Low Impact Development strategies use careful site design and decentralized stormwater management to reduce the environmental footprint of new growth. This approach improves water quality, minimizes the need for expensive pipe-and-pond stormwater systems, and creates more attractive developments.

FACT SHEET #1

LOW IMPACT SITE DESIGN

Overview

Conventional development strategies treat stormwater as a secondary component of site design, usually managed with “pipe-and-pond” systems that collect rainwater and discharge it off site. In contrast, Low Impact Development embraces hydrology as an integrating framework for site design, not a secondary consideration. Existing conditions influence the location of roadways, buildings, and parking areas, as well as the nature of the stormwater management system.

LID site design is a multi-step process that involves identifying important natural features, placing buildings and roadways in areas less sensitive to disturbance, and designing a stormwater management system that creates a relationship between development and natural hydrology. The attention to natural hydrology, stormwater “micromanagement,” nonstructural approaches, and landscaping results in a more attractive, multifunctional landscape with development and maintenance costs comparable to or less than conventional strategies that rely on a pipe-and-pond approach.

Sensitive site landscaping is an important component of Low Impact Development. Ecological landscaping strategies seek to minimize the amount of lawn area and enhance the property with native, drought-resistant species; as a result, property owners use less water, pesticides, and fertilizers. The maintenance of vegetated buffers along waterways can also enhance the site and help protect water quality.

Applications and Design Principles

LID site planning is similar to Conservation Subdivision Design (CSD) process, though LID site planning can be applied to both residential and nonresidential development as well as redevelopment projects. The four step process of CSD (identify conservation areas; locate home sites; align streets and trails; draw in lot lines) provides a serviceable framework for the LID site design process, which involves designing a stormwater management system in conjunction with the second and third steps of the CSD process.

Management Objectives

- Develop a site plan that reflects natural hydrology.
- Minimize impervious surfaces.
- Treat stormwater in numerous small, decentralized structures.
- Use natural topopgraphy for drainageways and storage areas.
- Preserve portions of the site in undisturbed, natural conditions.
- Lengthen travel paths to increase time of concentration and attenuate peak rates.
- Use “end of pipe” treatment structures only for quantity/rate controls of large storms.

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Site Analysis

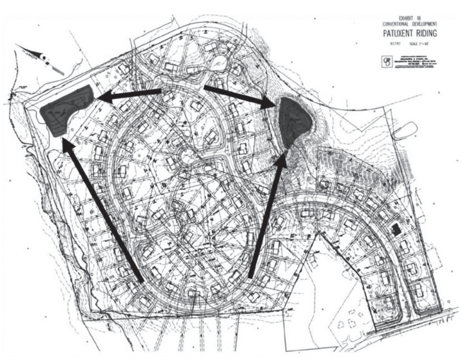
An LID site planning strategy will begin with an assessment of environmental and hydrologic conditions on a site and identification of important natural features such as streams and drainageways, floodplains, wetlands, recharge groundwater protection areas, high-permeability soils, steep slopes and erosion-prone soils, woodland conservation areas, farmland, and meadows. This investigation will help to determine what "conservation areas" should be protected from development and construction impacts, and what site features (such as natural swales) might be incorporated into the LID stormwater system.

The site analysis will also identify a "development envelope" where development can occur with minimal impact to hydrology and other ecologic, scenic, or historic features. In general, this will include upland areas, ridge lines and gently sloping hillsides, and slowly permeable soils outside of wetlands. The remainder of the site should be left in a natural undisturbed condition. It is important to protect mature trees and to limit clearing and grading to the minimum amount needed for buildings, access, and fire protection; lawn areas increase runoff that must be managed, whereas preservation of wooded areas reduces the volume of stormwater that must be treated. Construction activity, including stockpiles and storage areas, should be confined to those areas that will be permanently altered, and the construction fingerprint should be clearly delineated.

Locate Development and Roadways

Based on the development envelope from the site analysis, developers and their consultants should prepare potential site development layouts. These layouts should minimize total impervious area; reflect the existing topography; and utilize existing drainageways, swales, depressions, and storage areas in their natural state. The goal is to minimize the amount of runoff that must be treated in a stormwater management system.

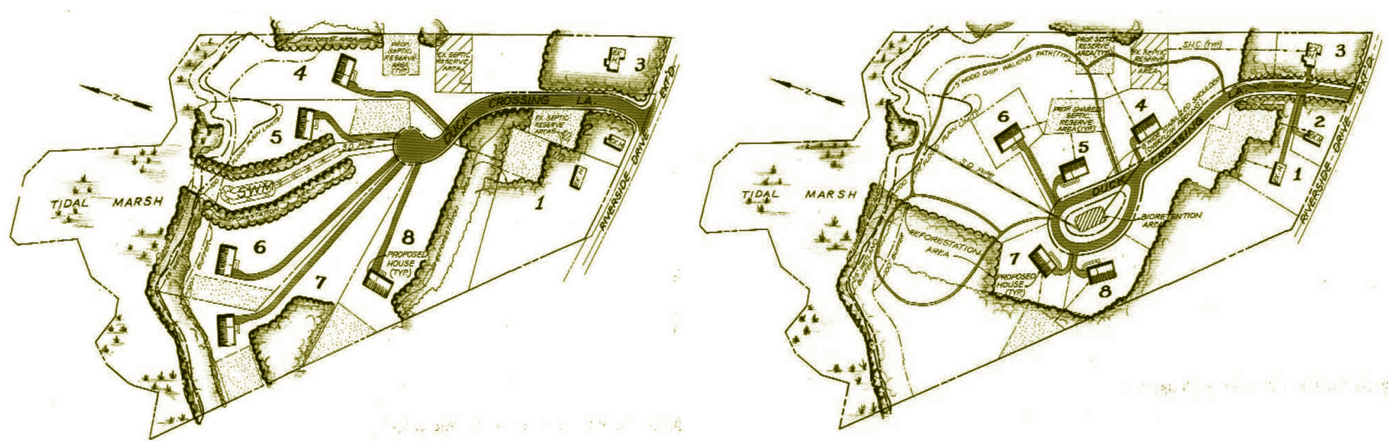
In order to reduce site coverage but not square footage, site development layouts may include buildings clustered together, parking structures (instead of lots), or taller buildings with a smaller footprint relative to floor area. However, these strategies may conflict with local land use regulations that address density, height, frontages, and lot coverage, so consultation with local officials is critical to help them



Conventional development strategies (above) concentrate stormwater runoff in storm sewers and deliver it to a few large ponds for treatment at the end of the pipe. Low Impact Development (right) seeks to create multiple small "sub-watersheds" on a site and treats runoff close to the source in smaller structures.

Cover, top: A clustered subdivision with smaller setbacks and preserved natural areas (left) contrasts with a conventional subdivision where all the trees have been removed.

Cover, bottom: A schematic diagram of a conservation subdivision design plan.



Above: Two alternative designs for an eight-lot subdivision. The low-impact on the right uses shared driveways and a one-way loop road to minimize impervious surfaces. The preservation of natural areas and the creation of trails adds value to the properties. *Images: Center for Watershed Protection*

understand the rationale for the proposed development plan. Other strategies for minimizing impervious surfaces include reduced road widths, smaller parking areas, permeable paving, and green roofs, all of which are described in greater detail in other LID fact sheets.

Once approximate building locations are known, general roads alignments can be identified. Roads should not cross steep slopes, where cutting and filling will unnecessarily disturb drainage patterns; instead, roadways should follow existing grades and run along existing ridge lines or high points. As a rule of thumb, roadways should run parallel to contours on gentle slopes, and perpendicular to the contours on steeper slopes. Large expanses of parking should be broken up into multiple smaller parking lots; this will help to reduce grading on hilly sites, since separate parking areas can be placed at different elevations.

Above: A commercial site design that uses clustering and multiple parking areas to protect water resources and provide opportunities for low impact stormwater management techniques. This design provides the same square footage and parking spaces as a conventional design that encroaches on a nearby marsh (at top). *Image: Center for Watershed Protection*

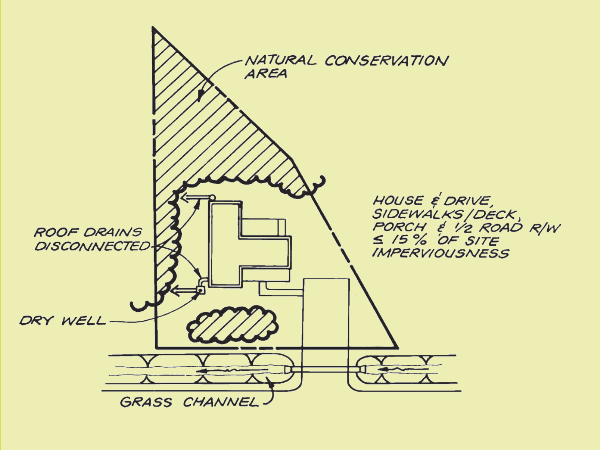
Create a Decentralized Stormwater System

The actual location of buildings and the alignment of roadways should be determined in conjunction with the design of the stormwater management system. The goal of this process is to minimize "directly connected impervious area"—those impervious areas that drain directly into a pipe-and-pond stormwater system. Designers should seek to maintain or create small sub-watersheds on the site and "micromanage" the runoff from these sub-watersheds in small decentralized structures, such as swales, bioretention areas, infiltration structures, and filter strips. Paved surfaces should be graded and crowned so that they form multiple "mini-watersheds;" the runoff from each small drainage area should to a different bioretention area, swale, or filter strip. Roof runoff should be sent to rain barrels, cisterns, dry wells, and vegetated areas via level spreaders.

LID site design should also seek to maximize the travel time for stormwater runoff. Conventional pipe systems increase the speed of stormwater runoff, resulting in bigger peak discharge rates (and therefore bigger ponds) at the end of the pipe. In contrast, LID seeks to increase the time of concentration (the average travel time for rainfall) through a variety of techniques: retain stormwater in small structures close to the source (described above), provide as much overland or sheet flow as possible, use open drainage systems, provide long travel paths, and use vegetation to increase surface roughness.

Wherever possible, site design should use multifunctional open drainage systems such as vegetated swales or filter strips which also help to fulfill landscaping or green space requirements. Swales and conveyances can be designed to increase travel length (and time of concentration) with long flow paths that loop around parking lots or other features, rather than more direct routes. The result is increased infiltration and more attenuated peak discharge at the downstream end of the site—the peak comes later and is smaller.

LID stormwater structures (such as bioretention areas and infiltration trenches) should be sized to treat the stormwater from frequent, low intensity storms for



Above: A lot layout that uses infiltration, disconnection of rooftop runoff, conservation and vegetated swales to treat runoff.

water quality and infiltrate it into the ground or slowly release it; they should not be expected to completely manage the peak discharge rate or volume from large storms. Volume and rate controls at the downstream end of the site may still be necessary, but much smaller as a result of LID site design, decentralized stormwater management, and long travel paths.

Benefits and Effectiveness

- A comprehensive approach to site design is the most effective, cost-efficient means of minimizing stormwater runoff. A small investment in design at the outset of the project can reduce the expense associated with conventional stormwater systems.
- An LID site design approach based on natural hydrology will integrate the built space into the natural environment, giving the development integrity and an aesthetically pleasing relationship with the natural features of the site. Many LID stormwater management structures also serve as site landscaping.
- Developers who take a careful, comprehensive approach to site design—one that accommodates local development goals and protects important resources—run into less resistance from neighbors and local boards concerned about the aesthetic and environmental impacts of development.
- Site designs that involve a minimal amount of clearing, grading, and road/parking lot construction have lower overall site development costs.
- Small, distributed stormwater "micromanagement" techniques offer an advantage over centralized systems because one or more of the individual structures can fail without compromising the overall integrity of the stormwater management strategy for the site.
- Smaller decentralized facilities feature shallow basing depths and gentle side slopes, which reduce safety concerns as compared to deep ponds that must be fenced off.

Limitations

- The comprehensive LID site analysis and design process can rarely be conducted "in house" by developers; it requires the assistance of knowledgeable and qualified engineers and landscape architects.
- Some LID site designs that seek to cluster development and reduce lot coverage may conflict with local land use regulations or public perceptions about what type of development is desirable (a compact multistory building may be more visible than a single story building with a larger footprint.) Consequently, public education is necessary as well as cooperation among developers, advocates, and regulators who recognize the values of the LID site design approach.

Maintenance

There are no particular maintenance requirements associated with an LID site design, but by reducing the amount of stormwater runoff and associated stormwater management structures, LID can reduce the amount of maintenance required on a site.

Cost

The cost of an LID site design will vary depending on the site. The expertise necessary to create a comprehensive site plan may cost more than a simple engineering plan that ignores natural conditions and treats stormwater using a "pipe and pond" system; however, the resulting plans are commonly less expensive to construct and maintain, and the additional landscaping and aesthetic value of an LID development will add a premium to the sales price.

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This publication is one component of the Massachusetts Low Impact Development Toolkit, a production of the Metropolitan Area Planning Council, in coordination with the I-495 MetroWest Corridor Partnership, with financial support from US EPA. The Massachusetts Low Impact Development Interagency Working Group also provided valuable input and feedback on the LID Toolkit.

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FACT SHEET #2

ROADWAY AND PARKING LOT DESIGN

Overview

One of the simplest ways to cut down on stormwater runoff is to reduce the amount of impervious cover associated with roadways and parking lots. Careful design is the key to reducing pavement while still providing good site access and adequate parking. Good road and parking lot design can also create opportunities for decentralized stormwater management in bioretention areas, roadside swales, and infiltration structures. Basic strategies for roadway design include low-impact roadway layouts, narrow road widths, shared driveways, and open-section roadways. Parking lots designers should look at strategies to break up large parking lots, maximize shared parking, rethink parking requirements, and use permeable paving where appropriate.

Alternative road and parking designs may offer cost savings for developers, because there is less pavement to construct and less stormwater runoff to treat. In some cases, more compact parking may allow higher site densities. The primary impediment to these strategies may be resistance at the permitting stage. Many communities stringently enforce elaborate and often excessive roadway and parking standards in an effort to prevent development. Developers, advocates, and regulators who understand the benefits of Low Impact Development need to work together to point out that alternative designs can provide safe access and sufficient parking, as well as environmental and aesthetic benefits.

Applications and Design Principles

Roadway Width

Excessively wide streets are the greatest source of impervious cover (and stormwater runoff) in most residential developments. Some local codes require streets up to 40 feet wide in subdivisions with only a dozen houses. These inappropriate standards result from blanket application of high volume/high speed road design criteria, overestimates of on-street parking demand, and the perception that wide streets result in faster emergency response times.

Narrower road sections and alternative road profiles can reduce stormwater runoff and mitigate its impacts, while still allowing safe travel, emergency

Design Objectives

- Reduce total impervious surface.
- Reduce road/parking construction costs.
- Provide safe access and adequate parking.
- Minimize disturbance to natural site hydrology.
- Create opportunities for stormwater treatment and infiltration.
- Improve site appearance.

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Above: Excessively wide streets (top) with conventional curb-and-gutter profiles create large volumes of runoff and concentrate it in storm sewers. Low-impact roadways (bottom) use a narrower, more traditional design that enhances neighborhood character. Less runoff is created and it is directed to roadside swales for treatment and conveyance.

Cover, top: A narrow roadway design can allow for on-street parking as well as plenty of room for safe travel and emergency vehicle access.

Cover, bottom: This photo shows a perforated curb that directs runoff into a roadside bioretention area with a drop overflow inlet into the storm drain system. This approach treats the "first flush" of runoff using a low-impact technique and directs the remaining stormwater to conventional practices. *Photo: Lower Columbia River Estuary Partnership*

Right: A schematic diagram of an open-section roadway, with permeable paving parking lanes and roadside swales. Swales should be located between the roadway and a sidewalk, where present. *Image: Valley Branch (MN) Watershed District*

vehicle access, and adequate parking. For most low-traffic roads, a 24' road width is sufficient to accommodate two way traffic, and even narrower widths should be used in very low traffic conditions (e.g., a six-lot subdivision.) The National Fire Protection Administration Uniform Fire Code (2003) recommends a minimum unobstructed width of just 20 feet, with the recognition that local authorities can set lower standards if turnouts or alternate exits are available.

Recommended Minimum Street Widths

Source	Width (feet)
National Fire Protection Administration	20
Massachusetts State Fire Marshall	18 (minimum)
AASHTO	22
Institute of Transportation Engineers	22
Prince George's County, Maryland	20
Portland, Oregon	18 (on-street parking on one side) 26 (parking both sides)

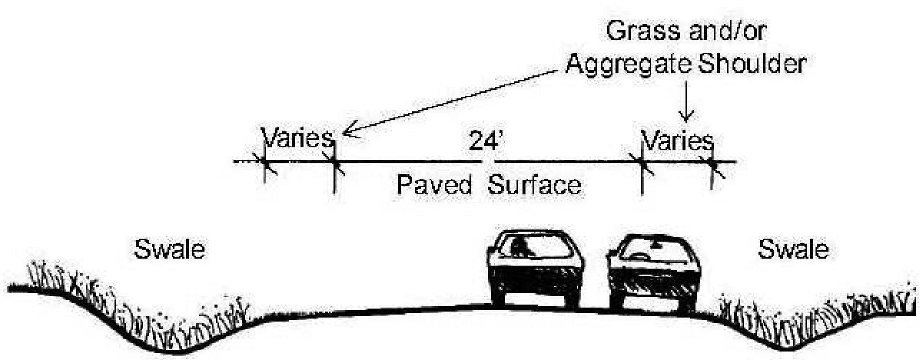
Source: Center for Watershed Protection

In order to achieve the environmental benefits of narrower street widths, regulators must make clear that they are willing to adjust site design standards to provide developers with the opportunity to try alternative designs. One preliminary step is to require parking on one side of the street only. This is appropriate where most houses have off–street parking. Design standards can also allow parking lanes or road shoulders made of permeable paving, such as grass pavers or paving blocks.

Some communities are moving to roadways that us a single travel lane and one or two "queuing lanes," which can be used for either parking or travel. This strategy can reduce street width by a third, and it does not affect travel except when two cars need to pass each other at the spot where a third car is parked, in which case one car pulls into the queuing lane until the oncoming car has passed. Research indicates that "tight streets" actually improve traffic safety by encouraging vehicles to slow down in residential neighborhoods. Throughout Massachusetts, many older neighborhoods built before current standards were enacted have narrow streets that function well, calm traffic, and lend character to the community.

Roadway Profile

Curbs and gutters concentrate stormwater runoff and increase its velocity, impeding decentralized treatment and infiltration. LID strategies recommend open-section roadways flanked by filter strips and swales instead of curbs and gutters. These LID techniques, built on the model of "country drainage," help to filter roadway runoff, promote infiltration, and reduce runoff velocity, resulting in lower peak discharge rates. If properly designed, open section roadways will be no more prone



to flooding than conventional roadway profiles. If curbs are deemed necessary to stabilize the roadway edge, the design can use invisible curbs (same level as the road surface), periodic curb cuts, or perforated curbs to allow stormwater to run off the roadway edge.

Roadway layout

The location and layout of roadways can also be modified to improve post-development hydrology. Roadways should be placed to avoid crossing steep slopes where significant cut and fill will be required. They should run parallel to contours on gentle slopes and perpendicular to contours on steeper slopes. Design of a roadway network may involve some give and take between reducing total roadway length and road layouts compatible with existing topography. On low-speed streets, clearing and grading should be limited to a small strip of land (5') on either side of the roadway and sidewalk.

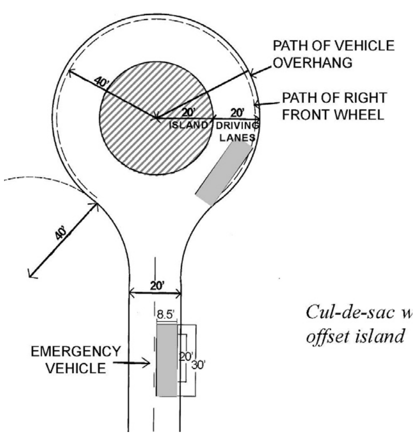
Above: Periodic curb cuts in an urban setting allow for streetside infiltration. *Photo: Lower Columbia River Estuary Partnership*

In residential subdivisions, shared driveways can reduce site development costs as well as impervious surface coverage. Property owners will also realize some savings through shared snow plowing costs. Driveways can be limited to 9 feet in width. They should be sloped or crowned so that they drain evenly onto adjacent vegetated areas (not onto the street) where the runoff will infiltrate or travel via sheetflow.

Turnarounds and Cul-de-Sacs

Many residential streets end in large cul-de-sacs up to 80 feet across, which generate large amounts of runoff during storms. Alternative designs can reduce runoff and improve neighborhood character, while still providing sufficient room for fire trucks and school buses to maneuver. One simple approach (applicable to both new construction and retrofits) is to create a landscaped island in the middle of a standard-size cul-de-sac. A 30-foot island in an 80-foot diameter cul-de-sac will reduce the impervious surface by 15%; if the island is designed and built as a bioretention area, and the roadway graded appropriately, this strategy can also treat roadway runoff.

Below: A 20-foot diameter landscaped island in a cul-de-sac can reduce impervious surface by 25%. Cul-de-sac islands can also be designed to treat and infiltrate runoff through bioretention. *Image: Valley Branch (MN) Watershed District*

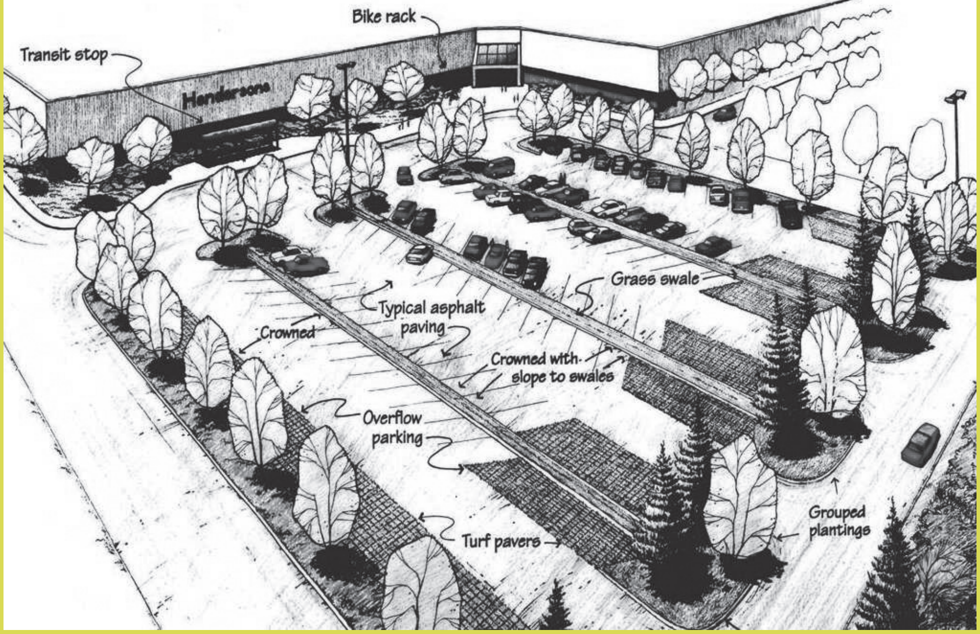


Other design changes can produce even greater benefits. Reducing the radius of a cul-de-sac from 40 feet to 30 feet yields a 45% reduction in paved surface (5,000 sq. ft versus 2,800 sq. ft.) A T-shaped hammerhead occupies even less space but still provides sufficient room for turning vehicles and fire trucks (though it may require a 3-point turn.) Depending on the length of the street, designers should consider a one-way loop road with parking on one side. Cul-de-sac design is definitely one area where regulatory standards prevent creative designs; regulators should consider re-wording their regulations to replace geometric standards with performance standards.

Parking Lots

Expansive parking lots that drain to just a few catch basins create large volumes and high velocities that require the use of pipe-and-pond stormwater techniques. The LID approach encourages designers to create multiple smaller parking lots separated by natural vegetation and bioretention areas. On hilly sites, the creation of multiple parking areas at different elevations can reduce the amount of grading necessary and preserve natural hydrology.

Permeable paving is rarely appropriate for use in high traffic parking lots, but some success has been found with hybrid parking lots, which use conventional paving for driveways and aisles, and permeable paving for stalls. Permeable paving may also be appropriate for overflow parking areas, which are generally used only a few weeks out of the year.



Above: A schematic drawing of a parking lot that uses a variety of low impact techniques. Parking areas are separated by vegetated swales that convey runoff to bioretention areas, and permeable paving is used for overflow parking at the periphery of the lot. A bike rack and transit stop help to reduce the number of auto trips to the site. *Image: Robert W. Droll, ASLA*

Other strategies include reducing the total number of parking spaces and reducing the size of some parking spaces. Many communities have provisions for shared parking, so that mixed use developments, or single-use developments near other uses, can share parking according to a formula based on the peak demand periods; residents use the parking spaces at night and customers or employees use the same spaces during the day. Parking spaces designed for compact cars can also help to limit impervious coverage.

Considering the aesthetic and environmental impacts of large parking areas, community boards might consider parking maximums, as well as parking minimums, in order to prevent oversized parking lots and ensure that supply is in line with demand.

Benefits and Effectiveness

- Narrower roadways, smaller parking areas, and smaller stormwater management systems result in lower site development costs.
- A hierarchy of streets sized according to daily needs yields a wide variety of benefits: lower average speeds, more room for trees and landscaping, improved aesthetics, and reduced heat island effect.
- Designs that reduce the amount of parking and break it up into multiple smaller lots separated by vegetation create more attractive developments.

Limitations

- Alternative roadway and parking designs may conflict with local codes, which often have strict requirements for road widths and drainage systems. However, many boards may be willing to adjust their standards if developers, advocates, and neighbors support the alternative design.
- Emergency service access is a common concern with reduced street widths. Where possible, these concerns can be addressed through education or multiple points of access to a site.

Cost

Narrower streets and smaller parking lots cost less than conventional streets because less grading, base material, and pavement is required. Open section roadways cost considerably less than standard designs due to the elimination of curbs and gutters.

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Shared Parking Guidelines; Institute of Transportation Engineers, Washington DC; 1995.

The American Planning Association (www.planning.org) has published a variety of reports on parking standards, as part of its Planners Advisory Service.

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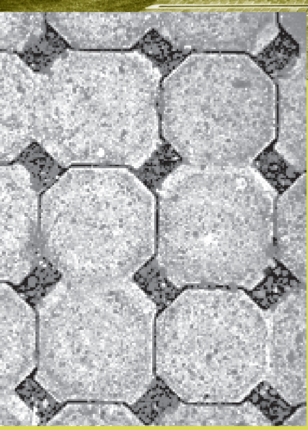
FACT SHEET #3

PERMEABLE PAVING



Overview

Since impervious pavement is the primary source of stormwater runoff, Low Impact Development strategies recommend permeable paving for parking areas and other hard surfaces. Permeable paving allows rainwater to percolate through the paving and into the ground before it runs off. This approach reduces stormwater runoff volumes and minimizes the pollutants introduced into stormwater runoff from parking areas.

All permeable paving systems consist of a durable, load bearing, pervious surface overlying a crushed stone base that stores rainwater before it infiltrates into the underlying soil. Permeable paving techniques include porous asphalt, pervious concrete, paving stones, and manufactured “grass pavers” made of concrete or plastic. Permeable paving may be used for walkways, patios, plazas, driveways, parking stalls, and overflow parking areas.

Applications and Design Principles

Permeable paving is appropriate for pedestrian-only areas and for low- to medium-volume, low-speed areas such as overflow parking areas, residential driveways, alleys, and parking stalls. Underlying soils should have a permeability of at least 0.3” per hour; less permeable soils will require an underdrain. Permeable paving is an excellent technique for dense urban areas because it does not require any additional land. With proper design, cold climates are not a major limitation; porous pavement has been used successfully in Norway, incorporating design features to reduce frost heave.

Permeable paving is not ideal for high traffic/high speed areas because it generally has lower load-bearing capacity than conventional pavement. Nor should it be used on stormwater “hotspots” with high pollutant loads because stormwater cannot be pretreated prior to infiltration. Heavy winter sanding may clog joints and void spaces.

Management Objectives

- Reduce stormwater runoff volume from paved surfaces
- Reduce peak discharge rates.
- Increase recharge through infiltration.
- Reduce pollutant transport through direct infiltration.
- Improve site landscaping benefits (grass pavers only.)

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Cover: A driveway in Connecticut built with manufactured paving stones. Lower photo shows paving stone detail. P*hoto: University of Connecticut, Jordan Cove Urban Monitoring Project*

Above: A parking lot with concrete grass paver parking stalls. Lower photo shows grass paver detail. *Photos: Lower Columbia River Estuary Partnership*

Right: A schematic cross section of permeable paving. In some applications, the crushed stone reservoir below the paving is designed to store and infiltrate rooftop runoff as well. *Image: Cahill Associates, Inc. 2004*

Three Major Types of Permeable Paving

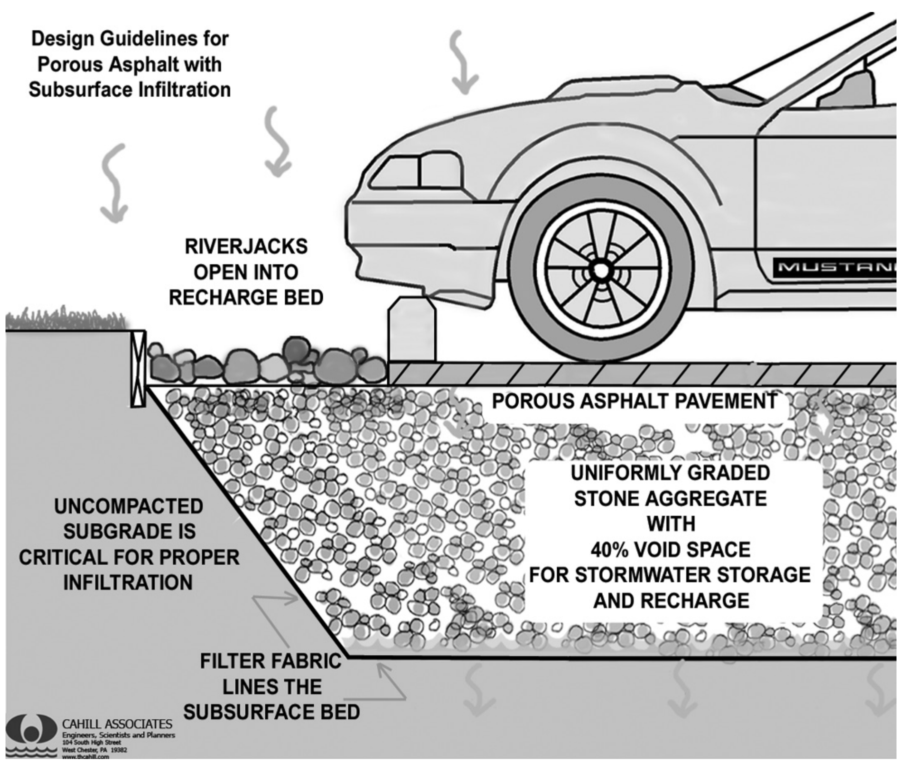
- Porous asphalt and pervious concrete appear to be the same as traditional asphalt or concrete pavement. However, they are mixed with a very low content of fine sand, so that they have 10%-25% void space and very low runoff coefficients.
- Paving stones (aka unit pavers) are impermeable blocks made of brick, stone, or concrete, set on a sand or crushed stone base. Joints are filled with stone or sand to allow water to percolate downward. Runoff coefficients range from 0.1 – 0.7, depending on rainfall intensity, joint width, materials, and base layer permeability. Open cell designs and coarse bed material can yield runoff coefficients less than 0.3.
- Grass pavers (aka turf blocks or grid pavers) are a type of open-cell unit paver in which the cells are filled with soil and planted with turf. The pavers, made of concrete or synthetic, distribute the weight of traffic and prevent compression of the underlying soil. Runoff coefficients are similar to grass, 0.15 to 0.6.

Each of these techniques is constructed over a base course that doubles as a reservoir for the stormwater before it infiltrates into the subsoil. The reservoir should consist of uniformly-sized crushed stone, with a depth sufficient to store all of the rainfall from the design storm. The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface. Some designs incorporate an "overflow edge," which is a trench surrounding the edge of the pavement. The trench connects to the stone reservoir below the surface of the pavement and acts as a backup in case the surface clogs.

Benefits and Effectiveness

Porous pavement provides groundwater recharge and reduces stormwater runoff volume. Depending on design, paving material, soil type, and rainfall, permeable paving can infiltrate as much as 70% to 80% of annual rainfall.

Porous pavement can reduce peak discharge rates significantly by diverting stormwater into the ground and away from the pipe-and-pond stormwater management system.



Above: A parking lot with conventional asphalt aisles and paving stone parking stalls. Paving stones are most appropriate for low-speed, low-traffic areas. *Photo: Lower Columbia River Estuary Partnership*

- Grass pavers can improve site appearance by providing vegetation where there would otherwise be only pavement.
- Porous paving increases effective developable area on a site because portions of the stormwater management system are located underneath the paved areas, and the infiltration provided by permeable paving can significantly reduce the need for large stormwater management structures on a site.

Limitations

- Permeable paving can be prone to clogging from sand and fine sediments that fill void spaces and the joints between pavers. As a result, it should be used carefully where frequent winter sanding is necessary because the sand may clog the surface of the material. Periodic maintenance is critical, and surfaces should be cleaned with a vacuum sweeper at least three times per year.
- In cold climates, the potential for frost is minimized with 24-hour design times for the reservoir. Some design manuals recommend excavating the base course to below the frost line, but this may not be necessary in rapidly permeable soils. In addition, the dead air and void spaces in the base course provide insulation so that the frost line is closer to the surface.
- Permeable paving should not receive stormwater from other drainage areas, especially any areas that are not fully stabilized.
- Permeable paving can only be used on gentle slopes (<5%). It should be used judiciously in high-traffic areas or where it will be subject to heavy axle loads.
- Snow plows can catch the edge of grass pavers and some paving stones. Rollers can be attached to the bottom edge of a snowplow to prevent this problem.

Above: A handicap-accessible park pathway made of permeable paving stones.
Photo: GeoSyntec Consultants, Inc.

Maintenance

- Post signs identifying porous pavement areas.
- Minimize use of salt or sand during winter months
- Keep landscaped areas well-maintained and prevent soil from being transported onto the pavement.
- Clean the surface using vacuum sweeping machines. Paving stones may require periodic addition of joint material to replace material that has been transported.
- Monitor regularly to ensure that the paving surface drains properly after storms.
- Do not reseal or repave with impermeable materials.
- Inspect the surface annually for deterioration.
- Grass pavers may require periodic reseeding to fill in bare spots.

Design Details

- For all permeable paving, base course is a reservoir layer of 1”-2” crushed stone; depth to be determined by storage required and frost penetration.
- Permeable paving require a single-size grading of base material in order to provide voids for rainwater storage; choice of materials is a compromise between stiffness, permeability, and storage capacity. Use angular crushed rock material with a high surface friction to prevent traffic compaction and rutting.
- The design may also include a 2” thick filter course of 0.5” crushed stone, applied over the base course. A geotextile fabric may be laid at the top of the filter layer to trap sediment and pollutants.
- For grass pavers, use deep-rooted grass species whose roots can penetrate the reservoir base course. Irrigation may be required but should be infrequent soakings so that the turf develops deep root systems. Grass pavers are not suitable for every day, all day parking because the grass will get insufficient sunlight. Better for use as occasional overflow parking.
- The introduction of dirt or sand onto the paving surface, whether transported by runoff from elsewhere or carried by vehicles, will contribute to premature clogging and failure of the paving. Consequently, permeable paving should be one of the last items to be built on a development site, after most heavy construction vehicles are finished and after the majority of the landscaping work is completed.

Cost

On most sites, permeable paving costs more than conventional asphalt or concrete paving techniques. In the case of porous asphalt and pervious concrete, construction costs may be 50% more than conventional asphalt and concrete. Construction costs of paving stones and grass pavers varies considerably and will depend on the application. As with any site improvement or stormwater management structure, property owners should provide a budget for maintenance of permeable paving, at an annual rate of 1%-2% of construction costs.

Permeable paving reduces the need for stormwater conveyances and treatment structures, resulting in cost savings elsewhere. Permeable paving also reduces the amount of land needed for stormwater management and may satisfy requirements for greenspace, allowing more development on a site.

Local Case Study

West Farms Mall – West Hartford, CT

Grass pavers were installed at the West Farms Mall off of I-84 at exit 40, to handle peak-season overflow parking associated with a mall expansion. Over four acres of reinforced turf was designed to accommodate 700 spaces of overflow parking for the peak shopping seasons. There are a few drains installed in the reinforced turf but are only used during very heavy storms. Because the reinforced turf works so well the existing storm drainage system did not have to be enlarged for the additional parking. The overflow parking area needs to be mowed on a regular basis and treated like a regular lawn. The area also needs to be plowed as any parking would be. Rollers were fit to the bottom of the snow plow so the reinforced turf would not be damaged. The manager of the Westfarms facility is satisfied with the turf.

Websites

www.unh.edu/erg/cstev/index.htm (University of NH)
www.invisiblestructures.com/GP2/whole_lotof_turf.htm
www.uni-groupusa.org/case.htm
www.nemo.uconn.edu/ (University of CT)
www.lowimpactdevelopment.org/epa03/pavespec.htm
www.epa.gov/ednnrmrl/repository/abstrac2/abstra2.htm
www.forester.net/sw_0503_advances.html
www.icpi.org (Interlocking Concrete Pavement Institute)

This publication is one component of the Massachusetts Low Impact Development Toolkit, a production of the Metropolitan Area Planning Council, in coordination with the I-495 MetroWest Corridor Partnership, with financial support from US EPA.
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FACT SHEET #4

BIORETENTION AREAS

Overview

Bioretention is an important technique that uses soil, plants and microbes to treat stormwater before it is infiltrated or discharged. Bioretention "cells" are shallow depressions filled with sandy soil, topped with a thick layer of mulch, and planted with dense vegetation. Stormwater runoff flows into the cell and slowly percolates through the soil (which acts as a filter) and into the groundwater; some of the water is also taken up by the plants. Bioretention areas are usually designed to allow ponded water 6-8 inches deep, with an overflow outlet to prevent flooding during heavy storms. Where soils are tight or fast drainage is desired, designers may use a perforated underdrain, connected to the storm drain system.

Bioretention areas can provide excellent pollutant removal and recharge for the "first flush" of stormwater runoff. Properly designed cells remove suspended solids, metals, and nutrients, and can infiltrate an inch or more of rainfall. Distributed around a property, vegetated bioretention areas can enhance site aesthetics. In residential developments they are often described as "rain gardens" and marketed as property amenities. Routine maintenance is simple and can be handled by homeowners or conventional landscaping companies, with proper direction.

Applications and Design Principles

Bioretention systems can be applied to a wide range of development in many climatic and geologic situations; they work well on small sites and on large sites divided into multiple small drainages. Common applications for bioretention areas include parking lot islands, median strips, and traffic islands. Bioretention is a feasible "retrofit" that can be accomplished by replacing existing parking lot islands or by re-configuring a parking lot during resurfacing. On residential sites they are commonly used for rooftop and driveway runoff.

Management Objectives

- Provide water quality treatment.
- Remove suspended solids, metals, nutrients.
- Increase groundwater recharge through infiltration.
- Reduce peak discharge rates.
- Reduce total runoff volume.
- Improve site landscaping.

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Above: This bioretention cell at a office park also helps to fulfill site landscaping requirements. *Photo: Low Impact Development Center*

Right: This schematic diagram shows parking lot runoff directed to a bioretention cell, with pretreatment by a grassed filter strip. *Image: Prince George's County (MD) Bioretention Manual*

Cover, top: A rain garden in a Connecticut Subdivision infiltrates rooftop and driveway runoff, and can be marketed as an extra amenity. *Photo: University of Connecticut, Jordan Cove Urban Monitoring Project*

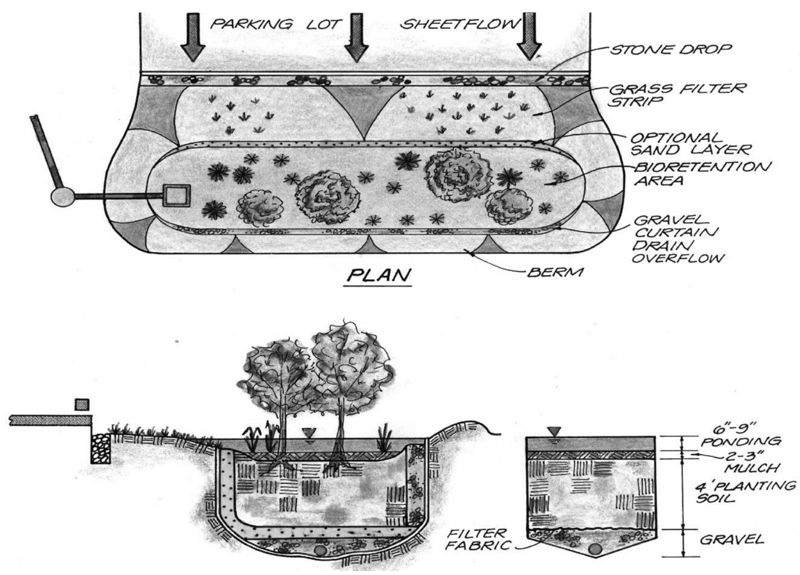
Cover, bottom: A narrow bioretention cell in a parking lot, planted with small trees to reduce the urban heat island effect. *Photo: Low Impact Development Center*

Bioretention cells are usually excavated to a depth of 4 feet, depending on local conditions. Generally, cells should be sized (based on void space and ponding area) to capture and treat the water quality volume (the first 0.5" or 1" of runoff, depending on local requirements.) Some manuals suggest a minimum width of 15', though much narrower bioretention cells have been installed in parking lot islands and are functioning well. Regardless of size, some type of filter should cover the bottom of the excavation. Filter fabric is commonly used but can be prone to clogging; consequently some engineers recommend a filter of coarse gravel, over pea gravel, over sand.

The cell should be filled with a soil mix of sandy loam or loamy sand. The area should be graded to allow a ponding depth of 6-8 inches; depending on site conditions, more or less ponding may be appropriate. The planting plan should include a mix of herbaceous perennials, shrubs, and (if conditions permit) understory trees that can tolerate intermittent ponding, occasionally saline conditions (due to road salt), and extended dry periods. The soil should be covered with 2-3" of fine-shredded hardwood mulch.

In very permeable soils, some bioretention areas can be designed as "off-line" treatment structures (no overflow necessary), but in most situations they will be an "on-line" component of the stormwater management system, connected to downstream treatment structures through an overflow outlet or an overflow drop inlet installed at the ponding depth and routed to the site's stormwater management system. Ideally, overflow outlets should be located as far as possible from runoff inlets to maximize residence time and treatment. In general, bioretention area should be designed to drain within 72 hours. In slowly permeable soils (less than 0.3 inches/hour) a perforated underdrain can be installed at the bottom of the excavation to prevent ponding.

Bioretention areas work best if designed with some pretreatment, either in the form of swales or a narrow filter strip. A stone or pea gravel diaphragm (or, better yet, a concrete level spreader) upstream of a filter strip will enhance sheet flow and better pre-treatment.



Benefits and Effectiveness

- Bioretention areas remove pollutants through filtration, microbes, and uptake by plants; contact with soil and roots provides water quality treatment better than conventional infiltration structures. Studies indicate that bioretention areas can remove 75% of phosphorus and nitrogen; 95% of metals; and 90% of organics,

Above, top: Bioretention cells are designed to allow ponded water six inches deep, which should infiltrate into the ground within 72 hours after a storm.

Above, middle: A large bioretention cell adjacent to a parking lot can reduce or eliminate expenses on storm sewers and detention basins. *Photo: Low Impact Development Center*

Above, bottom: Maintenance of rain gardens can generally be handled by homeowners. *Photo: Low Impact Development Center*

bacteria, and total suspended solids. Bioretention areas qualify as an organic filter according to the Massachusetts Stormwater Policy.

- In most applications, bioretention areas increase groundwater recharge as compared to a conventional "pipe and pond" approach. They can help to reduce stress in watersheds that experience severe low flows due to impervious coverage.
- Low-tech, decentralized bioretention areas are also less costly to design, install, and maintain than conventional stormwater technologies that treat runoff at the end of the pipe. The use of decentralized bioretention cells can also reduce the size of storm drain pipes, a major driver of stormwater treatment costs.
- Bioretention areas enhance the landscape in a variety of ways: they improve the appearance of developed sites, provide wind breaks, absorb noise, provide wildlife habitat, and reduce the urban heat island effect.

Limitations

- Because bioretention areas infiltrate runoff to groundwater, they may be inappropriate for use at stormwater "hotspots" (such as gas stations) with higher potential pollutant loads. On these sites, the design should include adequate pretreatment so that runoff can be infiltrated, or else the filter bed should be built with an impermeable liner, so that all water is carried away by the underdrain to another location for additional treatment prior to discharge.
- Premature failure of bioretention areas is a significant issue that results from lack of regular maintenance. Ensuring long-term maintenance involves sustained public education and deed restrictions or covenants for privately-owned cells.
- Bioretention areas must be used carefully on slopes; terraces may be required for slopes >20%.
- The design should ensure vertical separation of at least 2' from the seasonal high water table.

This parking lot bioretention cell is being constructed with an impermeable liner and a perforated underdrain, to provide retention and treatment of runoff (but not infiltration).

Maintenance

- Bioretention requires careful attention while plants are being established and seasonal landscaping maintenance thereafter.
- In many cases, maintenance tasks can be completed by a landscaping contractor working elsewhere on the site.
- Inspect pretreatment devices and bioretention cells regularly for sediment build-up, structural damage, and standing water.
- Inspect soil and repair eroded areas monthly. Re-mulch void areas as needed. Remove litter and debris monthly.
- Treat diseased vegetation as needed. Remove and replace dead vegetation twice per year (spring and fall.)
- Proper selection of plant species and support during establishment of vegetation should minimize—if not eliminate—the need for fertilizers and pesticides.
- Remove invasive species as needed to prevent these species from spreading into the bioretention area.
- Replace mulch every two years, in the early spring.
- Upon failure, excavate bioretention area, scarify bottom and sides, replace filter fabric and soil, replant, and mulch.

Cost

Bioretention areas require careful design and construction, the price of which will depend on site conditions and design objective. Generally, the cost of bioretention areas is less than or equal to that of a catch basin and underground chambers intended to treat the same area. Additionally, bioretention areas treat and recharge stormwater thereby reducing the amount/size of piping needed and the size of downstream basins and treatment structures.

Design Details

- Where bioretention areas are adjacent to parking areas, allow 3" of freeboard above ponding depth to prevent flooding.
- Determine the infiltrative capacity of the underlying native soil through an infiltration test using a double-ring infiltrometer. Do not use a standard septic system percolation test to determine soil permeability.
- Soil mix should be sandy loam or loamy sand with clay content less than 15%. Soil pH should generally be between 5.5-6.5, which is optimal for microbial activity and adsorption of nitrogen, phosphorus, and other pollutants. Planting soils should be 1.5-3% organic content and maximum 500ppm soluble salts.
- Planting soils should be placed in 1'-2' lifts, compacted with minimal pressure, until desired elevation is achieved. Some engineers suggest flooding the cell between each lift placement in lieu of compaction.
- Planting plan should generally include one tree or shrub per 50 s.f. of bioretention area, and at least 3 species each of herbaceous perennials, shrubs, and (if applicable) trees to avoid a monoculture.
- The bioretention landscaping plan should meet the requirements of any applicable local landscaping requirements.
- During construction, avoid excessive compaction of soils around the bioretention areas and accumulation of silt around the drainfield.
- In order to minimize sediment loading in the treatment area, only runoff from stabilized drainage areas should be directed to bioretention areas; construction runoff should be diverted elsewhere.

Additional References

Design Manual for Use of Bioretiention in Stormwater Management; Department of Environmental Resources, Prince George's County, MD; 1993.

Bioretention as a Water Quality Best Management Practice, Article 110 from Watershed Protection Techniques; Center for Watershed Protection; 2000 http://www.cwp.org/Downloads/ELC_PWP110.pdf

Storm Water Technology Fact Sheet, Bioretention, United States Environmental Protection Agency, Office of Water; 1999 http://www.lowimpactdevelopment.org/epa03/biospec. htm

Bioretention Fact Sheet, Federal Highway Administration www.fhwa.dot.gov/ environment/ultraurb/3fs3.html

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FACT SHEET #5

VEGETATED SWALES

Overview

Vegetated swales are an important Low Impact Development technique used to convey stormwater runoff. These open, shallow channels slow runoff, filter it, and promote infiltration into the ground; as a result, runoff volumes are smaller, peak discharge rates are lower, and runoff is cleaner. This approach contrasts with conventional stormwater strategies that rely on gutters and pipes that increase the velocity of runoff and do nothing for water quality.

Swales are not just ditches under another name—they must be carefully designed and maintained to function properly. The vegetation in swales, usually thick grass, helps to trap pollutants (suspended solids and trace metals), and reduce the velocity of stormwater runoff; stormwater also percolates through the natural substrate.

Vegetated swales can replace curb and gutter systems as well as storm sewers that convey runoff. Swales require more room than curb and gutter systems but they require less expensive hardscaping; furthermore, the reduction in discharge rate and volume means that downstream treatment facilities can be smaller. Swales also double as landscaping features, increasing the value and attractiveness of the site, as well as its appeal to neighbors and regulatory boards.

Applications and Design Principles

Water quality swales are widely applicable on residential, commercial, industrial, and institutional sites. The amount of impervious cover in the contributing area to each swale should be no more than a few acres, and swales should not be used in areas where pollutant spills are likely. Grassed swales can be used in parking lots to break up areas of impervious cover. Roadside swales can be used in place of curb and gutter systems, except where there are numerous driveways requiring culverts. Where sidewalk and road are parallel, swale should be between the sidewalk and the road.

Management Objectives

- Provide water quality treatment; remove suspended solids, heavy metals, trash.
- Reduce peak discharge rate.
- Reduce total runoff volume.
- Infiltrate water into the ground.
- Provide a location for snow storage.
- Improve site landscaping.

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Vegetated swales may be parabolic or trapezoidal in cross section. Longitudinal slopes should be as low as possible, and never more than 4%; swales should follow natural topography and drainage patterns to the extent possible. Swales work best in sandy loams that facilitate infiltration; very sandy soils may be prone to erosion under high runoff velocities. Check dams placed along the length of the swale can help to slow the runoff even more and promote greater infiltration and pollutant removal. Careful hydrologic design is necessary to ensure adequate pretreatment of the water quality volume and nonerosive conveyance of large storms.

In some applications, swales are designed with a 2- to 3-foot deep soil bed of loamy sand to promote greater infiltration; on denser sites, this bed may include a perforated underdrain to ensure rapid drainage of the swale if groundwater infiltration is slow. In such applications, the runoff would end up (via the underdrain or swale termination) in the conventional stormwater system, but the swale would still provide considerable quality, quantity, and rate benefits.

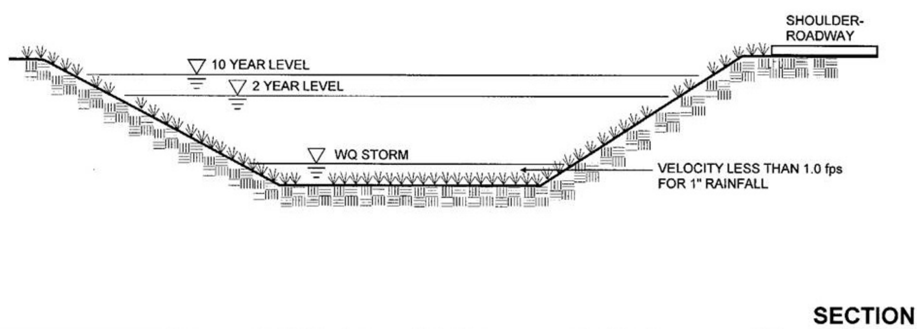
Benefits and Effectiveness

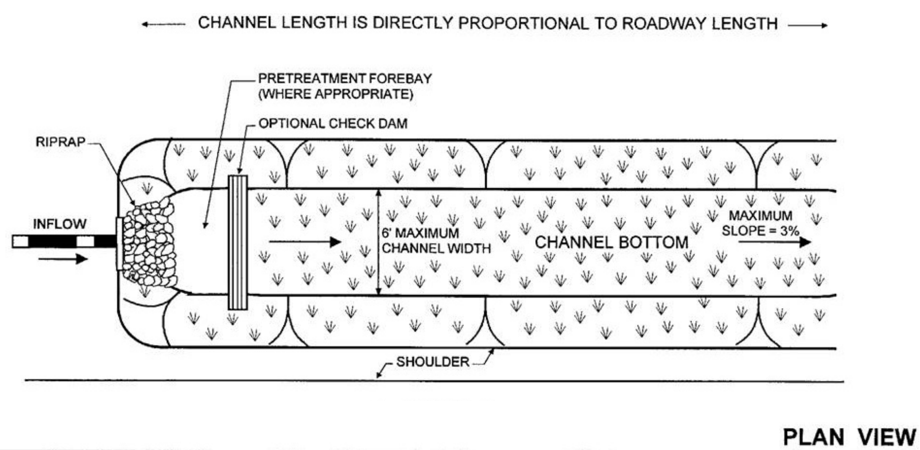
- Swales help to control peak discharges by reducing runoff velocity, lengthening flow paths, and increasing time of concentration.
- Infiltration through the natural substrate helps to reduce total stormwater runoff volume.
- Swales provide effective pretreatment for downstream BMPs by trapping, filtering and infiltrating particulates and associated pollutants. The design rate for TSS removal is 70%.
- Swales accent the landscape and may help to satisfy landscaping and greenspace requirements.
- Swales can provide a location for snow storage during winter months.
- Roadside swales effectively keep stormwater flows away from street surfaces.
- Construction may cost less than conventional curb and gutter systems.

Cover, top: Stone check dams in this roadside swale serve to slow run-off, promote settling, and increase infiltration. *Photo: Virginia Stormwater Management Handbook*

Cover, bottom: This swale in a residential neighborhood fits in with the landscaping. *Photo: University of Connecticut, Jordan Cove Urban Monitoring Project*

Below: A meandering grassed swale filters runoff and helps to improve site landscaping. *Photo: Low Impact Development Center.*





Above: This roadside swale can provide a convenient location for snow storage. As the snow melts, sand is filtered by the vegetation and some of the runoff will infiltrate. *Photo: University of Connecticut, Jordan Cove Urban Monitoring Project.*

Limitations

- Each grassed swale can treat a relatively small drainage area of a few acres, depending on land use and soil type. Large areas should be divided and treated using multiple swales.
- Swales are impractical in areas with steep topography.
- A thick vegetative cover is needed for these practices to function properly. Grass must not be mowed too short.
- Swales should be used carefully on industrial sites or areas of higher pollutant concentrations. If used, they should be part of a "treatment train" that includes other treatment BMPs.
- Swales can be subject to channelization, if erosive velocity is exceeded.
- Soil compaction can reduce infiltration capacity.
- Swales are not effective at reducing soluble nutrients such as phosphorous.
- In some places, the use of swales is restricted by law; many local municipalities may require curb and gutter systems in residential areas.

Maintenance

- Permits for water quality swales should specify schedules and responsibility for inspection and maintenance. Since swales may be located on private residential property, it is important for developers to clearly outline the maintenance requirements to property purchasers.
- Inspect on a semi-annual basis; additional inspections should be scheduled during the first few months to make sure that the vegetation in the swales becomes adequately established. Inspections should assess slope integrity, soil moisture, vegetative health, soil stability, compaction, erosion, ponding, and sedimentation.
- Mow at least once per year, but do not cut grass shorter than the design flow

Above: Swales can be used on commercial sites to convey runoff around the site and to help slow peak discharge rates. *Photo: Lower Columbia River Estuary Partnership*

depth because the effectiveness of the vegetation in reducing flow velocity and pollutant removal may be reduced. Grass cuttings should be removed from the swale and composted.

- Remove accumulated sediment when it is 3" deep or higher than the turf, to minimize potential concentrated flows and sediment resuspension.
- Irrigate only as necessary to prevent vegetation from dying.
- The application of fertilizers and pesticides should be minimal.
- Reseed periodically to maintain dense turf.
- Remove trash or obstructions that cause standing water.
- Prevent off-street parking or other activities that can cause rutting or soil compaction.

Cost

Vegetated swales typically cost less to construct than curbs and gutters or underground stormwater conveyance pipes. The cost of construction will depend on local conditions and management objectives. As with any stormwater management structure, property owners should provide a budget for ongoing maintenance, such as regular mowing and repairs as necessary.

Design Details

- The topography of the site should generally allow for a longitudinal slope of no more than 4% and no less than 0.5%. Flatter slopes can result in ponding, while steeper slopes may result in erosion (depending on soil type, vegetation, and velocity.) Use natural topographic low points and drainageways to minimize excavation.
- Underlying soils should be a sandy loam or a similar soil type with no more than 20% clay. Soil augmentation may be necessary.
- Side slopes should be 3:1 or flatter for maintenance and to prevent side slope erosion. Swale bottoms should generally be between 2 and 8 feet in width.
- Use pea gravel diaphragms for lateral inflows.
- Check dams can be utilized to establish multiple cells. Check dams at 50-foot intervals (<2' drop) help to maximize retention time, increase infiltration, promote particulate settling, and decrease flow velocities. Check dams are not necessary with very low longitudinal slopes. Provide for scour protection below check dam.
- Outlet protection must be used at any discharge point from swales to prevent scour.
- Select grass species that produce fine, uniform, and dense cover and that can withstand prevailing moisture conditions.
- Temporary erosion and sediment controls should be utilized during construction.
- Keep heavy equipment out of the channel during construction to minimize compaction. Even a bobcat grader can compact soils and reduce potential infiltration. Use excavator with a swing arm and work from the side of the swale.
- Mulch anchoring should be done immediately after seeding.

Additional References

- *Massachusetts Stormwater Management Policy: Volume Two: Stormwater Technical Handbook*; Massachusetts Department of Environmental Protection and Massachusetts Coastal Zone Management; 1997
- *Grassed Swales*; from The Wisconsin Stormwater Manual, University of Wisconsin-Extension Service; 2000

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FACT SHEET #6

GRASS FILTER STRIPS

Overview

Grass filter strips are low-angle vegetated slopes designed to treat sheet flow runoff from adjacent impervious areas. Filter strips (also known as vegetated filter strips and grassed filters) function by slowing runoff velocities, filtering out sediment and other pollutants, and providing some infiltration into underlying soils. Because they use sheet flow and not channelized flow, filter strips are often more effective than swales at removing suspended solids and trash from runoff. They provide good "pretreatment" of stormwater that will then be routed to another technique such as a bioretention area.

Filter strips were originally used as an agricultural treatment practice, but have recently been used in more urban and suburban locations. They differ slightly from buffer strips, which are natural vegetated areas alongside streams and lakes; buffer strips are left undisturbed for habitat protection and visual screening, while filter strips are altered areas designed primarily for stormwater management. Like many other LID techniques, vegetated filter strips can add aesthetic value to development. They cost significantly less than "hardscaped" stormwater infrastructure and also provide a convenient and effective area for snow storage and treatment.

Applications and Design Principles

Filter strips are appropriate for roadside applications and along the edge of small- to medium-sized parking lots, so long as the tributary area extends no more than 60 feet uphill from the buffer strip. They can also be used to treat roof runoff that is discharged over a level spreader. Filter strips are ideal components of the outer zone of a stream buffer, or as pretreatment to another stormwater treatment practice. They are generally require too much land area for applications in urban areas. The contributing drainage area should generally be less than five acres.

Management Objectives

- Remove suspended solids, heavy metals, trash, oil and grease.
- Reduce peak discharge rate and total runoff volume.
- Provide modest infiltration and recharge.
- Provide snow storage areas.
- Improve site landscaping.

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Filter strips work best when they are at least 20 feet long (downhill axis), though shorter strips will still provide some treatment. They should have slopes between 1% and 15%, preferably in the lower end of that range. It is critical for filter strips to be planar or convex, since any undulation in the surface or obstructions can cause concentrated flow that leads to erosion, channelization, and loss of water quality benefits.

The design should seek to keep runoff velocity in the low to moderate range (less than 2 feet per second) in order to maximize water quality benefits. This can be done by limiting the size of the contributing impervious surface. Both the top and toe of the slope should be as flat as possible to encourage sheet flow. A pea gravel or cement level spreader (with a lip) at the top of the filter strip will improve sheet flow and will capture some sediment.

Some filter strips are designed with a pervious berm at the downhill end of the filter strip, to detain water temporarily, increasing infiltration and reducing peak discharge rates. This berm can significantly enhance water quality benefits if it is designed to impound the water quality volume.

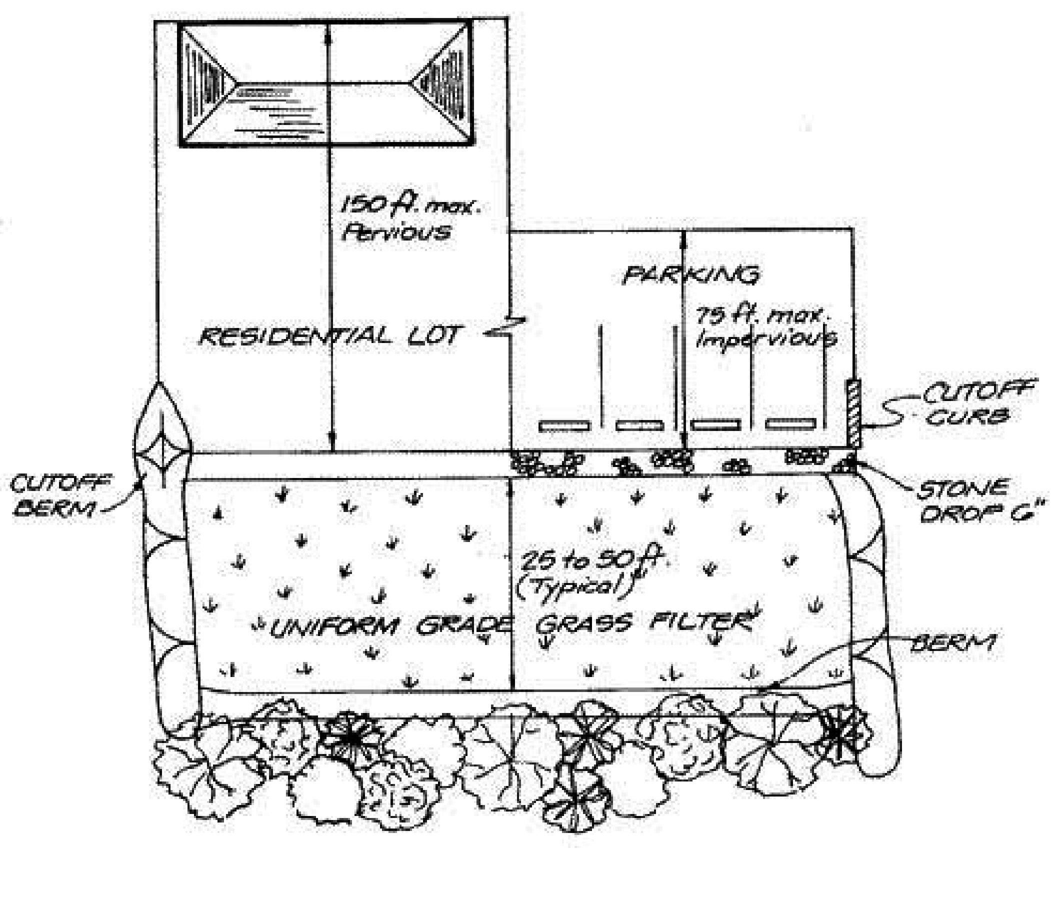
Cover, top: This 40-foot wide filter strip provides water quality pretreatment of runoff from the adjacent highway. *Photo: California Stormwater Quality Association.*

Cover, bottom: A filter strip adjacent to this filling station provides room for snow storage and can remove sediment and organics from runoff. *Photo: Steve Haubner, Atlanta Regional Commission*

Below right: A plan view of filter strips in residential and commercial settings. *Image: Center for Watershed Protection*

Benefits and Effectiveness

- Filter strips provide runoff pretreatment by trapping, filtering and infiltrating particulates and associated pollutants. TSS removal rates range from 40%-90%. Effectiveness depends largely on the quantity of water treated, the slope and length of the filter strip, the type of vegetation, and the soil infiltration rate.
- Vegetated filter strips also reduce runoff velocities and increase the time of concentration as compared to channelized flow, resulting in a reduction of peak discharge rates.
- Filter strips may provide groundwater recharge as runoff infiltrates into soil; recharge may be considerable if design incorporates a ponding area at the toe of the slope.



Above: Here a filter strip is being used as pretreatment for parking lot runoff directed to an infiltration basin. Note concrete level spreader (at right) to facilitate sheetflow across filter strip. *Photo: California Stormwater Quality Association*

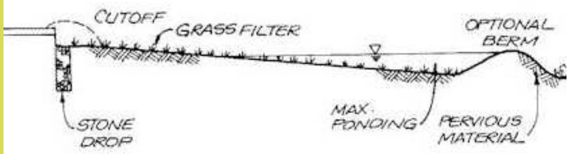
- Filter strips can serve as a location for snow storage during winter months and will also help to trap and treat the salt and sand in snow when it melts.
- Filter strips are inexpensive to construct, especially when compared to conventional curb-and-gutter systems.
- Vegetated filter strips help to accent the natural landscape by providing green space adjacent to parking lots and roadways.

Limitations

- Because filter strips infiltrate runoff to groundwater, they could be inappropriate at stormwater "hotspots" (such as gas stations) with higher potential pollutant loads. They should be combined with other BMPs to ensure adequate treatment of polluted runoff prior to discharge.
- Channelization and premature failure may result from poor design, imprecise construction, or lack of maintenance. Proper design requires a great deal of finesse, and slight problems in the construction, such as improper grading, can render the practice less effective in terms of pollutant removal.
- Filter strips have low removal rates for nutrients, so they must be used in conjunction with other best management practices.
- Filter strips often require lots of space, making them often infeasible in urban environments where land prices are high.

Maintenance

- Inspect level spreader monthly and remove built-up sediment.
- Inspect vegetation monthly for rills and gullies and correct. Fill any depressions or channels. Seed or sod bare areas.
- In the year following construction, inspect the filter strip regularly to ensure that grass has established. If not, replace with an alternative species. Allow natural succession by native grasses and shrubs if it occurs.



This diagram shows a filter strip designed with a berm to impound water, resulting in improved water quality treatment and increased infiltration. *Image: Center for Watershed Protection*

- Mow grass, as rarely as 2-3 times per year, to maintain 4" to 6" of dense grass cover. Grass clippings should be collected and composted elsewhere. Provide a minimum of fertilizer only when necessary. Mow when the soil is dry and firm to prevent rutting.
- Semi-annually, remove sediment that has accumulated to prevent berms or channels.

Cost

Filter strips cost considerably less to construct than many hardscaped stormwater management structures such as curbs, storm sewers, and ponds. The primary direct expenses are clearing, grading, and seed or sod. Additional expenses may include construction of a level spreader at the top of the strip or a berm at the toe of the slope.

The most significant cost of filter strips may be an indirect expense, which is the cost of the land, which may be very valuable in dense urban settings. In many cases, however, open spaces and buffers are required by municipal landscaping or zoning regulations, and filter strips may be used to satisfy these requirements. Established vegetated buffers may also add value a property.

Design Details

- The limiting design factor for filter strips is not total drainage area but rather the length of flow contributing to it. Because sheetflow runoff becomes concentrated flow as distance increases, the contributing area to a vegetated buffer should be no more than 60 feet for impervious surfaces, and 100 feet for pervious surfaces.
- Slopes should be between 1% and 15%, though slopes less than 5% are preferred. The top and toe of the slope should be as flat as possible.
- The filter strip should be at least 20' long (downhill length) to provide water quality treatment. Minimum width is 8' or 0.2 X length of flow over the impervious surface upstream of the filter strip.
- Depth of sheetflow should be less than 0.5" for the design storm. Depending on the pollutant removal required, residence time should be at least 5 minutes, preferably 9 minutes or more.
- Use Manning's equation to calculate velocity, assuming hydraulic radius equals depth, with n values of 0.20 for mowed grass slope and 0.24 for infrequently mowed grass slope. Normal velocity should be <1.0 feet/second for design flow, with maximum permissible velocity of 3.0 feet/second for peak discharge during 10-year storm.
- Use a cement level spreader or pea gravel diaphragm at the top of the slope.
- Filter strips can be designed with a pervious berm of sand and gravel at the toe of the slope. This feature provides an area for shallow ponding at the bottom of the filter strip. Runoff ponds behind the berm and gradually flows through outlet pipes in the berm. The volume ponded behind the berm should be equal to the water quality volume.
- Designers should choose a grass that can withstand calculated flow velocities, and both wet and dry periods. Also consider depth to groundwater and choose facultative wetland species if appropriate.
- If filter strip will be used for snow storage, use salt tolerant vegetation (e.g., creeping bentgrass.)
- During construction, divert runoff from unstabilized areas away from filter strips.
- Protect the underlying soil from compaction to the extent possible: work from outside the boundaries of the filter strip or use oversized tires and lightweight equipment.

Additional Resources

Mass Highway Department Stormwater Handbook
(www.mhd.state.ma.us/mhd/environ/publications.htm)
www.stormwatercenter.net

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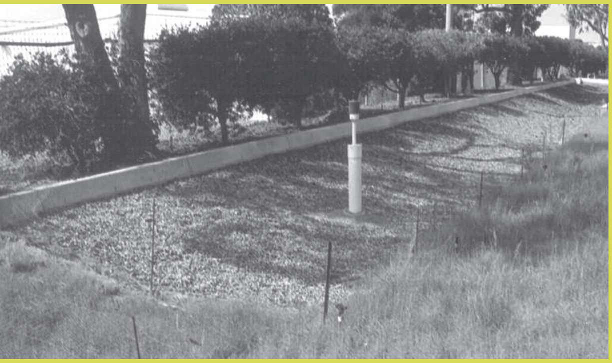
MASSACHUSETTS **LOW IMPACT DEVELOPMENT** TOOLKIT

FACT SHEET #7

INFILTRATION TRENCHES AND DRY WELLS



Overview

Infiltration trenches and dry wells are standard stormwater management structures that can play an important role in Low Impact Development site design. Dispersed around the site, these infiltration structures can recharge groundwater and help to maintain or restore the site's natural hydrology. This approach contrasts with conventional stormwater management strategies, which employ infiltration as a secondary strategy that occurs in large basins at the end of a pipe.

Dry wells and infiltration trenches store water in the void space between crushed stone or gravel; the water slowly percolates downward into the subsoil. An overflow outlet is needed for runoff from large storms that cannot be fully infiltrated by the trench or dry well. Bioretention, another important infiltration technique, is discussed in another fact sheet. Infiltration trenches do not have the aesthetic or water quality benefits of bioretention areas, but they may be useful techniques where bioretention cells are not feasible.

Applications and Design Principles

Infiltration structures are ideal for infiltrating runoff from small drainage areas (<5 acres), but they need to be applied very carefully. Particular concerns include potential groundwater contamination, soil infiltration capacity, clogging, and maintenance. Pretreatment is always necessary, except for uncontaminated roof runoff. Trenches and dry wells are often used for stormwater retrofits, since they do not require large amounts of land; directing roof runoff to drywells is a particularly cost-effective and beneficial practice. Whether for retrofits or new construction, multiple infiltration structures will be needed to treat large sites; they are often used in the upland areas of large sites to reduce the overall amount of runoff that must be treated downstream.

Trenches and dry wells are tough to site in dense urban settings, due to the required separation from foundations, and because urban soils often have poor infiltration capacity due to many years of compaction. Infiltration trenches and dry wells should not receive runoff from stormwater hotspots

Management Objectives

- Remove suspended solids, heavy metals, trash, oil and grease.
- Reduce peak discharge rate and total runoff volume.
- Provide modest infiltration and recharge.
- Provide snow storage areas.
- Improve site landscaping.

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(such as gas stations) unless the stormwater has already been fully treated by another stormwater treatment practice to avoid potential groundwater contamination.

Infiltration structures must be constructed with adequate vertical separation from the groundwater table, generally 2' or more between the bottom of the trench or pit and the seasonally high groundwater table. Soils must be sufficiently permeable (at least 0.3"/hour) to ensure that trenches can infiltrate quickly.

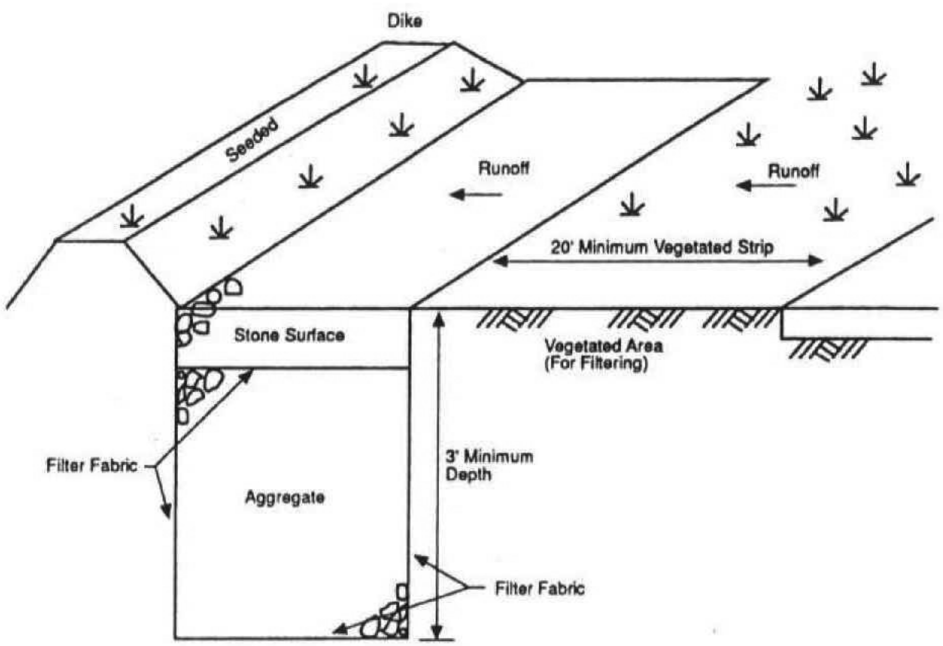
Infiltration trenches and dry wells operate on similar principles, though trenches are linear troughs and dry wells are round or square in plan view. In both cases, the excavated hole or trench, 3'-12' deep, is lined with filter fabric and backfilled with washed, crushed stone 1.5"-3" in diameter. The bottom of infiltration trenches is often filled with a 6"-12" filter layer of washed, compacted sand. A 4"-6" perforated PVC observation well will permit monitoring of the structure and observation of drainage time.

Trenches and dry wells should be designed to store the design volume and infiltrate it into the ground through the bottom of the trench or well within 72 hours. Because of their limited size, infiltration structures are best used to infiltrate the first inch/half inch of runoff from frequent small storms; they are not effective for infiltrating the runoff from large storms. Overflow from trenches and dry wells should be directed to a swale or other conveyance, sized to prevent erosion.

Because dry wells and infiltration trenches can be prone to clogging, pretreatment of stormwater runoff is a necessity. Where dry wells accept roof runoff through a system of gutters and downspouts, screens at the top of downspouts should suffice. For runoff from paved surfaces, designers should use grass swales, filter strips, settling basins, sediment forebays, or a combination of two or more strategies to pretreat stormwater before it is discharged to an infiltration trench or dry well. In groundwater protection areas (Zone II and Interim Wellhead Protection Areas) infiltration may only be used for uncontaminated rooftop runoff.

Above, top: A perforated pipe delivers rooftop runoff to the full length of this infiltration trench, under construction. After completion the area will be covered with sod and the trench will be invisible. *Photo: Cahill Associates, Inc. 2004*

Above: A roadside infiltration trench that receives runoff via periodic curb cuts; this trench may be prone to clogging because there is no pretreatment. *Photo: Lower Columbia River Estuary Partnership*



Right: A schematic section of an infiltration basin. *Image: American Groundwater Trust, Plainfield CT Stormwater Manual*

Above, and Cover: The parking lot runoff directed to this infiltration basin is pretreated by a vegetated filter strip. Note concrete level spreader (at right) to facilitate sheetflow across filter strip. *Photo:California Stormwater Quality Association*

Benefits and Effectiveness

- Dry wells and infiltration trenches reduce stormwater runoff volume, including most of the runoff from small frequent storms. Consequently, downstream pipes and basins are smaller, and the local hydrology benefits from increased base flow.
- Dry wells and infiltration trenches also reduce peak discharge rates by retaining the first flush of stormwater runoff and creating longer flow paths for runoff.
- Infiltration structures are moderately expensive to construct and can help to reduce the size of downstream stormwater management structures.
- These techniques have an unobtrusive presence; they do not enhance the landscape (like bioretention areas do), but they have a lower profile than large infiltration basins.

Limitations

- Infiltration trenches and dry wells cannot receive untreated stormwater runoff, except rooftop runoff. Pretreatment is necessary to prevent premature failure that results from clogging with fine sediment, and to prevent potential groundwater contamination due to nutrients, salts, and hydrocarbons.
- Infiltration structures cannot be used to treat runoff from portions of the site that are not stabilized.
- Rehabilitation of failed infiltration trenches and dry wells requires complete reconstruction.
- Infiltration structures are difficult to apply in slowly permeable soils or in fill areas.
- Where possible, the design should maintain a minimum separation from paved areas (generally 10', depending on site conditions) to prevent frost heave.
- Unlike bioretention areas, infiltration trenches and dry wells do not help meet site landscaping requirements.

Above: Precast concrete drywell inserts prior to installation.
Photo: Lower Columbia River Estuary Partnership

Maintenance

- After construction, inspect after every major storm for the first few months to ensure stabilization and proper function.
- On a monthly basis, remove sediment and oil/grease from pretreatment devices, overflow structures, and the surface of infiltration trenches.
- Semi-annually, check observation wells 3 days after a major storm. Failure to percolate within this time period indicates clogging
- Semi-annually, inspect pretreatment devices and diversion structures for sediment build-up and structural damage.
- If ponding occurs on the surface of an infiltration trench, remove and replace the topsoil or first layer of stone and the top layer of filter fabric.
- Upon failure, perform total rehabilitation of the trench or dry well to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate.

Cost

Infiltration trenches and dry wells are moderately expensive to construct. Because trenches and dry wells can infiltrate stormwater closer to the source, conveyance structures such as swales and pipes can be downsized. It is important that developers and property owners provide a budget for maintenance activities, since lack of maintenance is the primary cause for premature failure of infiltration structures.

Design Details

- Determine infiltration rate of underlying soil through field investigations; use a minimum of one boring at each dry well, two borings at each infiltration trench, with at least one additional boring every 50 feet for trenches over 100 feet. Base trench/drywell sizing on the slowest rate obtained from soil infiltration tests. Determine the infiltrative capacity of the soil through an infiltration test using a double-ring infiltrometer. Do not use a standard septic system percolation test to determine soil permeability.
- Do not use trenches or dry wells where soils are >30% clay or >40% silt clay.
- Use of vertical piping for distribution or infiltration enhancement may cause the trench or drywell to be classified as an injection well which needs to be registered with the state.
- Trim tree roots flush with the trench sides in order to prevent puncturing or tearing the filter fabric. Since tree roots may regrow, it may be necessary to remove all trees within 10 feet of the infiltration structure and replace them with shallow-rooted shrubs and grasses.
- If used, distribution pipes should have perforations of 0.5" and should be capped at least 1 foot short of the wall of the trench or well.
- For infiltration trenches receiving runoff via surface flow, a horizontal layer of filter fabric just below the surface of the trench, covered with 2"-6" of gravel or crushed stone, will help to retain sediment near the surface; this will prevent clogging and allow for rehabilitation of the trench without complete reconstruction.
- Required set backs for surface water supply (Zone 1 and Zone A): 400 feet setback from a source and 100 feet from tributaries. Required setback from private wells: 100 feet
- Required setback from septic systems: 100 feet. Required setback from building foundations: 10 feet for drywells and 20 feet for infiltration trenches.
- Because of clogging problems, infiltration trenches and drywells should never be used to infiltrate runoff from drainage areas that are not completely stabilized. For best performance, contractors, should avoid compaction of soils around trenches and dry wells during construction.

Additional information

Massachusetts Stormwater Management Policy: Volume Two: Stormwater Technical Handbook; MA DEP & MA CZM; 1997

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FACT SHEET #8

CISTERNS AND RAIN BARRELS

Overview

Cisterns and rain barrels are simple techniques to store rooftop runoff and reuse it landscaping and other nonpotable uses. They are based on the idea that rooftop runoff should be treated as a resource that can be reused or infiltrated. In contrast, conventional stormwater management strategies take rooftop runoff, which is often relatively free of pollutants, and send it into the stormwater treatment system along with runoff from paved areas.

The most common approach to roof runoff storage involves directing each downspout to a 55-gallon rain barrel. A hose is attached to a faucet at the bottom of the barrel and water is distributed by gravity pressure. A more sophisticated and effective technique is to route multiple downspouts to a partially or fully buried cistern with an electric pump for distribution. Where site designs permit, cisterns may be quite large, and shared by multiple households, achieving economies of scale. Stored rain water can be used for lawn irrigation, vegetable and flower gardens, houseplants, car washing, and cleaning windows. When rain barrels or cisterns are full, rooftop runoff should be directed to drywells, stormwater planters, or bioretention areas where it will be infiltrated.

Applications and Design Principles

Cisterns and rain barrels are applicable to most commercial and residential properties where there is a gutter and downspout system to direct roof runoff to the storage tank. They take up very little room and so can be used in very dense urban areas. Rain barrels and cisterns are excellent retrofit techniques for almost any circumstance.

Management Objectives

- Reduce water demand by providing an alternative source for irrigation needs.
- Reduce peak discharge rates and total runoff

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Above: A low-profile cistern "head house" opens to reveal the electric pumps that distribute water throughout this residential property.
Photo: Rainwater Recovery, LLC

Below, right: Construction of a large underground cistern at a commercial site; this vault consists of a weight-bearing skeleton wrapped in a waterproof membrane. *Photo: Rainwater Recovery Systems, LLC*

Cover, top: A rain barrel at the Discovery Museum in Acton, MA.
Photo: GeoSyntec Consultants, Inc.

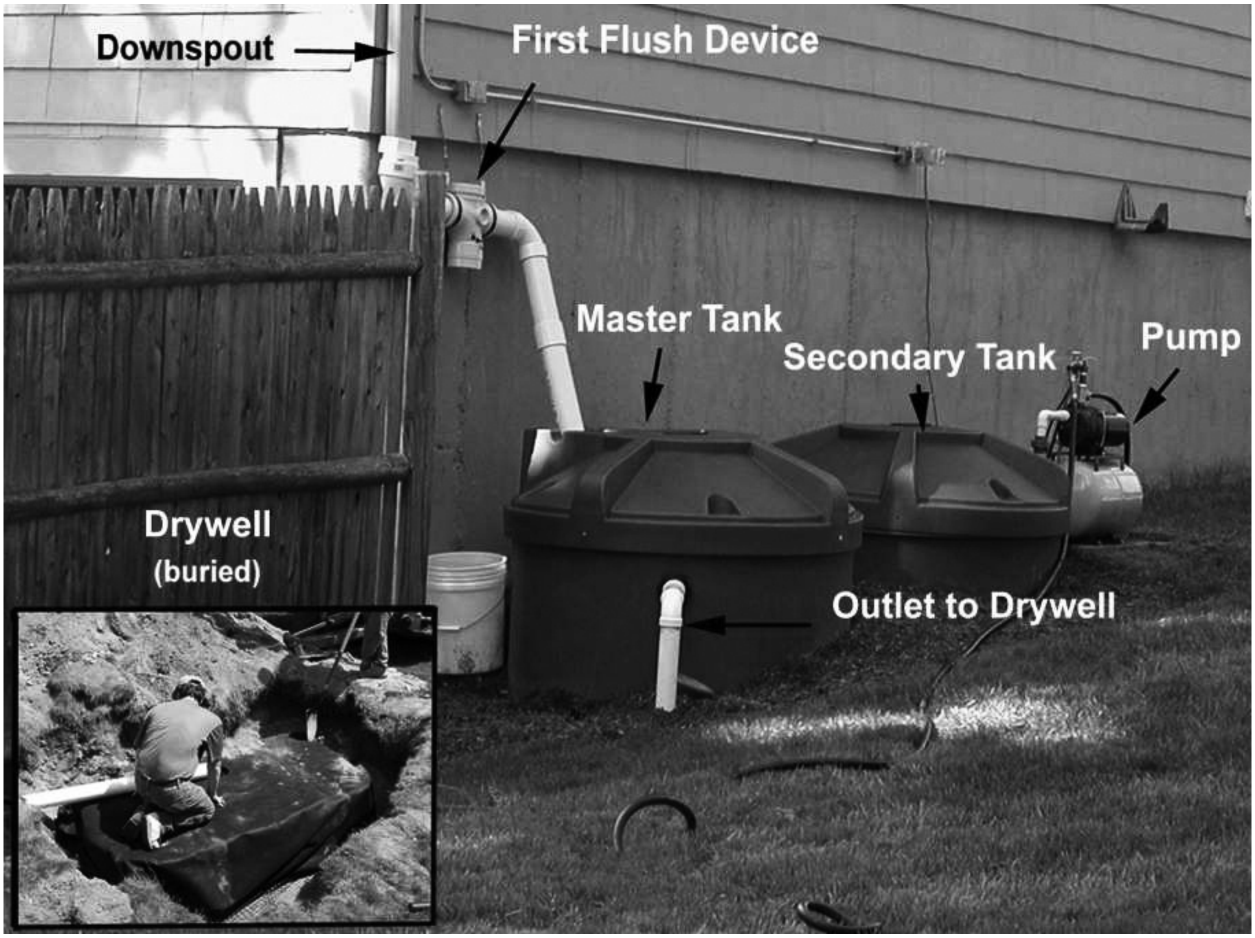
Cover, bottom: A 400-gallon cistern at a group home in Ipswich provides water landscaping and gardening.
Photo: Charles River Watershed Association

Rain barrels are 50-100 gallon covered plastic tanks with a hole in the top for downspout discharge, an overflow outlet, and a valve and hose adapter at the bottom. They are used almost exclusively on residential properties. Since rain barrels rely on gravity flow, they should be placed near, and slightly higher than, the point of use (whether a garden, flower bed, or lawn.) The overflow outlet should be routed to a dry well, bioretention area, or rain garden. It is important for property owners to use the water in rain barrels on a regular basis, or else they fill up and no additional roof runoff can be stored. It is recommended that each house have at least two rain barrels; a one inch storm produces over 500 gallons of water on a 1000 square foot roof.

Cisterns are partially or fully buried tanks with a secure cover and a discharge pump; they provide considerably more storage than barrels as well as pressurized distribution. Cisterns can collect water from multiple downspouts or even multiple roofs, and then distribute this water wherever it needs to go through an electric pump. Property owners may use one large tank or multiple tanks in series. Either way, the overflow for the systems should be a drywell or other infiltration mechanism, so that if the cistern is full, excess roof runoff is infiltrated, and not discharged to the stormwater system. Some cisterns are designed to continuously discharge water at a very slow rate into the infiltration mechanism, so that the tank slowly empties after a storm event, providing more storage for the next event.

Benefits and Effectiveness

- Rain barrels and cisterns can reduce water demand for irrigation, car washing, or other nonpotable uses. Property owners save money on water bills and public water systems experience lower peak demand and less stress on local water supplies.
- Property owners who have cisterns and rain barrels can use stored water for landscape purposes, even during outdoor watering bans.
- If installed and used properly, rain barrels and cisterns can reduce stormwater runoff volume through storage, and will also help to reduce the peak discharge rate.



Above, top: The SmartStorm Rainwater Recovery System, developed by the Charles River Watershed Association; the cisterns and pumps can be easily hidden by landscape plantings. *Photo: Charles River Watershed Association.*

Above: A half-dozen 400-gallon cistern tanks installed in series to provide greater storage capacity. *Photo: Rainwater Recovery Systems, LLC*

Limitations

- The stormwater volume/peak discharge rate benefits of cisterns and rain barrels depend on the amount of storage available at the beginning of each storm. One rain barrel may provide a useful amount of water for garden irrigation, but it will have little effect on overall runoff volumes, especially if the entire tank is not drained in between storms.
- Greater effectiveness can be achieved by having more storage volume and by designing the system with a continuous discharge to an infiltration mechanism, so that there is always available volume for retention.
- Rain barrels and cisterns offer no primary pollutant removal benefits. However, rooftop runoff tends to have few sediments and dissolved minerals than municipal water and is ideal for lawns, vegetable gardens, car washing, etc.
- Rain barrels must be childproof and sealed against mosquitoes.
- The water collected is for nonpotable uses only.

Cost

The cost of rooftop runoff storage varies widely, from a homeowner-installed rain barrel to a commercially constructed underground cistern vault. Most rain barrels and cisterns do not retain enough stormwater to downsize the site's

The overflow outlet from this rain barrel drains into an adjacent rain garden. *Photo: GeoSyntec Consultants, Inc.*

stormwater management system, but can provide cost savings because they reduce the demand for potable water for landscaping and irrigation. The cost-benefit ratio will depend on how much landscaping/irrigation water the property owner uses, and the unit cost of water from the local public water supply.

Commercially available rain barrels begin at approximately $60 for a 55-gallon barrel. Larger barrels may be available at correspondingly higher prices. Most rain barrels can be installed by homeowners. Rain barrels can be assembled by homeowners for lower cost but some of the parts may be hard to find. Some watershed associations or municipalities offer rain barrels at a discount or provide rebates.

Cisterns are more expensive due to the larger size and multiple "moving parts." Installation of buried cisterns can also be expensive. One system available in Massachusetts (SmartStorm) costs $3000 for an 800 gallon two-tank system complete with pump and drywell structure. A common cistern shared by multiple properties may result in considerable economies of scale because there is only one excavation, one tank or set of tanks, and one pump.

Design Details

- Because of the low pressure of the discharge, rain barrels are most effectively used with a drip irrigation system.
- Rain barrels should be childproof and secured against disturbance by people or animals. Any openings should be sealed with mosquito netting.
- If present, a cistern's continuous discharge outlet should be placed so that the tank does not empty completely, ensuring water availability at all times, while also providing at least some storage capacity for every storm.
- A diverter at the cistern inlet can redirect the "first flush" of runoff which is more likely to have particulates, leaves, and air-deposited contaminants washed off the roof.
- Minimize leaves and debris in the storage tank by placing a screen at the top of the downspout.
- Screen rain barrels and exposed cisterns with shrubs or other landscaped features.
- Direct overflow from rain barrels and cisterns to a dry well, infiltration trench, rain garden, bioretention area, or grassed swale sized to infiltrate the overflow volume. Use pond routing to account for retention of early runoff in the storage tank. MA Stormwater Policy does not require treatment of most roof runoff prior to infiltration.

Additional information

http://www.rainwaterrecovery.com/about.html
www.crwa.org (Charles River Watershed Association)

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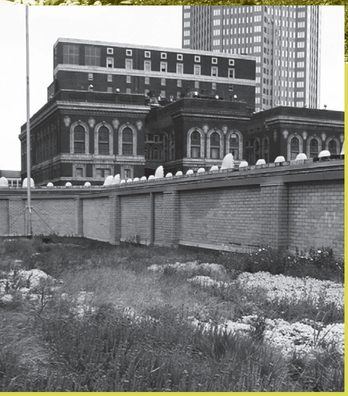
FACT SHEET #9

GREEN ROOFS



Overview

A green roof is a low-maintenance vegetated roof system that stores rainwater in a lightweight engineered soil medium, where the water is taken up by plants and transpired into the air. As a result, much less water runs off the roof, as compared to conventional rooftops. Green roofs have been in use in Europe for more than 30 years; they are easy to incorporate into new construction, and can even be used on many existing buildings.

Green roofs provide an extra layer of insulation that reduces heating and cooling costs, and they are likely to last much longer than conventional roofs, since the roofing material itself is shielded from ultraviolet light and thermal stress. The vegetation on green roofs also improves air quality, enhances the appearance of the building, and reduces the urban "heat island" effect.

There are two distinct types of green roofs: extensive green roofs require less than 6" of soil medium and support mostly herbaceous plants; these utilitarian "roof meadows" generally have no public access and require little maintenance. In contrast, intensive green roofs include shrubs and small trees planted in more than six inches of growing medium; they are often designed as accessible building amenities. This fact sheet focuses on extensive green roofs and their stormwater management benefits. Both types of green roofs seek to transform rooftops from "wasted space" into a form of infrastructure that has environmental, economic, aesthetic, and social benefits.

Applications and Design Principles

Green roofs are appropriate for commercial, industrial, and residential structures, especially those with a wide roof area. They can be incorporated into new construction or added to existing buildings during renovation or re-roofing. Most green roofs are built on flat or low-angle rooftops, but some have been installed on pitched roofs up to 40% slope, with special design features to prevent slumping and ensure plant survival.

Green roofs are appropriate anywhere it is desirable to reduce the overall amount of stormwater runoff. They are an excellent technique to use in dense urban areas, in areas where infiltration is difficult due to tight soils or shallow bedrock, or on sites where infiltration is undesirable due to existing soil contamination. Because green roofs return rainwater to the atmosphere,

Management Objectives

- Reduce total runoff volume through rainwater storage and evapotranspiration.
- Reduce peak discharge rates.
- Reduce heating and cooling costs through roof insulation.
- Extend roof life.

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Above, top: The Ford Dearborn Truck Assembly Plant in Dearborn Michigan has a 10-acre green roof that is a 2004 Green Roof Awards of Excellence Winner.
Photo: William McDonough + Partners

Above, bottom: The Fencing Academy of Philadelphia was retrofit with a 3.5"-thick green roof, installed over the existing roof structure.
Photo: © 2005, Roofscapes, Inc. Used by permission; all rights reserved.

Right: A schematic diagram of a green roof system. *Image: City of Portland, OR Environmental Services.*

Cover, top: A green roof at the Yorktown Square Condominiums in Falls Church, VA. This installation was a 2005 Green Roof Awards of Excellence Nominee.
Photo: Building Logics, Inc.

Cover, bottom: This green roof at the Heinz 57 Center in Pittsburgh is located on the 14th floor and requires no irrigation. It is a 2005 Green Roof Awards of Excellence Nominee.
Photo: © 2005, Roofscapes, Inc. Used by permission; all rights reserved.

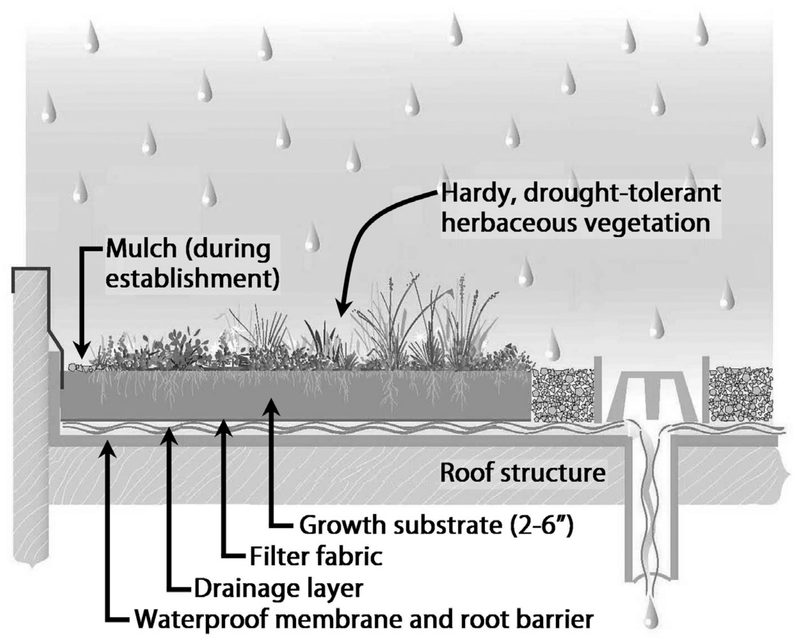
Opposite top: Workers conduct semi-annual maintenance at the Life Expression Wellness Center in Pennsylvania.
Photo: © 2005, Roofscapes, Inc. Used by permission; all rights reserved

they should not be used in situations where groundwater recharge is a priority, such as in stressed basins with chronic low-flow conditions. In these circumstances, roof runoff should be infiltrated whenever feasible.

Like conventional roofs, the basic element of a green roof is a waterproof membrane over the roof sheathing. The system also includes a root barrier; a drainage layer; filter fabric; and 2"-6" of a lightweight growth substrate consisting of inorganic absorbent material such as perlite, clay shale, pumice, or crushed terracotta, with no more than 5% organic content. Substrates should not be too rich in organic material such as compost, because of the potential for settling, nutrient export, and too-rapid plant growth. Gravel ballast is sometimes placed along the perimeter of the roof and at air vents and other vertical elements, in order to promote drainage and facilitate access.

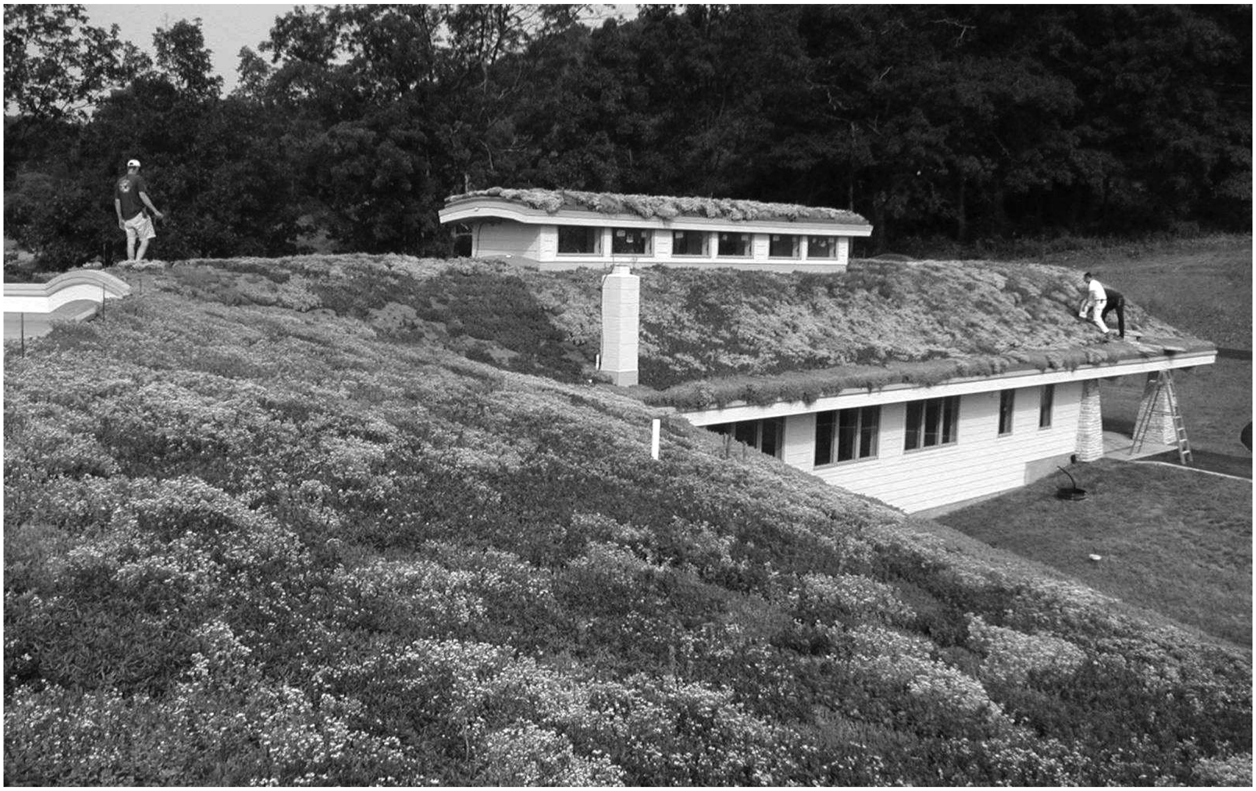
Extensive green roofs require moderate structural support which can be easily accommodated during design for new construction; existing roofs may be adequate or may require additional structural supports that can be added during re-roofing or renovation. An extensive green roof may weigh approximately 10-25 pounds per square foot when fully saturated, whereas a conventional rock ballast roof weighs approximately 10-12 pounds per square foot (neither figure includes potential snow load.)

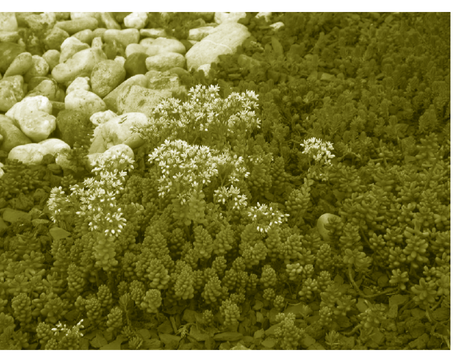
Vegetation on extensive green roofs usually consists of hardy, low-growing, drought-resistant, fire-resistant plants that provide dense cover and are able to withstand heat, cold, and high winds. Varieties commonly used include succulents such as sedum (stonecrop) and delosperma (ice plant.) During dry periods, these plants droop but do not die back; when it rains, they quickly revive and absorb large



amounts of water. Grasses and herbs are less common on green roofs because to survive dry periods they require either irrigation or deeper substrate that retains more water.

A common concern about green roofs is the potential for leaks. The performance of green roofs has improved dramatically since the 1970s, when many leak problems were associated with the first generation of green roofs. Current waterproofing materials, root barriers, and rigorous design and construction standards have largely eliminated these problems; low-cost electronic grids installed under the membrane during construction can also help to pinpoint leaks and minimize repair costs.





Above, middle: A photo of the green roof at the Bruker Deltronics Headquarters in Billerica, MA. *Photo: © 2005, Roofscapes, Inc. Used by permission; all rights reserved.*

Above, bottom: A close up of low-growing, spreading green roof vegetation. *Photo: Building Logics, Inc.*

Benefits and Effectiveness:

- Green roofs effectively reduce stormwater runoff. Researchers at North Carolina State have found that a 3" green roof can retain approximately 0.6" of rain for each rainfall event, even when storms come on consecutive days. The Center for Green Roof Research at Penn State University reports that a 4" green roof can retain 50% of total rainfall over a series of storm events.
- Green roofs reduce peak discharge rates by retaining runoff and creating longer flow paths. Research indicates that peak flow rates are reduced by 50% to 90% compared to conventional roofs, and peak discharge is delayed by an hour or more.
- Green roofs lower heating and cooling costs because the trapped air in the underdrain layer and in the root layer help to insulate the roof of the building. During the summer, sunlight drives evaporation and plant growth, instead of heating the roof surface. During the winter, a green roof can reduce heat loss by 25% or more.
- Because green roofs shield roof membranes from intense heat and direct sunlight, the entire roofing system has a longer lifespan than conventional roofs.
- The presence of a green roof helps to reduce air temperatures around the building, reducing the "heat island" effect and reducing the production of smog and ozone, which forms in the intense heat (175 degrees) over large conventional roofs. The vegetation on green roofs also consumes carbon dioxide and increases the local levels of oxygen and humidity.
- Green roofs have demonstrated aesthetic benefits that can increase community acceptance of a high-visibility project; they may also add value to the property if marketed effectively.

Above: Installation of eight inches of soil medium using pneumatic equipment at the Oaklyn Branch Library in Evansville, IN. *Photo: © 2005, Roofscapes, Inc. Used by permission; all rights reserved.*

Limitations

- Load restrictions are usually the main limitation for green roofs in retrofit applications. A professional engineer must assess the necessary load reserves and design a roof structure that meets state and local codes.
- Slopes greater than 15% require a wooden lath grid or other retention system to hold substrate in place until plants form a thick vegetation mat.
- Green roofs should not be used where groundwater recharge is a priority, such as in aquifer recharge areas or watersheds experiencing low-flow stresses.
- The initial construction cost is higher than conventional roofs.

Maintenance

- Green roofs require some support during establishment and then yearly maintenance thereafter. Plants or sprigs should be irrigated until established, and additional plants or sprigs added to ensure good plant coverage if necessary. With drought-resistant vegetation, irrigation of an extensive green roof is rarely necessary after the two-year establishment period.
- Weeding and mulching may be needed during the establishment period and periodically thereafter over the life of the roof. Any woody plants which become established on the roof need to be removed regularly.
- If necessary (many roofs can survive on deposition of airborne nitrogen and biomass breakdown), application of a slow-release fertilizer once a year will ensure continued vigorous growth of the vegetation. Soluble nitrogen fertilizers and compost should not be used due to the potential for nutrient and bacteria export.

Cost

Green roofs start at $5 per square foot. They generally cost more to install than conventional roofs, but are financially competitive on a life-cycle basis because of longer life spans (up to 40 years), increased energy efficiency, and reduced stormwater runoff. If the application is a retrofit, structural upgrades may increase the cost somewhat.

Design Details:

- Waterproof membranes are made of various materials, such as modified asphalts (bitumens), synthetic rubber (EPDM), hypolan (CPSE), and reinforced PVC. The most common design used in Europe is 60-80 mil PVC single-ply roof systems. Modified asphalts usually require a root barrier, while EPDM and reinforced PVC generally do not. Attention to seams is critical because some glues and cements are not always root impermeable.
- The underdrain layer may be constructed of perforated plastic sheets or a thin layer of gravel. Pitched roofs and small flat roofs may not require an underdrain.
- Vegetation should be low-growing, spreading perennial or self-sowing annuals that are drought tolerant. Appropriate varieties include sedum, delospermum, sempervivium, creeping thyme, allium, phloxes, anntenaria, ameria, and abretia. Vegetation may be planted as vegetation mats, plugs or potted plants, sprigs (cuttings), or seeds. Vegetation mats are the most expensive but achieve immediate full coverage. Potted plants are also expensive and labor intensive to install. Sprigs are often the most cost effective option, even considering that initial irrigation is necessary and repeat installations may be required due to mortality. Conventional sod should not be used because it requires irrigation, mowing, and maintenance.
- Access routes should be identified during the design phase, and access paths of gravel or other inert materials provided, as well as safety harness hooks for inspection and maintenance personnel.

For more information

www.greenroofs.org (Green roof industry association; training and design courses)
www.greenroofs.com (The Green Roof Industry Resource Portal)
www.bae.ncsu.edu/greenroofs/ (North Carolina State University)
hortweb.cas.psu.edu/research/greenroofcenter/ (Penn State University)
www.greeninggotham.org/home.php
www.roofmeadow.com (North American Green Roof Provider)

This publication is one component of the Massachusetts Low Impact Development Toolkit, a production of the Metropolitan Area Planning Council, in coordination with the I-495 MetroWest Corridor Partnership, with financial support from US EPA. The Massachusetts Low Impact Development Interagency Working Group also provided valuable input and feedback on the LID Toolkit.