PUBLIC WORKS TECHNICAL BULLETIN 200-1-132
31 OCTOBER 2013

GUIDELINES FOR SUSTAINABLE PARKING AREAS, INCLUDING NATIVE VEGETATION CONSIDERATIONS, IN SUPPORT OF LOW IMPACT DEVELOPMENT

Public Works Technical Bulletins are published by the US Army Corps of Engineers. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new Department of Army policy.

DEPARTMENT OF THE ARMY
US Army Corps of Engineers
441 G Street NW
Washington, DC 20314-1000

CECW-CE

Public Works Technical Bulletin 31 October 2013

No. 200-1-132

Facilities Engineering
Environmental

GUIDELINES FOR SUSTAINABLE PARKING AREAS, INCLUDING NATIVE VEGETATION CONSIDERATIONS, IN SUPPORT OF LOW IMPACT DEVELOPMENT

1. Purpose

a. This Public Works Technical Bulleting (PWTB) provides an introduction to Low Impact Development (LID) and the benefits of implementing permeable parking practices in Army installation areas. It includes recommendations for selecting commercially available, environmentally friendly, sustainable, permeable parking support systems.

b. All PWTBs are available electronically at the National Institute of Building Sciences' Whole Building Design Guide (WBDG) webpage, which is accessible through the following link:

http://www.wbdg.org/ccb/browse_cat.php?o=31&c=215

2. Applicability

This PWTB applies to all US Army public works activities and facilities having unsupported overflow parking lots and/or permeable parking and storage facilities.

3. References

a. Army Regulation (AR) 200-1, *Environmental Protection and Enhancement*, 28 August 2007.

b. UFC 3-210-10, “Low Impact Development,” Department of Defense, 15 November 2010.

c. EO 13514, “Federal Leadership in Environmental, Energy and Economic Performance,” 5 October 2009.

d. Executive Order (EO) 13112, “Invasive Species,” 3 February 1999.

4. Discussion

a. AR 200-1 requires that Army installations comply with federal environmental regulations.

b. UFC 3-210-10 provides technical criteria, technical requirements, and references for the planning and design of applicable projects to comply with stormwater requirements under Section 438 of the Energy Independence and Security Act (EISA) enacted in December 2007.

c. Goal 2 of EO 13514 established targets to improve water resources management and the reduction of stormwater runoff.

d. Among the duties EO 13112 assigns to federal agencies, is preventing the introduction of invasive species, detecting and control such species in a cost-effective and environmentally sound manner, and providing for restoration of native species and habitat conditions in ecosystems that have been invaded.

e. LID is a stormwater management approach developed in the mid-1980s. The goal of LID is to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source (Low Impact Development Center 2007). Permeable pavement systems are one of many LID practices that function to infiltrate stormwater. More information on other LID stormwater management techniques can be found within PWTB 200-1-116 (Svendsen 2012).

f. When a permeable support system is properly designed, installed, and maintained, there are a multitude of benefits at a site, including improved water quality, reduction of runoff, and reduced demand on stormwater infrastructure. While the permeable system may cost more initially, the products typically will save capital expenditures over the lifetime of the system.

g. Appendix A contains an introduction to the benefits of implementing permeable parking practices, a list and description of traditional parking surface products and permeable parking surface products and a brief description of each, plus a chart of native grasses suitable by state.

h. Appendix B contains a list of possible cantonment and training area applications, a description of their parking and/or storage needs, and a table of pavement recommendations by application.

i. Appendix C presents benefit-cost considerations and lessons learned from the application of common permeable parking practices in various case studies. These lessons produced recommendations for specific installation area pavements, as summarized in Table B-1, Appendix B.

j. Appendix D provides a list of references and abbreviations used in this document, and a chart to convert measurements in this PWTB to the SI system.

5. Conclusions

When a permeable support system is properly designed, installed, and maintained, there are a multitude of benefits at a site, including improved water quality, reduction of runoff, and reduced demand on stormwater infrastructure. While the permeable parking support systems may cost more initially than traditional parking support structures, the total life-cycle costs and meeting the requirements needed of LID goals make the selection of permeable parking support system a feasible and cost-effective solution for vehicle and pedestrian demands. However, it is important to note that these structures require more upkeep than traditional structures. Additional equipment and planning may be required to keep these structures performing optimally.

6. Points of Contact

a. Headquarters, US Army Corps of Engineers (HQUSACE) is the proponent for this document. The point of contact (POC) at HQUSACE is Mr. Malcolm E. McLeod, CEMP-CEP, 202-761-5696, or e-mail: Malcolm.E.Mcleod@usace.army.mil.

b. Questions and/or comments regarding this subject should be directed to the technical POC:

US Army Engineer Research and Development Center (ERDC)
Construction Engineering Research Laboratory (CERL)
ATTN: CEERD-Niels Svendsen
PO Box 9005

Champaign, IL 61826-9005
Tel. (217) 373-3448
FAX: (217) 373-7266
e-mail: Niels.G.Svendsen@usace.army.mil

FOR THE COMMANDER:

JAMES C. DALTON, P.E., SES
Chief, Engineering and Construction
U.S. Army Corps of Engineers

APPENDIX A:
LOW-IMPACT DEVELOPMENT AND PARKING SURFACES

Introduction

As stated in the preceding section's discussion points, low impact development (LID) is a stormwater management approach designed to mimic a site's predevelopment hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source (Prince George's County 1999). Permeable pavement systems are one of many LID practices that function to infiltrate stormwater; other LID stormwater management techniques can be found in PWTB 200-1-116 (Svendsen 2012).

Permeable pavements allow water to pass through the surface (in the case of porous asphalt and concrete) or through void spaces (in the case of concrete pavers or grid pavers), to reduce runoff volume and improve water quality (University of Rhode Island 2005). This infiltration of runoff can reduce nuisance flooding, recharge groundwater supplies, filter out pollutants, and help keep drinking water healthy (ibid.). Furthermore, since infiltration takes place at the source rather than being transported downstream to rivers and streams via storm sewers, the amount of infrastructure can potentially be reduced. Reductions of infrastructure add to the desirability of LID practices such as permeable pavement systems.

Permeable pavement installations are appealing due in part to the amount of locations where implementation is possible such as parking lots, sidewalks, roads, and alleys. Many permeable materials can be adapted upon installation to create a stronger subgrade level in order to withstand the design demands. Acceptable materials for permeable support system for parking lots include: porous asphalt (PA), porous concrete (PC), concrete pavers, and plastic turf reinforcing grids (PTRG) that support vegetation (Brattebo and Booth 2003). Additionally, every installed permeable surface support system can be designed to integrate sub-drainage and geotextile liners, if necessary.

Not only can permeable support systems improve groundwater recharge, but also they can deliver additional benefits to the site. Systems which are properly designed, installed, and maintained deliver long-term stormwater treatment and a reduced life-cycle cost. The US Environmental Protection Agency (USEPA) conducted a series of case studies across the continental United

States (USEPA 2007) and reported that the total capital costs of comprehensive LID stormwater management approaches were 15%-80% less than conventional techniques.

LID practices such as permeable pavements are meant to complement and potentially reduce the need for traditional stormwater management infrastructure. The integration and implementation of these techniques, however, still requires an evaluation and analysis of how the permeable pavement installations will affect the overall hydrology in the area. For example, additional underdrain techniques may be necessary to improve infiltration into soils with low permeability.

Traditional Parking Surface Support Products

Parking lots have traditionally been fabricated from materials such as gravel, asphalt, and concrete. The purpose here is to describe where these conventional materials excel and where they may be limited in a parking lot application, including how they are best maintained and relevant costs.

Gravel

Despite its popularity, there are several drawbacks to using gravel. Dust pollution and vehicular damage due to “whip-off” of materials may occur from traffic. Also, inadequate crowns may lead to “washboarding” or corrugation (Skorseth and Selim 2000). Other errors in installation, such as inadequate subgrade strength and marginal gravel depths, may cause the gravel road to fail when carrying heavy loads.

When selecting gravel for a parking lot, the USEPA (2012) suggests using “riverbed” or “washed” gravel that is hard and rounded but has enough edges to allow for vehicle traction. To minimize dust, avoid using gravel mixtures that contain fine dirt particles. While there are a number of dust suppressant products available on the market today, it is imperative to consider the amount of vehicle traffic and type of soil among other factors (USEPA 2008). Without the use of suppressants, dust pollution and safety are compromised. Additionally, the lifetime costs of the road or parking lot is increased due to the constant application of suppressant products.

Recommended gravel maintenance includes periodic reshaping of the surface, filling depressions with replacement gravel, and regrading with a blade angle between 30 and 45 degrees, while travelling no faster than 5 mph (Skorseth and Selim 2000).

Bitumin Asphalt (Asphalt)

In the United States, 85% of parking lots are comprised of bitumen asphalt (asphalt). Asphalt has several advantages relative to concrete to explain its popularity. Asphalt’s advantages include ease of snow removal, ease of resurfacing, and resistance to frost heave (National Asphalt Paving Association 2009). Furthermore, asphalt is the most recycled material in the United States, with approximately 80.3 million tons of old pavements being reclaimed each year (Asphalt Paving Association of Michigan n.d.). According to the Asphalt Pavement Alliance (n.d.), asphalt is an economical, environmentally friendly, and fast-to-construct material for parking lots. In a comparative cost report, hot mix asphalt with light aggregate ranged from $0.10-$1.50 per square foot installed, with an estimated lifetime between 7-20 years (USEPA 2005).

While asphalt may sound appealing, it also has some negative impacts. Those negative impacts include that asphalt adds to the urban heat island effect, potentially produces unsafe ponding during storms, and generates high levels of stormwater runoff. Furthermore, as stormwater drains from urban asphalt, it picks up nutrients and pollutants such as nitrogen, phosphorus, oil, grease, heavy metals, and trash. The pollutants impair water quality and degrade the riparian systems that many plant and animal species depend on for survival (US Department of Housing and Urban Development 2003).

Asphalt cannot be installed and forgotten; it needs to be maintained and repaired on a regular basis. While all maintenance costs add up, preventive maintenance is proven to be six to ten times more cost effective than a “do nothing” maintenance strategy (USDA 2009). Lack of maintenance, poor drainage, inadequate thickness, accumulated wear, and other causes all contribute to the eventual need for significant repairs, which cost significantly more money. To prevent significant emergency repairs, routine maintenance is required to fix common problems including potholes, deteriorated joints, and structural failures (Walker 2008).

Concrete

While projections show that installed concrete, costing $0.30-$4.50 per square foot, is more expensive than traditional asphalt, concrete does have a longer lifetime of approximately 15-35 years (USEPA 2005). Additionally, the market has shown a gradual increase of about 4.6% in the cost of concrete, while the cost of asphalt goes up and down with the price of a barrel of oil (Florida Concrete and Products Association 2011).

The production of Portland cement also uses old tires and other byproducts that normally go into landfill (ibid.). Concrete is naturally light in color, thus allowing it to be considered an urban heat island reduction pavement (USEPA 2005). Furthermore, concrete’s brighter reflectivity can lower infrastructure and ongoing lighting costs, while boosting safety for vehicles and pedestrians. Comparative research by the Portland Cement Association demonstrated that concrete parking areas require fewer lighting elements than other surfaces and can yield energy savings up to 60% (National Ready Mix Concrete Association 2011). The average energy input required to make one ton of cement is 4.64 million Btu (Portland Cement Association 2009). According to the US Department of Energy (2010), US cement production accounts for only 2.4% of the nation’s energy consumption, a lower energy consumption than iron and steel mills at 11% and paper mills at 15%.

Concrete can be installed directly on properly prepared and compacted subgrade, The subgrade needs to be compacted to a required 95% density as determined by American Society for Testing and Materials (ASTM) D 1557 (ASTM 2012). However, adjustment of the concrete mix is necessary for compatibility with specific subgrade contents such as salt or sulfur. Maintenance for a concrete parking lot includes: stain removal through the use of chemicals and power washers, removal of any unwanted vegetation, and the sealing of cracks (Florida Concrete and Products Association 2011).

Energy Consumption in Procuring Traditional Materials

There has been increased national interest in sustainability and life-cycle costs of materials. As often happens, such interest and related concerns translate to government actions. Through the NET Zero Energy for Military Installations report for the National Renewable Energy Laboratory (NREL; Booth et al. 2010), there has been a call for each military installation to produce as much energy as it consumes within a single year. This concept means that by limiting the energy that goes into parking lot surface support materials and installments, the energy production goal can be limited an equal amount. Furthermore, structural investments such as parking lots need to have life cycle costs included into their final analysis. The purpose behind this inclusion is to save the installation from unnecessary spending on any given investment in the years to come.

The combustion of fossil fuels is a major source of greenhouse gases that have been recognized as contributing to global warming. This process also produces ground level ozone that is a significant component of “smog.” The emissions from coal-fired thermal electric plants combine with water vapor in the atmosphere to create “acid rain” and other toxic emissions. With the increased awareness of the damages done by the combustion of fossil fuels, society has turned the focus on energy consumption. The construction industry is not exempt from fossil fuel-related concerns, and several studies have been undertaken to estimate the amount of energy being consumed, particularly in the construction of roads where large machinery is employed and the quantities of material either consumed or moved is high (Collings and Jenkins n.d.). A detailed study in New Zealand by Patrick and Moorthy (2008) reported energy consumption data in procuring traditional materials, as shown in Table A-1.

Permeable Parking Surface Support Products

Porous Asphalt

First developed by the Franklin Institute of Philadelphia during the 1970s, PA enables stormwater to be mitigated through its large void spaces. While standard asphalt and PA are both comprised of fine and coarse aggregates that are held together by a bituminous-based binder, the amount of fine aggregates is reduced in PAs. This reduction allows for a larger void space of typically 15%–20% in the mixture (NC State University 2011). Using PAs in parking lots as well as roadways has several benefits: reduction of runoff volume and rate, pollutant filtering, flow dispersion, and groundwater recharge (DoD 2010). Another benefit is PA’s ability to enhance safety in the event of a rainstorm. The system is designed to collect and filter stormwater water during rain events by draining and removing it from the drivable surface (Figure A-1), leaving the surface safe and clear of hazardous ponding (Figure A-2).

Table A-1. Energy consumed in procuring traditional materials (data from Patrick and Moorthy 2008).

Material or Activity	Energy Used
Material procurement	
Graded Crushed Stone (GCS)	**50 MJ/t**
Hot Mix Asphalt (HMA) manufacture	**30 MJ/t**
Cement	**70 MJ/t**
Bitumen	**60 MJ/t**
Material haulage	**1 MJ/t km**
Construction activity	
Milling[1]	**5 MJ/t**
In situ recycling/stabilizing	**10 MJ/t**
Processing aggregate layer	**66 MJ/t**
Ditto per m^2 for 150 mm thick layer	**10 MJ/m^2**
Compacting and finishing layer[2]	**10 MJ/m^2**
HMA paving and compaction	**20 MJ/t**

NOTE: Since they were not covered by the Patrick and Moorthy study, the following two energy consumption rates were derived: [1] Milling - half the energy consumed under the “In situ recycling / stabilizing” heading has been adopted as being both realistic and conservative for milling. [2] Compacting and finishing a new pavement layer is required for estimating energy consumed in compacting, leveling, and finishing off the material mixed by a recycler. Half the energy that Patrick and Moorthy estimated is consumed for “processing aggregate layer” (expressed in terms of MJ/m^2) was considered realistic (thereby allowing 50% for mixing). Units expressed in this table are megajoules (MJ), ton (t), kilometers (km), and meters (m).

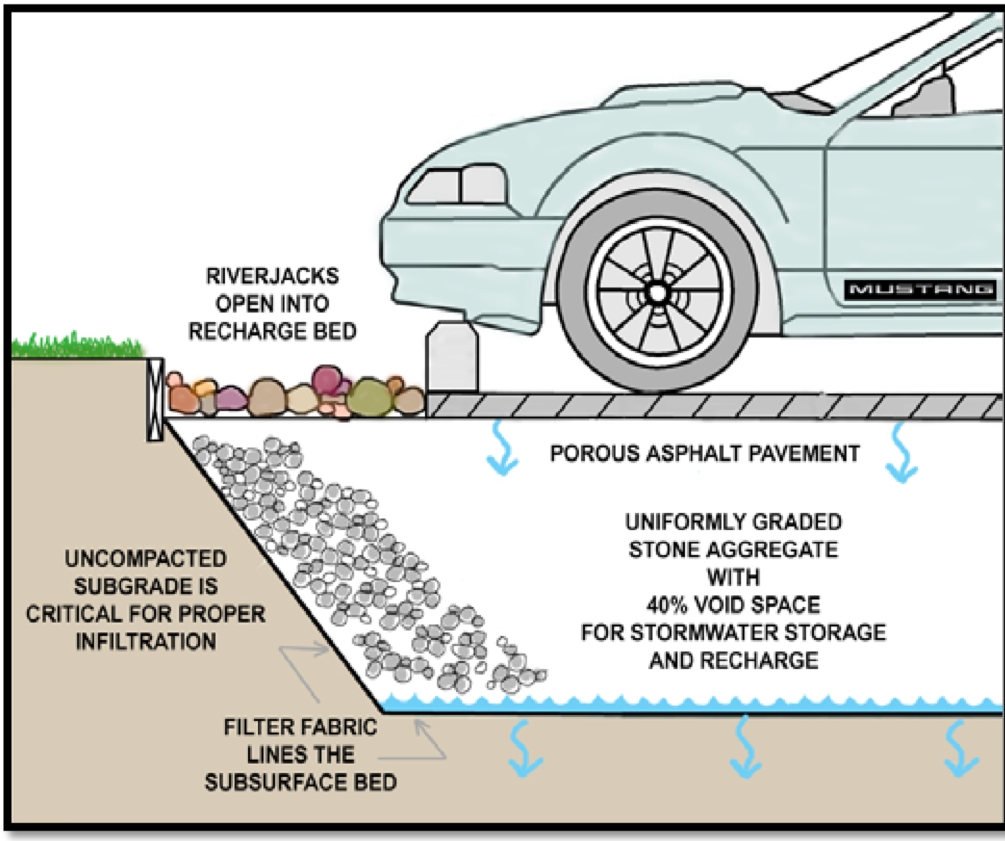

Figure A-1. Stormwater's flow path through porous asphalt system (DoD 2010).

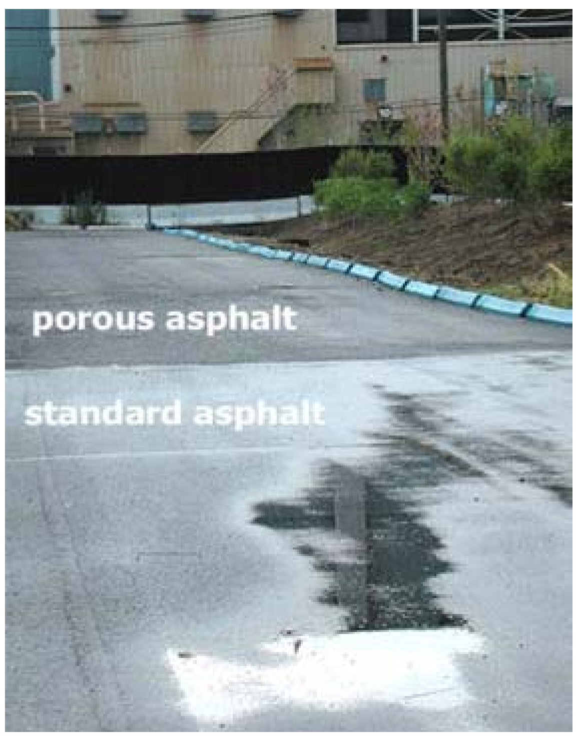

Figure A-2. Visual comparison of porous asphalt and standard asphalt after a storm (DoD 2010).

The main appeal of using PA is that it can be applied wherever standard asphalt is suitable (USEPA 2008). It also can be used for pedestrian applications such as greenways, and for low-volume, low-speed vehicular traffic applications such as parking lots, curbside parking lanes on roads, and residential or side streets (Agouridis et al. 2011). PA's uses include applying it within freeze-thaw climates, where PA not only is effective but also can reduce winter maintenance. The system is designed to speed the rate at which snow and ice melt, which in turns lessens the salt amount required (UNH Stormwater Center 2010). Typical maintenance involved with PA involves cleaning by a vacuum or street sweeper at least twice a year to remove sediments and debris that would clog the surface pores of the asphalt (DoD 2010).

The total cost of installing PA is comparable to standard asphalt — about $.50 to $1.00 per square foot (DoD 2010). While subsurface costs exceed that for traditional asphalt, the complete system expenditure is less (NAPA 2009; USEPA 2008). The savings occur because the quantity of stormwater pipes, inlets, and retention basins is significantly reduced when using a PA paving system.

Pervious Concrete

PC allows rainwater to drain through its surface (Figure A-3). This drainage significantly reduces runoff volume and peak flows, decreases surface temperature, improves water quality, and eliminates imperviousness (UNH Stormwater Center 2010). Pavement technology such as this creates more efficient land use by reducing or eliminating the need for retention ponds, swales, and other stormwater management devices. By using land more efficiently for stormwater treatment, pervious concrete has the ability to lower overall project costs. Furthermore, it can reduce government stormwater impact fees. Although high in initial cost relative to other pavement options, well-maintained pervious concrete has a long lifespan (National Ready Mix Concrete Association 2011). Pervious concrete cost can range between $2.00 and $6.50 per square foot, depending on base layer requirements and location (DoD 2010).

The system is composed of several layers, all of which are key components to the successful operation of the permeable surface (Figure A-4). The compressive strength of pervious concrete is usually less than that of conventional concrete, making it ideal for sidewalks and parking lots (Agourdis et al. 2011). PC can be designed to attain a compressive strength ranging from 400–4000 psi, though strengths of 600–1500 psi are more common (National Ready Mix Concrete Association 2011). Furthermore, a key parameter to design for is the subgrade soil at the site. To compensate for the lower structural support capacity of clay soils, additional sub-base depth is often required. The increased depth also provides additional storage volume to compensate for the lower infiltration rate of the clay subgrade (USEPA 2003).

There has been some concern as to whether PC is a suitable material for hardened surfaces in areas of the country where materials are susceptible to the effects of freeze-thaw. The resistance of any concrete to these effects depends on the subsurface permeability, material saturation, the rate of freezing, and the material distance to a free surface where ice can safely form. The most critical constraint of the aforementioned is material saturation. To control material saturation requires additional sub-base preparation and possibly an underdrain system to move water away from the pavement rapidly. Furthermore, research studies have indicated that generally, cold weather and frost penetration do not negatively impact surface infiltration rates. Permeable concrete freezes as a porous 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. In general, the selection of permeable pavements systems infers that the designer is trying not only to achieve a hardened surface, but also that he/she is trying to incorporate a stormwater treatment system.

Figure A-3. Pervious concrete enables water to flow through its profile, (USEPA).

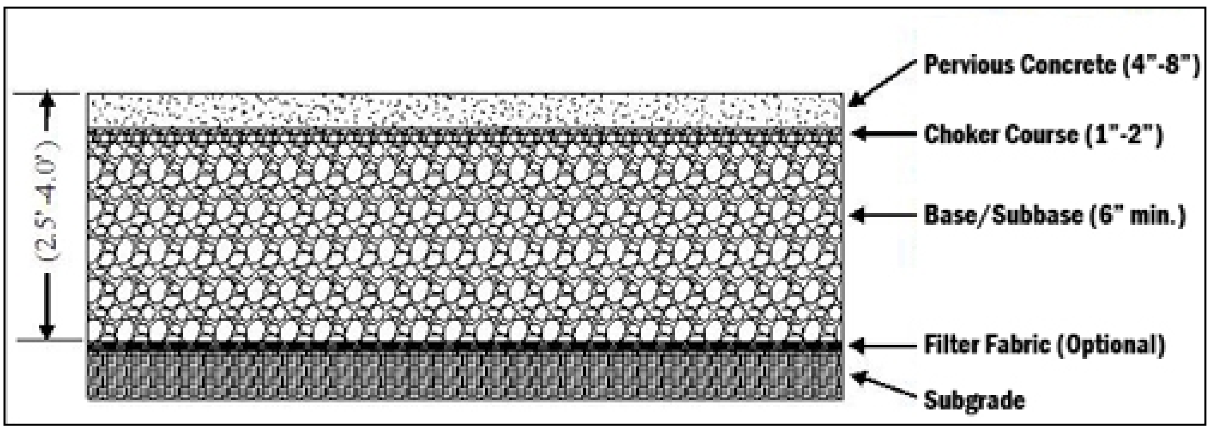

Figure A-4. Typical profile of a pervious concrete system (USEPA).

High-Density Polyethylene Products

3D Cellular Confinement Systems (Geocells)

Originally developed by USACE in the 1970s, “grid confinement” systems have improved greatly over the years. Geocells were initially created from aluminum, then their material transitioned to non-ultraviolet (UV)-stabilized polyethylene, and are now predominantly made of high density poly-ethylene (HDPE) materials (Presto Products 2012). Geosynthetics such as HDPE geowebs are easy to place because virtually all installations can be accomplished with in-house crews (Figure A-5).

Figure A-5. Installation of a geoweb and liner (Gesford and Anderson 2007).

Additionally, geosynthetic materials cost very little. Low installation costs and low material costs mean lower project costs or the possibility of a greater installed surface area (Presto Products 2012). However, research indicates that the tensile strength and stiffness of HDPE-based geocells, particularly in long-term performance, are unsuitable for heavy support applications (Kief and Toan 2011).

The geometry of the geocells is the key for erosion control and soil stabilization. The cells can be filled with a multitude of materials, depending upon the application demands of the site. Fill materials include: aggregate, sand, and soil. Material stabilizers are added for environmental durability against leaching of additives, oxidation, and UV exposure (Kief and Toan 2011). Furthermore, most HDPE geocell manufacturers offer both perforated/textured or smooth products. One applicable benefit of having a perforated system is that since there is a high degree of frictional interaction developed between the aggregate infill and the cell wall, that fact directly increases the stiffness of the system by reducing the ability of a shear plane developing between the infill and the cell wall (Permathene 2005).

Plastic Turf-Reinforcing Grids

Figure A-6. Parking lot outside of a stadium uses plastic grid pavers (covered by grass for overflow parking lot; USEPA 2005).

Plastic grid pavers (PTRGs) are applicable in almost the same locations as geocells, such as the overflow parking lot in Figure A-6. All PTRGs are fillable with the same materials: gravel, sand, or soil and grass mix. They are primarily constructed from recycled plastics, a process which further improves their green footprint. Additionally, if light-colored aggregate is used, the pavement surface will stay cool by reflecting solar radiation. Grass systems mitigate the heat island effect through the natural cooling process of evapotranspiration, which is the evaporation of water from plant material (USEPA 2005). Infiltration is improved when grass is used, as the plant roots help increase and maintain the permeability of the underlying fill (Agouridis et al. 2011).

PTRGs cost $1.50–$3.00 per square foot, including materials and installation (USEPA 2005). These prefabricated systems are built for supporting pedestrian or light traffic loads. They do not have as much intrinsic strength as do concrete pavers; the load-bearing capacity of plastic grid pavers ranges from 24,000 lbs/ft^2 (1149 kPa) to 823,680 lbs/ft^2 (39440 kPa) (University of Rhode Island 2005). While both plastic and concrete units perform well for stormwater management and traffic needs, plastic units tend to provide better turf establishment and longevity, largely because the plastic will not absorb water and diminish soil moisture conditions (Pennsylvania DEP 2005).

HDPE Surface Turf Reinforcement

HDPE surface turf reinforcement (STR) systems are typically comprised of recycled materials forming the HDPE, have flexible characteristics, and are long lasting. STR systems have been developed to support easy-installation. Turf reinforcement products are able to be used in an overflow or light traffic parking lot setting, as shown in Figure A-7. Some STR systems are able to be applied over pre-existing grass if the site is suitable. If the existing site is found to be unsuitable, STR systems are typically blended with a high sand-content growing medium to form a stabilized root zone that can support heavier loads than regular grass can. This subsurface medium can be placed 4-, 6-, or 8-in. thick; the deeper depth of installation would be in anticipation of heavier loads such as vehicles (University of Rhode Island 2005).

Figure A-7. Driveway paved with Turfguard (University of Rhode Island 2005).

Product costs typically range from $.60 to $1.00 per square foot, with additional costs accrued for a base thicker than 4 in. Regardless of installation method, expected maintenance includes mowing, irrigation, seeding, and fertilizing (if needed).

Concrete Pavers

Modular porous concrete paver systems are described as, “a pavement surface composed of structural units with void areas that are filled with pervious materials such as sand or grass turf” (Georgia 2001). These pavers are often very attractive and are especially well suited to plazas, patios, small parking areas, etc. (Pennsylvania DEP 2005). The pavers come in a variety of designs and load-bearing capacities (Figure A-8) including permeable interlocking concrete pavers (PICP) and concrete grid pavers (CGP). Porous paver systems should be used in applications where the pavement receives tributary runoff only from impervious areas. The ratio of the contributing impervious area to the porous paver surface area should be no greater than 3:1, with a slope no greater than 2% (Georgia 2001).

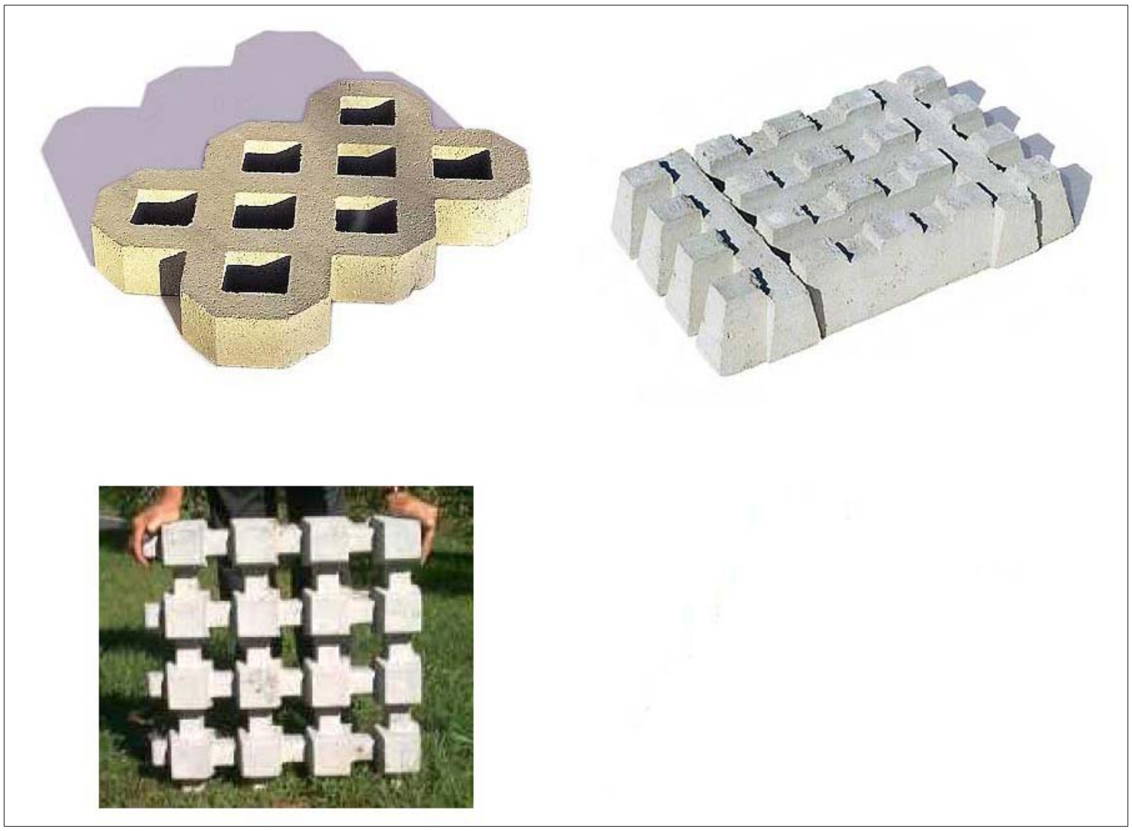

Figure A-8. Examples of concrete permeable pavers (Georgia 2001).

For meeting LID stormwater requirements, the use of a storage area beneath is encouraged. However many concrete paver products recommend compaction of the soil and do not include a drainage/storage area (similar to the one shown in Figure A-9), and therefore, they do not provide optimal stormwater management benefits. A system with a compacted subgrade will not provide optimum infiltration (Pennsylvania DEP 2005).

In addition, there is the difficulty and cost of rehabilitating the concrete paver surfaces, should they become clogged. Concrete paving blocks require that the surface be kept clean of organic materials (e.g., leaves), and periodic vacuuming and low-pressure washing should be used to clear out voids and extend the pavers' functional life. Conventional street sweepers should be used with vacuums, brushes, and water ideally four times a year, but the actual required frequency will be determined by local conditions. With interlocking systems, additional aggregate fill material may also need to be added after cleaning (Low Impact Development Center 2007).

Costs vary for concrete paving block systems, mainly due to the variation of base depths required as well as site accessibility; costs can range from $5.00–$10.00 per square foot installed (Low Impact Development Center 2007). As is typical of most LID permeable systems, cost estimates are slightly greater than for more typical landscaping treatment (due to the increased number of plantings, additional soil excavation, backfill material, use of underdrains, etc.). Note that landscaping expenses that would be required regardless of the bioretention installation should be subtracted when determining the net cost (ibid.).

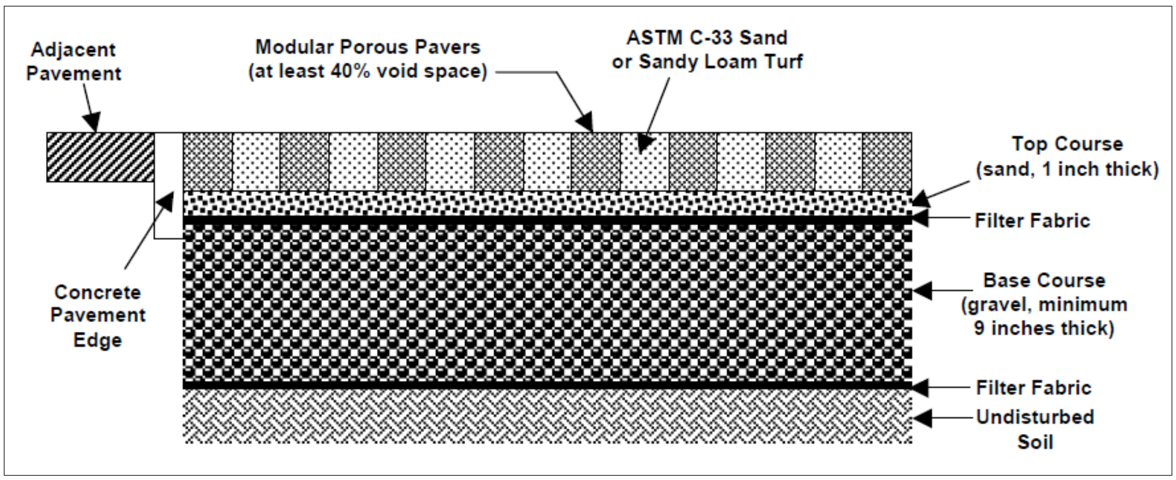

Figure A-9. Recommended profile design of a porous paver system (Pennsylvania DEP 2005).

Natural, Untreated Parking Site

Without the implementation of vegetated permeable parking lot support systems, most natural overflow parking sites would be altered and incur damage when subjected to traffic. Typical damage includes compaction, rutting, vegetation removal due to tracking, and vegetative loss resulting from increases in the soil’s bulk density. Damages to the vegetative surface will vary by vehicle type and weight, soil type, and soil moisture content.

Compaction increases within the soil profile as its moisture content increases (Figure A-10). Compacted soil stresses the newly planted vegetation by making root penetration difficult;

newly established vegetation typically then becomes stunted and remains smaller than vegetation established in undisturbed soil (Oregon DEQ 2001).

Maintenance includes irrigation, mowing, reseeding, and fertilizing as needed by the site; maintenance and inspections should be performed regularly. The use of natural grass areas for parking is only recommended for temporary parking of vehicles during dry conditions.

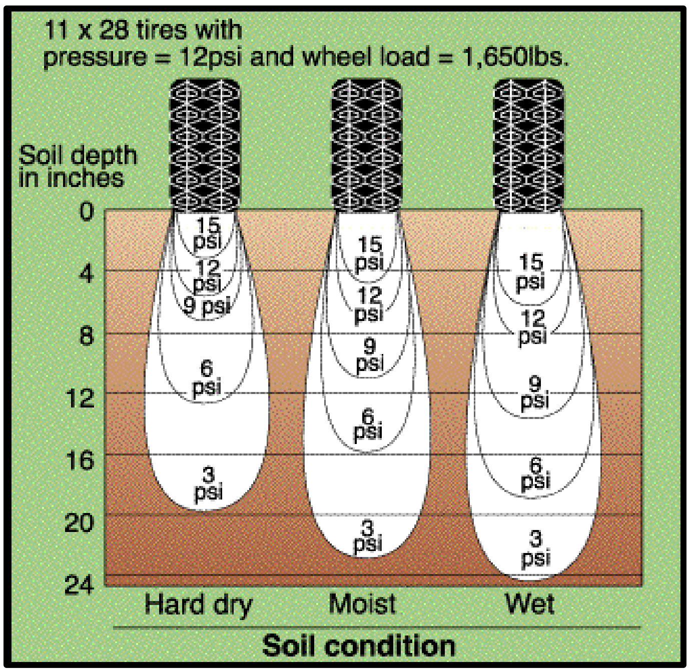

Figure A-10. Typical relationships between soil loading and the depth of soil compaction [Oregon DEQ 2001].

Permeable Systems, Additional Components

There are several options that can provide additional benefits to the site and the stormwater management program, when they are correctly designed into the permeable system. The following are examples of common additions and their subsequent benefits.

- The filter blanket is placed to prevent downward migration of material into the reservoir course (University of New Hampshire n.d.).
- The optional underdrain in the reservoir course is for hydraulic relief and is typically raised for enhanced groundwater recharge (ibid.). Perforated pipes can be added near the top of the reservoir to discharge

excess stormwater from large events (Agouridis et al. 2011).Subdrainage may be implemented for sites with low permeability soils (UNH Stormwater Center 2010). It is recommended that an observation well be installed at the down-gradient end of the permeable pavement to monitor performance (Agouridis et al. 2011).

- Nonwoven geotextile filter fabric (geotextile) is used only for stabilizing the sloping sides of the porous asphalt excavation (UNH Stormwater Center 2010). The sides of the system may be lined with geotextile fabric to prevent an influx of fines; however, a bottom lining is only recommended with poor structural soils. Geotextiles should be used with caution as they can lead to premature clogging (ibid.).

Permeable Products Best-fit Chart

Table A-2 summarizes the characteristics and costs of various types of permeable products along with standard gravel, concrete and asphalt so that the best fit selection can be made for each situation.

Table A-2. Permeable products best-fit chart with standard gravel, concrete and asphalt for reference.

Permeable Paving	Description	Limitations	Maintenance	Cost Estimate
Porous Asphalt	Enables stormwater to be mitigated through its large void spaces; min. of 15% void spaces.	Needs to be installed by an experienced supplier, dries quickly	Swept/vacuumed and/or power washed before rainy seasons	$3.0–$4.50 per square foot (2–4 in. thickness) The cost of asphalt fluctuates with the price of oil and can vary widely. Various state transportation agencies keep indices of asphalt prices.
Permeable Concrete	Enables stormwater to be mitigated through its large void spaces; min. of 15% void spaces.	Needs to be installed by an experienced supplier, dries quickly	Swept/vacuumed and/or power washed before rainy seasons	$2.00–$6.50 per square foot (4–8 in. thickness)
Geocells	Cells can be filled with a multitude of materials, depending on the application and demands of the site.	Unsuitable for heavy load support applications	*Vegetated:* -May need occasional reseeding -Requires mowing and irrigation *Non Vegetated:* -May need occasional refilling of aggregate media	$.30–$.80 per square foot, unfilled

Permeable Paving	Description	Limitations	Maintenance	Cost Estimate
Plastic Turf Reinforcing Grids	Applicable in almost the same location types as geocells and able to be filled with the same materials.	Load-bearing capacity ranges from 24,000 lb. per square foot to 823,680 lb per square foot	*Vegetated:* -May need occasional reseeding -Requires mowing and irrigation *Non Vegetated:* -May need occasional refilling of aggregate media	$1.50–$3.00 per square foot
HDPE Mesh	Used to form a stabilized root zone that can support heavier loads than regular grass.	Overflow or light traffic parking lot setting	Mowing, irrigation, seeding, and fertilizing if needed	$.60–$1.00 per square foot
Concrete Pavers	Structural units with void areas that are filled with pervious materials such as sand or grass turf.	Not to be used for traffic exceeding 35 mph	Periodic vacuuming, low-pressure washing, and may need occasional refilling of aggregate media	$5.00–$10.00 per square foot installed
Gravel	Standard			$1.70–$6.00 per square foot installed
Concrete	Standard Portland Cement			$2.50–$4.50 per square foot (4–8 in. thickness)

Permeable Paving	Description	Limitations	Maintenance	Cost Estimate
Asphalt	Standard Asphalt			$2.00 -3.00 per square foot (2–4 in. thickness) The cost of asphalt fluctuates with the price of oil and can vary widely. Various state transportation agencies keep indices of asphalt prices

Vegetated Permeable Parking

Successful installation and maintenance of a vegetated permeable parking support system offers additional benefits beyond groundwater recharge, removal of petroleum, oil, and lubricants (POLs), and reduction of stormwater runoff. System benefits also include reduction of heat island effect, additional permeability from root zone, and aesthetic value.

A variety of grasses can be used in the system. It is imperative to choose a grass species appropriate for the location; changing to another can be costly and labor intensive (Nicholson n.d.). Additionally, in most Army applications, native grasses are preferable because turfgrasses may encroach on maintaining native grass habitat as designated in EO 13112. Furthermore, there are alternatives to both turfgrass and native grasses that show promise.

Turfgrass

Turfgrass is a very popular option for American lawns and yards. According to the Lawn Institute, there are over 40 million acres (163,800 km^2) of turfgrass covering US soil.[1] While this emerald

[1] Calculated from NASA satellite data in Milesi et al.2005, 426.

green covering may be idolized, there are many maintenance practices involved with it. Constant mowing and watering along with herbicide and pesticide applications are all part of common maintenance practices. Unfortunately, these practices are not very “green” or environmentally friendly. Additionally, the water that runs off and is carried away by storm drains eventually empties into nearby streams, where it is carried into local lakes and groundwater. The pollutants in this stormwater can raise river and lake water temperatures, harming aquatic life. Furthermore, non-native and introduced turfgrasses greatly reduce biodiversity in a given area (Kopp et al. 2010).

Turfgrasses must be selected according to their adaption to the particular site and intended use. Improper seed selection and/or poor seed quality will lead to poor turf. Installment of a poorly suited turfgrass will result in a weak, thin, and unattractive turf that is subject to soil erosion and weed encroachment (Murphy 1996). Traditional species used in lawns include Kentucky bluegrass, fine fescues, perennial ryegrass, and tall fescue. Local university-based, cooperative extension offices can provide insight into selecting and establishing the best vegetation, whether it’s a turfgrass seed or seed mixture.

Mowing should be performed on a regular schedule that is based on regional and site-specific conditions. During growing seasons, the turf should be trimmed at least once a month. The site’s vegetation should also be inspected annually for unwanted growth, which should be removed. Furthermore, the vegetation should be maintained at a minimum of 85% surface coverage. If the damage to vegetation is greater than 50%, then the area should be reestablished in accordance with the original specifications (New Jersey DEP 2004). The use of chemical pesticides and fertilizers should be avoided whenever possible.

Non-Traditional Options

Ground cover

Ground covers are plants which spread across the ground but do not grow tall, so no cutting is required. Areas planted in ground cover need little to no maintenance. Ground covers are usually chosen for texture, density, and how well they spread and choke out the weeds. They enhance the soil by acting as mulch, and some ground covers are nitrogen-fixing (Eartheasy.com 2012). During the first year, new plantings of ground cover will require weeding and mulching, but once established, little care is needed.

Many ground covers are available, but only those with requirements that match site conditions will offer a lower-maintenance alternative to turfgrass. Besides being adapted to the site's climate, native ground covers are a great choice for supporting local biodiversity. When selecting ground covers for the site, consider the factors outlined by Kopp et al. (2010).

- Required light conditions (sun, shade, part sun)
- Required soil conditions (moist/dry, clayey/sandy, acidic/neutral)
- Hardiness (tolerance for low winter temperatures)
- Deciduous/evergreen
- Mature height
- Ornamental features (flowers, fruit, fragrance, fall color, foliage size and shape)
- Cost (plugs are less expensive in larger quantities than containerized plants)
- Ability to withstand foot traffic
- Growth rate (how fast plants will achieve desired coverage)

Alternative turfgrass mixes

Figure A-11. A healthy seeding of "No Mow Lawn Mix" (Lawn Reform Coalition).

To reduce the large maintenance commitment involved with turfgrass, there are several new grass mixtures available. “No Mow Lawn Mix” is great for open, sunny swaths where native prairie grasses once grew such as the cooler, medium-rainfall areas of the upper Midwest, Northeast, and Pacific Northwest (Figure A-11; Kaiser 2010). No Mow Lawn Mix costs about $.02 per square foot. There are also hardy alternative mixes such as Eco-Lawn, which thrives even in difficult spots such as in clay soils (Kaiser 2010).

Native Grasses

The Great Lakes Office of the USEPA states, “Native plants (also called indigenous plants) are plants that have evolved over thousands of years in a particular region. While native grasses generally take longer to establish than their introduced counterparts, they will outlast them. Native grasses have withstood the test of time and developed resistances to environmental threats such as drought, soil acidity, and diseases. They have adapted to the geography, hydrology, and climate of that region. Native plants occur in communities, that is, they have evolved together with other plants” (USEPA Great Lakes Office n.d.). Native plants possess greater genetic diversity but, as a result, less predictability of shape and size. Native plants have evolved to grow in local conditions and to predictable sizes (PlantNative 2009).

Native plants do not require watering (except during establishment), chemical pesticides and fertilizers, or frequent cutting. While many turfgrasses have been developed from native predecessors, most turfgrasses have proved to be less resistant to pests and disease. Native vegetation is the most logical planting to use in areas where plants or grass will not be maintained by high fertilization, soil additives, watering, and insecticides (Seedland website). According to alternative grass guru John Greenlee, “a lawn is the cheapest thing to plant but it becomes the most expensive thing in the garden to maintain” (Scripps Howard/HGTV 2012). Using proper planting and management techniques, especially during the establishment years, will significantly improve plant health, reduce weed problems, and increase the likelihood of success (USEPA n.d.).

Warm- and cool-season native grasses

An initial classification for grasses is the verification between warm or cool season grasses. While native cool-season grasses only take one to two seasons to fully establish, native warm-season or cool-season grasses usually take two to three years to become fully established (USEPA n.d.). According to the EPA, native cool-season grasses are an excellent option when shorter native grasses are desired. As with any vegetation installation, it is important to select the proper vegetation for the local climate. Table A-3 is designed to assist in deciding which type of grass best meets the demands of the site.

Table A-3. Comparison of cool- and warm-season grasses (adapted from USEPA n.d.)

Cool vs. Warm Season Grasses	
Cool Season	Warm Season
• growth rate highest in spring & fall	• growth rate highest in midsummer
• water/nutrient needs moderate-high	• efficient use of water/nutrients
• utilize on 15%-30% of incoming sunlight(shade tolerance)	• utilize 80% of incoming sunlight
• rapid establishment	• slow establishment (roots develop initially)

Old-field vegetation

Old-field vegetation of grasses and forbs is a possible sustainable alternative to turfgrass communities (Kwit and Collins 2008). In addition to their benefits to wildlife, native warm-season grasses have a number of physical characteristics that make them attractive to land managers. Most native grass species spend their first year after planting developing a strong root system that will eventually extend 5-15 ft into the soil (Foster 2010).

Predeveloped mixes

New drought-tolerant mixes are being developed and tested. One such product is “Habiturf,” a combination of native species that includes buffalo grass, blue grama, and curly-mesquite. The grasses are mixed together to produce a more dense turf than Bermuda grass, with a long leaf and light green color (Figure A-12; Sanders 2011). Mark Simmons, Director of the Lady Bird Johnson Wildflower Center's Ecosystem Design Group said, “its benefits are many, including the fact that it requires less mowing and less watering — once it's established, it can be watered once every two weeks to keep it green or even less if you want to let it go dormant and let it recover once rainfall starts again - and its density attracts fewer weeds” (in Sanders 2011).

Figure A-12. A well-established Habiturf lawn (Lawn Reform Coalition).

Native grass installation and maintenance

Native grass seedlings can take up to 4 years to become fully established. To ensure seeding success, careful planning is essential (Ohlenbusch 1997). While there have been machines developed specifically to address the physical characteristics and demands of native seeds, they are not suitable to sites where the support system product is nearly flush with the seedbed surface. One feasible method of placing native vegetation in that configuration is to broadcast seeds and then rake them evenly into the surface. Lightly cover the grass seed with a top dressing made of organic material and keep moist to secure germination (manufacturer recommendation, Drivable Grass®). When sowing seeds, it is important to note that most native grass seeds cannot emerge from deeper than 0.5-1.0 in.

Good management of a seeded grass stand is a must due to the investment of time, money, and labor involved. However, once established, native plants do not need fertilizers, herbicides, pesticides, or watering, thus benefiting the environment and reducing maintenance costs (USEPA 2008). By mowing down native landscaping in early spring and removing debris from the area, the exposed soil will be warmed by the sun and thus will mimic the natural fire cycle. Mowing can be done every spring, or mowing can be rotated by mowing portions in the fall and letting portions grow untouched for a few seasons (ibid.). Each technique favors different plants, and thus encourages a variety of plants to emerge.

Native Upland Graminoids

Table A-4 lists the upland, graminoid (grass) plants with mature heights and their native areas (states) in the United States.

Table A-4. Native upland, graminoid (grass) plants with mature heights and native areas in the United States (USDA).

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
ACLEL	Achnatherum lemmonii (Vasey) Barkworth var. lemmonii	Lemmon's needlegrass	CPC	3	AZ, CA, ID, MT, NV,OR, UT, WA
ACLE9	Achnatherum lettermanii (Vasey) Barkworth	Letterman’s needlegrass	CPC	2	AZ, CA, CO, ID, MT, NM,NV, OR, UT, WY
ACNED	Achnatherum nelsonii (Scribn.) Barkworth ssp. dorei (Barkworth & Maze) Barkworth	Dore's needlegrass	CPC	3	AZ, CA, CO, ID, MT, NM, NV, OR, SD, TX, UT, WA, WY
ACOCO	Achnatherum occidentale (Thurb.) Barkworth ssp. occidentale	western needlegrass	CPC	2	CA
ACSP12	Achnatherum speciosum (Trin. & Rupr.) Barkworth	desert needlegrass	CPC	2	AZ, CA, CO, NM, NV, OR, UT
ACTH7	Achnatherum thurberianum (Piper) Barkworth	Thurber's needlegrass	CPC	2	CA, CO, ID, MT, NV, OR, UT, WA, WY
AGPA8	Agrostis pallens Trin.	seashore bentgrass	CPC	2	CA, ID, MA, MT, NV, OR, WA
ANHA	Andropogon hallii Hack.	sand bluestem	CPC	6.1	AZ, CO, IA, IL, IN, KS, MN, MT, ND, NE, NM, OK, SD, TX, UT, WY
ARAR6	Aristida arizonica Vasey	Arizona threeawn	CPC	2	AZ, CO, NM, NV, OK, TX, UT

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
ARDI5	Aristida divaricata Humb. & Bonpl. ex Willd.	poverty threeawn	CPC	1.3	AZ, CA, CO, KS, NM, OK, TX
ARPUL	Aristida purpurea Nutt. var. longiseta (Steud.) Vasey	Fendler threeawn	CPC	1.4	AZ, CA, CO, IA, ID, KS, LA, MN, MT, NC,ND, NE, NM, NV, OK, OR, SC, SD, TX, UT, WA, WY
ARGIT8	Arundinaria gigantea (Walter) Muhl. ssp. tecta (Walter) McClure	switchcane	CPC	25	AL, AR, FL, GA, LA, MD, MS, NC, NJ, NY, OK, SC, TN, VA
BLTR	Blepharoneuron tricholepis (Torr.) Nash	pine dropseed	CPC	3	AZ, CO, NM, TX, UT
BOBA3	Bothriochloa barbinodis (Lag.) Herter	cane bluestem	CPC	4	AZ, CA, CO, FL, HI, NM, NV, OK, SC, TX, UT
BOBR	Bouteloua breviseta Vasey	gypsum grama	CPC	2.5	NM, TX
BOCU	Bouteloua curtipendula (Michx.) Torr.	sideoats grama	CPC	3	AL, AR,AZ, CA, CO, CT, DC, FL, GA, HI, IA, ID, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO, MS, MT, ND, NE, NJ, NM, NY, OH, OK, OR, PA, SC, SD, TN, TX, UT, VA, WA, WI, WV, WY
BOER4	Bouteloua eriopoda (Torr.) Torr.	black grama	CPC	2	AZ, CA, CO, KS, NM, NV OK, TX, UT, WY
BOGR2	Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	blue grama	CPC	1	AZ, CA, CO, CT, FL, IA, ID, IL, KS, MA, ME, MI, MN, MO, MT, ND, NE, NM, NV, NY, OH, OK, SC, SD, TX UT, WI, WY

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
BOHI2	Bouteloua hirsuta Lag.	hairy grama	CPC	0.5	AR, AZ, CO, FL, GA, IA, IL, KS, LA, MD, ME, MN, MO, MS, MT, ND, NE, NM, NV, NY, OH, OK, SC, SD, TX, UT, WI, WY
BRAN	Bromus anomalus Rupr. ex Fourn.	nodding brome	CPC	2	NM, TX
BRCA5	Bromus carinatus Hook. & Arn.	California brome	CPC	4	AK, CA, OR, WA
BRIN2	Bromus inermis Leyss.	smooth brome	CPC	2.5	AK, AR, AZ, CA, CO, CT, DC, DE, GA, IA, ID, IL, IN, KS, KY, LA, MA, MD, ME, MI, MN, MO, MS, MT, NC, ND, NE, NH, N NM, NV, NY, OH, OK, OR, PA, RI, SC, SD, TN, TX, UT, VA, VT, WA, WI, WV, WY
BRMA4	Bromus marginatus Nees ex Steud.	mountain brome	CPC	4	AK, AZ, CA, CO, CT, IA, ID, IL, KS, MA, ME, MT, NE, NH, NM, NV, NY, OR, SO, UT, WA, WY
BRSI	Bromus sitchensis Trin.	Alaska brome	CPC	5	AK, CA, OR, WA
CABR	Calamagrostis breweri Thurb.	shorthair reedgrass	CPC	5	CA, OR
CARU	Calamagrostis rubescens Buckley	pinegrass	CPC	3	CA, CO, ID, MT, NV, OR, UT, WA, WY
CASTS5	Calamagrostis stricta (Timm) Koeler ssp. stricta	slimstem reedgrass	CPC	3	AK
CALO	Calamovilfa longifolia (Hook.) Scribn.	prairie sandreed	CPC	4.5	CO, IA, ID, IL, IN, KS, MI, MN, MO, MT, ND, NE, NM, NY, OH, PA, SD, WA, WI, WY
CAEX4	Carex exserta Mack.	shorthair sedge	CPC	1	CA, NV, OR

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
CAFI	Carex filifolia Nutt.	threadleaf sedge	CPC	1.2	AK, AZ, CA, CO, ID, KS, MN, MT, ND, NE, NM, NV, OR, SD, UT, WA, WY
CAGE2	Carex geyeri Boott	Geyer's sedge	CPC	1.5	CA, CO, ID, MT, NM, NV, OR, PA, UT, WA, WY
CAHA2	Carex halliana L.H. Bailey	Hall's sedge	CPC	2.5	CA, OR, WA
CAMA13	Carex mariposana L.H. Bailey ex Mack.	Mariposa sedge	CPC	2	AS, CA, ID, NV
CARO5	Carex rossii Boott	Ross' sedge	CPC	1	AK, AZ, CA, CO, ID, MI, MN, MT, ND, NE, NM, NV, OR, SD, UT, WA, WY
CAER2	Cathestecum erectum Vasey & Hack.	false grama	CPC	1	AZ, TX
DAUN	Danthonia unispicata (Thurb.) Munro ex Macoun	onespike danthonia	CPC	0.8	CA, CO, ID, MT, NV, OR, SD, UT, WA, WY
DEBE2	Deschampsia beringensis Hultén	Bering's tufted hairgrass	CPC	3.2	AK, CA, OR, WA
DEFL	Deschampsia flexuosa (L.) Trin.	wavy hairgrass	CPC	2.6	AK, AL, AR, CT, DC, DE, GA, KY, MA, MD, ME, MI, MN, NC, ND, NH, NJ, NY, OH, OK, PA, RI, SC, TN, VA, VT, WI, WV
DICA8	Digitaria californica (Benth.) Henr.	Arizona cottontop	CPC	4	AZ, CO, NM, OK, TX
ELEL5	Elymus elymoides (Raf.) Swezey	squirreltail	CPC	1.5	AZ, CA, CO, DC, ID, IL, KS, KY, MO, MT, ND, NE, NM, NV, OK, OR, SD, TX, UT, WA, WY

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
ELTR7	Elymus trachycaulus (Link) Gould ex Shinners	slender wheatgrass	CPC	3	AK, AZ, CA, CO, CT, IA, ID, IL, IN, KS, KY, MA, MD, ME, MI, MN, MO, MT, NC, ND, NE, NH, NJ NM, NV, NY, OH, OR, PA, RI, SD, TX, UT, VA, VT, WA, WI, WV, WY
ERIN	Eragrostis intermedia Hitchc.	plains lovegrass	CPC	2.7	AL, AR, AZ, CA, FL, GA, KS, LA, MA, ME, MO, MS, NC, NM, OK, SC, TN, TX, VA
ERTR3	Eragrostis trichodes (Nutt.) Alph. Wood	sand lovegrass	CPC	3.5	AL, AR, CO, IA, IL, IN, KS, LA, MI, MN, MO, MS, NE, NM, NY, OH, OK, SD, TN, TX, VA, WI, WY
FEAR2	Festuca arizonica Vasey	Arizona fescue	CPC	2	AZ, CO, NM, NV, TX, UT
FECA4	Festuca campestris Rydb.	rough fescue	CPC	1.5	CO, ID, MT, OR, WA
FEOC	Festuca occidentalis Hook.	western fescue	CPC	3	AK, CA, ID, MI, MT, OR, SD, UT, WA, WI, WY
FETH	Festuca thurberi Vasey	Thurber's fescue	CPC	2	AZ, CO, NM, SC, UT, WY
FEVI	Festuca viridula Vasey	greenleaf fescue	CPC	2.5	CA, ID, MT, NV, OR, WA
HECOC8	Hesperostipa comata (Trin. & Rupr.) Barkworth ssp. comata	needle and thread	CPC	3	AZ, CA, CO, IA, ID, IL, IN, KS, MI, MN, MT, ND, NE, NM, NV, NY, OK, OR, RI, SD, TX, UT, WA, WI, WY
HESP11	Hesperostipa spartea (Trin.) Barkworth	porcupinegrass	CPC	4	CO, IA, IL, IN, KS, MI, MN, MO, MT, ND, NE, NM, OH, OK, PA, SD, WI, WY
HECO10	Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	tanglehead	CPC	0.7	AZ, CA, FL, HI, NM, TX

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
HIBE	Hilaria belangeri (Steud.) Nash	curly-mesquite	CPC	0.8	AZ, NM, TX
KOMA	Koeleria macrantha (Ledeb.) Schult.	prairie Junegrass	CPC	1.5	AK, AL, AR, AZ, CA, CO, DE, HE, IA, ID, IL, IN, KS, KY, LA, MD, ME, MI, MN, MO MS, MT, ND, NE, NM, NV, NY, OH, OK, OR, PA, SD, TX, UT, VT, WA, WI, WY
LEDU	Leptochloa dubia (Kunth) Nees	green sprangletop	CPC	3	AZ, CA, CO, FL, KS, MD, MO, MS, NC, NM, OK, SC, TX
LEFL4	Leymus flavescens (Scribn. & J.G. Sm.) Pilg.	yellow wildrye	CPC	3	ID, MT, OR, UT, WA
LEMOM2	Leymus mollis (Trin.) Pilg. ssp. mollis	American dunegrass	CPC	4	AK, CA, IL, MA, ME, MI, NH, OR, PA, WA, WI
LESA4	Leymus salinus (M.E. Jones) Á. Löve	saline wildrye	CPC	2.3	AZ, CA, CO, ID, MT, NM, NV, UT, WY
MECA2	Melica californica Scribn.	California melicgrass	CPC	4	CA, OR
MEIM	Melica imperfecta Trin.	smallflower melicgrass	CPC	3.2	AZ, CA, NV
MESU	Melica subulata (Griseb.) Scribn.	Alaska oniongrass	CPC	3.3	AK, CA, CO, ID, MT, NV, OR, SD, WA, WY
MUCU3	Muhlenbergia cuspidata (Torr. ex Hook.) Rydb.	plains muhly	CPC	1.4	AR, CO, IA, IL, IN, KS, KY, MI, MN, MO, MT, ND, NE, NM, OH, OK, PA, SD, TN, VA, WI, WY
MUPO2	Muhlenbergia porteri Scribn. ex Beal	bush muhly	CPC	2.8	AZ, CA, CO, NM, NV, OK, TX, UT
MUPU2	Muhlenbergia pungens Thurb.	sandhill muhly	CPC	1.5	AZ, CO, NE, NM, SD, TX, UT, WY
MURE	Muhlenbergia repens (J. Presl) Hitchc.	creeping muhly	CPC	1	AZ, CO, NM, TX, UT

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
NACE	Nassella cernua (Stebbins & R.M. Love) Barkworth	nodding needlegrass	CPC	2.6	CA, HI
NALE2	Nassella lepida (Hitchc.) Barkworth	foothill needlegrass	CPC	3	CA
NAPU4	Nassella pulchra (Hitchc.) Barkworth	purple needlegrass	CPC	3	CA
NAVI4	Nassella viridula (Trin.) Barkworth	green needlegrass	CPC	2	AZ, CA, CO, IA, ID, IL, KS, MN, MT, ND, NE, NM, NY, SD, UT, WI, WY
PIMI7	Piptatherum micranthum (Trin. & Rupr.) Barkworth	littleseed ricegrass	CPC	2.5	AZ, CA, CO, ID, MT, ND, NE, NM, NV, OK, SD, TX, UT, WY
PLJA	Pleuraphis jamesii Torr.	James' galleta	CPC	2	AZ, CA, CO, KS, NM, NV, OK, TX, UT, WY
PLMU3	Pleuraphis mutica Buckley	tobosagrass	CPC	2.3	AZ, CA, NM, OK, TX
PLRI3	Pleuraphis rigida Thurb.	big galleta	CPC	3	AZ, CA, NM, NV, UT
POFEF	Poa fendleriana (Steud.) Vasey ssp. fendleriana	muttongrass	CPC	2.6	AZ, CA, CO, MT, ND, NE, NM, NV, OK, SD, TX, UT, WY
POGL	Poa glauca Vahl	glaucous bluegrass	CPC	2	AK, AZ, CA, CO, ID, ME, MI, MN, MT, NH, NM, NV, NY, OR, PA, SD, UT, VT, WA, WI, WY
POGLG	Poa glauca Vahl ssp. glauca	glaucous bluegrass	CPC	2.1	AK, CO, ID, ME, MI, MN, MT, NH, NM, NY, OR, PA, UT, VT, WI, WY
POMA26	Poa macrantha Vasey	seashore bluegrass	CPC	0.4	AK, CA, OR, WA
PSSPI	Pseudoroegneria spicata (Pursh) Á. Löve ssp. inermis (Scribn. & J.G. Sm.) Á. Löve	beardless wheatgrass	CPC	2.5	CO, ID, MT, NE, NM, NV, OR, TX, UT, WA, WY

Symbol	Scientific Name	Common Name	Data Source	Max. Ht. (ft)	Native States
PTKI	Ptilagrostis kingii (Bol.) Barkworth	Sierra false needlegrass	CPC	1.4	CA
SABR18	Saccharum brevibarbe (Michx.) Pers.	shortbeard plumegrass	CPC	6.5	AL, AR, DE, FL, GA, IL, LA, MD, MS, NC, OK, SC, TN , TX, VA
SCSCD	Schizachyrium scoparium (Michx.) Nash var. divergens (Hack.) Gould	little bluestem	CPC	4	AL, AR, DE, FL, KY, LA, MS, PA, TN, TX, WI
SCTE5	Schizachyrium tenerum Nees	slender little bluestem	CPC	3	AL, FL, GA, LA, MS, OK, TX
SEVU2	Setaria vulpiseta (Lam.) Roem. & Schult.	plains bristlegrass	CPC	3	AZ, CO, MS, NM, TX
SPIN5	Sporobolus interruptus Vasey	black dropseed	CPC	2.5	AZ
SPWR2	Sporobolus wrightii Munro ex Scribn.	big sacaton	CPC	5.5	AZ, CA, NM, OK, SC, TX, UT

APPENDIX B:
PAVEMENT APPLICATIONS FOR MILITARY INSTALLATIONS

This appendix provides recommendations of sustainable pavement products by location, both on and off post. These recommendations are taken from the researched sources to assist in providing insight to best-fit products for various pavement applications and summarized in Table B-1. These recommendations are based not only on a compilation of case studies' findings but also on the reporting of relevant published reports. Additional details on the recommendations are given in the text that follows Table B-1.

Table B-1. Recommendations of sustainable pavement products by location.

Cantonment Location	Recommended Sustainable Pavement
Barracks	Pervious asphalt (PA) or pervious concrete (PC); also permeable interlocking concrete paver (PICP) or concrete grid paver (CGP) systems
Dayshift parking	PICP ideally; PA or PC if cost is an issue
Residential parking	PA, PC
Recreational parking	PA or PICPs
Overflow parking	Vegetated permeable systems such as geocells, PTRG, or HDPE-surface turf reinforcement
Tactical Equipment Maintenance Facility	PA, PC, and PICP
Motor Pool and other long-term storage	PC or PICP (with aggregate fill)
Sidewalks	PC, PICP
Recreational trails	PA
Bivouac areas (within cantonment)	Plastic turf grid pavers (PTRGs) or geocells
Parade grounds	Green turf with addition of PTRGs, geocells, or HDPE surface turf replacement (STR)
Recreational vehicle storage lots	PC or PICP (with aggregate fill)

Non-Cantonment Location	Recommended Sustainable Pavement
Combat vehicle trail	Articulated concrete block (ACB))
Misfire pits	ACB system
Bivouac area	PTRG
Staging areas	PA, PC, or PICP (only for areas such as sidewalks and office parking)
Landing zones	Geocells or PTRGs

Cantonment Applications

Single-Soldier Housing (Barracks) Parking

Parking is available for privately owned vehicles (POVs) such as trucks, cars, vans, and motorcycles. Parking is only allowed on the designated parking lots (not on the grass or sidewalk). PA and PC treatments would work well in this scenario because of the low traffic speed and improved driving safety (due to improved traction and reduced hydroplane conditions). PICPs and CGPs would also be suitable. Filling the appropriate voids with aggregate rather than vegetation would be suitable for frequently trafficked locations.

Dayshift Parking

Parking in these areas takes place during an estimated 251 working days each year, with staff vehicles using them at least 8 hr each work day. PICP would be ideal in this situation because it provides aesthetic value to the site as well as allows stormwater to infiltrate. If cost is an issue, PA or PC would also be an improvement to the stormwater management plan for this site.

Residential Parking

For families who live within the cantonment in single-family housing units, driveways are typically composed of graded asphalt or concrete. Unless site slope constraints inhibit the system, PA and PC would best fit into this type of site due to their low cost and traditional style. However, for permeable surface support systems to be successful, the proper maintenance needs to be performed by the tenant.

Recreational Parking

Designated parking areas that are to be utilized for patrons of local parks and playgrounds are typically composed of asphalt. While these parking lots do not typically receive as steady a use as the dayshift parking lots, they are still utilized by residents. Since these lots are traditionally composed of asphalt, the site would be an acceptable location for PA systems. To increase aesthetic value to the location, permeable pavers may also be installed as an alternative to PA.

Overflow Parking

Overflow parking is used when all parking spaces of the dayshift's paved lots are occupied. Vehicles are then directed to park on unsupported gravel or grass areas instead. Parking of this type typically occurs several times a year. Damages occur to both the vegetation (if present) as well as the soil below through compaction from vehicular weight. As these sites are used only when the designated parking lots are fully occupied, it would be best to retain their vegetated state, but it also would be advisable to develop one of the vegetated permeable systems such as geocells, PTRG, or HDPE-surface turf reinforcement. Furthermore, while vegetation (especially native varieties) may take longer to establish, it can reduce the maintenance costs over the lifetime of the system compared to a traditional pavement.

Tactical Equipment Maintenance Facility

The Tactical Equipment Maintenance Facility (TEMF) Army Standard Design defines an entire complex of facilities for the maintenance, repair, deployment, mission planning/rehearsal, training, and sustainment of equipment assigned to a unit other than aircraft. It defines space and equipment to maintain vehicles and associated equipment for all levels of maintenance below depot level for Table of Organization (TOE)/Table of Distribution and Allowances (TDA) equipment. Typical operations within the primary vehicle maintenance shop (VMS) within the TEMF complex include inspection, lubrication, preventive maintenance, diagnostic analysis, welding, body work, replacement of direct exchange systems, mobile maintenance team support, replacement of major components, repair of emission control system, performance of body and frame repair, and administration and scheduling of vehicle use and maintenance (USACE n.d. – Savannah Tactical).

Avoiding areas of excessive, heavy vehicular traffic as well as possible locations with hazardous liquids, there are opportunities to incorporate some areas such as sidewalks and reception office parking into a permeable parking system with the use of PA, PC, and PICP materials.

Motor Pool and Long-Term Storage

Motor pool and long-term military storage sites are typically supported by concrete slabs over large areas to meet the demands of the installation. The site is usually required to store heavy loads including Humvees, trailers, and steel transportation containers for varying durations. PC and PICP systems can be designed to meet these heavier load-bearing demands while still allowing stormwater to infiltrate. For this type site where PICP is chosen, aggregate fill would be suitable filler for the permeable support system, as opposed to the use of vegetation which may be damaged from the friction of vehicle tires.

Sidewalks/Pedestrian Pathways

Entrances to office buildings as well as sidewalks are a common sight in cantonment areas. While these concrete walks are not required to handle a vehicular load, they often support a steady load of foot traffic during business days. As long as maintenance can be routinely scheduled, these areas are good candidates for PC and PICP systems.

Recreational Trails

Recreational trails placed throughout the cantonment are for enthusiasts to bike, walk, and run. Where available, these trails are typically formed with bitumen asphalt. PA could be introduced to trail sites, as it can typically be placed wherever asphalt is. It is important to schedule maintenance before rainy seasons to clear the pathways and ensure successful infiltration.

Bivouac Areas within Cantonment

Temporary encampments within the cantonment itself are expected to be built on flat, vegetated land away from the risk of water runoff. The vegetation can often be harmed by camping equipment, foot traffic (especially in wet conditions), as well as possible vehicle loads. To prevent such damages and reduce ponding conditions all while maintaining the vegetative ground cover, it is recommended to install and maintain a permeable system such as plastic grid pavers or geocells.

Parade Grounds

Parade grounds are dedicated to military drills, marches, parades, and public ceremonies. On most army posts, the main parade ground once functioned as the physical and organizational center of post life (NPS n.d.). These sites continue to see a great deal of foot traffic during events. To prevent vegetation damages while also maintaining the traditional use of green turf, it is recommended to install and maintain a permeable system such as plastic grid pavers, geocells, or HDPE STR.

Recreational Vehicle Storage Lots

Privately owned recreational vehicles (e.g., boat, camper, four-wheeler, snowmobile, or scooter) cannot be stored in barracks' parking lots. These vehicles are required to be stored in recreational vehicle storage lots. Since it will support a variety of vehicles and weights, the lot needs to meet the demand of the heaviest possible vehicle in order for the system to provide adequate support. PC and PICP systems can be designed to meet these heavy load-bearing demands while still allowing stormwater to infiltrate. For instances where PICP is chosen, aggregate fill would be suitable filler for the permeable support system as opposed to the use of vegetation, which may be damaged from the friction of vehicle tires.

Training Area Pavement Applications

Tank (Combat Vehicle) Trail – Turn Pads and Firing Positions

The use of an articulated concrete block (ACB) system is recommended for certain areas of combat vehicle trails. The following two paragraphs are excerpts from Tank Trail Designs (USACE 2005).

> "Another option for the designer at these locations or other high traffic areas is the use of articulated concrete blocks, also known as "cable concrete" blocks. A cable concrete system is composed of individual trapezoid shaped concrete blocks that are strung together with steel cables into 8 ft by 16 ft "mattresses" that are placed side-by-side, clamped, and staked to the ground to provide one homogeneous system. Gaps between individual blocks are filled with aggregate base that is worked into crevasses between the blocks."

> "The gradation requirements for the wearing surface, coarse gravel base course, and sand sub-base have been developed

using standard filter design criteria that enable water to flow freely through the granular fill and prevent the migration of the smaller particles from the wearing surface downward or from the subgrade upward where frost is a possibility."

Figure B-1. Tank trail intersection (center of photo) that has been hardened with cable concrete and stabilized with bollards (USACE 2005).

Misfire Pits

Misfire pits are typically composed of either concrete or gravel to support the weight of the vehicle. An additional option is the use of ACB systems. However, the pit is a low spot relative to the neighboring topography; any runoff water from a storm will flow towards this point and collect there. Soil permeability is a major site constraint at these locations. Site selection and design of misfire pits should consider topography, amended soils, underdrain systems, and land contouring to minimize water ponding issues. Under situations where soil permeability does not create excessive ponding conditions, ACB systems may be used to prevent the misfire pit from being flooded and to provide support. ACB systems will not only support tank traffic, but also will provide a substantial distance between the drivable surface and the ground itself, while still allowing water to permeate the soil below.

Bivouac Areas within Training Areas

Temporary encampments within training areas are commonly set up on vegetated land, away from the risk of water runoff. The vegetation can often be harmed by camping equipment, heavy foot traffic, and heavy vehicle loads. It is recommended to install and maintain a permeable system such as a plastic grid paver system that meets the area's load-bearing demands.

Staging Areas

The mission of the Installation Staging Area (ISA) is to facilitate the deploying unit by ensuring equipment is properly prepared and correctly documented prior to departing the installation, and that the equipment arrives at the port of embarkation (POE) in accordance with call forward movement schedules (USAG Bamberg n.d.). The site is frequently used to transport various shipments and has a steady traffic of vehicles, including freight trucks containing cargo. The site is typically asphalt or concrete paving; however, there are substantial amounts of area within the facility to facilitate permeable paving. Depending on the location of the heavy vehicular traffic as well as possible hazardous liquids, there are opportunities to incorporate some areas such as sidewalks and reception office parking into a permeable parking system with the use of PA, PC, and PICP materials.

Landing Zones

Training area landing zones do not typically have any permanent ground support system. Due to constant and repeated use, the area and its subsurface can be damaged by constant foot traffic as well as the weight of the aircraft itself. Recommendations include installing a permeable support structure, such as geocells or plastic grid pavers, which can reduce and almost eliminate the negative impacts of this form of training exercise. Field-use helipads are also being manufactured in the form of rigid above-ground systems that interlock; products such as this reduce dust pollution.

APPENDIX C: BENEFIT-COST CONSIDERATIONS FOR DESIGN AND MATERIALS AND LESSONS LEARNED

Stormwater Management

Stormwater consists of melted snow and rainwater that runs off roads, lawns, and other sites. When stormwater is absorbed into the ground, it is filtered and ultimately replenishes aquifers or flows into streams and rivers. Impervious surfaces, such as pavement, prevent precipitation from naturally soaking into the ground. Instead, the water runs rapidly into the existing stormwater drainage network of detention ponds, storm drains, sewer systems, and drainage ditches and can cause the following problems (USEPA 2011):

- downstream flooding
- stream bank erosion
- increased turbidity (muddiness created by stirred up sediment) from erosion
- habitat destruction
- changes in the stream flow hydrograph (a graph that displays the flow rate of a stream over a period of time)
- combined sewer overflows
- infrastructure damage
- contaminated streams, rivers, and coastal water

By integrating the use of permeable parking lot systems into an existing or new stormwater management plan, the negative effects listed above can be minimized. The need for stormwater transportation infrastructure, such as pipes, detention basins, and drains can also be limited as their load has been decreased through implementation of the permeable systems.

Pollution Loads and Treatment

Since there is no filtering system in the traditional parking lot, the water from the storm drains empties into nearby streams detention ponds or storm drainage network, where it is carried into local lakes and groundwater (some drainage networks may have water treatment at end of drainage pipe). Through the integration of permeable pavement in various parking sites, stormwater that once fell on impervious asphalt or concrete can now be filtered as it falls on the pervious materials and infiltrates the various subgrade layers within the system. The water can then either be transported elsewhere via stormwater piping, stored in underground cisterns to be reused in a garden or other application, or simply continue to recharge the groundwater, whichever is designed and planned. The results of a permeable pavement system pollutant removal and water quality improvement test performed in 2003 are displayed in Table C-1 and Table C-2.

Table C-1. Percentage of pollutant removed by porous pavement (Loechl et al., 22).

Pollutant	Pollutant Removal (%)*
Total suspended solids	95
Total phosphorus	65
Total nitrogen	82
NOx	NA
Metals	98-99
Bacteria	NA
* Data based on fewer than five data points.	

Table C-2. Water quality effectiveness (2003_Cerl Schematics, pg 27).

Material	Water Quality Effectiveness
Conventional asphalt / concrete	Low
Brick (in loose configuration)	Medium
Natural stone	Medium
Gravel	High

Material	Water Quality Effectiveness
Wood mulch	High
Cobbles	Medium
Structural turf	High

Utility Costs

The water harvesting and runoff mitigation produced from the use of permeable parking areas represents a cost savings in downstream flood and erosion control and facilitates groundwater. Costs for increased flood control and restoration of degraded environmental systems resulting from impervious urban development are borne by the taxpayer and society as a whole.[2] Furthermore, if a cistern water collection system is integrated with the permeable pavement system, then infiltrated water can be collected and reused, saving further on water costs.

Maintenance Costs and Scheduling

The cost comparison in Table C-3 provides a general insight into both the expected initial material costs and maintenance costs involved with each material chosen for supporting a parking area. The recommended maintenance scheduling is shown in Table C-4.

Table C-3. Parking area material cost comparison (BASMAA 1999).

Material	Initial Cost	Maintenance Cost
Asphalt/Concrete	Medium	Low
Pervious concrete	High	High
Porous asphalt	High	High
Turf block	Medium	High
Brick	High	Medium

[2] Personal knowledge of author from presentation of graduate paper by Jerry Schneider, "*Pavement Design for Vehicular Parking and Access*" during LA 632 - Landscape Technology class at Cal Poly Pomona at Pomona, California in 1997.

Material	Initial Cost	Maintenance Cost
Natural stone	High	Medium
Concrete unit paver	Medium	Medium
Gravel	Low	Medium
Wood mulch	Low	Medium
Cobbles	Low	Medium

Table C-4. Recommended maintenance and scheduling for various permeable support system materials (adapted from New York 2007, Chapter 9).

Maintenance Activity	Scheduling
Ensure paved area is clear of sediments	As needed
Mow upland and adjacent areas, and seed bare areas	Monthly
Ensure paved area is clear of debris	Monthly
Monitor that paved area dewaters between storms	Monthly and after storms >0.5 in.
Vacuum sweep routinely to keep surface free of sediments	3 to 4 times per year
Clean inlets draining to the subsurface bed	Biannually
Inspect the paved surface for deterioration	Annually

Site Conditions

In order for a permeable parking site to be successfully implemented into the stormwater management system, the site must be adapted if it does not initially meet the recommended criteria. The advisable site conditions include: slopes less than 0.5%, minimum field-verified safety factor of 2, permeability rate of 0.5 in. per hour, and a minimum distance of 100 ft up-gradient and 10 ft down-gradient from neighboring building foundations. If a site has a lower infiltration rate than recommended by the USEPA, then modification using gravel and/or sand and/or the use of an underdrain is required. For these low-permeability soils, a high ratio of bottom surface area to storage volume is needed. The minimum infiltration rates are summarized in Table C-5 for the top four soil groups recommended as candidates for permeable parking lots.

Table C-5. Estimated soil infiltration rates (Agourdis et al. 2011).

Soil Texture*	Hydrologic Soil Group	Minimum Infiltration Rate (in/hr)
Sand	A	8.27
Loamy Sand	A	2.41
Sandy Loam	B	1.02
Loam	B	0.52
Silt Loam*	C	0.27
Sand Clay Loam*	C	0.17
Clay Loam*	D	0.09
Silty Clay Loam *	D	0.06
Sandy Clay*	D	0.05
Silty Clay*	D	0.04
Clay*	D	0.02

*Silt loam, sand clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay soils have infiltration rates below the recommended minimum of 0.5 in/hr. Silt loam at 0.27 in./hr is listed by the US EPA as acceptable but not recommended.

NOTE: Shaded area highlights those soil types with less than the recommended 0.5 in./hr infiltration rate.

It is also important not to place permeable support systems near “hot spots” or areas generating significant concentrations of pollutants (Agourdis et al. 2011). Examples of hot spots include vehicle service areas, gas stations, and chemical storage facilities.

Lessons Learned

Permeable Concrete

Design

Because PC is continuously being implemented into stormwater management systems, continual case studies provide insight into delivering the best product and experience possible. The agreed-on golden rule for a successful permeable pavement is “design for what your system can handle.” This rule can be accomplished by correctly designing the site to prevent stormwater run-on and subsequent system overloading.

Moisture in Concrete

The next most important factor in the success of a permeable concrete system is the moisture level in the mixture. Typically the water/cement materials (w/cm) ratio must be low to maximize strength and to prevent clogging of pores. Concrete mix that is too wet will clog the pores with its paste; contrarily, if the mix is too dry at the time of installation then it will ravel and make the surface unsafe. To prevent concrete that arrives with a correct w/cm ratio from drying by the end of the load, smaller batches are recommended (3-5 cu. yd). A small amount of water may be added near the end of the load to prevent raveling; however, this does weaken the concrete. Since the moisture content is so crucial, there is a rule of thumb for the wind: if there is a 10 mph wind, do not pour or stop the pour. The risk of surface raveling is just too great under that condition. Upon completion of the pour and roller compaction, curing should be done immediately and occur for a duration of 7 days.

Maintenance

Maintenance also plays a significant role on the successful installation of the permeable concrete system. For best results, sweeping and vacuuming are recommended to be performed four times a year, especially before wet seasons. It is also important to inform maintenance staff that salt is not to be used as it will reduce the concrete material and shorten its lifetime. Sand application is also not recommended as it can clog the pores and prevent drainage.

Permeable Asphalt

Design

The design of permeable asphalt systems is crucial, just as it is for any permeable pavement system. It is suggested to design the system as if it won't be pervious someday, whether it's from a lack of maintenance, funds, or ignorance. Permeable systems do tend to work best over well-drained soils. If soils are poor (e.g., clayey), provide deep trench drains to release water that has been detained in the clay.

Installation

If multiple construction projects are occurring on the same location site, it is important to plan to install the permeable asphalt last. Installing it last will decrease its chances of accumulating construction silt runoff among other things. Some contractors don't like it because it is not only messy, but porous asphalt also cools quicker, demanding a shorter delivery schedule with less time for installation. It is recommended that both the designer and installer have experience with these types of systems.

Maintenance

During maintenance, the use of a pressure washer, vacuum, or combination of the two should be used regularly. It is crucial to inform maintenance staff that the system is not to be sealed or repaired with any impermeable material.

Permeable Pavers

Installation

While designing a system for what it must be able to handle, it is also important to follow all manufacturer's instructions and recommendations. Through case studies involving the use of permeable pavers, a common settling of pavers has been noticed. A pervious pavement block study in Portland, Oregon, suggested the site's settling was a result of the heavy loads from garbage trucks over areas that had received insufficient compaction during construction. Recommended corrective measures were picking up the pavers and much of the base rock, compacting the subgrade with a small plate compactor, and re-laying (and recompacting) the street materials (Oregon 2001).

Maintenance

Frequent sweeping of the paver system was also recommended for improved performance. In the case of the Portland study, street sweeping occurred only three times during the first year. As a result, weeds grew in the pavers, particularly in large zones in front of some driveways. Researchers anticipate that more frequent use of their new, more powerful sweeper will eliminate the weed problem (Oregon 2001).

Conclusions

When a permeable support system is properly designed, installed, and maintained, there are a multitude of benefits at a site, including improved water quality, reduction of runoff, and reduced demand on stormwater infrastructure. While the permeable parking support systems may cost more initially than traditional parking support structures, the total life-cycle costs and the requirements needed to meet LID goals make the selection of permeable parking support system a feasible and cost-effective solution for meeting vehicle and pedestrian demands. However, it is important to note that these structures require more upkeep than traditional structures. Additional equipment and planning, such as sweeping/vacuuming and vegetation maintenance, may be required to keep these structures performing optimally.

Appendix D: REFERENCES, ABBREVIATIONS, and UNIT CONVERSIONS

References

Agouridis, Carmen T., Jonathon A. Villines, and Joe D. Luck. 2011. *Permeable Pavement for Stormwater Management*. AEN-108. University of Kentucky College of Agriculture. Accessed 24 May 2012. http://www.ca.uky.edu/agc/pubs/aen/aen108/aen108.pdf.

Asphalt Pavement Association of Michigan (APAM). n.d. "Reclaimed Asphalt Pavement (RAP)" presentation. Okemos, MI: APAM.

Asphalt Pavement Alliance. n.d. "Why Asphalt?" Accessed 3 May 2012. http://asphaltroads.org/why-asphalt/why-asphalt.html.

ASTM Standard D698-12. 2012. "Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft lbf/ft3 (600 kN m/m3))." West Conshohocken, PA: ASTM International. http://enterprise.astm.org/filtrexx40.cgi?+/usr6/htdocs/newpilot.com/SUBSCRIPTION/REDLINE_PAGES/D698.htm

AASHTO Standard T-99. 2010. "Standard Method of Test for Moisture-Density Relations of Soils Using a 2.5-kg (5.5-lb) Rammer and a 305-mm (12-in.) Drop." Englewood, CO: The American Association of State Highway and Transportation Officials (www.transportation.org) Text available at http://engineers.ihs.com/document/abstract/CEDGIBAAAAAAAAAA

Barton, Susan, and Rebecca Pineo. 2009. *Groundcover Alternatives to Turf Grass*. University of Delaware, Cooperative Extension. Accessed 6 June 2012. http://ag.udel.edu/udbg/sl/vegetation/Groundcovers.pdf.

BASMAA (Bay Area Storm Water Management Agencies Association)New Development Committee. 1999. *Start at the Source: Design Guidance Manual for Stormwater Quality Protection*. San Fracisco, CA: BASMAA. Available online at http://www.cccleanwater.org/Publications/StartAtTheSource/Start_At_The_Source_Full.pdf.

Booth, Samuel, John Barnett, Kari Burman, Josh Hambrick, and Robert Westby. 2010. Net Zero Energy Military Installations: A Guide to Assessment and Planning. NREL/TP-7A2-48876. Washington, DC: NREL (National Renewable Energy Laboratory).

Brattebo, Benjamin O. and Derek B. Booth. 2003. Long-term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. *Water Research* 37(18): 4369-4376. doi:10.1016/S0043-1354(03)00410-X

Collings, D. C., and K. J. Jenkins. 2010. *Whole-of-Life Analyses of Different Pavements: The Real Picture*. Paper 49 in Chapter 3 of *Compendium of Papers from the First International Conference on Pavement Preservation*. Accessed 19 June 2012. http://trid.trb.org/view.aspx?id=919026.

DoD (Dept. of Defense). 2010. *UFC 3-210-10, Low Impact Development*. Available online at The Whole Building Design Guide. Accessed 16 May 2012. http://www.wbdg.org/ccb/DOD/UFC/ufc_3_210_10.pdf.

Eartheasy.com. “Lawn Alternatives .” 2012. Accessed 6 June 2012. http://eartheasy.com/grow_lawn_alternatives.htm.

Florida Concrete and Products Association (FCPA). 2011. “Parking Lot FAQ.” *Florida Concrete & Products Association, Inc.* . Accessed 3 May 2012. http://www.fcpa.org/promotion/concrete-parking-lots.html.

Foster, Shirley. *Restoring the Tallgrass Prairie: An Illustrated Manual for Iowa and the Upper Midwest*. Iowa City: University of Iowa Press, p 194.

Georgia, State of. 2001. *Georgia Stormwater Management Manual, Vol 2: Technical Manual*. State of Georgia: Atlanta Regional Commission. Accessed 3 May 2012. http://documents.atlantaregional.com/gastormwater/GSMMVol2.pdf

Gesford, Alan L., and John A. Anderson. 2007. *Environmentally Sensitive Maintenance for Dirt and Gravel Roads*. Version 1.1, Pennsylvania Department of Transportation. Accessed 3 May 2012. http://water.epa.gov/polwaste/nps/sensitive.cfm.

Hunt, William H. 2011. “Urban Waterways.” 12-CALS-2353. Published by North Carolina Cooperative Extension – NC State University, College of Agriculture and Life Sciences (CALS) and North Carolina A&T State University. http://www.bae.ncsu.edu/stormwater/PublicationFiles/PermPaveMaintenance2011.pdf.

Johnson, Ann. 2000. *Best Practices Handbook on Asphalt Pavement Maintenance*. Manual 2004-04, Ed. Pamela J. Snopl. Minneapolis: Minnesota Technology Transfer Center, University of Minnesota: Minnesota LTAP. Accessed 19 June 2012. http://www.mnltap.umn.edu/publications/handbooks/documents/asphalt.pdf.

Kaiser, Laura Fisher. 2010. "Low-Maintenance Lawn Alternatives: Turf Grasses." Houselogic website. Accessed 6 June 2012. http://www.houselogic.com/home-advice/lawns/low-maintenance-lawn-alternatives-turf-grasses/.

Kief, Dr. Ofer, and Truong Dang Toan. 2011. *Neoweb 3D Cellular Confinement System for Structured Pavement Reinforcement of Roads & Railways*. Geotec Hanoi 2011-ISBN 978-604-82-000-8. Accessed 3 May 2012. http://www.prs-med.com/images/PDF/pavementreinforcement1.pdf

Kopp, Jason, Amanda Swearingen, Fen Jim Liew, Tracy Lawler, and Sarah Olson. 2010. *Sustainable Alternative Vegetation on Public Landscapes*. http://www.forestry.umn.edu/prod/groups/cfans/@pub/@cfans/@forestry/documents/asset/cfans_asset_288767.pdf

Kwit, Charles and Beverly Collins. 2008. "Native Grasses as a Management Alternative on Vegetated Closure Caps." *Environmental Management* 41(6): 929–936. doi: 10.1007/s00267-008-9090-x.

Lawn Reform Coalition website. Accessed 6 June 2012. http://www.lawnreform.org/.

Low Impact Development (LID) Urban Design Tools website. Accessed 3 May 2012. http://lid-stormwater.net/.

Loechl, Paul M., Annete L. Stumpf, Eric D. Johnson, Richard J. Scholze, Brian M. Deal, and Michelle J. Hanson. 2003 (n.p.). *Design Schematics for a Sustainable Parking Lot*. US Army Corps of Engineers research report.

Milesi, Christina, Steven W. Running, Christopher D. Elvidge, John B. Dietz, Benjamin T. Tuttle, and Ramakrishna R. Nemani. "Mapping and Modeling the Biogeochemical Cycling of Turf Grass in the United States." Environmental Management 36(3): 426-438. Accessed online: http://secure.ntsg.umt.edu/publications/2005/MREDTN05/MappingCristinaMIlesi.pdf

Murphy, James A. 1996. “Selection of Turfgrass Species and Varieties.” In *66th Annual Michigan Turfgrass Conf. Proceedings* 25:125-130. Accessed 21 June 2012. http://archive.lib.msu.edu/tic/mitgc/article/1996125.pdf.

NAPA (National Asphalt Pavement Association). 2009. *Black and Green: Sustainable Asphalt, Now and Tomorrow*. Special Report 200. Accessed online at http://www.asphaltpavement.org/images/stories/sustainability_report_2009.pdf.

National Ready Mix Concrete Association. 2011. *Concrete Parking: Economic Benefits*. Web article, accessed 3 May 2012. http://www.concreteparking.org/benefits/economic.html.

New Jersey Department of Environmental Protection. 2004. “Standard for Pervious Paving Systems.” Chapter 9.7 in *New Jersey Stormwater Best Management Practices Manual* . Accessed 21 June 2012. http://www.njstormwater.org/bmp_manual/NJ_SWBMP_9.7.pdf.

New York State Department of Environmental Conservation. 2010. Chapter 9 in *New York State Stormwater Design Manual* www.dec.ny.gov/chemical/29072.html.

Nicholson, Russ. n.d. *Factors to Consider when Selecting a Turf Grass.* Non-published; posted on New-Grass.org website. Accessed 21 June 2012. http://www.htpa.org/PDF%20Files/FactorstoConsiderwhenSelectingaTurfGrass.pdf

NPS (National Park Service). n.d. “Parade Ground Restoration at Fort Baker.” Golden Gate National Recreation Area. Accessed 23 May 2012. http://www.nps.gov/goga/historyculture/parade-ground-restoration.htm.

Ohlenbusch, Paul D. 1997. *Establishing Native Grasses*. MF-2291. Manhattan, KS: Kansas State University, Dept. of Agronomy, Agricultural Experiment Station and Cooperative Extension Service. www.ksre.ksu.edu/library/crpsl2/mf2291.pdf.

Oregon Department of Environmental Quality (DEQ), Northwest Region. 2001. *Restoring Soil Health to Urbanized Lands*. Accessed 1 May 2012. http://www.deq.state.or.us/lq/pubs/docs/sw/compost/RestoringSoilHealth.pdf.

Patrick, J. and Moorthy, H. 2008. “Quantifying the Benefits of Waste Minimisation in Road Construction.” Paper presented at Recycling and Stabilisation Conference, New Zealand Institute of Highway Technology, Takapuna Beach, Auckland, New Zealand in June 2008.

Pennsylvania Dept. of Environmental Protection, Bureau of Watershed Management. 2005. *Pennsylvania Stormwater Best Management Practices Manual (2nd Draft)*. Accessed 3 May 2012. http://www.dep.state.pa.us/dep/subject/advcoun/stormwater/Manual_DraftJan05/cover-toc-jan-rev.pdf.

Permathene, Inc. 2007. "Geocell: Cellular Geosynthetic for Retention of Soil on Slopes ." Brochure accessed 3 May 2012. http://www.permathene.com/documents/catalogue/single/erosion/geocell.pdf.

PlantNative.com. 2009. "How to Naturescape." Accessed 6 June 2012. http://www.plantnative.org/how_intro.htm.

Portland Cement Association. 2009. *Report on Sustainable Manufacturing*, 5th edition. Accessed 3 May 2012. http://cement.org/smreport09/images/shared_images/sustainreport08.pdf.

Prince George's County. 1999. Low-Impact Development: An Integrated Design Approach. Largo, Maryland: Prince George's County Maryland Department of Environmental Planning Division.

Presto Geosystems. n.d. *Presto Geosystems* . Appleston, WI: Presto Products Company. Accessed 6 June 2012. http://www.prestogeo.com.

Public Works and Government Services Canada. "Reducing Energy Use." Chapter 4,*The Environmentally Responsible Construction and Renovation Handbook*. Accessed 19 June 2012. http://www.tpsgc-pwgsc.gc.ca/biens-property/gd-env-cnstrctn/page-4-eng.html.

Sanders, Joshunda. 2011. "Native Seed Mix offers Alternative to Bermuda Grass." Article published October 14, 2011 by *Statesman.com*. Austin, TX: Cox Media Group . Availabe online at: http://www.statesman.com/life/gardening/native-seed-mix-offers-alternative-to-bermuda-grass-1914298.html.

Scripps Networks, LLC – HGTV.com. 2012. "Try a Meadow as a Lawn Alternative." Accessed 6 June 2012. http://www.hgtv.com/gardening/try-a-meadow-as-a-lawn-alternative/index.html.

Skorseth, Ken, and Ali. A. Selim. 2000. *Gravel Roads: Maintenance and Design Manual*. South Dakota Local Transportation Assistance Program (LTAP). Accessed 16 May 2012. http://www.sdstate.edu/engr/ltap/upload/Gravel-manual-T21.pdf.

Svendsen, Niels. 2012. *Guidance for Low-Impact Development (LID) Site Selection and Integration on Military Lands*. PWTB 200-1-116. Washington, DC: HQUSACE.

University of New Hampshire Stormwater Center. 2010. *2009 Biannual Report*. *Tools for Clean Water and Healthy Coasts*. CICEET, Accessed 14 May 2012. http://ciceet.unh.edu/news/releases/unhsc_report_2009/report.pdf.

University of New Hampshire Stormwater Center website. n.d.. Accessed 16 May 2012. http://www.unh.edu/unhsc/.

University of Rhode Island. 2005. *“Permeable Pavement: What’s It Doing on My Street?”* Accessed 1 May 2012. http://www.uri.edu/ce/wq/NEMO/Publications/PDFs/PP.WhatsItDoingOnMySt.pdf.

US Army Garrison Bamberg. n.d. *Installation Staging Area Standard Operating Procedures*. Accessed 6 June 2012. http://www.bamberg.army.mil/directorates/dol/docs/ISA%20SOP%20DRAFT.pdf.

USACE (US Army Corps of Engineers). n.d. “Savannah Tactical Equipment Maintenance Facility .” Savannah, GA: US Army Corps of Engineers, Savannah District. Accessed 6 June 2012 http://mrsi.usace.army.mil/cos/savannah/SitePages/temf.aspx

______. 2005. “Tank Trail Design.” Available online: http://apps.hnc.usace.army.mil/rdg/files/Tank%20Trail%20Design%20-%20Proposed%20Additions.pdf.

US Dept. of Housing and Urban Development (HUD). 2003. *The Practice of Low Impact Development* . Office of Policy Development and Research. Prepared by NAHB Research Center, Inc., Contract No. H-21314CA. Accessed 3 May 2012. www.huduser.org/publications/pdf/practlowimpctdevel.pdf.

USEPA (US Environmental Protection Agency). n.d. *Using Native Grasses for Ecological Restoration* . (Workshop PowerPoint presentation). Accessed 14 June 2012. http://www.epa.gov/reg3hscd/risk/eco/restoration/workshops/Using_Native_Grasses_for_Ecological_Restoration.pdf.

______. 2000. “Field Evaluation of Permeable Pavement for Stormwater Management: Olympia, Washington.” EPA-841-B-00-005B (POC: Derek Booth). Retrieved from EPA website: http://water.epa.gov/polwaste/green/upload/pavements.pdf.

______. 2005. *Reducing Urban Heat Islands: Compendium of Strategies*. Office of Atmospheric Programs. Accessed 3 May 2012. www.epa.gov/hiri/resources/pdf/BasicsCompendium.pdf.

______. 2007. *Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices*. Publication number EPA 841-F-07-006, December. http://water.epa.gov/polwaste/green/costs07_index.cfm .

______. 2008. *Green Parking Lot Resource Guide.* EPA-510-B-08-001 Washington, DC: US Environmental Protection Agency, Office of Solid Waste and Emergency Response (5101T). http://nepis.epa.gov/EPA/html/Dlwait.htm?url=/Exe/ZyPDF.cgi?Dockey=P100D97A.PDF

______. 2011. Greening EPA: "Stormwater Management." " Accessed 6 June 2012. http://www.epa.gov/oaintrnt/stormwater/index.htm.

USEPA, Pacific Southwest, Region 9. 2012. "Unpaved Roads and Unpaved Parking Lots: Applying and Maintaining Reasonably Available Control Measures (RACM)." *Accessed* 16 May 2012. http://www.epa.gov/region9/air/phoenixpm/fip/racm.html.

USEPA, Great Lakes National Program Office. n.d.. "Green Landscaping: Greenacres." *Landscaping with Native Plants*. Accessed 6 June 2012. http://www.epa.gov/greenacres/nativeplants/factsht.html.

Walker, Dwight. 2008. "Repair of Asphalt Parking Lots and Driveways." *Asphalt:* Fall 2008. Asphalt Institute. Accessed 3 May 2012. Article available in online archives at http://www.asphaltmagazine.com/news/detail.dot?id=a8ecb171-f951-4c8a-808f-9703c5f2033a.

Abbreviations

Abbreviation	Meaning
ACB	articulated concrete block
AR	Army Regulation
AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CECW	Directorate of Civil Works, U. S. Army Corps of Engineers
CEMP	Directorate of Military Programs, U. S. Army Corps of Engineers
CERL	Construction Engineering Research Laboratory
CGP	concrete grid pavers
CPC	Climate Prediction Center
DoD	Department of Defense
HDPE	high-density poly-ethylene
ERDC	Engineer Research and Development Center
FCPA	Florida Concrete and Product Association
HMA	hot mix asphalt
HQUSACE	Headquarters, US Army Corps of Engineers
ISA	Installation Staging Area
LID	low-impact development
PA	porous asphalt
PC	permeable concrete
PICP	permeable interlocking concrete pavers
POC	point of contact
POE	port of embarkation

Abbreviation	Meaning
POL	petroleum, oil, and lubricants
POV	privately owned vehicle
PTRG	plastic turf reinforcing grids
PWTB	Public Works Technical Bulletin
STR	surface turf replacement
TDA	Table of Distribution and Allowances
TEMF	Tactical Equipment Maintenance Facility
TOE	Table of Organization and Equipment
UFC	United Facilities Criteria
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
UV	ultraviolet
WBDG	Whole Building Design Guide

Unit Conversion Factors

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
inches	0.0254	meters
inch-pounds (force)	0.1129848	newton meters
miles per hour	0.44704	meters per second
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per square foot	4.882428	kilograms per square meter
square feet	0.09290304	square meters
tons (2,000 pounds, (mass)) per square foot	9,764.856	kilograms per square meter
yards	0.9144	meters