PERMEABLE PAVEMENT

PT-2

3 POINTS

GOAL

Improve flow control and quality of stormwater runoff through use of permeable pavement technologies.

CREDIT REQUIREMENTS

Use a permeable (porous) pavement or pavers to control and treat at least 50% of the 90th percentile average annual rainfall event post-construction runoff volume to 25 mg/L concentration of total suspended solids (TSS) or less.

Details

Low impact development (LID) stormwater controls must be considered in the scope and budget of the project for this credit to be applicable AND permeable pavement must be considered a feasible design best management practice within the stormwater management plan. This means that the feasibility study completed for PR-8 Low Impact Development must clearly show that permeable pavement (of any type) is appropriate for application on the project.

DOCUMENTATION

- Copy of the drainage or hydrology report and supporting calculations showing treatment area and percent treatment achieved. This document may be included as part of the submittal requirements for PR-8 Low Impact Development, but relevant permeable pavement calculations, areas, and treatment levels should be highlighted for this credit.
- Copy of the permeable pavement mix design. The mix design should have the following items highlighted:
    - Name of permeable technology, if used (e.g. pavers, turf, etc.)
    - Total tons of pavement on the project, including portland cement concrete and asphalt concrete (hot, warm and cold mix)
    - Total air voids in the mix (or manufacturer-tested voids specifications for pavers based on method of installation)
    - Total tons of permeable pavement used
- Copy of the maintenance plan in-place for the permeable pavement(s).
- Photo of the permeable pavement(s) installed on the project.

RELATED CREDITS

- ✓ PR-8 Low Impact Development
- ✓ EW-2 Runoff Flow Control
- ✓ EW-3 Runoff Quality
- ✓ EW-4 Stormwater Cost Analysis
- ✓ PT-4 Cool Pavement
- ✓ PT-5 Quiet Pavement

SUSTAINABILITY COMPONENTS

- ✓ Ecology
- ✓ Expectations
- ✓ Experience

BENEFITS

- ✓ Reduces Water Pollution
- ✓ Restores Habitat
- ✓ Creates Habitat
- ✓ Reduces Manmade Footprint
- ✓ Increases Aesthetics

APPROACHES & STRATEGIES

Following some of these key design and maintenance elements will promote maximum performance of permeable pavements. (Pennsylvania Department of Environmental Protection: PDEP, 2006)

Design Elements

- Use a mix design for the pavement with significant permeability (> 8 inches per hr).
- Use an open-graded subbase with minimum 40% void space (typically a washed aggregate).
- Design the pavement surface and stone bed to suitable for design traffic loads.
- Ensure placement on uncompacted sub-grade.
- Use nonwoven geotextile underlayments.
- Use level infiltration bed bottoms to prevent pooling.
- Do not place on trafficked slopes with grades over >5% (without careful design).
- Provide positive stormwater overflow from beds.
- Do not place bed bottom on compacted fill; fill with stone, as needed.
- Protect from sedimentation during construction.
- Line bed with nonwoven geotextile.
- Provide perforated pipe network along bed bottom for distribution.
- Allow three foot buffer between bed bottom and seasonal high ground water table and two feet for bedrock.
- Place infiltration beds on upland soils when possible.
- **Attempt to make periodic maintenance easy for owners in the design process**. Pavement areas should be accessible and slope gradually to accommodate standard maintenance vehicles.

Clog Prevention Maintenance

- Vacuum the pavement twice per year (or align with rainy season).
- Maintain planted areas adjacent to pavement.
- Immediately clean any soil deposited on pavement.
- Do not allow construction staging, soil/mulch storage, etc. on unprotected pavement surface.
- Clean inlets draining to the subsurface bed twice per year.

Winter Snow/Ice Removal

- Monitor the permeable pavement in the winter. Porous pavement systems generally perform better and require less treatment than standard pavements.
- Do not apply abrasives such as sand or cinders on or adjacent to porous pavement.
- Place snowplow blades slightly higher than for conventional pavements.
- Apply salt as necessary; however, keep in mind that salts will infiltrate, so organic deicers are preferable.

Maintenance Repairs

- **Do not seal-coat permeable pavement surfaces.**
- Patch damaged areas less than 50 square feet with porous or standard pavement.
- Patch damaged areas larger than 50 square feet with an approved permeable pavement.

Example: Types of Permeable Pavement

Porous Asphalt

Porous asphalt, developed about 1970, greatly resembles non-porous asphalt except the fines (very fine sand and dust) have been removed, leaving additional air voids where the fines would have been. This leaves space for water to flow through and collect. Large aggregate is also used to raise the void space. Asphalt is typically designed with a small amount of air voids, typically 4% of the total mix volume, in order to allow the binder to migrate a little. The binder remains somewhat soft long after pavement is laid, and sometimes moves into these voids, which is called migration. There were problems in the past with early porous asphalt, as the binder would migrate into the higher void spaces, blocking the travel path of the water. This has been ameliorated with the use of additives and additional binders. (North Carolina Department of Environment and Natural Resources, 2007; Hun-Dorris, 2005)

Additives and additional binders are often used to enhance the characteristics of porous asphalt. Polymers keep the binder from migrating into the void spaces. Polymer-reinforcing fibers assist with cohesion of the mix. (Hun-Dorris, 2005)

Figure PT-2.1: The appearance of porous asphalt is much the same as non-porous asphalt. The porous asphalt is placed over course of porous aggregate beneath a temporary geotextile fabric, which is to prevent clogging issues during construction. (Photo by K. Hansen, National Asphalt Pavement Alliance)

Porous Concrete

Porous concrete, much like porous asphalt, has the fines removed in order to create voids. It was also developed in the 70s. Portland cement concrete (PCC) is typically made with coarse aggregate (gravel), fine aggregate (sand), water, cement, and optional additives. In porous concrete, the fines are greatly reduced or entirely removed. Fifteen to twenty-five percent (15-25%) void spaces may be achieved, with an average flow rate of around 480 inches per hr. (Hun-Dorris, 2005) The appearance of porous PCC is generally rougher than nonporous. See Figure PT-2.2. Finishing during the construction process may create an impervious layer on the surface and attention needs to be paid to the process to prevent this from happening.

Figure PT-2.2: Porous concrete surface course in West Seattle, Washington. Quarter provided for scale. (Photo by J. Anderson)

Block Pavers

Concrete pavers, or porous paver blocks, are interlocking units which are partially pervious. Water drains through the areas between each block. These spaces can be filled with gravel or grass, and offer drainage and an attractive finish. Void space (open area) of pavers tends to be 13-15% (Hun-Dorris, 2005). Paver blocks are typically used in low traffic areas, such as walking paths or driveways, and are easy to install. See Figure PT-2.3.

Figure PT-2.3: A variety of permeable pavers, bricks, and non-porous asphalt. (Photo by Sean Thayer)

Other Permeable Pavements

Other permeable pavements include open graded aggregates, artificial turf and turf reinforcement.

Open graded aggregate. Open-graded aggregate is washed to remove fines and is typically made of single-sized, angular pieces. This allows for low settling compaction, and void spaces may constitute up to 40% of the material. Open-graded aggregate is extremely permeable. This kind of base has a strong tendency to segregate and steps must be taken through production, transport, and placement to offset this tendency. Regularly wetting the stone through the laydown and compaction processes keeps the material more stable.

Figure PT-2.4: Washed aggregate base with keys for scale.

Artificial turf. Artificial turf is typically the topmost layer of one or more other permeable layers, such as open graded aggregate. Artificial turf is rolled out in large sheets (see following photos) and pinned to the underlayer. The seams between lengths of turf are stitched. Artificial turf typically lasts for 12 to 15 years.

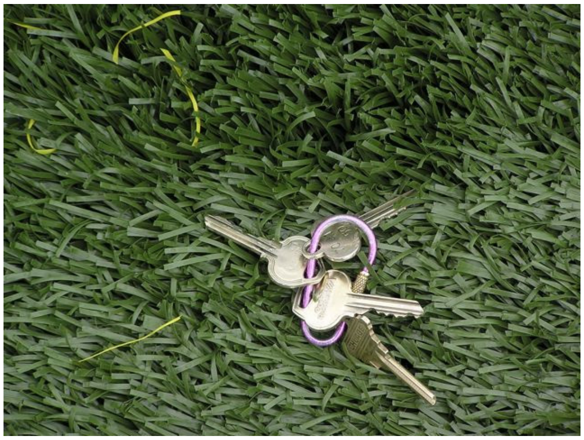

Figure PT-2.5: Permeable artificial turf (keys for scale). This material is typically laid over a base of washed open-graded aggregate.

Figure PT-2.6: Underside of permeable artificial turf, showing drainage holes.

Turf reinforcement. Similarly, turf reinforcement (commonly called “geogrid”) is typically achieved via an open plastic grid or honeycomb matrix that is filled with gravel at the surface, placed on a well-draining aggregate, over a layer of geosynthetic filter fabric, and finally on top of a well-draining soil subbase. Usually these installations are most common in gravel parking areas or emergency accessways that need a bit of extra reinforcement in order to carry a (low volume) vehicle load. We do not expect many Greenroads projects to be made of turf or geogrids or gravel, but these methods are technically valid and may be appropriate for pedestrian areas within the project right-of-way. See Figure PT-2.7.

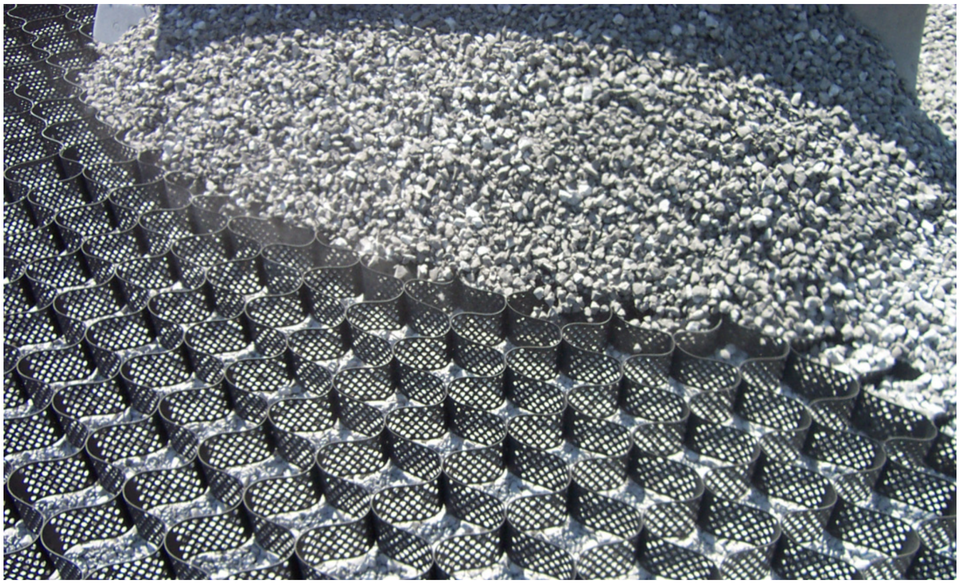

Figure PT-2.7: Turf reinforcing grid installed in gravel parking area in Pennsylvania to alleviate ponding issues. (Blair County Conservation District, n.d.)

Semi-Permeable Materials Not Suitable for Roadway Traffic

For purposes of this credit, we do not expect many Greenroads projects to be made of timber decking, wood mulch, shells or turf. These materials may be installed on a project as part of a low-impact development scheme (to reduce actual impervious surfaces, such as conventional concrete sidewalks); however, areas made with these materials do not count toward points in this credit.

Soft materials. Soft paving materials, such as wood mulch and crushed shells, are typically used for foot traffic. High void spaces allow for good permeability, and such materials tend to offer great aesthetic benefits.

Timber Decking. Decks allow for ease of walking through swampy or sandy areas while creating very low-environmental-impact structures. Wooden structures are also natural looking and aesthetically pleasing.

POTENTIAL ISSUES

1. Clogging of voids in the pavement. Routine maintenance is recommended to help prevent clogging and optimize infiltration rates.
2. Quality control and contractor familiarity varies widely with location, contractor and pavement type.
3. Pre-existing groundwater issues may not allow permeable pavements within certain distances of aquifers. However, quality treatment is provided by permeable pavements to some extent.
4. Long-term data is generally not available.
5. Permeable pavements may not be suitable for high volume traffic loads or arterials. However, shoulder areas and sidewalks may be appropriate applications to consider.

RESEARCH

Permeable pavement is a low-impact development technique that can be used as part of a comprehensive roadway stormwater management plan. The terms “permeable,” “porous” or “pervious” are used interchangeably to describe a pavement structural system that has more voids than a conventional paved surface such as concrete or asphalt. For stormwater design, permeable implies that the curve number (CN) for areas paved with these surface materials is lower than a conventionally paved surface. For composite mixes, such as asphalt and concrete, this generally means intentionally designing for a higher void ratio in the mix, i.e. fewer fine aggregates, larger coarse aggregate or introduction of air during mixing.

A permeable surface may also be achieved through a strategic layout of stone or masonry pavers and filling paver gaps with a well-draining material, which may be designed to withstand vehicular loading. This also provides an increase in overall void ratio over a large surface area. Further, artificial turf or grid reinforcement are other types of surfaces that may also be considered permeable "pavements," but in general for roadways that carry high volumes of traffic, there is no long-term performance data to justify that they offer enough structural capacity to carry those loads. Generally, the latter applications will be seen most commonly in pedestrian areas or areas with very low traffic volumes.

How Do Permeable Pavements Work?

Due to the increased void ratio, water is conveyed through the surface and allowed to (1) infiltrate, (2) evaporate, whereas conventional surfaces will not do so. (NCDWQ, 2007) A permeable pavement surface therefore becomes an active participant in the hydrological cycle: rainfall and snowmelt are conveyed back through soils into groundwater. Therefore, permeable pavements can become part of a stormwater infiltration system if appropriately designed, constructed and maintained. This means that key elements of the pavement must be considered: (1) long-term hydraulic capacity of the material, and (2) infiltration capacity of the base material. (City of Seattle, 2008)

Permeable pavements allow rainwater, snowmelt and air to pass through the matrix, recharging the groundwater table and refreshing soil nutrients. This reduces total volume of runoff flows leaving the paved surface. The void space captures water and slowly releases it to infiltrate the subgrade. This filtration process reduces the total quantity and concentration (generally) of pollutants that would otherwise runoff the paved surface and require treatment, volume control and flow attenuation. Typical pollutants removed or improved are hydrocarbons and heavy metals, (Hun-Dorris, 2005) as well as a number of other chemical compounds that are considered deleterious. (Geosyntec Consultants and Wright Water Engineers, 2008)

The air voids also allow for evaporation, which offers a cooling process on the surface and to the stormwater runoff. This is especially beneficial in cities which experience extremely high temperatures in summer - traditional "blacktop" temperatures can make some public spaces unusable in warmer weather. (Hun-Dorris, 2005)

Existing Literature

Stormwater quality and quantity performance data is relatively sparse for permeable pavements, especially for long term data. "Long-term" performance data (6 years) is available from four different pervious paver and turf reinforcing grid systems installed in urban parking lots in western Washington from Brattebo and Booth (2003). These lots were originally tested by Booth and Leavitt (1999) in 1997. Site soils were sands with a high hydraulic conductivity to isolate the pavement hydraulic conductivity. These two studies showed significantly or completely reduced surface runoff for winter storm conditions even long-term, except in one condition measured in the revisit by Brattebo and Booth: a 72-hour storm produced about four millimeters of surface flow.

In the UK, a porous asphalt parking lot was tested in place and monitored for flow control performance over a 13-month period. The results indicated that the pavements reduced peak flows and increased time of concentration. (Abbott & Camino-Mateos, 2003) A relatively recent study of another porous asphalt parking lot in Rhode Island by Boving et al. (2008) investigated the potential for contaminants to leach from the lot into the groundwater table directly below the lot's infiltration bed. They found a retention rate of more than 90% for metals, no bacteria, and a much lower rate for nutrients (27%). However, they detected polycyclic aromatic hydrocarbons (PAHs) at near minimum allowable levels.

Information on pavement structural performance in high-traffic volume roadway environments is very limited. Open-graded surface courses (OGFC) in Oregon have traditionally been installed to reduce noise and spray. However, they may theoretically also reduce surface flows via horizontal hydraulic conductivity, which occurs below the surface course and moves water to the shoulder areas, but this has not been well-studied. (City of Seattle, 2008)

However, the International Stormwater BMP (Best Management Practice) database (BMPDB) reports that, of six reporting permeable pavement sites, quality indicators for effluent heavy metal and total suspended solid concentration were as follows (shown compared to a detention pond) based on median values from mean effluent concentrations. For comparison, ranges are also provided.

Table PT-2.1: Constituent removal performance data for 6 permeable pavement installations and 25 detention ponds. (GeoSyntec Consultants and Wright Water Engineers, 2008)

Constituents	Unit	Value	Permeable Pavement Effluent (6 reporting)	Detention Pond Effluent (25 reporting)	Relative Removal (%)
Suspended Solids	(mg/L)	Median	16.96	31.04	183
		Range	5.90 – 8.72	16.07 – 46.01	-
Total Copper	(µg/L)	Median	2.78	12.10	435
		Range	0.88 – 8.78	5.41 – 18.80	-
Total Lead	(µg/L)	Median	7.88	15.77	200
		Range	1.64 – 37.96	4.67 – 26.87	-
Total Zinc	(µg/L)	Median	16.60	60.20	363
		Range	5.91 – 46.64	20.70 – 99.70	-
Total Phosphorus	(mg/L)	Median	0.09	0.19	211
		Range	0.05 – 0.15	0.12 – 0.27	-
TKN	(mg/L)	Median	1.23	1.89	154
		Range	0.44 – 3.44	1.58 – 2.19	-

In all six quality measures tested, permeable pavement installations treated effluent stormwater to a higher level of treatment than conventional detention ponds. Note that data for these statistics comes from 15 U.S. states and also the United Kingdom (UK) and Sweden, but neither the locations nor the types of these permeable pavements were specified, nor were the storm conditions when these data were measured. Additionally, data was not provided for influent treatment levels because it was not measured for the pavements or there were not enough samples for statistical analysis. However, the BMPDB maintains a working database and it is currently updating statistics for 2009.

Finally, studies on safety are also limited. One study of safety of surface course porous asphalt in Europe (where permeable pavements) are more common was inconclusive due to inconsistent reporting. (Elvik and Greibe, 2005)

Permeable Pavement Benefits

Permeable pavements offer many benefits, both aesthetic and practical. These include (Charles River Watershed Association: CWRA, 2008):

- Reduces stormwater runoff, total water volume, and flowrate
- Treats water runoff, including reduction of temperature
- Increases groundwater infiltration and recharge
- Provides local flood control
- Improves the quality of local surface waterways
- Reduces soil erosion
- Reduces the need for traditional stormwater infrastructure, which may reduce the overall project cost
- Increases traction when wet
- Reduces splash-up in trafficked areas
- Extends the life of paved area in cold climates due to less cracking and buckling from the freeze-thaw cycle
- Reduces the need for salt and sand use during the winter, due to little or no black ice
- Requires less snow-plowing
- Reduces groundwater pollution
- Creates greenspace (grass groundcover, shade from tree canopies, etc.)

- Offers evaporative cooling
- Porous pavements reduce the volume of stormwater, increase the recharge, control the peak rate, and offer a high outflowing water quality.
- Pollutants are removed: total suspended solids are reduced by 85%, NO_3 by 30%, and total phosphorous by 85%. (PDEP, 2006)

Cost Considerations

With a permeable pavement system, traditional stormwater systems may be reduced or bypassed entirely. This may reduce the total lifecycle cost of the project significantly. Cost depends on the system chosen, and varies widely. A washed aggregate gravel pathway that may be appropriate in some pedestrian areas will be extremely inexpensive and have extremely high hydraulic conductivities (Hun-Dorris, 2005).For surface courses, permeable asphalt is more expensive than traditional asphalt. The project specifics also significantly dictate the cost, and must be considered individually. (EPA, 2000)

- Porous asphalt, with additives, may cost more than standard asphalt on a unit area basis. Generally this depends on availability and contractor familiarity. (PDEP, 2006)
- Porous concrete as a material is generally more expensive than porous asphalt and requires more labor and experience for installation due to specific material constraints. (*ibid.*)
- Porous paver blocks vary in cost depending on type, manufacturer, order volume and site layout. (*ibid.*)

Design Elements

Design of permeable structures generally includes a permeable surface such as asphalt or portland cement concrete over a base of fines, which help to filter the water, and uniformly graded gravel, which stores the water as it infiltrates through the ground below the structure. An uncompacted soil base is highly recommended, and construction practices which emphasize this are critical for groundwater recharge. (CRWA, 2008)

The design of permeable pavements varies considerably due to location and cost considerations. However, three things must be considered regardless of which design is being considered: (1) the location and any unique features, hydrogeologic and geotechnical characteristics, local codes, etc.; (2) proper structural design; (3) and quality construction (Hun-Dorris, 2005). Soil beneath the permeable pavement structure must allow the accumulated water to drain, meaning these soils must not be overcompacted. Care must also be taken to ensure that debris and water drains away from the permeable structure, in all directions, to ensure that clogging does not become a problem.

Maintenance Requirements

Regular maintenance is recommended for permeable pavements. This may include re-sodding, laying gravel, and other small repairs. Other typical concerns for maintaining the permeable pavement are limited to aesthetics, snow and ice conditions and the prevention/repair of clogging.

Clog Prevention

More typically, maintenance of a permeable structure refers to vacuum sweeping, pressure washing, or air blowing to remove debris. Vacuuming is recommended (PDEP, 2006). Depending on the site, this may need to happen 2-4 times a year (CRWA, 2008). Clogging can be prevented or mitigated through proper routine maintenance of planted areas, cleaning up soil spills, thoughtful construction staging and storage of soils, covering permeable pavement installations during construction and cleaning drainage inlets at least twice a year or seasonally (PDEP, 2006). Proper design may prevent clogging, such as designing for drainage away from the porous section of pavement. This will keep debris from sweeping onto the pavement while allowing rain to infiltrate the soil below (PDEP, 2006).

Winter Maintenance

Winter maintenance for permeable pavements is simpler than that for typical pavements because the increased air voids and heat retention in the stone bed beneath the pavement tends to provide good snow melt, leading to reduced snow and ice problems. Abrasives that might promote localize clogging, such as sand, on or near the porous pavement should be avoided. Snow plowing may be used with caution, setting the blade about an inch higher than normal. Salt may be used; however, nontoxic organic deicers are preferred, as the contaminated water will go directly to the water table.

Repairs

Drainage structure repair has the highest priority, in order to keep the system working as designed. Pavement structural repairs will likely be limited primarily to areas that may have settled due to soft soils. These areas may be patched with standard or permeable pavement. Potholes will rarely be a problem, due to the lack of a freeze-thaw cycle as in typical pavements. Seal coats ought not to be used, as they would nullify the benefit of a permeable pavement.

GLOSSARY

OGFC	Open-graded friction course
Curve Number	A hydrological parameter that is used to model runoff
TKN	Total Kjeldahl Nitrogen
Permeable pavement	A pavement structural system that has more voids than a conventional paved surface such as concrete or asphalt

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