particular project. Primary considerations (i.e., fatal flaws or major design challenges) are those that would have an overriding influence on the decision to move forward with the project. Secondary considerations are those that have a lesser influence and usually

are taken into account as part of the design process when there are no overriding considerations. These factors may diminish the performance or acceptability of permeable pavement or may require additional design provisions (and associated costs) to avoid risks. Other considerations may have some influence on the decision to include permeable pavements for a particular project. The primary considerations should generally be weighted the highest to reflect their importance in moving forward with the project, while secondary and other considerations are useful to prioritize between sites and inform design, but are not generally fatal flaws.

#### A. Primary Considerations

- Availability of funding
- Status of environmental approval
- Safety
- Significant grades (>5 percent)
- Depth of water table
- Geotechnical risks
- Groundwater contamination risk

#### B. Secondary Considerations

- Stringent receiving water quality standards
- Sand use for winter maintenance
- Low soil infiltration rates
- Target design volumes and runoff rates
- Risk of flooding
- Mandates for stormwater quality control
- Mandates for drainage and peak flow control
- Maintenance protocols

#### C. Other Considerations

- Interest in innovation
- Presence of utilities
- Impact of unknown site conditions
- Risk of accidental chemical spill

This list of considerations reflects typical needs and expectations. Other constraints and project-specific considerations should be added or deleted as necessary. Each of these criteria is discussed in more detail in Table 1.

**Table 1. Permeable Pavement Use Considerations.**

<b>Importance Level</b>	<b>Description</b>
<b>Primary Considerations</b>	
Availability of funding	The initial capital construction cost of permeable pavement is typically higher than for conventional pavement. Overall long term life-cycle costs can be very competitive if consideration is given to stormwater quality and quantity benefits.
Status of environmental approval	In some jurisdictions, permeable pavement may not be permitted or may require additional environmental approvals.
Significant grades	Grades of more than 5 percent may pose significant design challenges. It may be necessary to bench the subgrade to promote water infiltration and/or to slow water to prevent channelization or scouring.
Depth of water table	Permeable pavements should not be used in areas where the water table is within 0.6 m of the top of the soil subgrade.
Geotechnical risks	Geotechnical risks may introduce added design complexity and may necessitate the use of an underdrain and/or impermeable liner.
Groundwater contamination risk	A variety of factors influence the potential for stormwater sources to contaminate groundwater, including soil characteristics, depth to groundwater, existing soil contamination, and application of salt for deicing.
<b>Secondary Considerations</b>	
Stringent receiving water quality standards	While the presence of and need to protect nearby aquatic resources may provide incentives for the use of permeable pavements in cases, for some protected watersheds, cold water streams, and other receiving waters with stringent water quality standards, the level of treatment provided by permeable pavements (for water discharged from underdrains) may not provide adequate protection from stormwater quality impacts.
Sand use for winter maintenance	Winter sand may clog permeable pavement systems resulting in reduced system permeability.
Low soil infiltration rates	Low soil infiltration rates may need to be supplemented with an underdrain to provide adequate drainage, which tends to reduce performance and increase costs.



<b>Importance Level</b>	<b>Description</b>
Target design volumes and runoff rates	Due to geometric factors, permeable pavements may be limited in terms of how much volume they can store. It may be necessary to include supplementary storage features to achieve water storage and infiltration goals.
Risk of flooding	Permeable pavements may not be capable of conveying flows from peak storm events. Areas subject to frequent flooding may require supplemental drainage features to ensure that the surface is drained.
Mandates for stormwater quality control	Permeable pavements may contribute substantially to water quality improvement. Where regulations require stormwater quality management, this may significantly incentivize the use of permeable pavement.
Mandates for drainage and peak flow control	Permeable pavements provide stormwater management alternatives to more costly practices to provide drainage and peak flow control.
Maintenance protocols	Permeable pavement systems require mandatory non-traditional maintenance practices such as vacuum sweeping, which may influence their applicability and desirability for a project.
<b>Other Considerations</b>	
Interest in innovation	Utilizing traditional impermeable surfaces for stormwater management provides opportunities for innovation.
Presence of utilities	The design and construction of permeable pavements may be problematic or require additional design features, such as cutoff walls, in areas where utilities are present.
Impact of unknown site conditions	Variability of soil conditions, presence of organics, potential for frost heave, etc. may impact pavement performance.
Risk of accidental chemical spill	While spills are relatively uncommon and tend to occur at low volumes that can typically be retained in the permeable pavement.

## KEY DESIGN CONSIDERATIONS

The design of permeable pavements must consider both the structural and hydrological situation and conditions. Some key design considerations are provided in Table 2.

**Table 2. Key Permeable Pavement Design Considerations**

<b>Feature</b>	<b>Description</b>
<b>Site Characterization</b>	
Drainage Path	In order to assess the suitability of a site for potential use for permeable pavement, the drainage patterns in the area surrounding the permeable pavement should be evaluated to determine its possible impact on the permeable pavement.
Traffic Type and Patterns	Assess traffic type and composition. Avoid using permeable pavements in high traffic areas subjected to traffic such as buses or heavy trucks. Avoid use where traffic will contaminate the pavement surface with dirt, oils and grease.
Winter Maintenance	Avoid the use of winter sand which may clog the pavement. Limit use of deicing chemicals if water is to be captured and re-used.
Groundwater Depth	Do not use permeable pavements in areas where the groundwater is within 0.6 m of the bottom of the pavement.
Subsurface Conditions	Underground utilities, presence of bedrock etc. may require special considerations.
Surrounding Land Use	Avoid use downstream of high sediment and/or contaminant generating activities.
<b>Structural Design</b>	
Traffic	Complete structural design suitable for the intended traffic. Consider current and future expected traffic types and frequency.
Subgrade Characteristics	Carefully evaluate subgrade structural capacity. Consider to be in "soaked" condition. Determine infiltration capacity. Assess need for compaction to uniform density.
Surface	Determine structural capacity of surface layer. Typically less than that of conventional pavement surfacing. Carefully assess impact of construction conditions and techniques on the stability of the surface.

Feature	Description
Base/Subbase	Determine structural capacity. Typically less than that of conventional materials. Select durable and crushed materials to maximize structural capacity and porosity for water storage. Select clean materials with very low fines contents.
Reliability	Assess design reliability and select appropriate value for intended traffic and maintenance activities.
<b>Hydrological Design</b>	
Design Storm	Determine expected storm duration, frequency and intensity.
Surface	Determine surface infiltration capacity both initially and long-term if subject to contaminant loads.
Surface Slope	Avoid surface slopes of > 5 percent. Design for runoff for permeable paver surfaces at higher slopes.
Subsurface Slope	Avoid subsurface slopes for infiltration designs. Consider berms and weir structures for sloped pavements.
Contributing Area Runoff	Determine runoff volume, speed, etc. from contributing areas. Consider potential contaminant loads.
Supplemental Surface Drainage	Design supplemental surface drainage for high intensity storms that may limit surface infiltration at times.
Subgrade Infiltration	Determine potential for subgrade water infiltration based on soil type, density, permeability, etc.
Underdrains	For partial or no infiltration designs, determine the type, location and need for underdrains. Specify outlet details and clean out provisions.
Outflow Details	Design outflow from underdrains to meet detention goals. Ensure
Geotextile	Assess the need for geotextile separators to prevent fines migration and layer intermixing.
Liner	Determine the need and type of impermeable liners for no-infiltration designs.

## KEY CONSTRUCTION CONSIDERATIONS

While the construction of permeable pavements is generally straight forward, it is necessary to ensure that everyone involved in the construction is fully aware of the ‘special’ considerations necessary to ensure that the pavements are constructed to the

highest level of quality to ensure a long life. Some of the key construction features are summarized in Table 3.

**Table 3. Permeable Pavement Construction Considerations.**

<b>Feature/Pavement Type</b>	<b>Description</b>
<b>All Permeable Pavements</b>	
Construction Timing	Do not schedule construction during cold weather or raining conditions. Site subgrades may be susceptible to moisture weakening.
Pre-Construction Meeting	Hold a pre-construction meeting to ensure that everyone is cognisant of the permeable pavement requirements and need to keep the site clean.
Subgrade Compaction	Avoid construction equipment traversing the subgrade resulting in compaction and a reduction of permeability.
Underdrains	Place underdrains in shallow trenches on top of 50 mm layer of base aggregate. Cover and protect from compaction damage. Connect and fit outlets.
Base/Subbase Placement	Place the base/subbase materials in lifts. End dump and push to prevent subgrade compaction if desired. Compact using appropriate compaction equipment. Start with 2 passes using vibrator roller then switch to non-vibratory compaction to avoid crushing of base/subbase materials.
Construction Protection	Avoid contamination with fines. Provide “Texas Gates” to dislodge dirt or wash stations for construction equipment as necessary.
<b>Permeable Interlocking Concrete Pavement</b>	
Paver Selection	Select appropriate paver types, thickness and placement orientation commensurate with the expect site use.
Bedding Layer	Select bedding layer to ensure that it is “choked” into the underlying layer. Ensure consistent thickness. Avoid excessive layer thicknesses.
Joint Filler	Select the appropriate joint filler material for the paver type. Ensure high frictional properties to promote friction between paves and joint filler while maximizing infiltration capacity.

Feature/Pavement Type	Description
<b>Pervious Concrete</b>	
Mix Design	Ensure mix design addresses maximum structural capacity and permeability. Utilize admixtures and fibres to promote curing and appropriate cement film thickness.
Placement	Utilize admixtures to promote cement hydration. Ensure adequate compaction to maximize layer uniformity.
Curing	Take steps to ensure adequate cement hydration, curing compounds, admixtures, surface moisture loss provisions, etc.
<b>Porous Asphalt</b>	
Mix Design	Ensure adequate asphalt cement film thickness but asphalt cement type selection, use of fibres, fillers, etc.
Placement	Utilize adequate compaction equipment, pay attention to temperature/viscosity during placement/compaction.

## CONCLUSIONS

The use of permeable pavement for stormwater management has gained rapid acceptance across North America. They provide the ability to utilize a traditional contributor to stormwater problem as a solution to both detain and “clean” stormwater. While the addition of water to a pavement can have detrimental effects on the structural capacity of a pavement, the careful design of permeable pavements can ensure that they can provide both long life and be effective in accommodating stormwater. Careful consideration of design features and construction techniques are necessary to ensure their success.

Key design features include a careful assessment of the permeable pavement site and its surrounding land use to ensure that the pavement surface does not become contaminated with sand/dust or vegetative matter. A rational assessment of the traffic to which the pavement will be exposed including truck, bus and other heavy vehicles will permit the designer to ensure that the pavement has sufficient structural capacity for its design life. A hydrological design taking into account rain water landing on the pavement and water shed from the surrounding area can be accommodated into the permeable pavement and then properly treated for water quality improvements and permitted to exit the pavement either through infiltration into the subgrade or controlled through underdrains. Construction processes and techniques should consider the protection of the permeable pavement from contaminants during construction and to ensure that the pavement is able to accommodate both vehicle loading and water

infiltration and exfiltration in accordance with the pavement design. Finally, with all pavements, maintenance practices should include occasional vacuum sweeping to ensure the longevity of the permeable surface with repairs completed to address any localized deficiencies such as settlement and ravelling etc.

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