Grassed Swales

Practice Description

In the context of BMPs to improve water quality, the term swale (a.k.a. grassed channel, dry swale, wet swale, biofilter, or bioswale) refers to vegetated, open-channel management practices designed specifically to treat and attenuate stormwater runoff for a specified water quality volume. Swales remove pollutants from stormwater by biofiltration, settling, and infiltration. Grassed swales filter pollutants as stormwater runoff moves through the leaves and roots of the grass. By reducing flow velocities and increasing a site’s time of concentration, grassed swales contribute to reducing runoff peaks. Grassed swales that are designed with check dams or incorporate depression storage promote infiltration and can help contribute to satisfying a site runoff capture/storage requirement.

Variations of the grassed swale include the grassed channel, dry swale, and wet swale. The specific design features and methods of treatment differ in each of these designs, but all are improvements on the traditional drainage ditch. These designs incorporate modified geometry and other features for use of the swale as a treatment and conveyance practice.

Planning Considerations

Grassed swales can be applied in most situations with some restrictions. Swales are well suited for treating highway or residential road runoff because they are linear practices. Swales are also useful as one of a series of stormwater BMPs or as part of a treatment train, for instance, conveying water to a detention pond and receiving water from filter strips. Furthermore, swales are highly recommended by the proponents of design approaches such as Low Impact Development and Better Site Design.

The use of grassed swales in new development can be a cost-effective alternative to curb and gutter installation. The swale practices are considered more aesthetically pleasing, although there is the potential for standing water and possible mosquito infestations.

The effectiveness of a swale in both reducing the flow rates and volume of runoff, and removing pollutants, is a function of the size and composition of the drainage area, the slope and cross section of the channel, the permeability of the soil, the density and type of vegetation in the swales, and the swale dimensions. Broad swales on flat slopes with dense vegetation are the most effective. Removal efficiencies are highest for sediment-bound pollutants.

Design Criteria

In addition to the broad applicability concerns described above, designers need to consider site conditions. In addition, they need to incorporate design features to improve the longevity and performance of the practice while minimizing the maintenance burden.

Converting Erosion- and Sediment-Control Devices

Swales are often used as erosion- and sediment-sediment control measures during active construction. The same swales can later be used as grassed swale BMPs; however, all of the sediment must be removed, the channel configuration and slope must be re-established (if necessary), and the proper vegetation must be established. See the Grass Swale practice under Runoff Conveyance in Chapter 4 of Volume 1 of this Manual for more information on grass swales as erosion- and sediment-control devices.

Siting Considerations

In addition to considering the restrictions and adaptations of grassed swales to different regions and land uses, designers need to ensure that this management practice is feasible at the site in question because some site conditions (i.e., steep slopes, highly impermeable soils) might restrict the effectiveness of grassed channels.

Drainage Area

Grassed swales should generally treat runoff from small drainage areas (less than 5 acres). If used to treat larger areas, the flows through the swale become too large to produce designs to treat stormwater runoff in addition to conveyance.

Capacity

The capacity of the swale must also be checked to ensure that it will be adequate after vegetation is fully established. The resistance to flow should be evaluated using the NRCS retardance factor for the vegetation selected (consult *Grass Swale* in Chapter 4 of Volume 1).

The flow depth of the design event should be evaluated using Manning’s equation for the swale type used (parabolic, trapezoidal, or V-shaped). The design requirement is that the swales convey the design discharge while maintaining a 0.5-foot freeboard and without exceeding the maximum permissible velocity.

If driveways or roads cross the swale, the capacity of the culvert crossing the road or driveway may determine the depth of flow for the design event. In these instances, the culverts should be checked to establish that the backwater elevation does not exceed the banks of the swale. If the culvert discharges to a minimum tailwater condition, the exit velocity for the culvert should be evaluated for design conditions. If the maximum permissible velocity is exceeded at the culvert outlet, riprap or another measure to prevent scour must be used.

Slope

Grassed swales should be used on sites with relatively flat slopes of less than 4 percent slope; 1 to 2 percent slope is recommended. When site conditions require installing the swales in areas with larger slopes, check dams can be used to reduce the influence of the slope. Runoff velocities within the channel become too high on steeper slopes. This can cause erosion and does not allow for infiltration or filtering in the swale.

Soils/Topography

Grassed swales can be used on most soils, with some restrictions on the most impermeable soils. In the dry swale (see Design Variations section below), a fabricated soil bed replaces on-site soils in order to ensure that runoff is filtered as it travels through the soils of the swale.

Groundwater

The required depth to groundwater depends on the type of swale used. In the dry swale and grassed channel options, the bottom of the swale should be constructed at least 2 feet above the groundwater table to prevent a moist swale bottom or contamination of the groundwater. In the wet swale option, treatment is provided by creating a standing or slow-flowing wet pool, which is maintained by intersecting the groundwater.

Design Considerations

Although there are different design variations of the grassed swale (see Design Variations), some design considerations are common to all designs. An overriding similarity is the cross-sectional geometry. Swales often have a trapezoidal or parabolic cross section with relatively flat side slopes (flatter than 3:1), though rectangular and triangular channels can also be used. Designing the channel with flat side slopes increases the wetted perimeter. The wetted perimeter is the length along the edge of the swale cross section where runoff flowing through the swale contacts the vegetated sides and bottom. Increasing the wetted perimeter slows runoff velocities and provides more contact with vegetation to encourage sorption, filtering, and infiltration. Another advantage to flat side slopes is that runoff entering the grassed swale from the side receives some pretreatment along the side slope.

Another similarity among designs is the type of pretreatment needed. In all design options, a small forebay should be used at the front of the swale to trap incoming sediments. A pea gravel diaphragm, a small trench filled with river-run gravel, should be constructed along the length of the swale and used as pretreatment for runoff entering the sides of the swale. Other features designed to enhance the performance of grassed swales are a flat longitudinal slope (generally between 1 percent and 2 percent) and a dense vegetative cover in the channel. The flat slope helps to reduce the flow velocity within the channel. The dense vegetation also helps reduce velocities, protects the channel from erosion, and acts as a filter to treat stormwater runoff. During construction, it is important to stabilize the channel while the vegetation is becoming established, either with a temporary grass cover or with natural or synthetic erosion-control products. In addition to treating runoff for water quality, grassed swales must convey runoff from larger storms safely. Typical designs allow the runoff from the 2-year storm (i.e., the storm that occurs, on average, once every two years) to flow through the swale without causing erosion. Swales should also have the capacity to pass larger storms (typically a 10-year storm) safely.

Ponding and Infiltration

Ponding can be beneficial if intended and accepted, or it can be a negative if unintended. If unintended and not designed for, extended periods of standing water may result in nuisance conditions and create complaints from residents. Mosquitoes are typically the biggest concern; however, they should generally not be a problem because of the frequent flushing of the ponded water. Also, if wetland vegetation develops, mosquito predators such as other insects and birds often mitigate the mosquito problem. If wetland vegetation and standing water are persistent concerns, these problems can be reduced by maintaining more uniform, steeper slopes in the swale invert or by installing underdrains.

If temporary retention of small amounts of water is desired for enhanced treatment of the stormwater and ecological and visual diversity, there are many ways to achieve that goal. The paragraphs below discuss several methods for retaining water or otherwise modifying the typical swale hydrology. The retained water will infiltrate, be lost through evapotranspiration, or slowly released downstream. It should be noted that the maximum allowable ponding time within a channel is 48 hours, and an underdrain system must be provided if that requirement cannot be met.

Check Dams

A check dam is constructed of earth, stone, or timber 3 to 6 inches high to retain runoff from routine events. A weep hole may be added to enable the area behind an earthen or timber dam to drain slowly. However, the weep hole may be subject to clogging. Shorter check dams can act as level spreaders to help distribute the flow along the swale's cross section.

Elevated Drop Inlets

A drop inlet can be used when a combined system of swales and storm sewers is being used. The swales would serve as the collector system, and the inlet into the main storm sewer system would be elevated slightly to retain runoff from routine events. The height of elevation would depend on the soil, the slope of the swale, and the tolerance for ponding. Wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

Elevated Culverts

Elevated culverts are used for the same purpose as check dams and elevated drop inlets, to retain runoff from routine events. As with elevated drop inlets, wetland vegetation may develop in the ponded areas if the underlying soils are poorly drained.

Depression Storage

Small depressions along the bottom of the swale will trap and store stormwater for later infiltration into the soils. These depressions will also likely accumulate sediment at a quicker pace than other parts of the swale, and will also probably develop wetland vegetation.

Underdrains

Underdrains can enhance the performance of swales by providing additional filtration through soil, similar to the process that takes place in bioretention facilities. These “bioretention” swales have a layer of engineered soil underlain by a gravel layer surrounding a perforated pipe. This configuration also reduces ponding time where standing water may be a concern.

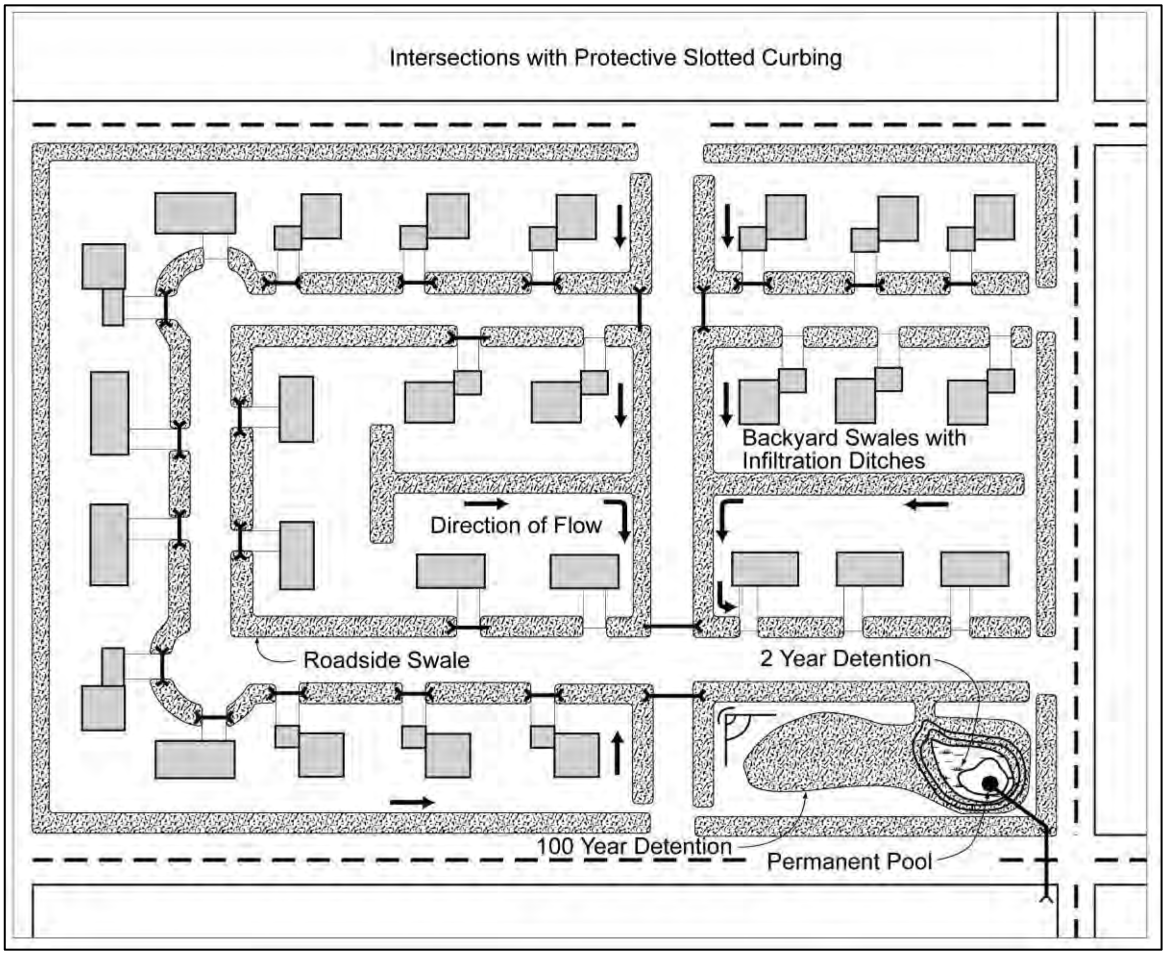

Figure 1 Schematic of Plan for Retrofit of Grassed Swales in Residential Subdivision

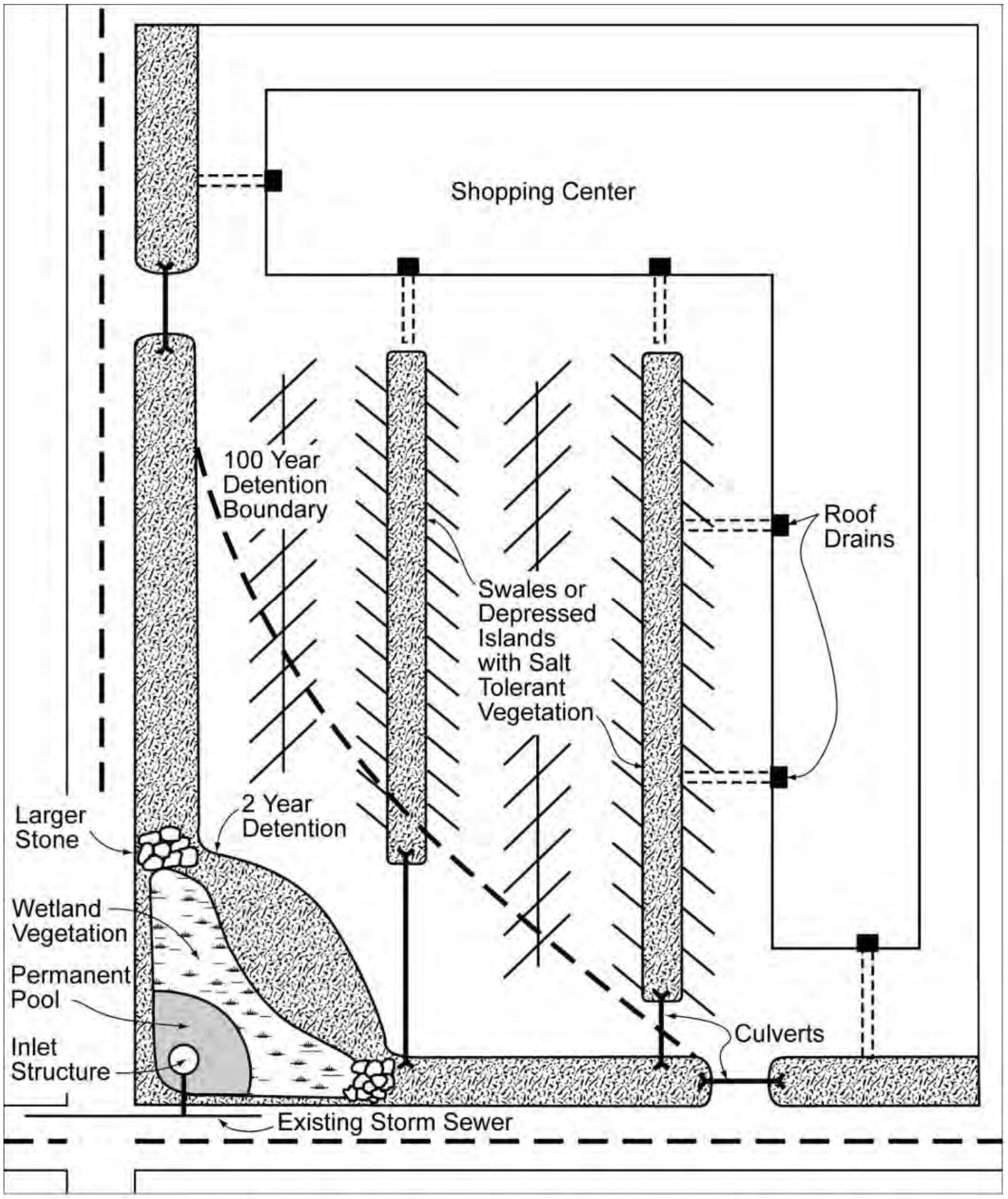

Figure 2 Example of Grassed Swale Used for Parking Lot

Design Variations

The following discussion identifies three variations of open-channel practices—the grassed channel, dry swale, and wet swale.

Grassed Channel

Of the three grassed swale designs, grassed channels are the most similar to a conventional drainage ditch, with the major differences being flatter side slopes and longitudinal slopes, and a slower design velocity for water quality treatment of small storm events. Of all of the options, grassed channels are the least expensive but also provide the least reliable pollutant removal. An excellent application of a grassed channel is as pretreatment to other structural stormwater practices. A major difference between the grassed channel and many other structural practices is the method used to size the practice. Most stormwater-management water quality practices are sized by volume. This method sets the volume available in the practice equal to the water quality volume, or the volume of water to be treated in the practice. The grassed channel is a flow rate-based design. Based on the peak flow from the water quality storm, the channel should be designed so that runoff takes, on average, 10 minutes to flow from the top to the bottom of the channel. A procedure for this design can be found in *Design of Stormwater Filtering Systems* (CWP, 1996).

Dry Swales

Dry swales are similar in design to bioretention areas (see *Bioretention Practice*). These designs incorporate a fabricated soil bed into their design. The native soil is replaced with a sand/soil mix that meets minimum permeability requirements. An underdrain system is installed at the bottom of the soil bed. This underdrain is a gravel layer that encases a perforated pipe. Stormwater treated in the soil bed flows into the underdrain, which routes this treated stormwater to the storm drain system or receiving waters. Dry swales are a relatively new design, but studies of swales with a native soil similar to the man-made soil bed of dry swales suggest high pollutant removal.

Wet Swales

Wet swales intersect the groundwater and behave similarly to a linear wetland cell (see *Constructed Stormwater Wetland Practice*). This design variation incorporates a shallow permanent pool and wetland vegetation to provide stormwater treatment. This design also has potentially high pollutant removal. Wet swales are not commonly used in residential or commercial settings because the shallow standing water may be a potential mosquito breeding area.

Construction Considerations

To maximize the infiltration capacity of the swale, compaction of the soil underlying the swale should be avoided. For example, equipment for excavating or grading should operate from the side of the swale instead of the bottom of the swale.

Before vegetation is established in a swale, the swale is particularly vulnerable to scour and erosion. Therefore, protecting the seedbed with a temporary erosion-resistant lining (such as a geosynthetic or fiberglass roving) or other suitable erosion controls is generally necessary. Most vendors will furnish information about the Manning's coefficient (*n*) and will also specify the maximum permissible velocity or allowable unit tractive force (also referred to as the "tractive stress") for the lining material. Swales should be constructed and vegetated early in the construction schedule, preferably before area grading and paving increase the rate of runoff.

Temporary erosion-resistant channel linings should be used to stabilize the swale until the vegetation becomes established. The vendor's instructions for installing channel linings should be followed. If velocities will be high, designers should consider sodding the swale or diverting runoff until vegetation is established.

Common Problems

Grassed swales are relatively low-maintenance BMPs, but some potential problems include the following:

- Ponded water makes swale difficult to mow, and can cause nuisance problems such as odors, discoloration, and mosquitoes.
- Erosion due to improper vegetation establishment.
- Sediment accumulation due to inadequate erosion-control upstream.

Maintenance

Routine maintenance of grassed swales will include the removal of trash and debris.

If bare soil or signs of erosion are evident, regrade the soil to remove gully erosion and then re-sod and water until established.

Sediment should be removed if it accumulates within the swale.

Infiltration Basin

Practice Description

An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater into the soil. This practice is believed to have a high pollutant-removal efficiency and can also help recharge the groundwater, thus increasing baseflow to stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

Planning Considerations

Infiltration basins have select applications. Their use is often sharply restricted by concerns over groundwater contamination, soils, and clogging at the site. They work best in relatively small drainage areas and in drainage areas that are completely impervious or stable (to minimize the amount of sediment going to the BMP). Infiltration basins are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the device to trap sediment and litter before it is washed into the device. Another approach is to construct infiltration devices at the downgradient edges of areas with permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the infiltration devices can be reduced significantly.

Design Considerations

When designing infiltration basins, designers need to carefully consider both the restrictions on the site and design features to improve the long-term performance of the practice.

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration basin designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, outlet, and landscaping.

Pretreatment

Pretreatment devices for removing sediment and solids must be used to protect infiltration devices from clogging. A few options for pretreatment include filter strips, grassed swales with check dams, concrete sumps, and forebays (sediment traps).

Consideration should be given to the inlet when infiltration facilities are designed. The type of inlet will depend on whether the upgradient source of runoff is overland flow or a concentrated source of discharge. Infiltration trenches require relatively even distribution over their length. An infiltration basin can be designed to accommodate a concentrated influent flow; however, an energy dissipater and/or level spreader may be needed.

Treatment

Treatment design features enhance the pollutant removal of a practice. For infiltration practices, designers need to stabilize upland soils to ensure that the basin does not become clogged with sediment. In addition, the facility needs to be sized so that the volume of water to be treated infiltrates through the bottom in a given amount of time. Because infiltration basins are designed in this manner, infiltration basins designed on less permeable soils should be significantly larger than those designed on more permeable soils.

Conveyance

Stormwater needs to be conveyed through stormwater-management practices safely and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. In general, infiltration basins should be designed to treat only small storms (i.e., only for water quality). Thus, these practices should be designed “off-line,” using a flow separator to divert only small flows to the practice.

Outlet Design

Infiltration devices, by their very nature, do not have regular outlet devices. (The stormwater entering the BMP leaves through the soils.) They should, however, be designed with dewatering provisions in the event of failure. It can be dewatered by pumping out or allowed to gravity-drain through a pipe. If a dewatering outlet pipe is installed to facilitate emergency draining, a lockable watertight valve must be installed and kept closed at all times.

Landscaping

Landscaping can enhance the aesthetic value of stormwater practices or improve their function. In infiltration basins, the most important purpose of vegetation is to reduce the tendency of the practice to clog. Upland drainage needs to be properly stabilized with a thick layer of vegetation, particularly immediately following construction. In addition, providing a thick turf at the basin bottom helps encourage infiltration and prevent the formation of rills in the basin bottom.

Siting Considerations

Infiltration practices need to be located extremely carefully. In particular, designers need to ensure that the soils on the site are appropriate for infiltration, and that designs minimize the potential for groundwater contamination and long-term maintenance problems.

Converting Erosion- and Sediment-Control Devices

Often, the same basin can be used during construction as an erosion- and sediment-control device and later converted to an infiltration basin. Before conversion, all accumulated sediment must be removed and properly disposed of. Then, the appropriate modifications to the basin depth, geometry, and hydrology, as well as inlet and outlet structures, etc., must be made. A minimum of 6 inches of bottom material (below the design bottom of the original sediment and erosion control device) must be removed prior to conversion to a stormwater BMP, so appropriate design bottom depth changes must be considered. It is essential that the site be completely stabilized before the erosion- and sediment-control devices are removed or converted.

Drainage Area

Infiltration basins have historically been used as regional facilities, serving for both water-quantity and water-quality control. In general, the practice is best applied to relatively small drainage areas (i.e., less than 10 acres).

Slope

The bottom of an infiltration basin needs to be completely flat to allow infiltration throughout the entire basin bottom.

Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the practice can infiltrate quickly enough to reduce the potential for clogging. Soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. A *site-specific* hydrogeologic investigation shall be performed to establish the suitability of site soils for the BMP. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inch per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests.

Groundwater

Designers always need to provide significant separation distance (2 to 5 feet) from the bottom of the infiltration basin and the seasonally high groundwater table, to reduce the risk of contamination. Infiltration practices should also be separated from drinking water wells.

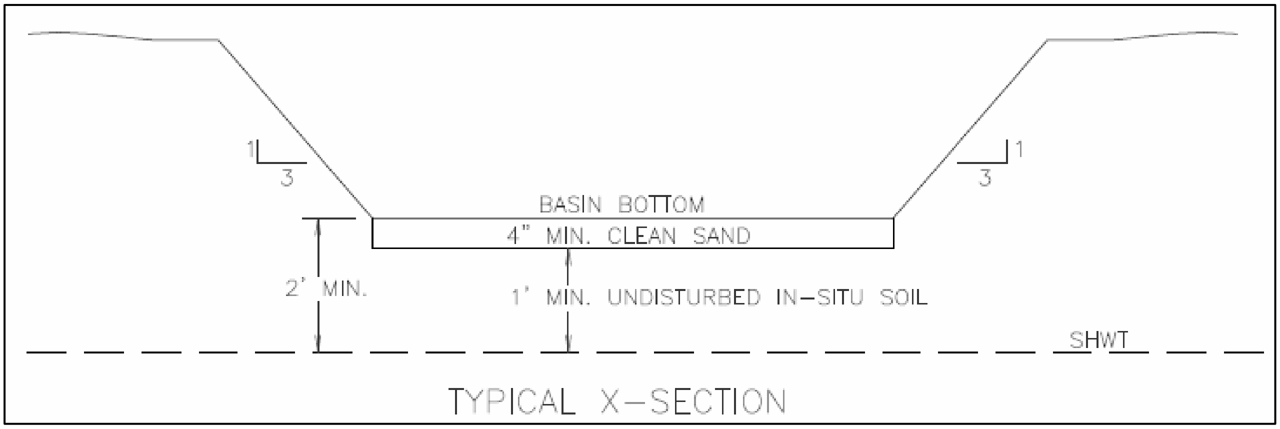

Figure 1 Typical Infiltration Basin: Cross Section
(Note: Retaining walls may be used in place of 3:1 vegetated side slopes)

Construction Considerations

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices, since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, lighter weight equipment and construction techniques that minimize compaction should be used.

Runoff shall not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

A minimum of one observation well shall be included in the design of an infiltration system to periodically verify that the drainage media are fully draining. The monitoring well shall consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

Length, Width, Depth and Geometry

The sizing of an infiltration device is determined by the dewatering requirements. Infiltration devices must be able to completely dewater within 5 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce the following equation for determining the effective infiltrating area needed:

$$A = \frac{V}{2 * (K * T)}$$

where:

A = effective infiltrating area (ft^2)
V = volume of water requiring infiltration (ft^3)
K = hydraulic conductivity of soil (in/hr)
T = dewatering time (days)

The volume of water requiring infiltration (V) is prescribed by the specific stormwater program that applies to the site, and the runoff characteristics of the site. If the infiltration device is not going to meet the volume control requirements, it is simply the volume of water that is diverted and stored for infiltration. The runoff capture storage volume of an infiltration device that is filled with a drainage medium is equal to the volume of the facility, multiplied by the porosity of the medium, plus any temporary ponding that may be allowed before the facility overflows.

The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be 5 days or less. A value of less than 3 days is recommended for use in the formula.

Once the effective infiltrating area (A) is obtained from the formula, it can still be somewhat difficult to translate that into actual infiltration device dimensions. The value for A used in the formula is actually the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is therefore often an iterative process using the effective infiltrating area (A); the correction factor for true surface areas of the in situ soil interface; and typical length, width, and depth recommendations.

Infiltration basins may appear in a variety of geometries. Runoff frequently is piped to these devices from stormwater inlets on patios, parking areas, roofs, and other impervious areas. These devices may also receive runoff via sheet flow.

Common Problems

Although infiltration basins can be useful practices, they have several limitations. Infiltration basins are not generally aesthetic practices, particularly if they clog. If infiltration basins are designed and maintained so that standing water is left for no more than 3 days, mosquitoes should not be a problem. However, if an infiltration basin becomes clogged and takes 4 or more days to drain, the basin could become a source for mosquitoes. In addition, these practices are challenging to apply because of concerns over groundwater contamination and sufficient soil infiltration. Finally, maintenance of infiltration practices can be burdensome, and they have a relatively high rate of failure.

Maintenance

Regular maintenance is critical to the successful operation of infiltration basins.

Immediately after the infiltration basin is established, the vegetation will be watered twice weekly if needed until the plants become established (commonly six weeks).

No portion of the infiltration basin will be fertilized after the initial fertilization that is required to establish the vegetation.

If areas of bare soil and/or erosive gullies form, regrade the soil to remove the gully, plant a ground cover, and water until it has established.

The vegetation in and around the basin will be maintained at a height of approximately six inches.

Should sediment accumulation reach 75% of the original design depth, the source of sediment should be identified and remedied. The sediment shall be removed and the basin restored to original design specifics.

Infiltration Trench

Practice Description

An infiltration trench (a.k.a. infiltration galley) is a rock-filled trench with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale and detention basin, and into the trench. There, runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. The primary pollutant removal mechanism of this practice is filtering through the soil.

Planning Considerations

Infiltration trenches have select applications. Although they can be applied in a variety of situations, the use of infiltration trenches is restricted by concerns over groundwater contamination, soils, and clogging.

Infiltration trenches are frequently used to infiltrate runoff from adjacent impervious surfaces, such as parking lots. In these cases, a filter strip should be installed between the pavement and the device to trap sediment and litter before they are washed into the device. Another approach is to construct infiltration trenches at the downgradient edges of areas with permeable pavement. In this case, the permeable pavement is the inlet to the device. Because water also will infiltrate through the base of the pavement, the size of the infiltration devices can be reduced significantly.

Design Criteria

Infiltration trenches are filled with large crushed stone or other media to create storage for the stormwater in the voids between the media. Other versions use precast concrete vaults with open bottoms to provide a large storage volume to hold stormwater for infiltration into the soil. Infiltration trenches are usually used to manage the runoff from parking lots and buildings.

Converting Erosion- and Sediment-Control Devices

Infiltration trenches shall not be used as sediment- and erosion-control devices.

Siting Considerations

Infiltration practices need to be sited extremely carefully. In particular, designers need to ensure that the soils on site are appropriate for infiltration and that designs minimize the potential for groundwater contamination and long-term maintenance.

Drainage Area

Infiltration trenches generally can be applied to relatively small sites (less than 5 acres), with relatively high impervious cover. Application to larger sites generally causes clogging, resulting in a high maintenance burden.

Slope

Infiltration trenches should be placed on flat ground, but the slopes of the site draining to the practice can be as steep as 15 percent.

Soils/Topography

Soils and topography are strongly limiting factors when locating infiltration practices. Soils must be significantly permeable to ensure that the stormwater can infiltrate quickly enough to reduce the potential for clogging. In addition, soils that infiltrate too rapidly may not provide sufficient treatment, creating the potential for groundwater contamination. To be suitable for infiltration, underlying soils must have an infiltration rate of 0.52 inch per hour or greater, as initially determined from NRCS soil textural classification (typically hydrologic soil groups A and B) and subsequently confirmed by field geotechnical tests. The infiltration rate and textural class of the soil need to be confirmed in the field; designers should not rely on more generic information such as a soil survey. Finally, infiltration trenches may not be used in regions of karst topography, due to the potential for sinkhole formation or groundwater contamination.

Groundwater

Designers always need to provide significant separation (2 to 5 feet) from the bottom of the infiltration trench and the seasonally high groundwater table, to reduce the risk of contamination. In addition, infiltration practices should be separated from drinking water wells.

Design Considerations

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are some features, however, that should be incorporated into most infiltration trench designs. These design features can be divided into five basic categories: pretreatment, treatment, conveyance, maintenance reduction, and landscaping.

Pretreatment

Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural stormwater-management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate "multiple pretreatment," using practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.

Treatment

Treatment design features enhance the pollutant removal of a practice. During the construction process, the upland soils of infiltration trenches need to be stabilized to ensure that the trench does not become clogged with sediment. Furthermore, the practice should be filled with large clean stones that can retain the volume of water to be treated in their voids. Like infiltration basins, this practice should be sized so that the volume to be treated can infiltrate out of the trench bottom in 24 hours.

Conveyance

Stormwater needs to be conveyed through stormwater management practices safely, and in a way that minimizes erosion. Designers need to be particularly careful in ensuring that channels leading to an infiltration practice are designed to minimize erosion. Infiltration trenches should be designed to treat only small storms, (i.e., only for water quality). Thus, these practices should be designed "off-line," using a structure to divert only small flows to the practice. Finally, the sides of an infiltration trench should be lined with a geotextile fabric to prevent flow from causing rills along the edge of the practice.

Maintenance Reduction

In addition to regular maintenance activities, designers also need to incorporate features into the design to ensure that the maintenance burden of a practice is reduced. These features can make regular maintenance activities easier or reduce the need to perform maintenance. As with all management practices, infiltration trenches should have an access path for maintenance activities. An observation well (i.e., a perforated PVC pipe that leads to the bottom of the trench) can enable inspectors to monitor the drawdown rate. Where possible, trenches should have a means to drain the practice if it becomes clogged, such as an underdrain. An underdrain is a perforated pipe system in a gravel bed, on the bottom of filtering practices, installed to collect and remove filtered runoff. An underdrain pipe with a shutoff valve can be used in an infiltration system to act as an overflow in case of clogging.

Landscaping

In infiltration trenches, there is no landscaping on the practice itself, but it is important to ensure that the upland drainage is properly stabilized with thick vegetation, particularly following construction.

Length, Width, Depth and Geometry

The sizing of an infiltration device is determined by the dewatering requirements. Infiltration devices must be able to completely dewater within 5 days. The time to dewater can be estimated roughly as the runoff capture volume for the device divided by the product of the hydraulic conductivity and the effective infiltrating area. This can be rearranged to produce the following equation for determining the effective infiltrating area needed:

$$A = \frac{V}{2 * (K * T)}$$

where:

A = effective infiltrating area (ft^2)
V = volume of water requiring infiltration (ft^3)
K = hydraulic conductivity of soil (in/hr)
T = dewatering time (days)

The volume of water requiring infiltration (V) is prescribed by the specific stormwater program that applies to the site, and the runoff characteristics of the site. If the infiltration device is not going to meet the volume control requirements, it is simply the volume of water that is diverted and stored for infiltration. The runoff capture storage volume of an infiltration device that is filled with a drainage medium is equal to the volume of the facility, multiplied by the porosity of the medium, plus any temporary ponding that may be allowed before the facility overflows.

The hydraulic conductivity of the soil (K) is the resultant value from the field testing performed on the site. The dewatering time (T) for infiltration devices must be 5 days or less. A value of less than 3 days is recommended for use in the formula.

Once the effective infiltrating area (A) is obtained from the formula, it can still be somewhat difficult to translate that into actual infiltration device dimensions. The value for A used in the formula is actually the larger of either the bottom surface area or one-half of the total (wetted) wall area. The determination of the length, width, and depth dimensions is therefore often an iterative process using the effective infiltrating area (A); the correction factor for true surface areas of the in situ soil interface; and typical length, width, and depth recommendations.

Trench depths shall be no more than 8 feet. It is recommended that the width of a trench (perpendicular to influent flow direction) be less than 25 feet. Broad, shallow trenches reduce the risk of clogging by spreading the runoff over a larger area for infiltration.

Construction Considerations

Care should be used during installation to minimize compaction of soil on the bottom and walls of infiltration devices, since this will reduce the permeability at the soil interface. To avoid compacting the drainage media, lighter weight equipment and construction techniques that minimize compaction should be used.

Runoff shall not be directed into an infiltration device until the drainage area is stabilized. A construction sequence must be followed that reflects the need to stabilize the infiltration device. The longevity of infiltration devices is strongly influenced by the care taken during construction.

Infiltration trenches should not be covered by an impermeable surface unless there is suitable maintenance access, the design specifies an H-20 loading capacity, and the application includes a cross section of the H-20 design. Direct access must be provided to all infiltration devices for maintenance and rehabilitation. OSHA safety standards should be consulted for trench excavation.

A minimum of one observation well shall be included in the design of an infiltration system to periodically verify that the drainage media are fully draining. The monitoring well shall consist of a 4- to 6-inch-diameter, perforated polyvinyl chloride (PVC) pipe with a locking cap. The well should be placed near the center of the facility or in the general location of the lowest point within the facility, with the invert at the excavated bottom of the facility.

Common Problems

Although infiltration trenches can be a useful management practice, they have several limitations. While they do not detract visually from a site, infiltration trenches provide no visual enhancements. Their application is limited due to concerns over groundwater contamination and other soils requirements. Finally, maintenance can be burdensome, and infiltration practices have a relatively high rate of failure.

Maintenance

Regular maintenance of infiltration trenches is needed to reduce the likelihood of BMP failure.

If grass filter strips are present, they should be monitored for areas of bare soil and/or erosive gullies. These items should be repaired immediately by re-grading the area and re-planting. The planted area should be protected using mulching until vegetation can be established.

Sediment accumulation can clog the filter strip, the flow diversion structure, or the trench itself. First, the source of the sediment should be identified and the erosion issues addressed. Then, the sediment should be removed and the device restored to initial design standards.

Permeable Interlocking Concrete Paving

Practice Description

Permeable interlocking concrete paving (PICP) consists of manufactured concrete units that reduce stormwater-runoff volume, rate, and pollutants. The impervious units are designed with small openings between permeable joints. The openings typically comprise 5% to 15% of the paver surface area and are filled with highly permeable, small-sized aggregates. The joints allow stormwater to enter a crushed stone aggregate bedding layer and base that supports the pavers, while providing storage and runoff treatment. PICPs are highly attractive, durable, and easily repaired; require low maintenance; and can withstand heavy vehicle loads.

Planning Considerations

PICP can replace traditional impervious pavement for most pedestrian and vehicular applications except high-volume/high-speed roadways. PICP has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from PICP allow it to be incorporated into municipal green infrastructure and low impact development programs. In addition to providing stormwater volume and quality management, light-colored pavers are cooler than conventional asphalt and help to reduce urban temperatures and improve air quality. The textured surface of PICP also provides traffic calming and provides an aesthetic amenity.

PICP should not be confused with concrete grid pavements (i.e., concrete units with cells that typically contain topsoil and grass). These paving units can infiltrate water, but at rates lower than PICP. Unlike PICP, concrete grid pavements are generally not designed with an open-graded, crushed stone base for water storage. Moreover, grids are for intermittently trafficked areas such as overflow parking areas and emergency fire lanes.

Design Criteria

PICP should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these design aspects. For example, PICP can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements to infiltrate runoff and initiate a treatment train. Several applications use PICP in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes PICP installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be places in the PICP to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the PICP scale required.

Specific design requirements relating to the structural stability of permeable pavements are beyond the scope of this manual. The reader is referred to the AASHTO Flexible Pavement Method for structural design requirements. The following guidelines are presented to ensure that permeable pavements are properly located, designed, and constructed to meet water quality objectives.

1. A washed aggregate base must be used, and washed 57-size stone is generally acceptable. Fine particles from standard “crusher run” will clog the pores at the bottom of the pavement and will not be allowed.
2. Low traffic volume – less than 100 axles per day. Areas with higher traffic volume may be able to use permeable pavement in parking stalls, and use regular pavement in drive aisles.
3. As shown in Figure 1 below, the seasonal high water table must be at least 2 ft below the base of the permeable pavement or gravel storage layer. Water tables approaching the permeable pavement system will not allow water to exfiltrate.

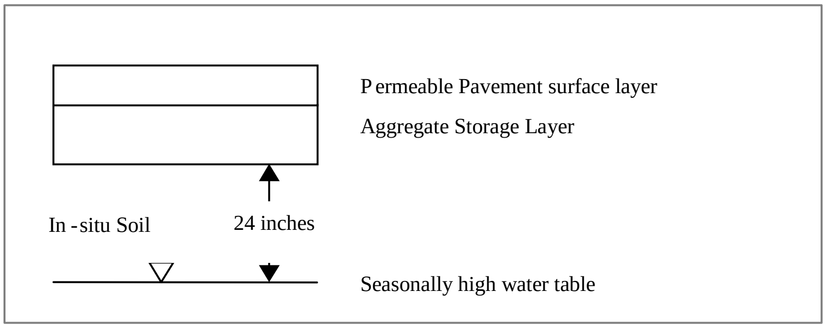

Figure 1 Schematic of Water Table Design Constraint

4. Permeable pavement should not be placed where upland land disturbance is occurring or will potentially occur. Land disturbance upland of the lot could result in frequent pavement clogging.

5. Avoid overhanging trees above the permeable pavement installation.

6. Steeper slopes can reduce the storage capacity of the permeable pavement, so it is important that the top of the soil subgrade (the bottom of the aggregate storage layer) be as close to flat as practicable (slope of ≤0.5%). If the top of the soil subgrade is >0.5%, baffles, partitions, berms, or terracing shall be installed to promote infiltration across the entire area of the subgrade and to reduce the potential for lateral flow. The surface of the permeable pavement shall be no more than 6%.

7. During preparation of the subgrade, special care must be made to avoid compaction of soils. Compaction of the soils can reduce the infiltration capacity of the soil.

8. Permeable pavement should not be designed to receive concentrated flow from roofs or other surfaces. Incidental run-on from stabilized areas is permissible, but the permeable pavement should be designed primarily to infiltrate the rain that falls on the pavement surface itself.

9. Permeable pavement systems are not allowed in areas, such as buffers, where impervious surfaces are not permitted.

10. The construction sequence will be inspected to ensure that the surface installation is planned to be completed after adjacent areas are stabilized with vegetation. Run-on to the permeable pavement from exposed areas can cause the system to perform ineffectively due to clogging.

Specific Design Considerations and Limitations

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the paver surface, and the storage capacity of the stone base/subbase are the key stormwater-design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains elevated above the subgrade clay soil are often used in PICP, further making it suitable for many clay soils by infiltrating some of the water and filtering and draining the remainder. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential or there is a high depth to bedrock or water table (NCSU, 2008).

Measures should be taken to protect PICP from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to pavers include filter strips and swales. Preventing sediment from entering the base or permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the PICP until these areas are stabilized.

Common Problems

PICP has the potential to become clogged with sediment if not protected from disturbed areas during construction activities.

Slope plays a role in applicability of PICP. Slopes greater than 2% may require additional design considerations, including terracing of soil subgrade.

PICP can cause safety concerns for disabled persons, bicycles, pedestrians wearing high-heels, and the elderly (SPU, 2009). Many PICP paver designs are ADA compliant, and other areas may require solid interlocking concrete pavements.

Maintenance

The most prevalent maintenance concern is the potential clogging of the openings and joints between the pavers. Fine particles that can clog the openings are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. However, while more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of PICP and other permeable pavements have found high infiltration rates initially, a decrease, and then a leveling off with time. With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. When substantially clogged, surface infiltration rates usually well exceed 1 inch per hour, sufficient in most circumstances to effectively manage stormwater. Permeability can be increased with vacuum sweeping or, in extreme circumstances, by replacing the aggregate between pavers.

Pervious Asphalt Pavement

Practice Description

Pervious asphalt, also known as porous, permeable, "popcorn," or open-graded asphalt, is standard hot-mix asphalt with reduced sand or fines that allow water to drain through it. Pervious asphalt over an aggregate storage bed will reduce stormwater runoff volume, rate, and pollutants. The reduced fines leave stable air pockets in the asphalt. The interconnected void space allows stormwater to flow through the asphalt and enter a crushed stone aggregate bedding layer and base that supports the asphalt while providing storage and runoff treatment. When properly constructed, pervious asphalt is a durable and cost-competitive alternative to conventional asphalt.

Planning Considerations

Pervious asphalt can be used for municipal stormwater-management programs and private development applications. The runoff volume and rate control, plus pollutant reductions, allow municipalities to improve the quality of stormwater discharges. Municipal initiatives, such as Portland's Green Streets program (shown in the photo above), use pervious asphalt to reduce combined sewer overflows by infiltrating and treating stormwater on site. Private development projects use pervious asphalt to meet post-construction stormwater quantity and quality requirements. The use of pervious asphalt can potentially reduce additional expenditures and land consumption for conventional collection, conveyance, and detention stormwater infrastructure.

Pervious asphalt can replace traditional impervious pavement for most pedestrian and vehicular applications. Open-graded asphalt has been used for decades as a friction course over impervious asphalt on highways to reduce noise, spray, and skidding. Highway applications with all-pervious asphalt surfacing have been used successfully for highway pilot projects in the United States; however, generally, pervious asphalt is recommended for low-volume and low-speed applications (Hossain et al., 1992). Pervious asphalt performs well in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from pervious asphalt allow it to be incorporated into municipal green infrastructure and low impact development programs. The appearance of pervious asphalt and conventional asphalt is very similar. The surface texture of pervious asphalt is slightly rougher, providing more traction to vehicles and pedestrians.

Design Criteria

Pervious asphalt should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these objectives. For example, pervious asphalt can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements or roofs to infiltrate runoff. Several applications use pervious asphalt in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes pervious asphalt installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be placed in the pervious asphalt to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the scale of permeable pavement required.

Pervious asphalt comprises the surface layer of the permeable pavement structure and consists of open-graded coarse aggregate, bonded together by bituminous asphalt. Polymers can also be added to the mix to increase strength for heavy load applications. The thickness of pervious asphalt ranges from 2 to 4 inches depending on the expected traffic loads. For adequate permeability, the pervious asphalt should have a minimum of 16% air voids. Additional subsurface components of this treatment practice (illustrated in Figure 1) include the following (National Asphalt Pavement Association, 2008):

- *Choke course* - This permeable layer is typically 1-2 inches thick and provides a level and stabilized bed surface for the pervious asphalt. It consists of small-sized, open-graded aggregate.
- *Open-graded base reservoir* - This aggregate layer is immediately beneath the choke layer. The base is typically 3-4 inches thick and consists of crushed stones typically 3/4 to 3/16 inch. Besides storing water, this high-infiltration rate layer provides a transition between the bedding and subbase layers.
- *Open-graded subbase reservoir* - The stone sizes are larger than the base, typically ¾ to 2½ inch stone. Like the base layer, water is stored in the spaces among the stones. The subbase layer thickness depends on water storage requirements and traffic loads. A subbase layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.
- *Underdrain (optional)* - In instances where pervious asphalt is installed over low-infiltration rate soils, an underdrain facilitates water removal from the base and subbase. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the

aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.

- *Geotextile (optional)* - This can be used to separate the subbase from the subgrade and to prevent the migration of soil into the aggregate subbase or base.
- *Subgrade* - The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted.

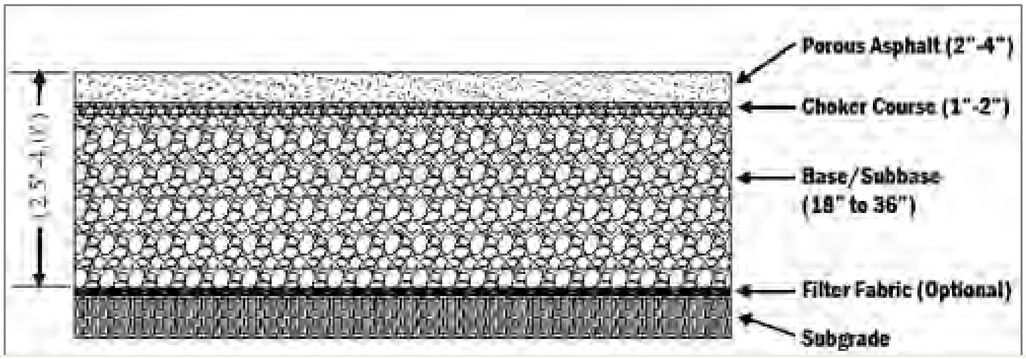

Figure 1 Typical Porous Asphalt Pavement Section (diagram adapted from USEPA, 1986)

The same equipment can be used for mixing and laying permeable asphalt as for conventional asphalt. The method for laying the asphalt will also be similar. During compaction of the asphalt, minimal pressure should be used to avoid closing pore space. Vehicular traffic should be avoided for 24 to 48 hours after pavement is installed.

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the pervious asphalt, and the storage capacity of the stone base/subbase are the key stormwater-design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains are often used when permeable pavements are installed over clay. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential, or if there is a high depth to bedrock or water table (Hunt and Collins, 2008).

Common Problems

Measures should be taken to protect permeable pavement from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to permeable pavement include filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the permeable pavement until these areas are stabilized.

Several factors may limit permeable pavement use. Pervious asphalt has reduced strength compared to conventional asphalt and will not be appropriate for applications with high volumes and extreme loads. It is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, stored, or where there is a potential for spills and fuel leakage. For slopes greater than 2 percent, terracing of the soil subgrade base may likely be needed to slow runoff from flowing through the pavement structure.

Maintenance

The most prevalent maintenance concern is the potential clogging of the pervious asphalt pores. Fine particles that can clog the pores are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. While more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of pervious asphalt and other permeable pavements have found high infiltration rates initially, followed by a decrease, and then leveling off with time (Bean et al., 2007). With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. When clogged, surface infiltration rates usually well exceed 1 inch per hour, which is sufficient in most circumstances for the surface to effectively manage intense stormwater events (Interlocking Concrete Pavement Institute, 2000). Permeability can be increased with vacuum sweeping. In areas where extreme clogging has occurred, half-inch holes can be drilled through the pavement surface every few feet or so to allow stormwater to drain to the aggregate base. A stone apron around the pavement connected hydraulically to the aggregate base and subbase can be used as a backup to surface clogging or pavement sealing.

Due to the well-draining stone bed and deep structural support of pervious asphalt pavements, they tend to develop fewer cracks and potholes than conventional asphalt pavement. When cracking and potholes do occur, a conventional patching mix can be used. Freeze/thaw cycling is a major cause of pavement breakdown; pervious asphalt parking lots can have a lifespan of more than 30 years because of the reduced freeze/thaw stress (Gunderson, 2008).

Cold weather and frost penetration do not negatively impact surface infiltration rates. Pervious asphalt freezes as a pervious medium rather than a solid block because permeable pavement systems are designed to be well drained; infiltration capacity is preserved because of the open void spaces (Gunderson, 2008). However, plowed snow piles should not be left to melt over the pervious asphalt, as they can receive high sediment concentrations that can clog the pavement system more quickly.

Permeable pavements do not treat chlorides from road salts but also require less applied deicer. Deicing treatments are a significant expense, and chlorides in stormwater runoff have substantial environmental impacts. Reducing chloride concentrations in runoff is achieved only through reduced application of road salts, because removal of chloride with stormwater BMPs is not effective.

Pervious Concrete

Photo Courtesy of pavementinteractive.org

Practice Description

Pervious concrete, also known as pervious, gap-graded, or enhanced porosity concrete, is concrete with reduced sand or fines and allows water to drain through it. Pervious concrete is often constructed over an aggregate storage bed to allow for stormwater infiltration and temporary storage. This aggregate layer not only provides temporary stormwater storage but also helps to support the concrete. Pervious concrete has less sand and fines than standard concrete, which leaves stable air pockets in the concrete that allow water to flow through. This void space is generally between 15 and 35 percent. When properly installed, pervious concrete is a durable and low-maintenance paving option.

Planning Considerations

Pervious concrete can be used for municipal stormwater management programs and private development applications. The runoff volume and rate control, plus pollutant reductions, allow municipalities to improve the quality of stormwater discharges. Municipal initiatives, such as Chicago’s Green Alley program, use pervious concrete to reduce combined sewer overflows and to minimize localized flooding by infiltrating and treating stormwater on site. Private development projects use pervious concrete to meet post-construction stormwater quantity and quality requirements. The use of pervious concrete can potentially reduce additional expenditures and land consumption for conventional collection, conveyance, and detention stormwater infrastructure. Public and private developments have used pervious concrete, which is a naturally brighter surface than traditional asphalt, to reduce lighting needs and increase nighttime safety.

Pervious concrete can replace traditional impervious pavement for most pedestrian and vehicular applications except high-volume/high-speed roadways. Pervious concrete can be designed to handle heavy loads, but surface abrasion from constant traffic will cause the pavement to deteriorate more quickly than conventional concrete. Pervious concrete has performed successfully in pedestrian walkways, sidewalks, driveways, parking lots, and low-volume roadways. The environmental benefits from pervious concrete allow it to be incorporated into municipal green infrastructure and low impact development programs. In addition to providing stormwater volume and quality management, the light color of concrete is cooler than conventional asphalt and helps to reduce urban temperatures and improve air quality (Grant et al., 2003; Vingarzan and Taylor, 2003). Unlike the smoothed surface of conventional concrete, the surface texture of pervious concrete is slightly rougher, providing more traction to vehicles and pedestrians.

Design Criteria

Pervious concrete should be designed and sited to intercept, contain, filter, and infiltrate stormwater on site. Several design possibilities can achieve these objectives. For example, pervious concrete can be installed across an entire street width or an entire parking area. The pavement can also be installed in combination with impermeable pavements or roofs to infiltrate runoff. Several applications use pervious concrete in parking lot lanes or parking stalls to treat runoff from adjacent impermeable pavements and roofs. This design economizes pervious concrete installation costs while providing sufficient treatment area for the runoff generated from impervious surfaces. Inlets can be placed in the pervious concrete to accommodate overflows from extreme storms. The stormwater volume to be captured, stored, infiltrated, or harvested determines the scale of permeable pavement required.

Pervious concrete comprises the surface layer of the permeable pavement structure and consists of portland cement, open-graded coarse aggregate (typically 5/8 to 3/8 inch), and water. Admixtures can be added to the concrete mixture to enhance strength, increase setting time, or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the expected traffic loads. Additional subsurface components of this treatment practice are illustrated in Figure 1 and include the following (National Ready Mix Concrete Association (NRMCA), 2008):

- *Choke course* - This permeable layer is typically 1-2 inches thick and provides a level bed for the pervious concrete. It consists of small-sized, open-graded aggregate.
- *Open-graded base reservoir* - This aggregate layer is immediately beneath the choke layer. The base is typically 3-4 inches thick and consists of crushed stones typically 3/4 to 3/16 inch. Besides storing water, this high-infiltration rate layer provides a transition between the bedding and subbase layers.
- *Open-graded subbase reservoir* - The stone sizes are larger than the base, typically 2½ to 2¾ inch stone. Like the base layer, water is stored in the spaces among the stones. The subbase layer thickness depends on water storage

requirements and traffic loads. A subbase layer may not be required in pedestrian or residential driveway applications. In such instances, the base layer is increased to provide water storage and support.

- *Underdrain (optional)* - In instances where pervious concrete is installed over low-infiltration rate soils, an underdrain facilitates water removal from the base and subbase. The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base.
- *Geotextile (optional)* - This can be used to separate the subbase from the subgrade and to prevent the migration of soil into the aggregate subbase or base.
- *Subgrade* - The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted.

Properly installed pervious concrete requires trained and experienced producers and construction contractors. The installation of pervious concrete differs from conventional concrete in several ways. The pervious concrete mix has low water content and will therefore harden rapidly. Pervious concrete needs to be poured within one (1) hour of mixing. The pour time can be extended with the use of admixtures. A manual or mechanical screed set ½ inch above the finished height can be used to level the concrete.

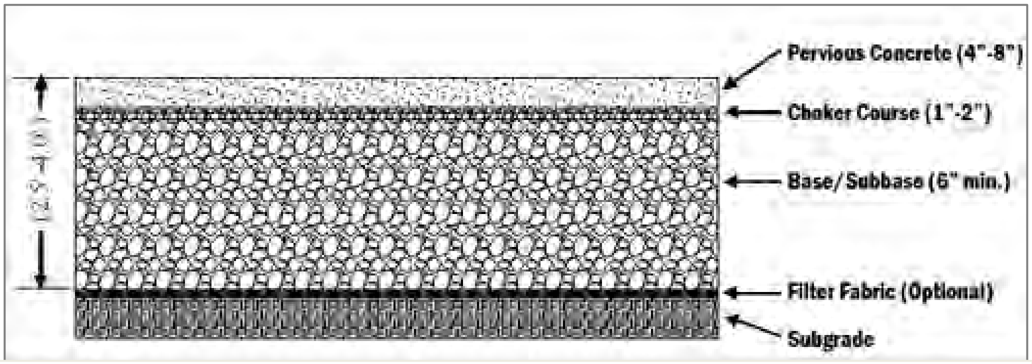

Figure 1 Typical Porous Asphalt Pavement Section (diagram adapted from USEPA, 1986)

Floating and troweling are not used, as these actions may close the surface pores. Consolidation of the concrete, typically with a steel roller, is recommended within 15 minutes of placement. Pervious concrete also requires a longer time to cure. The concrete should be covered with plastic within 20 minutes of setting and allowed to cure for a minimum of 7 days (NRMCA, 2008).

Siting Considerations

- Do not install in areas where hazardous materials are loaded, unloaded, or stored.
- Avoid high sediment-loading areas.
- Divert runoff from disturbed areas until stabilized.
- Do not use sand for snow or ice treatment.
- Periodic maintenance to remove fine sediments from paver surface will optimize permeability.

Common Problems

The load-bearing and infiltration capacities of the subgrade soil, the infiltration capacity of the pervious concrete, and the storage capacity of the stone base/subbase are the key stormwater design parameters. To compensate for the lower structural support capacity of clay soils, additional subbase depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade. Underdrains are often used when permeable pavements are installed over clay. In addition, an impermeable liner may be installed between the subbase and the subgrade to limit water infiltration when clay soils have a high shrink-swell potential, or if there is a high depth to bedrock or water table (Hunt and Collins, 2008).

Measures should be taken to protect permeable pavement from high sediment loads, particularly fine sediment. Appropriate pretreatment BMPs for run-on to permeable pavement include filter strips and swales. Preventing sediment from entering the base of permeable pavement during construction is critical. Runoff from disturbed areas should be diverted away from the permeable pavement until the areas are stabilized.

Several factors may limit permeable pavement use. Pervious concrete has reduced strength compared to conventional concrete and will not be appropriate for applications with high volumes and extreme loads. It is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, stored, or where there is a potential for spills and fuel leakage. For slopes greater than 2 percent, terracing of the soil subgrade base may likely be needed to slow runoff from flowing through the pavement structure. In another approach for using pervious concrete slopes, lined trenches with underdrains can be dug across slope to intercept flow through the subbase (ACPA, 2006).

Maintenance

The most prevalent maintenance concern is the potential clogging of the pervious concrete pores. Fine particles that can clog the pores are deposited on the surface from vehicles, the atmosphere, and runoff from adjacent land surfaces. Clogging will increase with age and use. While more particles become entrained in the pavement surface, it does not become impermeable. Studies of the long-term surface permeability of pervious concrete and other permeable pavements have found high infiltration rates initially, followed by a decrease, and then leveling off with time (Bean et al., 2007a). With initial infiltration rates of hundreds of inches per hour, the long-term infiltration capacity remains high even with clogging. Permeability can be increased with vacuum sweeping. In areas where extreme clogging has occurred, half-inch holes can be drilled through the pavement surface every few feet or so to allow stormwater to drain to the aggregate base. Many large cuts and patches in the pavement will weaken the concrete structure.

Cold weather and frost penetration do not negatively impact surface infiltration rates. Permeable concrete freezes as a pervious medium rather than a solid block because permeable pavement systems are designed to be well drained; infiltration capacity is preserved because of the open void spaces (Gunderson, 2008).