Porous Pavement

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Porous pavement (also known as permeable and pervious pavement) is a stormwater management facility that allows water to move through void spaces within the pavement and eventually infiltrate into underlying soils. In many cases, it can be used instead of conventional, impervious pavements for both vehicular and pedestrian traffic, without the need for any additional stormwater management feature such as a detention basin or a rain garden. These systems reduce volumes of runoff that would otherwise be produced by impervious surfaces such as parking lots, roads, and sidewalks. Three primary variations of porous pavement surfaces exist, providing several aesthetic options.

Porous pavements have fewer location restrictions than many other stormwater facilities and can be used almost anywhere impervious pavements are used (PBMP 2006). They have been used most widely in commercial parking lots because many believe that maintenance is more likely to be performed in these situations; however, porous pavements have also been used all over the world in many different environmental conditions for sidewalks, driveways, public and private roads, and highways. Furthermore, many pavements are being placed in upland areas where water has not yet pooled and soils tend to drain more efficiently (Hicks and Lundy 1998).

Photo courtesy of Dave Frentress

Decorative porous concrete sidewalk in China.

When properly installed and maintained, these pavements have worked well for over 20 years and in fact can outlast their impervious asphalt and concrete counterparts in durability (PSAT 2005, Hicks and Lundy 1998). For instance, in areas with freeze-thaw cycles, the pores in the pavement give the water a place to expand without breaking up the pavement.

Porous asphalt or concrete is similar to impervious concrete and asphalt, but the mix uses open-graded aggregate with no fines, creating interconnected voids that when properly designed result in a porous surface. There is no loss of structural support capacity when compared to impervious asphalt and concrete, because fines in the mix serve only to make

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it easier to compact, while the larger pieces of crushed aggregate provide enough structural stability even for high-traffic applications such as large trucks on highways.

Permeable pavers are paver units of stone, concrete, or another durable material set within and over a base rock. The gaps between the pavers—and occasionally within, if pavers are hollow—provide voids for water to reach sub-soils.

Flexible paving systems are prefabricated grids made of plastics or other solid materials, finished with clean sand/gravel or turf. The grids provide a stable surface while providing a porous media, and they sometimes resemble a traditional lawn.

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Permeable pavers at the Multnomah Arts Center, Portland, Oregon.

Design

HYDROLOGY DESIGN FOR STORMWATER INFILTRATION

Permeable pavements are generally sized to infiltrate a 2-year, 24-hour storm event. However, they should be able to pass a 100-year, 24-hour storm, which requires the construction of overflow or control structures to ensure that the pavement does not saturate and potentially destabilize. Porous pavements are designed to infiltrate rainfall falling directly onto the surface. Most porous pavements do this by storing stormwater in the voids of a uniformly sized (that is, all the same size) base rock below the pavement surface. Additional storage in the system can be achieved by increasing the depth of the rock base; infiltration of a larger storm such as the 25-year, 24-hour design used to mitigate downstream flooding can be achieved easily in soils with infiltration rates as low as 0.1 inches/hour. As a rule, though, infiltrating the 2-year storm will reduce runoff volumes from the site enough to mitigate downstream flooding impacts.

If the infiltration rate of the native subgrade soils and storage capacity in the base rock is properly balanced, porous pavements can be designed to infiltrate runoff from roofs or surrounding areas. These systems are sometimes referred to as "infiltration bed" or "rock trench," and the idea is that you're simply deepening the base rock you already have to create more storage in the voids. Water can be conveyed directly to the base rock via a perforated pipe (considered a UIC; more information is in the Permits section) or via infiltration through a vegetated surface facility such as a rain garden. All runoff, even from roofs, should be pretreated for sediment so the base rock or vegetated surface facility is protected from long-term clogging.

Runoff from other areas should never be via overland flow onto the pavement surface, as this is likely to clog the pavement voids (LIDMM 2008). For the same reason, the grading plan should be carefully designed to prevent landscape areas from draining toward porous pavements.

Since the placement of fill requires so much compaction that the process can give soil a similar density (and therefore similar runoff characteristics) to concrete, porous pavement should never be designed so that the bottom of the base rock sits on areas of new fill. The pavement section should always be situated in a cut in native, uncompacted soil. In impervious pavements, compaction of the soil provides a portion of the structural stability, allowing designers to reduce the depth of the base rock. In porous pavements, instead of compacting the subgrade, we use other means such as increasing the thickness of pavement surface or the depth of the base rock.

STRUCTURAL DESIGN FOR POROUS PAVEMENTS

Porous pavement surface thicknesses are calculated relative to estimated traffic weight and frequency (UDFCD 2008). Consult a geotechnical engineer to find the appropriate pavement section (surface and rock courses thicknesses as well as geotextile recommendations) for the site's soils in a "wet, uncompacted condition." This also will vary by porous pavement type.

Routing

Porous pavements should be designed to infiltrate appropriate volumes out of the bottom of the facility; however, a storm larger than the design storm should not be allowed to flow up through the pavement, because this could destabilize the pavement.

Underdrains are perforated pipes encased in gravel-filled trenches and can be used to convey water from large storm events down into the ground or to a stormwater conveyance system. Injecting stormater into the ground via perforated infrastructure triggers UIC requirements and increases the cost of porous pavement. When underdrains are used as an overflow for large storms, the pipe can be placed on the bottom of the facility for adequate cover, but should be regulated by a catch basin with a weir or some other structure that will allow as much water as possible to infiltrate within the desired time. (See details provided. To avoid UIC permitting requirements, use pipes perforated only on the top and side instead of all sides.)

If the underdrain is set on the bottom of the facility with no controls to allow water to back up into the rock base, the system will not be providing adequate water-quality treatment, since that process is largely a result of infiltration into the soil below. In this case, stormwater would have to be directed to another low impact development (LID) facility such as a rain garden to ensure that water-quality and volume-reduction goals have been met.


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Porous asphalt pavement next to impervious pavement.

CLOGGING DESIGN PRECAUTIONS

Design landscape slopes around porous pavements so that if they erode, the sediment will not reach the pavement surface. In addition, signage can prevent people from dumping landscaping materials on it. Porous pavements vary by manufacturer, so closely follow the instructions for design, construction, and installation, since clogging of the facility can easily happen during construction.

Having said all that, clogging is often less of an issue than people think. The infiltration rate of porous asphalt and concrete may exceed 2,000 inches per hour,[1] while long-term infiltration rates have been observed to fall to as low as 2 inches per hour.[2] Considering that the void ratio is so high when it's first installed, a "mostly clogged" surface can still be very effective. For example, the largest 2-year design storm in Oregon is 6.5 inches of rainfall in a 24-hour period. If that 6.5 inches just happened to concentrate over 6 of the 24 hours, a surface infiltration rate of 1 inch per hour would be all that is needed to pass the storm through the surface. *Consult your local municipal codes and guidelines prior to porous pavement installation.*

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1 http://www.perviouspavement.org/PDFs/ncsu_study.pdf
2 http://www.usawaterquality.org/conferences/2004/posters/beanNC.pdf

ACCEPTABLE SOIL INFILTRATION RATES

Porous pavements that only infiltrate the rainfall they receive—and not concentrated runoff from other areas—can be surprisingly effective even in slow-draining clay soils. For instance, in Portland, where rainfall patterns generate small, frequent storms, it's possible to infiltrate the entire 25-year, 24-hour design storm in clay soils with an infiltration rate of 0.1 inches per hour and a base-rock depth of only 10 inches. For porous pavements that receive runoff from other areas via a pipe, the minimum infiltration rate needed for the same area of pavement increases. Alternatively, the base rock could be expanded horizontally under landscape and imperious areas to increase the infiltration area and therefore increase the effective infiltration rate from the base rock as a whole.

Due to the continuous nature of our storms in western Oregon, soils should drain a storm event in 30 hours or less to be ready for the next storm.

When constructing over expansive soils, often found in the D soils group, an impermeable liner is suggested so rainfall does not expand the soils. An underdrain should accompany the liner. With this system, there are no water-quality treatment benefits and no reduction in stormwater volumes. It would be designed simply as a detention basin, which is not considered by many as low impact development. In expansive soils, we would recommend using an approach different from porous pavements.

BASE COURSE DESIGN

The base course should be uniformly graded (all the same size) and washed, crushed aggregate. Generally any rock that's all the same size has a void ratio between 30% and 40% (UDFCD 2008). Typical gradations are AASHTO #3, #4, or #67. Assume that your base rock has a void ratio of 30%, or have it tested by a lab using the ASTM C29 Bulk Density Test, and use this void ratio to determine the depth of rock needed to store the volume from the regulatory storm event. Depths generally range from 12 to 36 inches deep for vehicular traffic applications.

Physical Setting

Porous pavements can and have been used in the public right-of-way as well as on private property. They are generally not recommended for high traffic areas due to the higher risk of spills and levels of contaminants—not because porous pavements are unable to handle truck weights such as H-20 loading.

The Oregon Department of Transportation has used a "permeable friction course overlay," which is a layer of porous asphalt on top of the existing impervious asphalt, to reduce spray and consequent hydroplaning on I-5 and Highway 26. The University of Texas is doing some preliminary studies showing that total suspended solids may be reduced by up to 90% using this strategy, theorizing that a lack of spray means that pollutants aren't scoured from the undercarriage of cars to drop the solids in the first place.

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Pervious concrete was once thought to have too rough a surface for high-heeled shoes.

Porous pavements can be used

- where the seasonal high groundwater table is lower than 36 inchesfrom the bottom of the base rock
- where the bedrock is lower than 24 inches from the bottom of the base rock
- in poorly drained, low-infiltration rate soils such as clay
- in limestone bedrock
- under trees

Because porous pavement is an infiltration technique that could directly infiltrate contaminants into the groundwater, there are situations for which porous pavements are not applicable. These situations vary with state regulations, but in Oregon porous pavements shouldn't be used

- where the seasonal groundwater table is higher than 36 inches from the bottom of the base rock
- where bedrock is higher than 24 inches from the bottom of the base rock
- in areas of new fill (rule: fill < 5 years old)
- in contaminated soils
- in expansive soils
- on slopes exceeding 10%, unless the bottom of the facility can

be stepped down the hill with a series of berms, as in the figure below showing the geotextile
- in possible spill areas
- where cars or trucks may track a significant amount of dirt onto the surface

Construction

Like all stormwater management facilities, special care must be taken to properly construct a porous pavement. Since we rely on the native subgrade soils to infiltrate stormwater, porous pavement areas should be off-limits to construction traffic and stockpiling activities using orange protection or chain-link fence. Construction techniques such as using track equipment or excavating from the sides of the infiltration area should be used to protect the soils during excavation. If the soils are exposed to rain, fine soil particles will be picked up and moved around and may clog the native subgrade soils. Rake the surface to loosen soil before proceeding.

Once the native subgrade has been exposed, geotextile will be installed to preserve the voids in the overlying base rock (LIDMM 2008). The geotextile will be needed to function as a separator whenever storage of rainfall is needed; however, if soils infiltrate fast, then storage in the base rock may not be required and a geotextile may not be needed. Where geotextile fabrics are required, they should be high quality and resistant to punctures from sharp edges and rocks (UDFCD 2008). Sheets should overlap at least 18 inches and should be laid across the intended area with an additional 4 feet beyond the bed, to ensure that sediment and runoff do not enter the bed during construction (LIDMM 2008). This can be cut at the very end of construction.

Next, the base rock, if needed, will be installed. (Depending on the structural capacity and drainage characteristics of your native soils, base rock may not be needed for pervious concrete installations.) Dust or fine particles not washed away could clog the geotextile (Hicks and Lundy 1998), so not only should the base rock be delivered clean from the quarry, it should also be washed carefully on site. One successful method for this is to hose the rock off in the delivery truck when it arrives. Another method might be to dump the rock and wash off the pile. Because the wash water from these activities is wastewater, it's important to include such base rock-washing in your erosion and sediment control plan for the construction site and take steps to ensure that the wastewater doesn't enter a stormwater conveyance system. In both instances, scooping of the rock should be done from the surface and the rock should be closely monitored for fines. As you work your way down the pile, fines from above might only have been washed off halfway through. If careful attention isn't paid to this step, the geotextile fabric could become clogged, creating an unintentional impervious pavement at the bottom of the pavement section.

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Overlapping the geotextile.

Place base rock in 6-inch lifts by dumping rock at the beginning of the porous pavement area and backing over it to dump and spread the next 6-inch lift. Do not compact the pavement with vibratory compaction. Light compaction can be achieved simply by driving back over the 6-inch lift.

The rest of the pavement construction should proceed as directed below for the specific pavement type.

Because porous pavement surfaces are susceptible to clogging, there are several staging and construction phasing considerations. Never stockpile landscape, soil, or other materials on porous pavements. Construction is ideally completed at the very end of a project, which means that alternate access paths need to be developed ahead of time. A few planned unit developments in Oregon, including Pringle Creek outside of Salem, have had good results with building the pervious road network first and then requiring builders to protect the pavement with geotextile.

See the more detailed descriptions of each of the porous pavements below for additional pavement type-specific information regarding construction.

Maintenance for All Porous Pavements

On private land, a maintenance agreement is recommended. Ideally, grades on site were all designed and constructed to flow away from porous pavements. For those landscape areas that may flow toward the pavement, maintain them to avoid bare soil that may be transported to clog the surface. Inspect the pavement twice a year and remove trash and litter regularly, which may carry dirt that can also clog pavements. Notify all landscape contractors of their responsibility to help maintain the pavement by requiring them to identify an alternative place to dump landscape materials. Control structures, such as catch basins and manholes, should be cleaned out twice a year.

"Potholes in pervious pavement are unlikely, though settling might occur if a soft spot in the subgrade is not removed during construction. For damaged areas of less than 50 square feet, a depression could be patched by any means suitable with standard pavement, with the loss of porosity of that area being insignificant. The depression can also be fllled with pervious mix" (SMCOG 2008).

Care should be taken when using fertilizers, pesticides, herbicides, or fungicides near LID facilities. These are all potential pollutants that should never be used on LID facilities. Instead, integrated pest management is preferred for the entire site, but for the stormwater facility at a minimum.

SNOW AND ICE REMOVAL

Because porous pavements allow air to pass freely through them and because the ground tends to be warmer than the outside air, a convective process occurs that tends to melt snow and ice much faster on porous pavements than on impervious pavements. Snowplowing is fine; however, when snowplowing over pavers, the plow could catch edges (Barr 2001). Simply raise the plow height slightly. In Oregon, cinders—never salt—are used to manage icy roadways; however, cinders will clog the pavement. A number of environmentally sound, salt-free, liquid de-icers are available and should be used instead.

POLLUTANT REMOVAL

The primary function of porous pavement is runoff volume reduction. Secondary functions include flow attenuation, sediment control, and nutrient loading (Barr 2001). Though not designed for pollutant removal, there are two processes in which removal takes place: (1) in the aggregates, base pollutants can be adsorbed and sediments can settle out; and (2) in the native soils below the system, pollutants again can be sequestered or broken down by microbes (Field 2007). Based on published research, the Center for Watershed Protection estimated the total amount of phosphorus removed for level 1 and 2 designs to be 59 to 81% and nitrogen removed to be 59 to 81%. Runoff reduction was estimated at 45 to 75% (CWP&CSN 2008). Runoff reduction itself contributes to pollutant removal, simply by reducing the volume of pollutants going downstream. Other studies note porous pavement's effective removal of TSS, metals, and oils and grease (UDFCD 2008).

Design Guidelines for all Porous Pavement Types

Design criteria for all variations of porous pavement are similar in many respects. Differentiations are noted in the more detailed discussion of individual pavement types that follows.

POROUS ASPHALT

Porous asphalt (aka Porous Asphaltic Concrete) is a mixture of crushed aggregate (without the fines) and asphalt binder. Asphalt mixtures tend to experience surface scuffing and/or raveling on the pavement surface when containing less than 5.75 to 6% bituminous asphalt by weight. Scuffing protection can be enhanced by using an additional polymer-modified, Performance Graded Ashpalt Binder (PGAB). The surface of a successfully designed and installed porous asphalt typically will have a void ratio of 10 to 20%.

Installation of porous asphalt, as with other porous pavements, should follow the guidelines above for protecting the soil, installing the geotextile, and washing the base rock. Because asphalt is a flexible pavement, the base rock serves not only as storage for stormwater, but also as an integral part of the structural support for the pavement surface.

When the base rock is lightly compacted, it may be difficult to roll asphalt on top of it. The base rock can sometimes roll, causing a wavy appearance to the asphalt surface. The choker course sits between the base course and pavement surface to lock in, or choke, the larger base-rock aggregate below and stabilize the surface for rolling. Experimentation in the field is sometimes needed, but depths will generally range from 1 to 2 inches (PSAT 2005) and should be composed of a smaller, uniformly graded, clean and washed, crushed aggregate. Larger depths of choker course will not choke the pavement beneath it but will instead start to roll again like the base course, so, depending on the size of the base course aggregate, exceeding a depth of 2 inches probably will not be helpful.

This choker course is not always needed. At Pringle Creek outside of Salem, for instance, the base rock was sufficiently hard and had enough angular faces that it locked together on its own under light compaction. This is common in Oregon where our volcanic bedrock tends to be hard, but if you're not sure whether you need it, except for the additional cost it doesn't hurt to include it.

Placement of the porous asphalt is very similar to the process of placing impervious asphalt. It should be placed and rolled, but care must be taken not to over-compact the surface by using a small roller and limiting the passes. Careful construction staging should place installment during a time of the year when temperatures will not drop below 55°F during placement.

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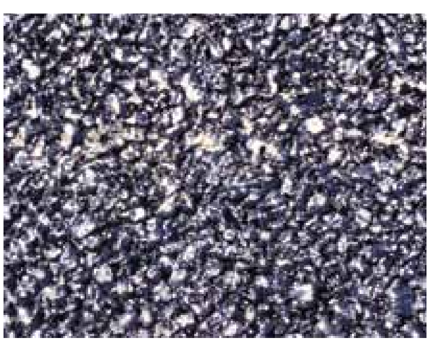

Closeup of porous asphalt.

A specification for porous asphalt with information about the additional infiltration beds that can infiltrate runoff from other areas can be found on the Web at http://www.unh.edu/erg/cstev/pubs_specs_info/unhsc_pa_spec_09_09.pdf (the University of New Hampshire Stormwater Center).

MAINTENANCE SPECIFIC TO ASPHALT

Porous asphalt should be vacuumed twice a year with standard street-cleaner equipment. If the pavement is in a public ROW where agencies sweep the streets with a vacuum truck, then porous pavements may not add any additional maintenance. Never apply a seal coat to porous asphalt.

PERVIOUS CONCRETE

Concrete mixtures are combinations of aggregate and Portland Cement. For pervious concrete, a low cement-to-water ratio should be used when mixing, and the mixture should be used within an hour of adding water (LIDMM 2008). Water should be added only once. Additional water can cause the cement to weaken and fail (UDFCD 2008). Depending on environmental conditions, the concrete should be covered within 15 minutes. On some very hot, dry days, pervious concrete may not be installable at all because of the cover limitation. Pervious concrete has no minimum temperature at which it can be installed.

Installation of pervious concrete, as with other porous pavements, should follow the guidelines above for protecting the soil, installing the geotextile, and washing the base rock. Because concrete is a rigid pavement, depending on the soil type the base rock may be needed only to store stormwater. The choker course is unnecessary because porous concrete isn't rolled like asphalt.

The installation of pervious concrete differs enough from impervious concrete that installation should always be done by a certified contractor. There are several certification programs in Oregon certified by the National Ready Mixed Concrete Association called the "NRMCA Pervious Concrete Technician" training. We strongly recommend you use a certified installer.

MAINTENANCE SPECIFIC TO CONCRETE

Porous concrete should be vacuumed twice a year with standard street-cleaner equipment. If the pavement is in a public right-of-way where agencies sweep the streets with a vacuum truck, then porous pavements may not need additional maintenance.

Seattle found that their vacuum trucks did nothing to remove sediments from their porous pavements, and Beaverton doesn't have the equipment, so both agencies are using pressure washing. Beaverton has some pervious concrete installations that have a very small aggregate, so detritus and trash are less likely to get stuck in the surface voids and clog the pavement. Pressure washing should be done at an angle to the pavement and not directly into it. Leaf blowers are also an option

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Impervious concrete installed next to pervious concrete on N. Gay Street (a public road) in Portland, Oregon.

during the dry season when material can be blown. The cleaning interval, which might range from every 6 months to 3 years, should be based on possible exposure to sediments.

Permeable Pavers

Pavers can be made of many different materials and can be bought new from a manufacturer. They might also be made of salvaged material such as bricks, stones, or sawcut concrete sidewalk squares. Pavers should be placed atop a lightly compacted leveling course. Space between pavers, called the infill course, should be between 8 and 20% of the paver size to allow for infiltration. The infill is a coarse sand that conforms to a standard specification such as ASTM C-33. The area should be lightly compacted and refilled if infill drops below the surface of the pavers. Both the leveling and infill courses should be clean and washed on-site, per the previous discussion of base rock with no fines or dirt.

In vehicular applications, the entire facility area should be contained by a 6-inch-thick perimeter of concrete (UDFCD 2008) or equivalent permanent structure.

Pavers are applicable in several settings where vehicle movement is low, such as airports, parking lots, aprons, and maintenance roads (UDFCD 2008). They are also an attractive option for plazas, parks, patios, and parking areas or low-speed streets (LIDMM 2008).

According to PBMP (2006), because several "paver products recommend compaction of the soil and do not include a drainage/storage area…they do not provide optimal stormwater management benefits. A system with a compacted subgrade will not provide significant infiltration." Check with the manufacturer to make sure they will offer a warranty without compaction.

MAINTENANCE SPECIFIC TO PAVERS

Permeable paver surfaces have a tendency to grow things in the spaces between them. This can be addressed through integrated pest management approaches such as hand-pulling, pouring hot water on the weeds, or using a torch. The City of Portland has a public street demonstration project where they hired a company with a large truck to burn all the weeds off at once.

Unclogging a clogged paver installation is relatively easy. Simply vacuum up the No. 8 rock in between the pavers and then replace it. For sustainability and cost reasons, you may also consider vacuuming the rock, washing it off, and replacing it. Take erosion control measures if you decide to wash it.

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Poured-in-place, impervious-concrete permeable pavers at the Broadway Cab Company in Portland, Oregon.

Porous Flexible Paving Systems

These concrete or plastic frameworks or matrices are filled with turf grass or gravel. The framework allows the site to retain structure and durability while the large spaces between the structure provide areas for infiltration. Prepare the subgrade and base rock as discussed in the general design guidelines for all pavements provided above, then fill the voids with growing medium to store runoff and provide infiltration to underlying soils (LIDMM 2008). “Plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions” (PBMP 2006).

This variation is best for fire access lanes, overflow parking, and infrequent parking use, especially when turf is a part of the design. They can also be used to supplement a narrowed standard pavement street to meet required widths for emergency vehicles (LIDMM 2008).

MAINTENANCE SPECIFIC TO FLEXIBLE PAVING SYSTEMS

For flexible paving systems with grass, maintenance is similar to turf. For flexible paving systems with gravel, broom or rake dislodged gravel back into place. Some manufacturers recommend or allow the use of fertilizers, pesticides, herbicides, or fungicides; however, we recommend using only integrated pest management approaches for porous pavements and all other LID facilities.

Maintenance activities include inspecting for bare soil, exposed rings, ruts, poorly growing grass from too much shade, and thatch. In the case of spills, ruts, or disturbance associated with access to underground utilities, the flexible paving systems may be cut with a sod cutter, set aside, and put back in placed after subgrade has been reconstructed. Aerating these areas should be avoided since this machinery will damage the pavement. Snow plowing may be done by “using standard truck-mounted snow plowing blades with small skids on the corners to keep the bottom of the blade”[3] about 1 inch above the grass surface. Thatch can be addressed by adjusting the mowing height. *Refer to the specific manufacturer’s maintenance requirements.*

Green Girl LDS

Concrete grass pavers were used in the Willamette Park overflow parking to grow grass and prserve site permeability in this low-traffic area.

Permits and Preconstruction Requirements

Consult your local planning and building department. Ask about the applicable permits, plumbing codes, and piping requirements. Find out if there are any maps, as-built drawings, or site-specific constraints. In many cases, if building a porous pavement on a nonresidential site, a commercial building permit is required, and a clearing, grading, and erosion control permit may be required if ground disturbance is large enough.

Prior to construction, the site should be investigated for suitability. This includes infiltration testing to determine infiltration rates and existence of impermeable soil strata (aka fragipan) or bedrock (Field 2007). In some cases, such as in the City of Portland, jurisdictions require these tests to be performed by a registered professional engineer when installing porous pavement streets (PSMM 2008).

UIC Regulations

A Class V Underground Injection Control (UIC) is a system designed “for the subsurface placement of fluids” and is regulated through the Oregon Department of Environmental Quality’s UIC program. This program protects groundwater resources from the injection of pollutants directly underground, and, depending on the potential for various pollutants to be on site, may be rule authorized or require a more formal permitting process. According to the U.S.

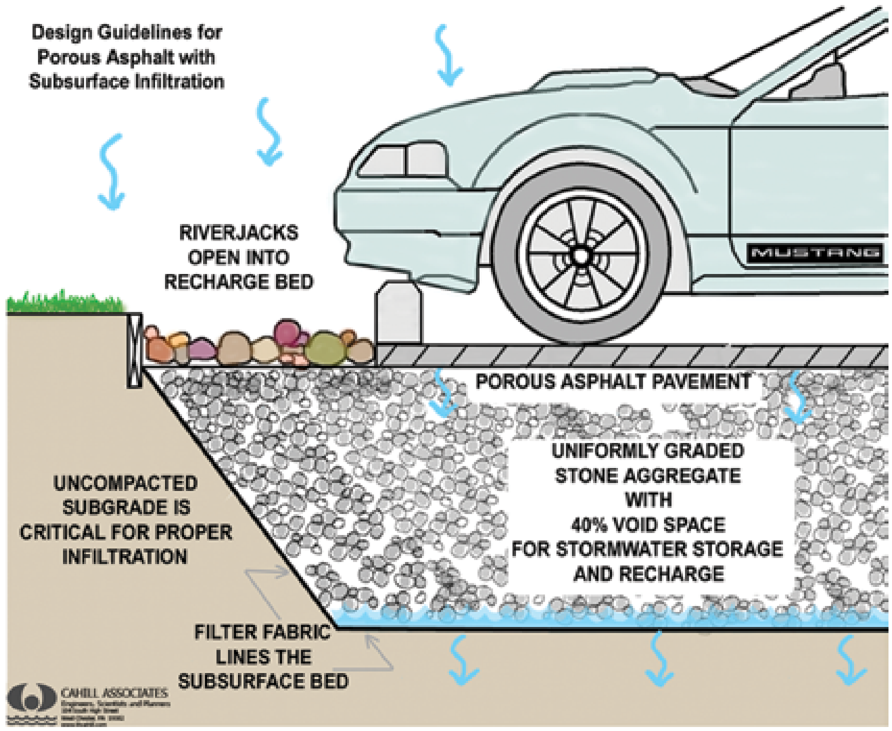
3 http://www.psparchives.com/publications/our_work/stormwater/lid/2009_Local_Assitance/005_Appendices/Grasspave2MaintenanceGuide.pdf

Environmental Protection Agency, a Class V UIC well is also by definition any bored, drilled, or driven shaft, or dug hole, that is *deeper than its widest surface dimension*. Given this, the following are guidelines to consider when designing a porous pavement to, avoid triggering state UIC requirements.

When sizing porous pavement, avoid designing a facility that is deeper than the widest surface dimension. Also, porous pavements designed and installed as discussed above may be considered a UIC if underdrains are used in the design. As mentioned in the routing discussion, underdrains composed of perforated pipe that convey runoff from other impervious areas into the ground trigger state UIC requirements. (See fact sheet on soakage trenches.) Routing runoff from large events exceeding the storage capacity of the base rock to a stormwater conveyance system using perforated pipe may also trigger UIC requirements depending on the type of perforated pipe used.

When conveying excess runoff from a large event to a stormwater conveyance system, use pipe that has a solid bottom and perforations only on the top and sides to avoid triggering state UIC requirements. This underdrain design can be used with controls to allow water to back up into the rock base so that infiltration and, therefore, stormwater treatment is enhanced while still allowing runoff exceeding the infiltration capacity of the facility to move into a stormwater conveyance system discharging to surface water.

Changing the detail with any potential design that might allow runoff



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A permeable perimeter wil convey runoff from a clogged pavement to the subsurface but may require a UIC permit.

to shortcut infiltration through the top of the facility could turn the facility into a UIC. For instance, as a "belt and suspenders" approach an edge drain such as the one shown in the figure has been widely used to ensure that rainfall will still infiltrate approximately where it falls even if the pavement becomes clogged to the point of imperviousness. The edge drain allows runoff to enter the storage rock below, which would be considered a UIC at the time that the pavement started generating runoff.

Additional guidance is available from the ODEQ at: http://www.deq.state.or.us/wq/pubs/factsheets/uic/uicstormwater.pdf

If you have questions about whether your design is a UIC, contact the Oregon DEQ UIC Program in the Water Quality Division.

Other

Porous pavement can be combined with impervious pavement such as providing strips of traditional pavement for tire tracks and filling in center strips and edges with geogrids (Barr 2001). To avoid clogging, make sure that the impervious pavement drains away from the porous pavement.

When considering porous pavement, as with all infiltration BMPs, the potential for groundwater contamination should be discussed and reviewed.

Using porous pavement can eliminate the need for stormwater facilities in the area that could compete for land with wooded and open-space areas. Fewer facilities also means lower cost (Hicks and Lundy 1998).

Impervious Pavements:	Porous Pavements:
increase runoff volumes from pre-developed conditions.	have no increased runoff.
degrade stream habitat. Increased runoff volumes and lengthened flows (caused by detention facilities) scour stream banks.	preserve pre-developed runoff patterns so volumes don't increase downstream.
increase the cycle of downstream floods & up-streams droughts by piping runoff as quickly as possible from the upstream to the downstream.	allow rainfall to infiltrate where it falls, so pollutants are dispersed.
are non-living.	are alive. Being open to the air, microorganisms live in the pavement section and "eat" any pollutants that might end up in the pervious pavement areas.
turn rainfall to run off that scours and concentrates pollutants.	allow rainfall to infiltrate where it falls to replenish groundwater.
increase runoff temperature, which increases temperatures of receiving streams.	infiltrate water so it has plenty of time to pass through the ground before it seeps out again to become stream flow.
discourage healthy tree growth.	encourage healthy tree growth by allowing air and moisture to get to the roots.
increases air temperatures (heat island effect), which increases the number of smog days.	can reduce air temperatures if they are light colored. Will reduce air temperatures by evaporation.
are prone to hydroplaning.	are used by ODOT to eliminate hydroplaning.
are more prone to freezing.	are less prone to freezing because the open air nature of the pavement section encourages convection of warmer air from the ground to circulate up and melt snow and ice faster.
are noisier than pervious pavements.	reduce noise by absorbing sound pressure into air voids.

Porous pavements have many functional differences to impervious pavements that are beneficial to water quality and quantity, stream health and biodiversity, air quality, and community safety and comfort.

Cost

Although porous pavements are more expensive that impervious pavements, there are several potential offsets such as reduced piping, curbs, excavation and fewer downstream stormwater facilities (Hicks and Lundy 1998, UDFCD 2008). Generally, the most expensive aspect of porous pavement installation is the underlying stone beds. Cost of the pavement itself will vary by type and manufacturer (LIDMM 2008). Where detention basins are required in large-lot subdivisions, the additional cost of porous pavements has been offset by the ability to sell an extra lot.

Regardless of type, cost is offset by

- infrastructure: pipes, detention ponds, water quality facilities, catch basins, manholes, and excavation
- more land for development
- value-added amenity
- lower stormwater fees in some jurisdictions
- lower permitting fees and timelines in some cases
- increased durability compared to impervious pavements

References and Resources

Barr Engineering Company. 2001. *Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates*. St. Paul, MN: Metropolitan Council Environmental Services..

Center for Watershed Protection and Chesapeake Stormwater Newtwork. 2008. Technical Memorandum: *The Runoff Reduction Method*. Elliot City, MD.

City of Portland: Bureau of Environmental Services. 2008. *Portland Stormwater Management Manual*.

Field, R., T. N. Tafuri, , S. Muthukrishnan, R. A. Acquisto, and **?** Selvakumar. 2006. *The Use of Best Management Practices (BMPs) in Urban Watersheds*. Lancaster, PA: DEStech Publications, Inc.

Glazier, G., and S. Samuels. 1991. Effects of Road Surface Texture on Traffic and Vehicle Noise. *Transportation Research Record* 1312:141–44.

Haselbach, L. 2008. *Pervious Concrete and Mitigation of the Urban Heat Island Effect*. Under review for the 2009 Transportation Research Board Annual Meeting.

Hicks, P. C., and J. R. Lundy. 1998. *Asphalt Pavement Design Guide*. Prepared for: Asphalt Pavement Association of Oregon. Revised Oct. 2003 by J. Huddleston, P. E.

Kevern, J., V. R. Schaefer, and K. Wong. 2008. *Temperature Behavior of a Pervious Concrete System*. Under review for the 2009 Transportation Research Board Annual Meeting.

North Carolina Division of Water Quality (NCDWQ). July 2007. *Stormwater Best Management Practices Manual*. Raleigh, NC.

Pennsylvania Stormwater Best Management Practices Manual. 2006. Publication No. 363-0300-002. http://www.blairconservationdistrict.org/SWBMP.htm

Pervious Concrete Technician certification info: http://www.nrmca.org/certifications/pervious/

Cost: http://www.epa.gov/owow/nps/lid/costs07/documents/factsheet-reducingstormwatercosts.pdf

http://www.rmc-foundation.org/images/PCRC%20Files/Hydrological%20&%20Environmental%20Design/Stormwater%20Quality%20Benefits%20of%20a%20Permeable%20Friction%20Course.PDF

Puget Sound Action Team. 2005. *Low Impact Development: Technical Guidance Manual for Puget Sound*. Publication No. PSAT 05-03. Olympia, WA: Washington State University Pierce County Extension.

Southeast Michigan Council of Governments. 2008. *Low Impact Development Manual for Michigan: A design Guide for implementers and reviewers*. Funded by the Michigan Department of Environmental Quality through a grant from the U.S. Environmental Protection Agency.

Urban Drainage and Flood Control District. Drainage Criteria Manual (Vol. 3). 2008. Denver, CO.

WEB SITES

http://www.unh.edu/erg/cstev/pubs_specs_info/unhsc_briggs_thesis_12_06.pdf

http://www.unh.edu/erg/cstev/pubs_specs_info/unhsc_pa_spec_09_09.pdf

http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_409.pdf

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