LOW IMPACT DEVELOPMENT DOCUMENTATION

Included in this appendix is additional information regarding Low Impact Development (LID).


   Discussed in this memorandum are 17 different LID techniques, which include rain barrels, cisterns, rain gardens, green roofs, porous pavement, and rooftop storage; among others. Each technique is discussed in detail, including advantages/disadvantages, costs, and maintenance requirements.

   Evaluation of Stormwater Reduction Practices.pdf

2. LID Quicksheet 1.2 User Manual dated May 6, 2005

   The manual provides documentation and user information for the LID Quicksheet 1.2. The Quicksheet allows the user to quickly evaluate various LID features on a development site to reduce the MMSD Chapter 13 detention requirements. The Unit Release Rate method is utilized by the Quicksheet for these analyses. LID features included in the Quicksheet include rain gardens, rain barrels, green roofs, cisterns, and permeable pavement.

   LIDQuicksheet12.pdf

3. LID Quicksheet 1.2 ordering information

   Please contact MMSD Records Management at (414) 225-2094 to obtain a CD including the Quicksheet. The cost of the Quicksheet CD is $25.
MEMORANDUM

EVALUATION OF STORMWATER REDUCTION PRACTICES

MARCH 1, 2003
EVALUATION OF STORMWATER REDUCTION PRACTICES

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INTRODUCTION

Integrated stormwater management is a comprehensive watershed-based approach that treats stormwater as a resource (not just a problem), manages stormwater at its source, and addresses the complete spectrum of rainfall events. This approach integrates onsite practices that promote infiltration, vegetation uptake, and detention, with other methods of managing or controlling stormwater. Within the Milwaukee Metropolitan Sewerage District (MMSD) service area, these other measures may include storage (including the Inline Storage System), infiltration/inflow removal, opportunistic sewer separation/low flow diversions, and other initiatives.

An integrated approach to stormwater management will help achieve MMSD’s core mission to:

- Eliminate SSOs
- Reduce CSOs
- Improve water quality
- Provide sound fiscal management

This memorandum describes and evaluates various onsite stormwater reduction practices. The onsite practices considered include:

- **Downspout Disconnection**—Disconnection of roof downspouts from sewers and conveying roof runoff to pervious land surfaces.

- **Rain Barrels**—Collection of roof runoff in 50-100 gallon barrels, with subsequent release to landscaped areas.

- **Cisterns**—Roof runoff collection systems that detain water in above-ground or underground storage tanks. Capacities range from several hundred to 10,000 gallons. Captured water may sometimes be reused for toilet, laundry, and lawn watering purposes.

- **Rain Gardens**—Small (several hundred square feet) vegetated depressions used to capture runoff and promote infiltration and evapotranspiration.

- **Green Roofs**—Soil and vegetation installed on top of a conventional flat or slightly sloped roof. A complete green roof system may include a watertight membrane, protective layer, insulation, irrigation system, drainage system, filter layer, soil, and plants.

- **Rooftop Storage**—Temporary storage of rainfall on a flat roof and the gradual release of this volume using restricted roof drain inlets.

**POTENTIAL BENEFITS OF INTEGRATED STORMWATER MANAGEMENT**

- **System Benefits**
  - Reduced CSOs/SSOs
  - Reduced conveyance, storage, and treatment costs
  - Increased storage available for sanitary flow during wet weather
  - Reduced peak flows and runoff volumes
  - Delayed runoff

- **Environmental Benefits**
  - Improved water quality
  - Reduced erosion, scouring, and drainage problems
  - Improved green space and habitat

- **Public Benefits**
  - Enhanced public education and involvement
  - Improved environmental stewardship
**Green Parking Lots**—Various measures used to reduce the effective impervious area of a parking lot and promote infiltration and/or evapotranspiration.

**Stormwater Trees**—Increasing the coverage of tree canopies to provide stormwater interception and evapotranspiration, along with other ecological benefits.

**Porous Pavement**—The use of porous asphalt or concrete, modular block systems, grass pavers, or gravel pavers to allow stormwater to percolate through the ‘pavement’.

**Inlet Restrictors/Pavement storage**—Flow regulation devices that allow the temporary storage of stormwater on streets and parking lots.

**Bioretention**—Landscaped depressions planted with grass, shrubs, and/or trees. Often utilize a sand/gravel underdrain, mulch, and soil amendments.

**Onsite Filtering Practices**—Practices such as sand filters, bioretention cells, swales, and filter strips that use a filter media (sand, soil, gravel, peat, or compost) to reduce stormwater runoff and capture pollutants.

**Pocket Wetlands**—Small constructed wetlands that can reduce peak flows and runoff volumes, and remove pollutants via settling and bio-uptake.

**French Drains and Dry Wells**—Gravel-filled trenches (french drains: horizontal; dry wells: vertical) used to capture roof runoff and allow it to percolate into the soil.

**Infiltration Sumps**—Below ground, perforated, cylindrical, concrete structures used to collect stormwater and allow it to percolate into the soil.

**Compost Amendments**—Incorporating decomposed organic material into the soil to improve performance for infiltration and vegetation.

**Stormwater Rules and Redevelopment Policies**—Land development and stormwater management criteria and requirements, including the Chapter 13 Surface and Stormwater Regulations.
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Downspout Disconnection

Description and Applicability

This practice involves disconnecting roof downspouts from sewers, directing downspouts away from impervious areas such as driveways and roads that provide direct connections to a public stormwater system, and directing them to a storage facility or pervious areas for infiltration. Downspouts can be directed to rain barrels, rain gardens, on-site filters, vegetated filters, French drains and swales (for more detail on these practices, refer to respective fact sheets). The most important issues to consider are contributing impervious area, soils permeability, slope of receiving area, and proximity to buildings (J.F. Sabourin & Associates, 1999). This method is most applicable to residential areas where there is a sufficient pervious surface (City of Detroit, 1996), but also has application in commercial and light industrial areas.

Advantages

- Low-cost
- Increased public awareness and involvement in CSO problems
- Vegetated areas for infiltration add aesthetics
- Promotes infiltration which reduces runoff volume and peak discharge

Disadvantages

- Must be applied broadly for appreciable volume and peak discharge reduction (City of Detroit, 1996)
- Requires owner buy-in and maintenance support
- Requires large on-lot pervious areas
- Must avoid causing foundation flooding or ice conditions

Existing Implementation Nationally and Internationally

Downspout disconnection programs are being implemented in many cities across the United States and Canada, including: Toronto, Ontario; Vancouver, B.C; Washington D.C.; Dearborn, Michigan; Fort Wayne, Indiana; Boston, Massachusetts; and Portland, Oregon. A 1999 modeling analysis conducted for the City of Toronto showed annual volume reductions of 26,000 gallons per house (based on 1,500 square feet of roof area and 27 inches of annual rainfall (J.F. Sabourin & Associates, Inc, 1999)). A 1996 modeling analysis conducted for the city of Detroit showed that a citywide implementation of residential downspout disconnection could reduce wet weather runoff volume by 5,056 million gallons per year. The reduction is based on a 40-44% reduction in directly connected impervious areas (City of Detroit, 1996). The City of Shaker Heights, Ohio requires downspout disconnection as part of its stormwater ordinance.
Costs

- Costs vary widely depending on the complexity of the disconnection. However, for a simple disconnection to a pervious area, costs for extensions, elbows, and splash pads usually run $10-20 per disconnection (J.F Sabourin & Associates, 1999). The City of Detroit (1996) disconnected 577 downspouts at an average cost of from $243 to $278 per downspout.
- For costs associated with supplemental storage and infiltration practices, refer to other fact sheets.

Maintenance

- On-site systems need to be maintained to ensure proper drainage to avoid nuisance flooding.

References


City of Shaker Heights, Ohio. 1998. Codified Ordinance Part 1, Title 7, Chapter 123.05. Storm and Sanitary Sewer Connections.
Rain Barrels

Description and Applicability

Rain barrels are storage devices that collect rainwater from rooftops and are designed to hold between 50-100 gallons of water. They are typically used in residential applications where the collected rainwater is then used for irrigating landscaped areas. Several factors must be considered before employing this practice, including: climate considerations, algae and mosquito control, physical site suitability, and homeowner ability and willingness to operate effectively (Sands and Chapman, 2003).

Advantages

- Reduces water utility bills
- The practice may not have an impact on CSO’s as a stand alone measure; however, it can reduce volumes and peak discharge for frequent events and could reduce costs at treatment plants (Sands and Chapman, 2003)
- Promotes water conservation and increases public awareness and involvement in CSO problems
- Can be retrofit into existing communities
- Requires little space

Disadvantages

- Requires strong homeowner buy-in
- Must have on-site infiltration capacity for rain barrel overflow for larger storm events
- Has limited effectiveness during winter
- Can create foundation problems if not maintained properly
- Can create mosquito problems if not properly maintained

Existing Implementation Nationally and Internationally

Rain barrel programs are being implemented in many communities across the United States and Canada, including: Portland, Oregon; Toronto, Ontario; Vancouver, B.C; Dearborn, Michigan; Fort Wayne, Indiana; and Boston, Massachusetts. These programs vary from simple rain barrel outreach programs to codified ordinances that permit rainwater collection and use. A 1999 study for the City of Toronto indicates that although rain barrels are not likely to reduce CSO’s, they can reduce volume and peak discharge for frequent storms (J.F. Sabourin & Associates, Inc, 1999). The City of Dearborn, Michigan has recently initiated a demonstration project where flows will be monitored in two adjacent neighborhoods to evaluate the effectiveness of rain barrel use (City of Dearborn).
Costs

- Although costs vary across manufacturers, the average cost of a single rain barrel ranges from about $100 to $150, with an average of about $120 (LID Center, 2003).

Maintenance

To avoid nuisance problems, rain barrels require proper maintenance. Mosquito control, ice formation, and overflow drainage are all critical issues that need to be addressed. Barrels should be emptied in winter to prevent ice formation.

References


Stuart, D. 2001. On-Site Runoff Mitigation with Rooftop Rainwater Collection and Use. King County (WA) Department of Natural Resources.
Cisterns

Description and Applicability

Cisterns are roof water collection devices that provide retention storage volume in above-ground or underground storage tanks. The water collected can be used for lawn and garden watering, household graywater needs or drinking water supply. Cisterns are generally larger than rain barrels, with some underground cisterns having capacities of 10,000 gallons. Storing rainwater on-site for later re-use also provides an opportunity for water conservation and the possibility of reducing water utility costs (LID Center, 2003).

Advantages

- Cisterns can reduce the volume of water entering public systems through rooftop storage of large amounts of rainfall
- Promotes water conservation and increased public awareness and involvement in CSO problems
- Reduces water utility bills
- Can be retrofit into existing communities
- Requires little space

Disadvantages

- Requires strong landowner buy-in
- Can be relatively expensive compared to rain barrels
- If collected water is used for drinking, expensive filtration and treatment systems may be required

Existing Implementation Nationally and Internationally

Due to the expense and sophistication of these systems, cisterns are not as popular as rain barrels for use in disconnection programs across the United States. Although most commonly used as a secondary source of water for gardening in residential areas, larger sized cisterns can be adapted for use to supplement potable water systems. Many municipalities are promoting the use of cisterns for potable water use as well as for commercial and industrial applications (LID Center, 2003). Because residential irrigation can account for up to 40% of domestic water consumption, water conservation measures such as cisterns can be used to reduce the demand on the municipal water system, especially during the hot summer months (LID Center, 2003). The newly constructed headquarters of the Chesapeake Bay Foundation, the Phillip Merrill Environmental Center, uses a cistern catchment system as one of several “green” design elements. The system captures rainwater for reuse in fire suppression, hand washing, mop sinks, the climate control system, and washing.
equipment (CBF, 2003). An ad hoc modeling analysis of cistern storage of residential rooftop runoff by MMSD found that a 500-gallon cistern would capture 6,700 gallons per year, and a 200-gallon cistern would capture 8,200 gallons per year.

Costs

- The cost of cisterns varies greatly depending on size, materials, and location (above or below ground) (LID Center, 2003). The costs can range from $400 for a 200 gallon above ground cistern to $5,000 for a 6,500-gallon underground cistern.
- The total cost of underground reservoirs is nearly double that of above-ground reservoirs (Stuart, 2001).

Maintenance

Maintenance requirements for cisterns are relatively low if they are only providing a supplemental supply of irrigation water. Cisterns designed for drinking water supply have much higher maintenance requirements, such as biannual testing for water quality and filtering systems. Cisterns, along with all their components and accessories, should undergo regular inspection at least twice a year. Replacement or repair of the unit as a whole, and any of its constituent parts and accessories should subsequently be undertaken if needed (LID Center, 2003).

References


Stuart, D. 2001. On-Site Runoff Mitigation with Rooftop Rainwater Collection and Use. King County (WA) Department of Natural Resources.
Rain Gardens

Description and Applicability

Rain gardens are small, vegetated depressions used to capture and infiltrate stormwater runoff. Runoff can enter the garden via sheet flow or downspout disconnection. A rain garden depression, usually 6 to 18 inches deep, is filled with an appropriate soil mixture and planted with native shrubs, grasses, and flowering plants. Water is detained in the ponding area (usually no more than 24 hours) until it either infiltrates or evapotranspires. Rain gardens can be applied to both new and existing developments. Due to space requirements, they are most applicable for residential and light commercial uses. They work best in areas with well-drained soils (University of Wisconsin-Extension Office). Performance can be enhanced in low permeable soils by providing an underdrain system or soil amendments.

Advantages

- Increased public awareness and involvement in stormwater management
- Rain gardens can reduce runoff volume and peak discharge
- Add aesthetics to neighborhoods

Disadvantages

- Can create flooding and visual nuisance if not properly maintained
- Require strong owner and community buy-in

Existing Implementation Nationally and Internationally

Numerous governmental and non-governmental organizations across the United States and Canada promote the use of rain gardens. In particular, Maryland, Minnesota, and Wisconsin are hotbeds for research and outreach. Prince Georges County Maryland has experimented with rain gardens since 1990 and has worked with several communities to implement rain garden programs. Preliminary research indicates that rain gardens, when applied broadly, can reduce volume and peak discharge. Rain garden program have also received strong citizen support (PGDER). The South River Federation in southern Maryland has undertaken a
rain garden retrofit program as part of a comprehensive watershed plan (Personal Communication, 2003). Edgewood College, Wisconsin, initiated a program to design and construct rain gardens on the Edgewood campus and conduct outreach activities as part of the Lake Wingra Watershed Management Program (Edgewood College, 2000). Extension offices for the Universities of Wisconsin and Minnesota conduct extensive rain garden research and outreach. For information on the effectiveness of rain gardens as an on-site infiltration practice, refer to fact sheet on on-site filters.

Costs

The cost to construct a rain garden includes labor for construction and design, plants, and soil mixture. Design and construction costs can vary widely depending complexity of the project. Cost estimates may range form $5 to $10/square foot (Partnership for Rain Gardens, personal communication).

Maintenance

- Must be properly maintained to ensure proper performance and reduce public nuisance.
- Require regular watering. However, this significantly reduced or eliminated if native plants are used.
- Weed management and aesthetic maintenance are critical for public acceptance

References

Prince Georges County, Department of Environmental Resources. Somerset Subdivision Water Quality Monitoring Program.

The Port Towns Community Development Corporation, Maryland, Rain garden program. http://www.porttowns.com/special/rain.html


Personal Communication. 2003. Drew Koslow, Executive Director of the South River Federation. 2/10/03.

Green Roofs

Description and Applicability

A green roof, a.k.a. ecoroof, is a layer of vegetation installed on top of a conventional flat or sloped roof. Extensive green roofs have a thin layer of soil and are usually composed of grasses and mosses, while intensive green roofs have a thicker soil layer and contain shrubs, trees and other vegetation and can also be designed for use by people. Green roofs may be installed on flat roofs or on roofs with slopes up to 30% provided special strapping and erosion control devices are used (Peck and Kuhn, 2003). A green roof may be installed on a newly constructed building, or an existing building can be retrofit with a green roof. Typically if a green roof is > 17 lbs/ft² (wet), a structural engineer should be consulted (Barr Engineering Co., 2003). Lightweight extensive green roofs can be used in most retrofit projects without costly structural reinforcement.

Reduction of runoff volume from green roofs is greater in areas where total annual rainfall is low because a greater percentage of rainfall is lost to evapotranspiration (Stephens, et al, 2002). Green roofs retain from 15 to 90% of rainfall (Roofscapes, Inc, 2003), with reports of 65 to 100% in summer and 10 to 40% in winter (The Cardinal Group, 2002; Liptan and Strecker, 2003). Green roofs are most effective in reducing runoff volume and rate for land uses with high percentages of rooftop coverage such as commercial, industrial and multifamily housing (Stephens, et al, 2002). Runoff reduction from green roofs is proportionally smaller if the primary land use is single-family homes (Stephens, et al, 2002).

Advantages

- Runoff volume reduction (50 to 60%, Roofscapes, Inc, 2003; Barr Engineering Co., 2003)
- Provides flow attenuation
- Extends the life of a conventional roof by up to 20 yrs (Velazquez, 2002)
- Provides increased insulation and energy savings
- Reduces air pollution
- Provides habitat for wildlife
- Increases aesthetic value
- Provides sound insulation
- Provides water quality treatment
Disadvantages

- Cost may be greater than a conventional roof
- Feasibility is limited by load-bearing capacity of roof (typical Ontario roof is designed for a live load of 40 lbs/ft², green roof can increase the weight of a roof by 16 to 200 lbs/ft², Peck and Kuhn, 2003)
- Must obtain necessary permits and comply with local building codes such as wind, moisture and fire resistance
- Requires more maintenance than a conventional roof
- Plant survival and waterproofing are potential issues
- May require irrigation

Existing Implementation Nationally and Internationally

Green roofs have been used extensively in Europe for some time. In North America, cities such as Portland, Oregon; Philadelphia, Pennsylvania; Vancouver, British Columbia; Toronto, Ontario; Minneapolis/St. Paul, Minnesota; and Chicago, Illinois are implementing green roof programs. Many of these cities offer incentives such as reduced stormwater, drainage or sewer fees for installing a green roof.

In Portland, Oregon, testing of green roofs showed rainwater retention on one roof ranging from 10% in the wet season to 100% in dry season (Liptan and Strecker, 2003). Another roof showed almost complete retention of a ¾ inch storm with a 4-inch soil roof (Liptan and Strecker, 2003). Beckman, et al (1997) estimate that if half the buildings in downtown Portland, Oregon had green roofs (219 acres), 66 million gallons of water would be retained per year and eliminate 17 million gallons of CSOs.

Maintenance

Green roof maintenance may include watering, fertilizing, and weeding, and is typically greatest in the first two years when plants are becoming established. Maintenance will largely depend on the type of green roof system installed and the type of vegetation planted.

Costs

Costs range from $5.60/ft² for extensive roofs to $15/ft² for intensive roofs plus cost of any structural reinforcement (Stephens, et al, 2002 and Norman Ammermann, personal communication). Operation and maintenance costs are $0.09 to $0.23/ft²/yr (Stephens, et al, 2002). Liptan and Strecker (2003) estimate a similar cost of $5/ft² to $12/ft² for a new green roof and $7/ft² to $20/ft² for a retrofit. Peck and Kuhn (2003) estimate that the cost of an extensive green roof ranges from $21.60/ft² to $42.00/ft², and the cost of an intensive green roof ranges from $40.30/ft² to $268.50/ft². Peck and Kuhn’s costs include re-roofing and membrane, green roof curbing, drainage layer, filter cloth, growing medium, plants, labor, two years of maintenance, and irrigation. Additionally, design costs are typically 5 to 10% of the total project cost and administration and design review costs are 2.5 to 5% of the total project cost (Peck and Kuhn, 2003).
References


Personal Communication, 2003, Norman Ammermann, FJA Christianson Roofing Co., Inc., Milwaukee, WI.


Rooftop Storage

Description and Applicability

Rooftop storage refers to the temporary storage (i.e., detention) of runoff on flat rooftops and the gradual controlled release of this volume using small control structures associated with the roof drains such as perforated weirs or gravel collars. In this design, water ponds around the control structures up to a maximum height. Above this maximum height, the downdrains operate at their full capacity. The structural capacity of the roof needs to be fully considered along with waterproofing considerations. This practice has primary applicability for commercial and industrial land uses (Prince George’s County, 2002).

Advantages

- Reduces peak discharges
- Does not require additional site space
- Cost-effective where adequate structural capacity and waterproofing exist

Disadvantages

- Requires structural assessment of roof
- May result in increased maintenance burden
- Requires waterproof roof

Existing Implementation Nationally and Internationally

Rooftop storage does not receive as much attention as more visible applications such as green roofs and cisterns these days; therefore, there are few well-documented cases of its use. Nevertheless, rooftop storage is often occurring in industrial and commercial settings unintentionally due to poor roof drain infrastructure. With very simple and inexpensive retrofits, rooftop storage can be provided for various water depths depending on structural and waterproofing specifications. In most cases, roofs designed to carry a snow load will be sufficient to hold the weight of significant rainfall depths (between 0.5 and 1.0 inches, for example) (MI DEQ, 2003). Fairfax County, VA (1995) design guidance requires roofs to have structural load carrying capacity for snow equivalent to 30 pounds per square foot (psf), which is roughly equivalent to 5.8 inches.

Costs

Costs are nominal assuming adequate structural and waterproofing is present. Costs are limited to downdrain modifications, which typically run for $100 or less per drain restrictor.
Maintenance

Periodic (particularly after large events) inspection and maintenance is recommended to ensure that outlets and downdrains are free of debris. In addition, regular inspection and repair is recommended for the waterproofing (MI DEQ, 2003).

References


Green Parking Lots

Description and Applicability

Green parking lots refer to several techniques applied together to reduce the contribution of parking lots to the total impervious cover in a lot. From a stormwater perspective, application of green parking techniques in the right combination can dramatically reduce impervious cover and consequently, the amount of stormwater runoff. Green parking lot techniques include setting maximums for the number of parking lots created, minimizing the dimensions of parking lots spaces, utilizing porous paving systems in overflow parking areas, using bioretention areas or other on-site filtering systems to treat stormwater, using stormwater trees to treat stormwater and provide shading and cooling, encouraging shared parking and providing economic incentives for structured parking. In terms of these MMSD fact sheets, green parking combines elements of redevelopment policy, porous paving systems, stormwater trees and on-site filtering practices. See these fact sheets for more detail on the individual practices.

All of these techniques can be applied to new development and some can be applied in redevelopment projects, depending on the extent and parameters of the project. This practice is most applicable in commercial, industrial and multifamily land uses because they have the greatest percentage of parking lot cover. In highly developed urban areas, some of these techniques can be incorporated into an existing parking as a retrofit, such as bioretention, stormwater trees, and porous paving systems.

Advantages

- All practices reduce impervious cover
- All practices contribute to one or more of the following: reduced stormwater runoff, reduced peak discharge, promoting infiltration or rainfall interception (0.07 ft³ of rainwater is intercepted by each ft² of tree canopy, McPherson, 2001)
- Resulting reduction of impervious cover contributed to reduced stormwater management costs
- Practices such as bioretention may also meet landscaping requirements
- Bioretention and stormwater trees provide pollutant removal
- Stormwater trees and bioretention provide aesthetic value
- Stormwater trees provide shade and cooling

Disadvantages

- Porous paving systems are most applicable in low-traffic areas
- Maintenance of porous paving systems may be difficult in cold climates
- Porous paving systems may not comply with handicap access requirements
• Shared parking may only be practical in mixed-use areas
• Structured parking may be limited by the cost of land versus construction
• Bioretention areas can be costly to construct
• Stormwater trees require good soils and enough space for planting and may conflict with utilities, sight lines or paved areas
• Maintenance is necessary for stormwater trees, porous paving systems and bioretention
• Bioretention cells can create public nuisance problems such as standing water if not properly maintained.

Existing implementation nationally and internationally

The California cites of Sacramento, Davis and Los Angeles have implemented parking lot shading ordinances that require 50% of the total paved area to be shaded within 15 years of the issuance of development permits (McPherson, et al, 2001). Annual benefits associated with parking lot tree shade in Sacramento was estimated to be $1.8 million annually (McPherson, et al, 2001).

A “green parking” lot at the Oregon Museum of Science and Industry in Portland, Oregon was designed with seven bioswales to filter runoff from the parking lot before it enters the Willamette River. This project provides water quality treatment as well as runoff reduction, does not have problems with standing water, and the design saved $78,000 as compared with a conventional parking lot (Thompson, 1996).

Costs

• The cost of planting 116,000 trees needed to meet the Sacramento parking lot shade ordinance’s 50% shade requirements was estimated to be $20 million (McPherson, et al, 2001).
• A reasonable cost for a tree pit is $200, while a street tree can cost $300 to $500 (JWE, 2001; Hammerschlag and Sherald, 1985).
• The City of Portland estimates it will cost $3,330 per acre to plant street trees in non-residential areas, $672 per acre to plant street trees in residential areas (planting approximately 10 trees per acre), and $300 per acre for operation and maintenance (City of Portland, 2000b).
• Bioretention areas cost about $6.40 per cubic foot of water quality treatment (CWP), or $10 to $40 per square foot, based on a need for control structures, curbing, storm drains, and underdrains (LID Center, 2003).
• Techniques that reduce impervious cover in parking lots by reducing total lot size or stall size actually generate cost savings through reduced paving and stormwater management costs
• “Green” porous paving system costs range from $2 to $4 per square foot (Stephens et al, 2002 and CWP, 1998).

Maintenance

• Bioretention cells need to be inspected and maintained periodically to avoid vegetation overgrowth, weeds, and to ensure proper function. Use of native vegetation reduces maintenance costs (LID Center, 2003).
Maintenance for stormwater trees typically includes watering, pruning, mulching, and fertilizing.

Porous paving systems require regular cleaning (hosing or sweeping), and turf pavers can require mowing, fertilization and irrigation.

References


Stormwater Trees

Description and Applicability

Stormwater trees are trees planted individually or in groups in urban areas such as: parking lots, right-of-ways, along streets, parks, schools, public lands, vacant land, highway cloverleafs, and neighborhood open spaces, to provide shade and stormwater retention and to add aesthetic value. Individual trees may be planted using tree pits, tree box filters or stormwater planters.

Stormwater planters can be designed to either filter or infiltrate stormwater. These planters can treat 10 times their surface area and are good choices for streetscapes and urban areas (City of Portland, 2000a). The infiltration planter has a 30-inch minimum width and the filter planter has an 18-inch minimum width with an impervious bottom (City of Portland, 2000a). These planters can retain water for 3 to 4 hours after a storm and can be placed underground or above grade (City of Portland, 2000a). If an infiltration stormwater planter is used, the subsoil should have an infiltration rate of 5 inches per hour (City of Portland, 2000a).

Tree pits must have a specific design for tree survival. The width and length of the hole should be proportional to the expected canopy width of the tree (Couenberg, 1993). Pits typically contain amended soils and reduce moisture near the concrete soil interface by using coarse sand or gravel near the surface (Couenberg, 1993).

Tree box filters are mini-bioretenion cells that are typically used in highly urban areas for street or parking lot trees. One 6’ x 6’ filter can treat ¼ acre of impervious surface and the target volume treated is 90% of the total annual runoff (Americast, Inc., 2003).

Stormwater trees are limited to areas where there is sufficient room to plant the tree (and allow it to grow), as well as to provide space for pedestrians, street parking, utilities, and adequate distance from structures. Good soil conditions are also important, and planting groups of stormwater trees may be more feasible on public land, such as schools and parks, due to ownership and available space. Stormwater trees provide the most benefit for locations with high annual rainfall and land uses with low impervious cover (Stephens et al 2002). This practice is most effective at reducing peak runoff rates in land uses with large amounts of open space (Stephens et al, 2002).
Advantages

- Reduces effective impervious cover
- Reduces stormwater runoff
- Provides aesthetic value
- Provides rainfall interception (0.07 ft\(^3\) of rainwater is intercepted by each ft\(^2\) of tree canopy, McPherson, 2001)
- Shade provides cooling and energy savings
- Provides habitat
- Provides pollutant removal
- Provides flow attenuation
- May be implemented with volunteers at low cost

Disadvantages

- Poor quality urban soils may require soil amendments or remediation
- May require volunteers to implement
- Long-term maintenance is required
- Must be implemented over large areas to see significant reduction in stormwater runoff
- Time required for trees to mature
- Inadequate space may be a limitation in urban areas
- Stormwater trees often have low survival rates because of poor soils, improper planting methods, conflicts with paved areas and utilities, inputs from road salt, lack of water, or disease
- Trees may require irrigation in dry periods

Existing Implementation Nationally and Internationally

Many cities nationally and internationally have urban forestry or street tree programs. The City of Portland, Oregon, has a Clean River Plan that includes planting trees and native vegetation along waterways as well as reforesting watersheds. Portland estimates that by increasing the current canopy cover by 2,956 acres through tree planting (excluding street trees), stormwater runoff will be reduced by 205 MG per year (City of Portland, 2000). This plan also includes planting 12,550 street trees in non-residential areas, and 50,350 street trees in residential areas, for a total of 62,900 trees. Portland estimates that the 1,021 acres of canopy this will create will reduce stormwater runoff by 290 MG per year (City of Portland, 2000b).

According to an analysis by Hey and Associates (2002), the current canopy cover in the Milwaukee combined sewer service area (10%) intercepts 121 MG per year at a treatment cost savings of $48,400. If tree canopy were increased to 40%, 484 MG per year would be intercepted, providing savings of $193,600 (Hey and Associates). The current tree cover in the Milwaukee area reduces stormwater flow by up to 22% annually, providing a cost savings of $15.4 million (American Forests, 1996). Trees at sample sites for this study in Milwaukee reduced runoff by 5.5% and reduced peak flow by 9.4% (American Forests, 1996). Seattle Street Edge Alternatives (SEA) Streets program has the goal of reducing peak flow and runoff volume from Seattle streets.
Existing streetscapes have been re-designed so that impervious cover is actually reduced, drainage is modified and trees are planted while providing aesthetic value and pedestrian walkways. This is all done at a comparable cost to regular curb and gutter street upgrades (City of Seattle, 2003).

Costs

Costs for reforestation, including soil amendments, range from $2.30/ft$^2$ for 6 inches of soil with grass and some trees, to $6.50/ft^2$ for 18 inches of soil with shrubs, ground cover and trees (Stephens et al 2002). Greening Milwaukee (2002) estimates tree-planting costs for Milwaukee at $40 per tree, and estimates supplies, materials and volunteer training at $2500 for 500 trees ($5 per tree). The City of Portland estimates it would cost $25,350,000 to reforest 2600 acres, at a unit cost of $9,750 per acre (with 100% canopy coverage), and an operation and maintenance cost of $400/acre (City of Portland, 2000).

A street tree filter is estimated to cost $5,500 (Nelson, 2002). Tree box filters cost $24,000 per impervious acre, including plants and two years of maintenance plus $1500 per unit for installation (Americast, Inc, 2003). A reasonable cost for a tree pit is $200, while a street tree can cost $300 to $500 (JWE, 2001; Hammerschlag and Sherald, 1985). The City of Portland estimates it will cost $3,330 per acre to plant street trees in non-residential areas, $672 per acre to plant street trees in residential areas (planting approximately 10 trees per acre), and $300 per acre for operation and maintenance (City of Portland, 2000b).

References


Porous Pavement

Description and Applicability

Porous paving systems have several design variants that have widespread application internationally. The four major categories are: 1) porous asphalt and concrete; 2) modular block systems; 3) grass pavers; and 4) gravel pavers. Each variant has specific design specifications and different levels of applicability. Porous asphalt and concrete are created with special mixtures of aggregate with asphalt and portland cement, respectively. Pavement courses are typically between 2 and 4 inches in depth. Graded stone and gravel base courses of variable depths underlay the pavement course (the depth is a function of how much storage infiltration is targeted). Modular block pavers are structural units such as concrete blocks, bricks, or reinforced plastic grids, with regularly spaced void areas that are filled with pervious material such as sand, gravel, or turf. Similar base courses as described for porous asphalt and concrete are used (ARC, 2001). Grass or turf pavers use rigid and flexible interlocking plastic units that provide structural stability while the voids are planted with soil and grass. Variations can include a turf over a root zone area comprised of a sand and synthetic mesh mixture that provides a natural turf surface and an engineered load-bearing root zone (Barr, 2001). Gravel pavers are similar to grass pavers, just with a gravel top layer overlying the rigid grid system. Non engineered systems, such as conventional gravel driveways and roads will also have less runoff potential but will not have as much storage capacity as the engineered systems.

Porous pavement systems are best used in low traffic and low load bearing areas such as parking lots (particularly overflow parking areas), parking lanes along residential streets, driveways, sidewalks, emergency access roads, maintenance roads and trails, road shoulders, etc. While some studies have indicated maintenance challenges in cold climate regions, others have indicated the performance is not limited in these situations so long as appropriate maintenance measures are taken (UDFCD, 2002 and Miller).

Advantages

- Have multiple applications (see above)
- Reduction in effective impervious area
- Runoff volume reduction through shallow infiltration
- Peak flow reduction and attenuation
- Some design variants are aesthetically appealing
- Grass paver systems can also be used in active recreational areas (i.e., ball fields) to promote surface drainage and provide a “softer” surface that can reduce injuries, all while providing desirable infiltration.
Disadvantages

- Cost
- Maintenance, particularly associated with cold climates
- Limited to low traffic areas and limited structural loading
- Handicap access can be issue
- Not appropriate for "hotspot" land uses
- Infiltration can be limited by underlying soil property
- Not effective on steep slopes

Existing Implementation Nationally and Internationally

Countless installations of the various design variants are in place both nationally and internationally. Field tests in Olympia WA indicate that concrete blocks that provide 40% void space can reduce runoff by up to 80% (EPA, 2000a). A Florida study demonstrated that sites using a combination of swales and permeable pavement generate 80-90% less runoff than sites without these measures (EPA, 2000b). In an Empirical modeling by Stephens et. al. (2002) indicates that a 50% reduction in runoff volume from 45 feet of paved road and sidewalk width can be achieved by using porous paving systems for the parking lanes and sidewalks. Hunt and Stevens (2001) reported Rational Formula “C” values of 0.28 for events greater than or equal to 1 inch. This compares to a “C” value of 0.9 typically used for pavement (70% reduction). Anecdotally, Cahill Associates of Pennsylvania reported that a 16-year-old porous pavement lot in Philadelphia (Morris Arboretum) reported zero discharge during Hurricane Floyd in 1999, after receiving nearly 10 inches of rain over a 24 hour period (it should be noted that soil permeability rates at the site are very high).

Costs

Varies depending on product, but $2-$4 per square foot ($87K-$174K per acre) is typical range (Stephens et. al., 2002 and CWP, 1998). Zabest Commercial Group, Inc. (S. Nikolas personal communication) reported a cost of $4 per square foot for a pervious concrete system. Conventional concrete pavement costs about $2.50 per square foot (S. Nikolas personal communication).

Maintenance

Turf pavers can require mowing, fertilization, and irrigation. Plowing of porous pavement is possible, but requires use of skids to keep blade off surface or at least use of flexible plastic/rubber piece on the bottom of blade (Barr, 2001). Sand and salt should not be applied on the surface and adjacent areas should be fully stabilized with vegetation to prevent sediment-laden runoff from clogging the surface. When cleaning, a vacuum-type sweeper is more effective than conventional broom sweepers. High pressure hosing is also recommended for porous asphalt and concrete surfaces (ARC, 2001).
References


USEPA. 2000a. *Field Evaluation of Permeable Pavements for Stormwater Management*. EPA 841-B-00-005B.

Inlet Restrictors and Pavement Storage

Description and Applicability

Inlet restrictors are flow regulation devices that are attached to catch basin outlets that reduce the rate of flow that would otherwise flow through the sewer system. The restrictors result in runoff “backing up” in the system, usually on the street or parking lot. Restrictors are best used in combination with street level storage devices such as curbs or berms. Berms are low structures (7-9 inches at the curb line) constructed across a street from curb to curb that temporarily impound water on the upstream side. They are longer (32 ft is typical) and more subtle features than traffic calming features such as humps and bumps. A variation on the use of inlet restrictors is to entirely block off catch basin inlets and route the flow via overland paths to a suitable discharge point such as an open channel or more optimal locations within the combined sewer system (EPA, 1999). This technique is commonly referred to as flow “slipping.” Inlet restrictors and street storage are best used in areas where streets have flat grades and low traffic volumes.

Advantages

- Reduces peak discharges
- Cost-effective
- Can reduce incidence of basement flooding
- Berms provide traffic calming benefit

Disadvantages

- Public perception/support
- Safety
- Limited to low traffic and flat sloped roads
- Require detailed modeling to accurately predict ponding depths and peak discharge reduction effects.

Existing Implementation Nationally and Internationally

Skokie and Wilmette, IL have implemented berms and flow restrictors over 8.6 and 2 square miles of town, respectively (EPA, 2000). The City of Chicago has installed over 200,000 flow restrictors and report that basement flooding complaints and property damage claims were more than cut in half comparing similar extreme rainfall events before and after installation (FEMA, 2003). Portland, ME pursued flow slipping techniques to divert runoff from 30 catch basins and estimated that this reduced CSS flow by 12 million gallons per year (EPA, 1999).

Costs

Skokie spent approximately $6 million on berms and restrictors or about $1,100 per acre served (Walesh, 1999). Chicago spent $75 million on their installation of over 200,000 restrictors at a cost of $375 per restrictor (FEMA, 2003).
Maintenance

No maintenance is directly associated with this measure other than routine maintenance associated with catch basins and street cleaning.

References


USEPA. 2000. *Street Storage for Combined Sewer Surcharge Control*. EPA 841-B-00-005C.


Bioretention

Description and Applicability

Bioretention areas are landscaping features adapted to treat stormwater runoff on the development site. They are commonly located in parking lot islands or within small pockets in residential land uses. Bioretention systems are generally applied to small sites. Bioretention areas typically cover about 5% of the area that drains to them. Surface runoff is directed into shallow, landscaped depressions. These depressions are designed to incorporate many of the pollutant removal mechanisms that operate in forested ecosystems. During storms, runoff ponds above the mulch and soil in the system. Runoff from larger storms is generally diverted past the facility to the storm drain system. The remaining runoff filters through the mulch and prepared soil mix. Typically, the filtered runoff is collected in a perforated underdrain and returned to the storm drain system.

Advantages

- Widely applicable
- Groundwater recharge
- Pollutant removal

Disadvantages

- Cannot be used to treat large drainage areas
- High cost

Existing Implementation Nationally and Internationally

Bioretention systems are applicable almost everywhere in the United States. Bioretention can be used as a stormwater retrofit, when modifying existing landscaped areas, or when a parking lot is being resurfaced. Some considerations when selecting a bioretention site are the drainage area, the slopes both at the site location tributary and on the land draining to it, soil and subsurface conditions, and the depth of the seasonably high groundwater table. Bioretention can be applied on many sites, with its primary restriction being the need to apply the practice on small sites (i.e., five acres or less). When used to treat larger areas, they tend to clog. In addition, it is difficult to convey flow from a large area to a bioretention area. Bioretention areas are best applied to relatively shallow slopes (usually about 5%). Sufficient slope is needed at the site to ensure that the runoff that enters a bioretention area can be connected with
the storm drain system. Bioretention areas can be applied in almost any soils or topography, since runoff percolates through a made soil bed, and is returned to the stormwater system. Pretreatment refers to features of a bioretention area that capture and remove coarse sediment particles. Incorporating pretreatment helps to reduce the maintenance burden of bioretention, and reduces the likelihood that the soil bed will clog over time. Several different mechanisms are used to provide pretreatment in bioretention areas. Runoff can be directed to a grass channel or filter strip to settle out coarse sediments before the runoff flows into the filter bed of the bioretention area. Other features may include a pea gravel bed, which acts to spread flow evenly and drop out larger particles. Treatment features enhance the ability of the bioretention site.

The bioretention system should be sized at between 5% and 10% of the impervious area draining to it. The practice should be designed with a soil bed that is a sand/soil matrix with a mulch layer above the soil bed. During storms, a small depth of water (6" to 9") should pond above the filter bed. Bioretention areas are designed with an underdrain system to collect filtered runoff at the bottom of the filter bed and direct it to the storm drain system. An underdrain may be a perforated pipe in a gravel bed, installed along the bottom of filter bed. Designers should also provide an overflow structure to convey flow from large storms (that are not treated by the bioretention area) to the storm drain system. Landscaping is critical to the function and appearance of bioretention areas. It is preferred that native vegetation is used for landscaping, where possible. Plants should be selected that can withstand the hydrologic regime they will experience (i.e., plants that tolerate both wet and dry conditions). At the edges, which will remain primarily dry, upland species will be the most resilient. Finally, it is best to select a combination of trees, shrubs, and herbaceous materials.

Costs

Bioretention areas are relatively expensive. A cost estimate developed by Brown and Schueler (1997), found that bioretention costs about $6.80 per cubic foot of water storage (2003 dollars). The Center for Watershed Protection estimated a cost of $13,000 to $30,000 per acre for bioretention.

Maintenance

Bioretention requires seasonal landscaping maintenance. In many cases, bioretention areas require intense attention initially to establish the plants, but less maintenance is required in the long term. In many cases, maintenance tasks can be completed by a landscaping contractor.

References


Prince George's County Department of Environmental Resources. 1997. Low Impact Development. Laurel, MD

On-Site Filtering Practices

Description and Applicability

On-site filtering practices refer to a diverse group of techniques for treating the quality of stormwater runoff. The techniques include bioretention cells, sand filters, vegetated swales, and vegetated filter strips. The common thread is that each utilizes some kind of filtering media, such as sand, soil, gravel, peat or compost to filter out pollutants entrained in stormwater runoff (Schueler & Claytor, 1996). In addition, most filtering practices are typically applied to small drainage areas (five acres or less) for the treatment of smaller storm events. Filtering practices are designed for pollutant removal; however, in certain situations they can be used to increase infiltration and flow path, thus providing some reduction in runoff volume and peak discharge. Filter strips and swales, for example, are effective practices for increasing flow path and time of concentration. Bioretention cells, swales, and filters can be designed without underdrains to promote infiltration.

- **Bioretention cells** are landscaped depressions (4 to 6 feet deep) that include a grass filter, sand layer, loamy soils, a mulch layer, and plantings of native trees and shrubs.
- **Sand filters** are surface or underground chambers that include a sedimentation reservoir and a sand filter layer (usually 18 to 24 inches) that are designed to treat polluted runoff.
- **Swales** are engineered grassed channels using up to 2.5 feet of filter media on the bottom of the swale to provide enhanced filtration while conveying the stormwater. They are designed with slopes of less than 4%.
- **Filter strips** receive sheet flow from impervious areas such as driveways and parking lots and are usually as wide as the area they treat. They are generally 25 to 75 feet long and are designed on slopes between 2% and 6%.

Advantages

- If designed correctly, can provide significant pollutant removal
- In certain situations, these practices can increase infiltration and flow path, thus reducing peak discharge (PGDER, 1999).
- Bioretention, swales, and filter strips can increase aesthetic value of developments
- Increased public awareness and involvement in stormwater management when coupled with a demonstration project
- Sand filters possess very few environmental limitations, require small amounts of land, and can be applied to most development sites (Schueler, 2000).
Disadvantages

- Bioretention cells and swales can create public nuisance problems such as standing water if not properly maintained.
- Sand filters can clog if not properly maintained (Schueler, 2000).
- Filter strips require large areas of land, typically equal to the impervious area they treat, so are not feasible for ultra-urban areas.
- Filter strips are not appropriate for slopes > 6% due to high-velocity runoff (CWP, 2003a)
- Swales are not appropriate for slopes > 4% due to high velocity runoff (CWP, 2003b).

Existing Implementation Nationally and Internationally

On-site filtering practices have been widely studied and promoted in many parts of the United States, particularly in Maryland, Florida, Washington State, and Portland, Oregon. The Low Impact Development Center (2000) conducted a synopsis of low impact development (LID) effectiveness studies in various parts of the United States, concluding that bioretention cells and grass swales were effective for pollutant removal and volume reduction.

A preliminary analysis of a two-year study in Florida (included in the LID center synopsis) indicates that re-directing parking lot runoff to swales can reduce average runoff volume from the parking lot by 30% (Rushton, 2001). In Carroll County, Maryland, an innovative modified sand-filter design was modeled and shown to contain and infiltrate all of the runoff from a 2.5-inch rainfall event (in a 24 hour period) (Covington, 2000). In Prince Georges County, Maryland, a preliminary analysis of an urban retrofit project indicated that swales and bioretention cells, when applied consistently in a community, can achieve some volume and peak discharge reduction (Mow-Seong Cheng, 2001).

Costs

- **Bioretention cells** (industrial and commercial application) can range between $10 to $40 per square foot, based on a need for control structures, curbing, storm drains, and underdrains (LID Center, 2003). For costs in residential application, see rain garden fact sheet.
- **Swales** have been estimated to cost $0.50 per cubic foot ($3,500 for a 5-acre residential area) (USEPA, 2003). Costs can vary depending on the use of underdrains.
- **Sand filters** can range from $3 to $6 per cubic foot ($35,000 - $75,000 for a 5-acre commercial site (USEPA, 2003). 
- **Filter strips** can range from $13,000 and $30,000 per acre (CWP, 2003a).
SECTION II
FACT SHEETS

Maintenance

- Bioretention cells and swales need to be inspected and maintained periodically to avoid vegetation overgrowth, weeds, and to ensure proper function. Use of native vegetation reduces maintenance costs (LID Center, 2003).
- Sand filters should be regularly inspected. Most filters exhibit diminished capacity after a few years due to surface clogging by organic matter, fine silts, hydrocarbons and algal matter (Schueler, 2000).
- Filters strips should be inspected periodically to ensure that sheet flow is occurring at the appropriate velocity. Signs of failure include rills, gullies, loss of vegetation, and soil erosion.

References


Pocket Wetlands

Description and Applicability

Pocket wetlands are a type of constructed stormwater wetland designed to receive runoff from limited drainage areas (i.e., less than 25 acres). Stormwater wetlands (a.k.a. constructed wetlands) incorporate wetland plants in a shallow pool. As stormwater runoff flows through the wetland, pollutant removal is achieved by settling and biological uptake within the practice. Stormwater wetlands are among the most effective stormwater practices in terms of pollutant removal, and also offer aesthetic value. While natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems. Stormwater wetlands are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands both in terms of plant and animal life (CWP, 2003).

Pocket wetlands are ideal for urban areas because they require less space than other types of stormwater wetlands. In a pocket wetland design, the bottom of the wetland intersects the groundwater, which helps to maintain the permanent pool. In the absence of a high groundwater table, supplemental irrigation may be required to sustain the wetland vegetation.

Advantages

- Reduces peak discharges and provides water quality treatment
- Reduces runoff volume through evapotranspiration
- Cost-effective where adequate structural capacity and waterproofing exist
- Provides habitat for wildlife
- Provides aesthetic value

Disadvantages

- Fairly high surface area to drainage area ratio
- Limited performance in cold climates
- Road salt used in cold climates can adversely impact vegetation
- May have negative public perception with respect to West Nile virus and other vectors
- May require supplemental irrigation with absence of high groundwater table

Existing Implementation Nationally and Internationally

Stormwater wetlands have widespread use throughout the United States and are a commonly recommended practice for use in meeting water quality and water quantity management criteria.
Costs

Costs are a function of facility size. Empirical cost-volume relationships exist which place costs for a one acre-foot storage facility at around $60,000 (CWP, 2003).

Maintenance

Stormwater wetlands require regular maintenance and inspection. Typical activities include sediment removal, plant harvesting, invasive species removal, and periodic plant replacement.

References

French Drains and Dry Wells

Description and Applicability

French drains and dry wells are gravel filled trenches designed to provide water quality treatment of rooftop runoff through infiltration. Runoff is directed to the trench via a downspout, is temporarily stored in the voids of the trench, and ultimately percolates into the ground. The terms French drain and dry well are often used interchangeably since they perform the same function; however, the design and applicability of each will differ slightly. A dry well is a vertical excavated trench with perforated pipes that run both vertically and horizontally through the aggregate. A french drain runs horizontally underground with the perforated piped along the bottom of the trench. These practices help prevent erosion, ponding and wet basements by promoting infiltration, and can even be used to filter out pollutants when combined with a layer of filtering soil. French drains are almost exclusively used for residential applications, while dry wells are often used for residential and commercial applications. These devices typically serve small drainage areas, such as a single rooftop (LAC, 2003). The use of these devices is restricted by soils, hydrology, and slope (LGPC, 2003).

Advantages

- Minimal space needed for installation
- Installation costs are low
- Increases groundwater recharge and time of concentration
- Can remove sediments and other particulates from stormwater
- May reduce runoff volume by promoting infiltration of rooftop runoff

Disadvantages

- Requires highly permeable soils underlying the devices (LAC, 2003).
- There may be a high risk of groundwater contamination for certain types of soils and geology (AZDEQ, 2000; Pitt, 2000).
- Infiltration practices can be prone to failure if not properly maintained (Galli, 1993)

Existing Implementation Nationally and Internationally

French drains and dry wells are widely accepted by many localities across the United States. By facilitating infiltration on-site, these practices can increase groundwater recharge and the time of concentration of stormwater flows. These devices are generally regarded as poor for pollutant removal. Research from British Columbia indicates that that the runoff volume reduction capability of infiltration practices decreases as total annual rainfall increases. The same research shows that on-lot infiltration can achieve a 10% reduction of total rainfall volume, depending land-use, soils, and annual rainfall (Stephens et al., 2001).
Costs

- Installation costs for a dry well chamber range from $900 to $1,400 (LGPC, 2003).
- Installation costs for a French drain range from $15-$17 per linear foot.

Maintenance

- Maintenance is typically limited to periodic replacement of the fill with clean rock.
- Periodic inspection is required to ensure that the stone fill is level to the ground surface and that the filter fabric has not become clogged with material.

References


Infiltration Sumps

Description and Applicability

Stormwater infiltration sumps are below-ground, perforated, cylindrical, concrete structures used to collect storm runoff and infiltrate it into the surrounding soil (City of Portland, 2002). Sumps are typically employed in road rights-of-way and are attached to catch basins, which serves as the pretreatment or sedimentation chamber. In some cases multiple sump chambers can be provided in series. The sump chambers are typically 25 to 35 feet deep and are surrounded with granular backfill to promote infiltration (EPA, 1999).

Infiltration sumps are best used in areas where the underlying soils are moderately to highly permeable, and the water table is well below the ground surface. They are generally more applicable in residential areas that are less than 50 percent impervious (EPA, 1999) and for smaller feeder streets as opposed to larger collector or arterial roads (Portland, 2002).

Advantages

- Take up no additional space
- Provides volume reduction and promotes groundwater recharge

Disadvantages

- Can disrupt traffic when installing
- Not effective in poor draining soils
- Not effective where water table is high
- Not advisable for use with hotspot land uses due to groundwater contamination risk
- May be considered an “injection well” which requires separate permit and approval

Existing Implementation Nationally and Internationally

Portland, OR installed approximately 4,000 infiltration sumps between 1994 and 1998. Combined with other CSO control programs, including a successful roof drain disconnection program, sewer separation, and stream diversion, Portland estimates that the total CSO volume will be reduced by 3 billion gallons per year (roughly half of the total CSO volume) (EPA, 1999).

Costs

Total costs can range from $2 to $8 per 1,000 gallons per year (EPA, 1999). The City of Portland reports that sumps cost between $5,000 and $10,000 per installation, which includes catch basin component. Typical design parameters include: 4 foot diameter, 30 foot depth, and serving 1.5 acres (Stevens, 2003).

Maintenance

Sumps need to be cleaned every two to three years to remove sediments and debris.
References


Compost Amendments

Description and Applicability

Amending urban soils with compost involves incorporating decomposed organic material into the existing soils to improve the quality of the soils for planting and infiltration. Compost amendments are typically used on urban soils that have become highly compacted and have low organic matter and nutrients. Many re-vegetation projects such as reforestation, turf conversion, rain gardens, or wildflower plantings can benefit from compost amendments, and compost may be added to any existing lawn areas.

Compost amendments are most effective in reducing stormwater runoff if application in a watershed is widespread. Various studies indicate that lawn runoff could be reduced by up to 74% by using compost amendments across a small watershed (NCDENR, 2000). Using compost amendments on steep slopes should not be a problem if proper guidelines are followed (use terracing and deep rooted plants). Sites that are not suitable for re-vegetation because of poor drainage are also not suitable for compost amendments unless subsurface collection systems are installed.

Advantages

- Decreased peak flows from all but the most severe storm events (storms up to 0.8 inches did not result in significant peak flows in amended soils, while without the amendment only storms of 0.4 inches could be similarly buffered, Harrison, et al, 1997)
- Greater lag time for hydrograph response (compost-amended plot required twice as much time to respond as non-amended plot under similar rainfall conditions, Harrison, et al, 1997)
- Improved water holding capacity (capacity doubled in compost-amended plots, total storage increased by 65%, Harrison, et al, 1997)
- Increased baseflow after storm event
- Reduced stormwater runoff volume (compost-amended plots generated 53% to 70% of the runoff from non-amended plots, Kolsti, et al, 1995, surface runoff from non-amended plots was 5.6 times greater than runoff from compost-amended plots, Pitt, et al, 1999)
- Increased infiltration rates (rates increased in compost-amended plots by 1.5 to 10.5 times, Pitt, et al, 1999)
- Increased evapotranspiration rates (rates in compost-amended plots increased by 30 to 100%, Pitt, et al, 1999)
- Decreased bulk density (compost amendments can decrease bulk density by 0.25 to 0.35 g/cm³, Kolsti, et al, 1995)
- Increased nutrient retention
- Reduced need for chemical use and watering
- Better plant survival rate
- Long-term cost-savings to the landowner
Disadvantages

- Initial installation cost may be higher
- Proper timing of applying amendments and re-vegetating may limit project feasibility
- Must be widely implemented to significantly reduce runoff volume

Existing Implementation Nationally and Internationally

Compost amendments are widely used in the Pacific Northwest. The increased moisture-holding capacity of compost-amended soils attenuates peak flows and reduces runoff, resulting in required storage volume reductions of stormwater management facilities. The City of Redmond, Washington Stormwater Utility staff estimated that for the 6-month, 24-hour storm, the detention volume required for an on-site stormwater facility dropped by 7% of the original detention volume after compost amendments were applied, at a cost savings of $8,640 (Chollak and Rosenfeld, 1997).

Maintenance

There is no maintenance associated with applying compost amendments. In fact, using compost amendments may significantly decrease the maintenance (i.e., watering, fertilization) related to lawn care or vegetation management.

Costs

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Large sites</th>
<th>Small sites</th>
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<tbody>
<tr>
<td>Soil prep with sod</td>
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<td>$0.92/ft²</td>
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<tr>
<td>Soil prep with hydoseeding</td>
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<td>$0.72/ft²</td>
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<td>Soil prep with irrigation system and sod</td>
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<td>Soil prep with irrigation system and hydoseeding</td>
<td>$1.47/ft²</td>
<td>$1.87/ft²</td>
</tr>
</tbody>
</table>

References


Redevelopment Policy

Description and Applicability

Land development and stormwater management criteria can have significant effects over time at reducing runoff volumes and peak discharges. In areas that are already developed, a policy approach can be applied with redevelopment criteria that require sites to reduce the amount of impervious surface by some specified amount. This reduction can be achieved by several of the other methods being described in this document, including green roofs, street trees, and porous pavement. Where impervious cover reduction is not achieved, criteria can specify that some portion of the redeveloped site be required to provide stormwater treatment.

In recent years, focus on techniques commonly referred to as better site design and low impact development practices have increased. Implementation of these approaches in street and lot designs associated with new development and redevelopment can significantly reduce runoff volumes and peak discharges through impervious surface reduction or disconnection and by breaking the site runoff into smaller and more diffuse paths where shallow groundwater infiltration can occur and longer and vegetated flow paths are provided.

Impervious area reduction techniques can be achieved by simple re-assessment of existing codes associated with subdivisions and other development such as streets and roads. Reducing parking ratios, road widths, driveway widths, setbacks, frontages, etc. can result in significant reduction in impervious surface. Allowing alternative designs for site features can also lead to reduced impervious surface, such as cul-de-sac variations, double track driveways and lanes, etc.

In September, 2001, the Milwaukee Metropolitan Sewerage District Commission adopted a comprehensive stormwater management rule to ensure that flood risk and flow volumes do not increase as a result of future development or redevelopment. The regulation, referred to as Chapter 13-Surface Water and Storm Water Rules, became effective on January 1, 2002. The rules apply to development that creates an increase in impervious area of one-half acre or more. The rules established a maximum runoff release rate of 0.5 cfs/acre for a 100-year recurrence interval storm; and 0.15 cfs/acre for a 2-year recurrence interval storm.

Advantages

- Reduces peak discharges and promotes groundwater recharge
- Cost-effective
Disadvantages

- Overly aggressive criteria can promote greenfield development and associated sprawl
- Benefits will be a function of how quickly areas are redeveloped
- Can require legislative action

Existing Implementation Nationally and Internationally

State of Maryland has a 20% reduction requirement for redevelopment sites or 20% of the current impervious surface must be treated (MDE, 2000). The City of Olympia, WA conducted a study and is implementing a plan that targets a 20% reduction in impervious surface through a variety of measures including parking code reform, use of porous pavement, and promotion of redevelopment (City of Olympia, 2003). Stephens et. al. (2002) empirically modeled the effect that multiple practices such as green roofs, compost amendments, shallow on lot infiltration and rain barrels can have assuming a 50-year redevelopment cycle for a 2.4 square mile subwatershed that redevelops to a higher density of commercial and multiple family land uses. Results indicate that, over time, as much as a 50% reduction in peak runoff rate from the 5-yr storm can be achieved along with a 67% annual runoff volume reduction. The scenario assumed soils with poor hydraulic conductivity (0.1 in/hr).

Costs

Costs associated with creating a redevelopment policy to decrease impervious cover are limited to code review and modification.

Maintenance

No maintenance is directly associated with this measure.

References


The integrated approach to stormwater management requires consideration of many new concepts and practices. However, a direct comparison of the costs and performance of these new practices to conventional engineered storm drainage systems, or for that matter to each other, should be handled with caution for a number of reasons:

1. The practices apply to different areas and situations. Some, such as rain barrels, apply only to residential areas, whereas others, such as rooftop storage, would be implemented only in large commercial/industrial/institutional buildings, and others, such as inlet restrictors, would be installed in paved areas. The level of performance (amount of water controlled) also varies widely.

2. Onsite stormwater reduction practices offer a widely-varying range of benefits beyond stormwater reduction, such as water quality benefits, groundwater recharge, habitat improvement, and educational values.

3. The integrated approach involves small scale, distributed practices that will have accumulated results—maybe not always more efficiently than engineered solutions, but often with improved benefits and increased participation and long term implementation.

4. The concepts of green infrastructure, sustainable development, and improved site design will require a mix of structural, nonstructural, institutional, and educational elements. Implementation of these elements will necessitate increased partnerships. The onsite practices attractive to private residents offer partnership opportunities with community and neighborhood groups, special interest groups (such as garden clubs), and municipalities. The practices that are more appropriate for institutional or commercial property owners offer MMSD the opportunity to partner with existing organizations that have many properties, such as school districts, banks, or developers.

5. The onsite practices offer a wonderful opportunity to educate the public about stormwater and watershed health and protection. Residential programs lend themselves to enhancing homeowner understanding of stormwater issues. Practices such as rain gardens or downsout disconnects are very tangible, easily understood concepts. Practices that involve established institutions allow MMSD to raise awareness among large groups of people, such as service organizations or tenants of properties. Practices such as roof gardens, when partnered with a school district, offer MMSD the chance to build an education program for school children and their parents. Establishing some sort of recognition program to residents/institutions who participate in stormwater reduction practices provide MMSD with additional education/awareness opportunities through publicity and media coverage.
It is helpful to evaluate the attributes and limitations of the stormwater reduction practices and to understand the conditions under which these practices perform best. For each practice, Table 1 summarizes the flow benefits, environmental features, implementability, function, operation and maintenance needs, and potential to promote environmental awareness.

The evaluation indicates that:

1. All practices provide some reduction in stormwater flow (otherwise, of course, they would not be included in the table). However, the level of hydrologic/hydraulic performance varies widely.

2. Three-fourths of the practices have the potential—depending on the design—to provide at least marginal benefits during “major” (> 1”) storms.

3. All but two of the practices may be expected to provide pollutant removal and water quality benefits.

4. While many practices are believed to be acceptable to the public, a fairly intensive public education program will be needed for successful implementation.

5. Over three fourths of the practices offer opportunities for partnerships.

6. About 65% of the practices utilize vegetation; 82% increase infiltration; and 53% involve stormwater storage.

7. Over one-half of the practices have a “good” or “very good” potential to help promote environmental responsibility and awareness.

8. A few practices—French drains, dry wells, and infiltration sumps—may have limitations in Southeastern Wisconsin that merit site specific soils investigations.

Table 2 presents the cost effectiveness of the practices. Capital costs and costs per impervious acre served are provided. Note that the amount of stormwater reduction varies: a rain barrel may store only ¼” of runoff from a roof, while a green roof may accommodate more than 2” of rainfall. The cost effectiveness estimates do not reflect these variations in performance. The integrated management strategic plan will assess the performance of the practices in more detail.

The cost per impervious acre served ranges from less than $1,000 per acre to $653,400 per acre. The median cost is approximately $16,000 per impervious acre.
Strategic Plan

The integrated stormwater management plan will:

- Describe the adverse effects of stormwater runoff on MMSD’s system and the environment
- Establish objectives
- Develop and evaluate a range of alternatives
- Recommend a plan to promote an integrated approach to stormwater reduction
- Identify the steps needed to best implement the plan.

The implementation program will proceed under Phase II of the stormwater reduction program. The implementation program will identify potential partners and participants, formalize an implementation strategy, outline procedures for review and evaluation, and recommend long-term projects and programs.
<table>
<thead>
<tr>
<th>Stormwater Reduction Practice</th>
<th>Flow</th>
<th>Environmental</th>
<th>Implementability</th>
<th>Function</th>
<th>Operation and Maintenance Needs</th>
<th>Environmental Awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Delays</td>
<td>Reduces Runoff Volume</td>
<td>Reduces Peak Flow</td>
<td>Increases Infiltration</td>
<td>Effective in Major Storms</td>
<td>Water Quality Protection</td>
</tr>
<tr>
<td>1. Downspout Disconnection</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Good</td>
</tr>
<tr>
<td>6. Rooftop Storage</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>8. Stormwater Trees</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Maybe</td>
</tr>
</tbody>
</table>
### Table 1
**Evaluation of Stormwater Reduction Practices (Continued)**

<table>
<thead>
<tr>
<th>Stormwater Reduction Practice</th>
<th>Flow</th>
<th>Environmental</th>
<th>Operability</th>
<th>Function</th>
<th>Operation and Maintenance Needs</th>
<th>Environmental Awareness</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Inlet Restrictors/ Pavement Storage</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>13. Pocket Wetlands</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>14. French Drains and Dry Wells</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>15. Infiltration Sumps</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
</tr>
<tr>
<td>16. Compost Amendments</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>17. Stormwater Rules and Redevelopment Policies</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Maybe</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Stormwater Reduction Practice</td>
<td>Capital Cost</td>
<td>$/Impervious Acre Served</td>
<td>Assumptions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>-------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Downspout Disconnection</td>
<td>$50 to $250/downspout.</td>
<td>$4,400-$21,800</td>
<td>Each downspout disconnection drains 500 square feet of roof.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Rain Barrels</td>
<td>$150/each rain barrel.</td>
<td>$13,100</td>
<td>Each rain barrel drains 500 square feet of roof.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Cisterns</td>
<td>$1,000 (500 gallon) to $5,000 (6,500 gallon underground).</td>
<td>$43,600</td>
<td>500-gallon cistern drains 1,000 square feet of roof. Water re-use may reduce water supply costs.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Rain Gardens</td>
<td>$5 to $10/square foot.</td>
<td>$21,800-$43,600</td>
<td>100 square foot rain garden drains 1,000 square feet of roof.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Green Roofs*</td>
<td>$15/square foot of roof for complete system.</td>
<td>$653,400</td>
<td>Complete green roof system includes watertight membrane, protective layer, insulation, irrigation and drainage system, filter layer, soil, and plants.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Rooftop Storage*</td>
<td>$100/drain restrictor. $5/square foot waterproofing.</td>
<td>$222,200</td>
<td>One restrictor per 1,000 square feet of roof. Waterproof entire roof.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Green Parking Lots</td>
<td>$200/tree pit. $13,000-$30,000/acre bioretention. $2/square foot turf pavers.</td>
<td>$10,000-$11,700</td>
<td>10% of parking lot area is bioretention, and 10% is turf paved.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Stormwater Trees</td>
<td>$40/tree</td>
<td>$670-$3,300</td>
<td>Each acre of trees receives drainage from one impervious acre. $670 per residential acre; $3,300 per commercial/industrial acre.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Porous Pavement*</td>
<td>$2-$4/square foot.</td>
<td>$81,700-$174,000</td>
<td>Lower cost is turf or gravel paver; higher cost is porous asphalt or concrete.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Inlet Restrictors / Pavement Storage</td>
<td>$400-$1,200 per restrictor.</td>
<td>$450-$1,350</td>
<td>Each inlet restrictor serves 1.5 acres (≥ 60% impervious.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. Bioretention</td>
<td>$13,000-$30,000/acre.</td>
<td>$6,500-$15,000</td>
<td>Each bioretention acre drains two impervious acres.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13. Pocket Wetlands</td>
<td>$60,000/acre/foot.</td>
<td>$16,000</td>
<td>0.5 acre, 3-foot deep pocket wetland serves 5 acres, ⅓ of which is impervious.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14. French Drains and Dry Wells</td>
<td>French drain: $15-$17 linear foot. Dry Well: $900 to $1,400/each.</td>
<td>$78,400-$122,000 (dry wells)</td>
<td>Each dry well drains 500 square feet of roof.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15. Infiltration Sumps</td>
<td>$5,000 to $10,000 per sump.</td>
<td>$5,500-$11,000</td>
<td>Each sump serves 1.5 acres (≥ 60% impervious.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
LID QuickSheet 1.2

A Spreadsheet for Determining the Capacity of LID Features to Meet MMSD Chapter 13 Requirements

USER MANUAL

May 6, 2005

The Milwaukee Metropolitan Sewerage District
Acknowledgments

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Low Impact Development Chapter 13 Guidance Project

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Spreadsheet Development

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Version History

1.0  Draft version released for Steering Team Review.

1.2  Final version.
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1. Introduction

MMSD Chapter 13 permits governmental units to require analyses of individual site developments to demonstrate that those developments meet one of two technical requirements for managing runoff. The requirements to be met for the site are:

1. Peak flow control that meets Unit Release Rate (URR) targets. Those targets are 0.15 cfs/acre for the 2-year return period storm and 0.50 cfs/acre for the 100-year return period storm.

2. Volume control that meets the Volumetric Design Procedure (VDP) target. The VDP requires that the amount of runoff that is discharged from the developed site during a critical time period does not exceed the amount generated under predevelopment conditions. The critical time period has been predetermined for different watersheds, as described in the MMSD Surface Water and Storm Water Rules (MMSD 2002).

This spreadsheet estimates the capacity of Low Impact Development (LID) design strategies to help meet the URR requirements and thereby reduce or eliminate the need for conventional detention storage to meet the Chapter 13 requirements. LID design involves:

1. Minimizing the capacity of the land surface to generate runoff.
2. Slowing down and dispersing the runoff.
3. Collecting and retaining the runoff in small, distributed storage volumes.
4. Infiltrating the runoff where possible.

To determine the collective effect of these strategies on the hydrology of a site, the spreadsheet incorporates a subset of the analytic methods described in Technical Release 55 (TR-55), *Urban Hydrology for Small Watersheds* (Soil Conservation Service, 1986)\(^1\) and Technical Release 20 (TR-20), *Computer Program for Project Formulation Hydrology* (Soil Conservation Service, 1983). The spreadsheet is intended to be used in conjunction with these reference documents. Both of these methods are based on the procedures for hydrologic analysis that are presented in the *National Engineering Handbook, Section 4* (Soil Conservation Service, 1985). Additionally, various LID design features are described in *Memorandum: Evaluation of Stormwater Reduction Practices* (MMSD 2003).

---

\(^1\) Note: Since the publication of TR-55 and TR-20, the Soil Conservation Service (SCS) has been renamed the National Resources Conservation Service (NRCS). The abbreviations SCS and NRCS are used within this document interchangeably.
Through the use of curve number (CN) and time of concentration (Tc) parameters, the procedures found in TR-55 and TR-20 can already take into account the manner in which LID influences the rate of runoff generation and the rate at which the runoff is conveyed across a site. Relative to the CN value for conventional site design, for example, the CN value might be decreased for an LID design because of reductions in the amount of impervious area. Likewise, the Tc value for an LID design might be increased on account of the greater use of vegetated swales rather than channelized stormwater conveyance systems.

Beyond the Tc and CN effects, however, LID design will also take advantage of opportunities for providing distributed retention storage. Retention may be provided, for example, in bioretention cells, in the gravel beds underlying permeable pavements, or on vegetated roofs. To directly account for the effect of distributed retention storage in a manner not currently available in TR-55 or TR-20, this spreadsheet has incorporated an adaptation of the TR-20 unit hydrograph calculations in a manner that treats the site retention volume as a uniform depth of storage across the drainage area.

2. General Guidelines

This spreadsheet requires the input of standard NRCS unit hydrograph parameters and additional information about the runoff storage capacity of specific LID features. These guidelines assume that the user already has a familiarity with the NRCS runoff calculation procedures for developing a composite CN value as an area-weighted average and for determining Tc values. Please refer to TR-55 and TR-20 for a detailed description of those procedures.

2.1. Terminology

The term retention in this document refers to the capture of runoff during a storm event so that it is not discharged from the site as surface flow, but is retained on site and subsequently infiltrated, evaporated, absorbed by vegetation, or withdrawn for consumptive use. Retention is carefully distinguished here from detention, which refers to runoff that is only temporarily stored, as in a detention pond, before it is released from the site.

The term rain garden is here used synonymously with the term bioretention cell. A rain garden is a landscaped depression that is designed to capture and infiltrate runoff.

2.2. Technical Issues

The spreadsheet sums the total retention storage volume provided on site and then obtains an average storage depth by dividing the total volume by the drainage area. Only after the runoff depth exceeds the storage depth during a design storm is a component of the runoff hydrograph generated. The rationale for adapting the NRCS unit hydrograph calculations in this manner is presented in Appendix A.

Care should be taken in the design and analysis of a site to ensure that the retention volumes entered into the spreadsheet are actually filled during the storm event. It is conceivable that the amount of runoff going into a rain garden, for example, will not actually fill the storage volume
available. In such a situation, the runoff volume, rather than the full capacity of the rain garden, will represent the amount of water that does not flow to the drainage area outlet.

The analysis of a site will require subdividing it into small drainage subareas and comparing the volume of runoff flowing into each retention feature with the capacity of that feature. The lesser of the runoff volume and the storage capacity should be aggregated with the rest of the on-site retention for input into the hydrograph calculations.

Because the effect of the storage depth is evaluated as if it is uniform across the site, it is left to the analyst and reviewer to determine whether this assumption is appropriate for a particular site design. The more uniform the distribution of retention is, the more appropriate the assumption. Figure 1 is an example of a residential area that makes considerable use of on-lot space for retention storage (as indicated by the small irregular shapes on the site). Although the placement of retention is not perfectly uniform, the wide distribution suggests that treating the storage depth as uniform may not be unreasonable for this design.

While LID features such as rain gardens and permeable pavements may be designed with underdrains, the calculations provided in the Quicksheet assume that no LID feature has an underdrain flow rate that contributes significantly to the peak of the runoff hydrograph. If the rate does become significant, then an additional analysis may be advisable to count that rate as being added to the hydrograph peak, or to route the runoff hydrograph through the device.

As with conventional approaches to stormwater management, some engineering judgment will be required to ensure that the parameter values selected in practice represent actual site conditions. Responsible design and analysis using this tool will seek to fully account for the capacity of LID features to reduce runoff. It is equally important, however, to avoid overestimating their capacity in a manner that would pose an increased risk of flooding and erosion downstream of the modeled drainage area.

### 3. Comparison of Conventional and LID Curve Number Calculations

Figures 2 and 3 show conventional and LID site plans for a 6.5-acre residential townhouse development. Tables 1 and 2 show the weighted curve number calculations for each site. The reduction in the curve number was achieved primarily by increasing the amount of wooded area. Additionally, the impervious area was somewhat reduced in the LID design by decreasing the road width.

According to the standard NRCS runoff depth calculation, for a 2.57-inch storm the lower curve number will reduce the depth of runoff from 0.9 to 0.6 inches. When the bioretention areas that have an average ponding depth of 6 inches and a subsurface storage capacity of 3 inches, the LID spreadsheet indicates that only 2.2% of the site area is needed to reduce the peak flow to a target level of 0.15 cfs/acre. Without the reduction in curve number, approximately 5.0% of the area would be needed.
For sites with no more than 30% impervious area, additional reductions in the curve number can be gained by disconnecting the impervious coverage. This encourages infiltration by preventing runoff from flowing continuously across hard surfaces from the point of runoff generation to the drainage area outlet.

Figure 1. Residential LID Case Study Site Plan
Source: Prince George’s County, MD, 1997
Figure 2. Conventional Site Example

Figure 3. LID Site Example
### Table 1. Area-Weighted CN Calculation for Conventional Design

<table>
<thead>
<tr>
<th>Hydrologic Soils Group</th>
<th>Cover Description</th>
<th>CN (Table 2-2 TR-55)</th>
<th>Area (Acres)</th>
<th>Product of CN x Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Lawn (fair condition)</td>
<td>69</td>
<td>3.2</td>
<td>220.8</td>
</tr>
<tr>
<td>B</td>
<td>Woods, Fair</td>
<td>60</td>
<td>0.7</td>
<td>42.0</td>
</tr>
<tr>
<td>B</td>
<td>Impervious</td>
<td>98</td>
<td>2.6</td>
<td>254.8</td>
</tr>
<tr>
<td>Sum of Products</td>
<td></td>
<td></td>
<td></td>
<td>517.6</td>
</tr>
<tr>
<td>+ Drainage Area</td>
<td></td>
<td></td>
<td></td>
<td>6.5</td>
</tr>
<tr>
<td>Weighted CN</td>
<td></td>
<td></td>
<td></td>
<td>80</td>
</tr>
</tbody>
</table>

4. Designing with the Spreadsheet

4.a. How the Spreadsheet is Organized

Within the spreadsheet file, five different sheets are available to the user by clicking on tabs at the bottom of the page. The portions of the spreadsheet available for user input and output are as follows:

- **ReadMe** Basic information about the use and function of the spreadsheet.
- **MainPage** The main page used for the input and output (Figures 4a and 4b).
- **SubareaCheck** Justifies use of retention volumes entered into MainPage.
- **RainDistribution** Allows the use of different temporal rainfall distributions.
- **OutputHydrograph** Provides LID hydrograph values for export.

4.b. Stepwise Overview of LID Site Design

Here is a brief overview of how to proceed using information available about your site:
1. For the proposed site design, determine drainage area divides, land use, and flow paths.
2. For comparison purposes, estimate the $CN$ and $Tc$ values assuming that no LID features are used on the site.
3. Enter the $CN$ and $Tc$ values into the spreadsheet to estimate a detention pond volume when no LID features are used.
4. Minimize the overall $CN$ and maximize the $Tc$ values for your LID site design, and enter those values into the spreadsheet.
5. Select the LID features that are feasible for the proposed site, considering the options described in *Memorandum: Evaluation of Stormwater Reduction Practices*.
6. Enter into the spreadsheet realistic values for the amount of retention storage that could be provided on site using the selected LID features at identified locations, and observe the calculated reductions in the peak flow runoff rate and detention pond size.
7. Add no more storage when the desired level of reduction in the peak flow value or the detention pond size is achieved, or if no additional storage will be provided due to site constraints.
8. Compare the volume of runoff flowing into each feature with the actual retention volume of that feature, and check to ensure that the volume considered in the calculations is the lesser of the two. The comparisons can be summarized in the sheet *SubareaCheck*.
9. Check the final site plan against spreadsheet input and finalize the two pages of *MainPage* as part of the Chapter 13 submittal.
10. If a detention pond needs to be sized, use the LID hydrograph values provided in the sheet *OutputHydrograph*.

Screenshots of the main page of the user interface are shown on the next two pages. Following the screenshots are line-by-line instructions for providing the input and interpreting the output of the spreadsheet.
**SITE SUMMARY**

Enter data into the shaded boxes only.

### Line PRECIPITATION and DRAINAGE AREA

1a. Return period for this storm event.

1b. NRCS Type II Rainfall distribution. See RainDistribution sheet to change.

2a. Total precipitation.

2b. Drainage area.

2c. CN minimum

### NoLID DESIGN

3a. Area-weighted average for the NoLID site design.

3b. Cannot be less than 5 minutes.

### LID DESIGN

**Standard CN Determination**

4a. Area-weighted average for the LID site.

**Optional CN Determination**

If option not used, enter zeroes in Lines 4b-4d.

4b. Composite CNp for pervious areas alone.

4c. Actual percent impervious.

4d. Decimal <= 1.0. Ratio of unconnected impervious area to total impervious area.

(Enter "0" as the ratio if total impervious area is greater than 30% of site.)

4e. CN result: 77 (The "CNr" in TR-55 Appendix F)

### LID Retention Features

For individual features, compare the contributing runoff with the capacity, and take the lesser of the two. Summarize on SubareaCheck sheet.

### Rain Garden Capacity

5a. Average ponding depth.

5b. Average soil mix depth available for retention (24 inches or less).

5c. Average fillable porosity.

5d. Storage per unit area.

5e. Rain Garden Coverage of drainage area used for rain gardens.

5f. (average of top and bottom areas)

6a. Capacity of each rain barrel.

6b. Number of rain barrels.

7a. Maximum Water Capacity (MWC).

7b. Multiplier between 0.33 and 0.67.

7c. Area.

8. Sum of all cistern volumes.

9a. Storage depth, or capacity per unit area.

9b. Paved area.

10. Additional storage not listed above.

Total

Figure 4a. First page of the main spreadsheet interface (MainPage tab)
**LID QuickSheet 1.1**

**URR SUMMARY**

Enter data into the shaded boxes only.

<table>
<thead>
<tr>
<th>Line</th>
<th><strong>Unit Release Rate Target</strong></th>
<th>0.50 cfs/acre</th>
<th>See User Manual to select value.</th>
</tr>
</thead>
</table>

### Site Runoff

<table>
<thead>
<tr>
<th>Line</th>
<th><strong>Depth</strong></th>
<th><strong>Volume</strong></th>
<th><strong>Reduction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>21a</td>
<td>inches</td>
<td>4.19</td>
<td>2.78</td>
</tr>
<tr>
<td>21b</td>
<td>ac-ft</td>
<td>34.91</td>
<td>23.13</td>
</tr>
<tr>
<td>22a</td>
<td>cfs</td>
<td>352.5</td>
<td>184.1</td>
</tr>
<tr>
<td>22b</td>
<td>cfs/acre</td>
<td>3.52</td>
<td>1.84</td>
</tr>
</tbody>
</table>

### Conventional Detention Needed to Meet Peak Flow Target

<table>
<thead>
<tr>
<th>Line</th>
<th><strong>Depth</strong></th>
<th><strong>Volume</strong></th>
<th><strong>Reduction</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>23a</td>
<td>inches</td>
<td>1.98</td>
<td>1.10</td>
</tr>
<tr>
<td>23b</td>
<td>ac-ft</td>
<td>16.49</td>
<td>9.18</td>
</tr>
</tbody>
</table>

**LID Split Flow Option.** If discharge above target rate is directed into retention at outlet, this retention volume can replace detention pond volume:

<table>
<thead>
<tr>
<th>Line</th>
<th><strong>Depth</strong></th>
<th><strong>Volume</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>24a</td>
<td>inches</td>
<td>0.79</td>
</tr>
<tr>
<td>24b</td>
<td>ac-ft</td>
<td>6.59</td>
</tr>
</tbody>
</table>

**Runoff Hydrographs for URR Analysis**

![Runoff Hydrographs](Figure 4b. Second page of main spreadsheet interface (Mainpage tab))
5. Site Summary

The Site Summary page (Figure 4a) is for the user to provide input values for the URR evaluation.

5.1. Precipitation and Drainage Area

1a. Enter the return period associated with the precipitation depth and peak target rate given. Both the 2-year and 100-year 24-hour storm events should be evaluated.

1b. This line shows the name of the design storm distribution that has been entered on the RainDistribution sheet.

2a. Input the rainfall depth designated by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) for the 2-year and 100-year 24-hour storm events. For the 2-year event, the rainfall depth is 2.57 inches, and for the 100-year event, the rainfall depth is 5.88 inches.

2b. Input the drainage area. If the site as a whole does not have uniform land cover and soil types, consider dividing it into separate drainage areas and using the spreadsheet multiple times.

2c. This output is for user information as CN values are input in the cells below.

5.2. NoLID Design

These values are used to generate a runoff hydrograph and estimate the detention pond volume if no LID strategies are implemented on the site. In Figure 4a, for example, the “No LID” CN value of 83 was taken from Table 2-2a of TR-55 as the value associated with 1/4-acre lots on hydrologic soil group C.

Because the LID design does not depend on these numbers, for practical reasons a detailed evaluation of the NoLID design may not be necessary. The calculations for the NoLID design are provided simply for comparison with the LID design.

3a. Enter the curve number for the NoLID design.

3b. Enter the time of concentration for the NoLID design.
5.3. LID Design

Taking Into Account the Preservation of Natural Features

The preservation of natural features on a site often helps to control runoff. Well-established naturally wooded areas or prairie are often characterized by thick vegetation and high levels of organic matter in the soil. These conditions promote rainfall interception and runoff infiltration. Where these features are preserved, a CN value can be selected from Table 2-2 of TR-55 to reflect the continued influence of these natural features on the generation of runoff from a site.

Additionally, sheet flow and shallow concentrated flow that is conveyed through naturally vegetated areas flows more slowly than runoff that travels across grassed lawns (for example). Consequently, the preservation of natural features can be taken into account for both the $T_c$ and $CN$ values selected for the site.

5.3.1. Standard CN Determination

4a. Enter an area-weighted average $CN$ value. This $CN$ value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

Accounting for Permeable Pavements in the Standard CN Determination

*Use one of the following sub-options, but not both.*

*Sub-Option A.* Incorporate permeable pavement $CN$ into the Line 4a value as part of the weighted average for the entire site. See Appendix C for a brief discussion of alternative values.

*Sub-Option B.* Treat the pavement as an impervious area when calculating the input for Line 4a but incorporate a determination of the total storage depth in Line 9a.

5.3.2. Optional CN Determination

For urban and residential districts, the $CN$ values published in Table 2-2a of TR-55 are based on sites that have the following characteristics:

(a) The percentage of impervious area shown in the table.
(b) The connection of impervious areas directly to the drainage system.
(c) Grass as the primary pervious ground cover.

An LID strategy typically involves reducing and disconnecting impervious areas, and increasing the density of vegetative cover using trees or native plants, for example. Because these methods help to reduce runoff, it is highly desirable to recalculate a composite curve number to fully
account for their effects. Lines 4b through 4e allow for a quick estimate of the effect of reducing and disconnecting the impervious area, assuming that the CN value for the pervious area does not change significantly. This approach is based on TR-55 p. 2-9 and TR-55 Appendix F.

In the example input shown in Figure 4a, the LID CN is based on a vegetative land cover of woods in good condition over hydrologic soil group C (CN=70). The impervious area has been reduced from an average of 38% for the No LID condition (TR-55 Table 2-2a) down to 30% here, and a portion of that is disconnected. This combination of factors results in a lower overall curve number of 77.

4b. The value entered should be the area-weighted average of the curve numbers associated with the different land covers (native plants, woods, grass, etc.) and should not include any impervious area or vegetated roof area. This CN value should include the vegetative cover for bioretention areas assuming that bioretention soils are the same as the surrounding soils. The subsurface porosity of bioretention cells is accounted for in Line 5c.

**Accounting for Permeable Pavements in the Optional CN Determination**

Use one of the following sub-options, but not both.

*Sub-option C.* Incorporate permeable pavement into the pervious CN value calculated in Line 4b and do not treat it as part of the impervious area in Line 3a. See Appendix C for a brief discussion of CN values for permeable pavement.

*Sub-option D.* Do not incorporate a permeable pavement CN into line 4b. Instead treat the pavement as an impervious area in Line 4b but incorporate a determination of the total storage depth in Line 9a.

4c. Use an actual impervious area. Vegetated roofs should be treated as impervious here. Vegetated roof retention is specifically accounted for in Lines 7a-7b.

4d. Treat as disconnected, for example: Roof downspouts that are not directly connected to the drain system, pavement area that conveys runoff into grassed swales rather than down a curb and gutter system. Conventional pavement or other impervious area that conveys runoff onto permeable pavement may be considered disconnected.

4e. This amount is computed automatically, and the letters “N/A” appear if zeroes are entered in Lines 4b and 4c.

4f. This input value must be entered manually and will be identical to the value shown in line 4a or 4e. It is the LID CN value used for the hydrograph calculations.

4g. This is the time of concentration for the LID design. All other conditions being equal, an increase in the Tc will result in a reduction in the peak runoff rate. A typical approach to LID site design will seek to maximize the Tc by using conveyances that slow down travel times without compromising the effectiveness of drainage away from buildings and off roadways. LID favors the use of shallow vegetated conveyances rather than sewer pipes, for example, open section road rather than curb and gutter, and the spreading of flows rather than the
concentration of flows. A discussion of how to determine runoff travel times and to calculate $Tc$ values is provided in Chapter 3 of TR-55.

5.3.3. LID Retention Features

The remaining input cells within the spreadsheet can be used for site components that retain runoff. The spreadsheet calculates the total retention volume as a depth across the drainage area, and for each time step checks to see whether that depth has been filled before generating runoff.

<table>
<thead>
<tr>
<th>The SubareaCheck sheet is provided to compare the capacity of each retention feature with the volume of runoff flowing into that feature. If the runoff volume is less than the capacity of the retention feature, then that runoff volume rather than the capacity should be counted in the MainPage input toward the reduction in runoff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Note that the volume check does not require a detailed analysis that generates an area-weighted $CN$ value based for each subarea contributing runoff. It is sufficient only to show that the storage volume will be filled. Consequently, evaluating the runoff from only a portion of the subarea (such as the impervious area) or selecting an obviously low curve number for the subarea may produce a volume that exceeds the retention capacity.</td>
</tr>
<tr>
<td>The SubareaCheck sheet also serves as a check on the underdrain flow for individual LID features, such as rain gardens and permeable pavements. The peak flow rate that occurs when the device is full may be controlled either by the size of the underdrain orifice or by the flow rate through the subsurface media. In either case, if the underdrain flow is substantial, it is conceivable that it may diminish the effectiveness of that feature in reducing the peak flow rate at the outlet.</td>
</tr>
<tr>
<td>An acceptable approach to accounting for the hydrologic influence of underdrains is left here to the judgment of the engineer and the reviewing agency. In some cases, relative to the peak flow rate for the entire site, the underdrain rate may be insignificant. In other situations, as when underdrain rates are significant and retention features are not along the same flow path, it may be acceptable to require the LID hydrograph peak plus the sum of the underdrain flow rates to equal the Unit Release Rate (URR) (cfs/ac) target.</td>
</tr>
</tbody>
</table>

5a-5c. These input lines indicate the typical capacity of the rain garden design no matter how many rain gardens are used within the drainage area. The ponding depth should be considered as an approximate average. While the ponding volume available in rain gardens can be readily estimated based on surface contours, estimating the volume of subsurface
storage will require consideration of the soil characteristics and behavior during a storm event.

The spreadsheet allows input of a value for fillable porosity. This is the amount of pore space assumed to be available within the soil prior to the design storm event.

The porosity of a soil is the measure of the void space in an oven-dried soil sample. A saturated soil has a water content equivalent to its porosity. As the soil drains by gravity to a moisture level known as the field capacity, more pore space becomes available to hold water. Over time, vegetation will extract moisture still further until the moisture level reaches the wilting point.

Figure 5 shows how soil properties will affect values of the field capacity and the wilting point. These values can be calculated using the software, Soil Water Properties from Texture (Saxton 2003), which is based on research by Saxton et al. (1996).

For the purpose of LID design and analysis, the value of the fillable porosity should be no greater than the difference between the porosity and the field capacity for soils in a rain garden.

![Figure 5. Moisture retention parameters associated with USDA soil texture classes](http://msw.cecs.ucf.edu/AndFiles/hlp2.html)

A question may arise as to whether the overall storage capacity of rain garden soils will diminish significantly over time. It will be reasonable to assume a constant value for the fillable porosity as long as the conditions at or near the soil surface do not impede infiltration.
due to silting or surface crusting, and the vegetation is maintained. The use of a vegetated filter strip or grassed area around a rain garden can help reduce the conveyance of sediment into the rain garden.

In light of the various factors that can affect infiltration rates and subsurface storage volumes, some consideration may be given to whether the value selected for the input will more likely err on the side of overestimating or underestimating runoff rates at the outlet during an actual storm event under typical conditions. A conservative approach to the analysis will involve using smaller values for porosity.

Some consideration may also be given to the fact that some of the infiltration capacity in a bioretention cell has been accounted for in the overall $CN$ value for the drainage area. Where surrounding soils are sandy with high rates of infiltration, a sandy bioretention soil may add little to the capacity of the bioretention area to reduce runoff and consequently a conservative value for the fillable porosity will be more desirable so that the infiltration capacity of the bioretention area is not double counted. When the surrounding areas have low rates of infiltration, however, larger values for the fillable porosity will be justified.

5d. This value is computed automatically.

5e. This is the area associated with the average design depth, roughly the average of the top and bottom of the ponding area.

5f. This value is computed automatically.

6a-6b. Rain barrels can be situated at roof downspouts to collect runoff.

7a-7c. The capacity of vegetated roofs to absorb rainfall is a function of vegetated roof design, and designs can vary considerably. The Maximum Water Capacity (MWC), is a benchmark number that is discussed in Appendix D. Reasonable values for the multiplier will generally lie between 0.33 and 0.67. The minimum value of the multiplier is the most conservative, because it represents only the initial abstraction, the amount of rainfall quickly absorbed by the roof at the beginning of the storm. Field capacity for a vegetated roof is typically about 0.50 of the MWC, which would leave the other 0.50 of the MWC available to absorb rainfall. Since evapotranspiration between storm events will reduce the moisture content from field capacity as far down as the wilting point, a value higher than 0.50 will tend to be more representative of the condition of the vegetated roof following a dry period. Because the antecedent moisture conditions for a vegetated roof will not generally be known, a median multiplier value of 0.50 is recommended.

8. This input value is the total volume of cistern storage provided on site.

9a-9b. The depth of storage entered here is the total depth of water storage provided in the permeable pavement system. This should take into account pore spaces in the pavement, as well as the aggregate base layers beneath the payment. A gravel layer 8 inches deep with a
16

typical porosity of 0.40, for example, will provide a water storage depth of 3.2 inches for each unit of pavement area.

10. This cell allows for the input of a combination of other retention volumes not already listed above. This might include, for example, sand filters, infiltration trenches or infiltration swales. The number entered here should be supported by calculations that show how a surface component and subsurface component of storage have been taken into account. As with the other retention volumes, this input value is interpreted as an added depth of storage evenly distributed across the drainage area.

6. URR Summary

The URR Summary page (Figure 4b) shows how the use of LID features affects the runoff hydrograph relative to the URR target.

6.1. Input

To determine whether your site design meets the URR requirements, enter input data required.

20. The MMSD Chapter 13 Uniform Release Rate flow target is 0.15 cfs/acre for the 2-year storm and 0.50 cfs/acre for the 100-year storm.

6.2. Output

The Output Summary and Runoff Hydrographs will change instantaneously in response to user input. (To easily view the input and output at the same time, select menu item View, then Zoom, and lower the magnification.)

21a-21b. For the NoLID site condition, the runoff depth is calculated using standard NRCS curve number calculations, and is equivalent to the area under the runoff hydrograph shown. For the LID condition, the depth is also equivalent to the area under the corresponding runoff hydrograph. That depth reflects both the curve number calculations based on land surface conditions and the combination of retention volumes associated with the LID components that have been sized on the Input page.

22a-22b. These peak flow values are obtained from the runoff hydrographs.

23a-23b. As illustrated in the hydrograph below the output tables, the detention volume is estimated as the area above a straight diagonal line that starts at the runoff target and runs tangent to the ascending limb of the runoff hydrograph. Drawing a diagonal line to a point near the beginning of the runoff hydrograph is a common approach to estimating detention volume.

24a-24b. Due to site constraints, LID features might not fully achieve the URR target. Such is the case for the example illustrated in Figure 4b. Consequently, a detention pond at the
drainage area outlet may still be seen as necessary. However, rather than routing the entire hydrograph through a detention pond, it may be more desirable to minimize the storage requirement at the outlet by splitting out the flow that exceeds the desired flow rate, placing only that excess flow into a retention area. Figure 6 illustrates the relationship between the split flow retention storage volume and the detention storage requirements at the outlet.

25. As indicated in the legend, the two runoff hydrographs represent the runoff pattern with and without an LID strategy applied. The beginning and ending time have been set at 8 and 18 hours, respectively so that the change in flow rate near the peak can be easily seen.

![Figure 6](image)

**Figure 6.** An example of how splitting flow at outlet can achieve a flow target for less than the volume required by detention

7. **Exporting the LID Hydrograph**

The LID hydrograph can be exported to other programs for subsequent routing calculations, such as those typically required in detention pond design and analysis. The *OutputHydrograph* sheet contains the hydrograph values presented in three different ways:

1. As originally calculated (Columns A and B).
2. Calculated on a user-selected time step (Columns H and I).
3. Arranged and formatted for export to TR-20 READHD records (Column J through N).
See the *OutputHydrograph* sheet itself for more information.

### 8. References


Appendix A.

Five Methods of Accounting for the Effect of Distributed Retention on the Runoff Hydrograph

Paul Koch, Ph.D., P.E.

This Appendix describes five options that were considered to account for the retention volume provided within a drainage area. Each of these options is derived in some way from the NRCS unit hydrograph method. A comparison of the options provides a rationale for ultimately selecting the one option incorporated into the spreadsheet.

The first two of these options performs calculations directly on the runoff hydrograph generated without taking into account retention storage. The remaining three options employ calculations that adjust the NRCS runoff depth formula before hydrograph components are generated.

Option 1. Truncated hydrograph

One approach to evaluating the impact of retention on a drainage area is to treat the retention as if it is all provided in-line at the downstream end of the drainage area, just above the outlet. A family of curves illustrating the results of this approach is shown in Figure A1. In that figure, the influence of the retention is represented by a vertical line representing an assumed rising limb of the hydrograph that corresponds to the moment that the retention storage is filled.

Note that for the retention to be expected to have any influence on the peak at all, it must have the capacity to capture all the flow up to and past the peak—an approach which is likely to result in fairly conservative designs. Where storage is provided with some uniformity upstream of the outlet, however, it stands to reason that some of that retention will reduce the peak to some degree even when the retention is provided in relatively small amounts.

Figure A1. Retention volume evaluated as a truncation of the runoff hydrograph
Option 2. Scalar Multiplication

A second option involves taking the NoLID ordinates and simply multiplying them by the ratio of the LID runoff depth to the NoLID runoff depth. For each flow rate represented in the NoLID runoff hydrograph an adjusted flow rate was calculated as

\[ q_{\text{adjust}} = q_{\text{NoLID}} \left( \frac{Q_{\text{LID}}}{Q_{\text{NoLID}}} \right) \]  

(A1)

where

- \( q_{\text{adjust}} \) = ordinate of adjusted runoff hydrograph
- \( q_{\text{NoLID}} \) = ordinate of runoff hydrograph for NoLID
- \( Q_{\text{LID}} \) = total depth of runoff associated with LID
- \( Q_{\text{NoLID}} \) = total depth of runoff associated with NoLID

A family of curves showing how the runoff hydrograph will be changed using this method with increasing amounts of retention is presented in Figure A2. This method requires only a direct adjustment in the magnitude of the runoff hydrograph. However, rather than reducing runoff by filling the retention capacity toward the beginning of the storm event, this method places the effect of much of the retention well after the hydrograph peak, significantly discounting the degree to which a uniform distribution of retention would actually reduce the peak.

![Figure A2](image-url)

**Figure A2.** Changes in runoff hydrograph when original hydrograph is multiplied by a scalar to account for retention storage

A Closer Look at Runoff Hydrograph Calculations

The standard method for generating a runoff hydrograph using the SCS unit hydrograph with convolution calculations offers several options for taking into account distributed retention volumes within a drainage area. The calculations involve these steps for each time increment:

1. Within the storm event, calculate the total rainfall up to that point in time.
2. Check the total rainfall against the capacity that needs to be filled on the land surface (the initial abstraction) before runoff can occur.
3. If the total rainfall exceeds the initial abstraction, construct a hydrograph that shows the effect of that single increment of excess rainfall on the runoff pattern at the outlet.
4. Repeat for the next time step within the storm, offsetting the resulting hydrograph by the time increment.
5. Add the components hydrographs to establish a total storm hydrograph for runoff at the outlet.

TR-55 provides this formula for calculating the depth of runoff:

\[
Q = \frac{(P - I_a)^2}{(P - I_a) + S}
\]

(A2)

where
- \( Q \) = runoff depth (in.)
- \( P \) = precipitation depth (in.)
- \( S \) = potential maximum retention after runoff begins
- \( I_a \) = initial abstraction, volume that must be filled before runoff begins. \( I_a = 0.2 \, S \)

Additionally, \( S \) is related to the \( CN \) as

\[
S = \frac{1000}{CN} - 10.
\]

(A3)

Current software implementations of TR-55 and TR-20 calculate Equations A2 and A3.

**Option 3. Subtract retention from rainfall**

If the retention distributed in a watershed is sufficiently uniform, it might be convenient simply to divide the total retention volume by the drainage area and subtract the result from the rainfall along with \( I_a \).

Letting \( R \) represent the total retention volume divided by total drainage area, the calculation of runoff using this approach can be formulated as follows:

\[
Q = \frac{(P - I_a - R)^2}{(P - I_a - R) + S}
\]

(A4)

Subsequently, the analyst can perform the usual unit hydrograph calculations. However, the approach is problematic because the volume of retention provided will never be fully accounted for. Just as runoff is always less than rainfall when the standard formula is used, the change in runoff volume will always be less than the volume of retention actually provided when the retention volume is first subtracted from the rainfall before the runoff depth is calculated.
For example, if the depth of precipitation is 2.57 inches over a drainage area having a CN of 80, then the depth of runoff is 0.94 inches. If the distributed retention depth is 0.39 inches, then subtracting the retention from the rainfall leads to a runoff of 0.67 inches. But since 0.94 - 0.67 = 0.27 rather than 0.39, it is clear that not all the retention depth has been accounted for using this approach. If it were, the final runoff value would be approximately 19% less.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure 3. It is worth noting that when the retention storage capacity is equated to the total runoff volume without retention, there is still some runoff. At the extreme, Equation 5 indicates that reducing the amount of runoff to zero requires that the amount of excess rainfall (P – Ia – R) be reduced to zero. Because this ignores the infiltration potential of the ground upstream of the retention area, the technical inadequacy of this approach is apparent.

![Figure A3. Changes in runoff hydrograph when storage is subtracted from rainfall](image)

Option 4. Subtract retention from runoff

Subtracting retention from the runoff generated by the land surface will account for the retention explicitly, as in this formula:

\[
Q = \frac{(P - I_a)^2}{(P - I_a) + S} - R
\]  

(A5)

Within the NRCS convolution calculations, the formula can be applied as follows: First the standard runoff volume is calculated, and then it is checked against the available retention volume to determine whether that volume has been filled. After the total runoff exceeds the total retention volume, a component of the runoff hydrograph is developed to represent the incremental amount of runoff generated in each succeeding time increment.
If the retention is constrained to a small percentage of the total drainage area, it seems reasonable to assume that the S value for the drainage area as a whole will not change. An upward or downward revision of S may be warranted depending on the effect of the retention facility on the local infiltration capacity. For rain gardens, which are typically designed with highly pervious soil mixtures, keeping the S representative of the surrounding land cover will constitute a conservative assumption, more likely leading to an overestimation rather than underestimation of runoff.

A family of curves showing how the runoff hydrograph will be changed using this method with different amounts of retention is shown in Figure A4. While this option is straightforward, current software implementations of TR-55 and TR-20 cannot calculate Equation A5. Adaptation of NRCS methods using the formulation for this option requires other software.

![Figure A4. Changes in runoff hydrograph when storage is subtracted from runoff](image)

Option 5. Adjust CN for 24-hour Storm Depth

A standard assumption given in TR-55 is that \( I_a = 0.2S \). Consequently, the NRCS standard runoff equation is sometimes expressed as

\[
Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (A5)
\]

Subtracting the total retention from the total runoff at the end of a storm event gives a runoff value that a different \( S \) value can be based on. The equation

\[
Q - R = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (A6)
\]
can be solved for a revised value of $S$, which will increase with increases in retention, and then a revised $CN$ value can be calculated from the revised $S$. That revised $CN$ can subsequently be used to generate a new runoff hydrograph.

This approach does properly account for the effect of the retention volume on the runoff volume for the storm as a whole. That is, the total area under the runoff hydrograph will be equivalent to $Q$ minus $R$. The remaining difficulty is that the effect of the retention volume is not fully accounted for until the end of the storm. By design, the placement of retention should typically result in the retention cells being filled well before the end of the storm, so that retention will actually have greater value in reducing the peak flow than a simple $CN$ adjustment would indicate.

Figure A5. Changes in runoff hydrograph when CN adjustment is made to account for retention storage

Runoff Depth Comparisons

There are significant differences in the depth of runoff calculated for these three different approaches. Figure A6 shows a comparison of depth calculations for Options 3, 4 and 5. Relative to the standard runoff curve, Option 3 moves the runoff curve to the right, and Option 4 moves it downward. Option 5 starts somewhat to the right of the standard curve, and ends where the difference in runoff is equal to the total depth of retention.

It is worth noting that the $CN$ adjustment method will produce a different $CN$ value for different depths of rainfall, even if the land cover, soil characteristics and amount of added retention remains the same. If, as Figure A6 shows, a $CN$ is determined using Equation A6 for a rainfall depth of 80 mm and retention depth of 10 mm, the amount of runoff generated for 60 mm of rainfall is approximately 13 mm. However, if a $CN$ is recalculated using Equation A6 for a rainfall depth of 60 mm, the amount of runoff is approximately 10 mm.
This presents a logical difficulty. Since the accumulation of precipitation from 0 to 80 mm passes through the value of 60 mm, it seems reasonable to expect that the runoff depth associated with 60 mm should be the same for the same land use and soil type, regardless of whether the storm lasts longer.

Figure A6. Comparison of depth of runoff calculations (CN = 80; overall retention depth = 10 mm)

**Runoff Peak Comparisons**

A comparison of the effect of the five options on the runoff peak is illustrated in Figure A7. The chart shows that accounting for the runoff volume as described in Option 4 results in the least amount of runoff for all but the highest levels of peak runoff reduction, and, overall, is nearly as efficient as detention in terms of achieving a relative reduction in peak flow for a given volume of storage. Option 4 was selected for implementation in the LID spreadsheet.
Figure A4. Comparison of different methods to account for runoff storage
(CN = 75, Tc=1 hr, D.A. = 1 km²)
Appendix B.

Summary of Spreadsheet Contents

Normally visible sheets:
1. ReadMe Describes basic program purpose and identifies developer.
2. MainPage Two-page user interface.
3. SubareaCheck Confirms that all retention volumes will be filled.
4. RainDistribution For inputting the temporal rainfall distribution.
5. OutputHydrograph Runoff hydrograph for the LID site design.

Normally hidden sheets:
6. PlotData Hydrograph data plotted on the output page.
7. Convolve Convolution calculations in metric (SI) units.
8. RainfallPlot Chart showing cumulative rainfall distribution for Type II storm.

Convolve receives user input from MainPage, performs computations in metric units and returns the output values in English units.
Appendix C.

Curve Numbers and Subsurface Storage for Porous Pavement and Permeable Pavers

NRCS Runoff Curve Numbers for Porous Pavement

<table>
<thead>
<tr>
<th>Gravel Subbase Thickness (inches)</th>
<th>Curve Number for Various Hydrologic Soil Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>10</td>
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</tr>
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<tr>
<td>30</td>
<td>49</td>
</tr>
<tr>
<td>36</td>
<td>47</td>
</tr>
</tbody>
</table>

Notes

- The CN values are based on Antecedent Moisture Condition II and an \( I_a \) of 0.25 inches.
- All the CN values are for properly maintained porous pavement. The CN values for porous pavement that is not properly maintained is the default CN for pavement, which is 98.

Limitations

- The infiltration rate of asphalt layer is not limiting. Minimum infiltration rate is 0.27 in/hr.
- The season high water table is greater than 2.0 feet below the gravel layer.
- There is at least 2.0 feet of soil below the gravel layer.
- The potential maximum retention after runoff begins includes storage in pavement gravel and soil.
General Suggestions Regarding Permeable Paver Systems

“There are […] no specific curve numbers for permeable pavements. […] CN = 65 is an average number based on the fact that virtually all permeable pavements can store about 2 inches of rainfall (in the base layer) before infiltrating it or draining it elsewhere (either into the subgrade, if permeable, or into a drainage system). This is an estimate based on storage capacity within open-graded bases (typically 30-40% of the total base volume).

“Many permeable pavements will be built on A or B soils and we know that thicker bases means more storage capacity, and when placed on A or B soils, there will be infiltration rather than runoff. However in any underlying soil case, the infiltration rate and storage capacity of the base will be greater than that of the underlying soil. Therefore, the $CN$ for permeable pavers will be lower than the underlying soil (substantially in some cases). The CN 65 is considered a starting point (conservative) considering the infiltration rate of permeable pavements are based on various factors - design storms, underlying soil, supplemental drainage (if used), pavement load, climate, etc. Unfortunately there isn't one uniform design.

“The 65 number was derived from TR - 55 Urban Hydrology for Small Watersheds, Table 2-1 Runoff depth for selected CNs and rainfall amounts. It is based on the fact that virtually any permeable pavement will infiltrate and store up to 2 inches of rainfall (virtually no runoff). In many cases, as I've mentioned it can store much more, resulting in an even lower curve number. You may be able to extrapolate from this to assign numbers for various soils.

“Though pervious pavements have been around awhile (asphalt and ready-mix concrete), interlocking permeable pavers have only been around (in the U.S.) for about 10 years, with most use over the last few years. Perhaps they will be measured in the future for CN values, though because of the variables, it might take a lot of testing over the entire country to get good average parameters. “

Donna DeNinno
UNI-GROUP U.S.A.
May 15, 2003
Appendix D.

Runoff Storage Capacity of Vegetated Roofs

See paper by Charlie Miller on the following pages.
Edited slightly as indicated by brackets.
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Disclaimer: This paper is provided here for informational purposes only. Providing this information does not constitute an endorsement of Roofscapes, Inc. by MMSD. Nor does it constitute an endorsement by Roofscapes, Inc., of the method of analysis associated with the LID Quicksheet.
Use of Vegetated Roof Covers in Runoff Management

By Charlie Miller, P.E.

The effectiveness of green roofs in reducing runoff impacts, especially in densely developed areas, is one of the principal reasons that they are so popular with city engineers in Germany. In Germany alone, more than 20 million square feet of new green roof are installed every year. Many cities require green roofs for buildings in districts that are plagued by chronic runoff-related problems.

*Initial abstraction* is an engineering term that describes the quantity of rainfall that must occur before appreciable runoff will commence. An approximate rule-of-thumb for a wide range of green roofs is that the initial abstraction will equal about 1/3 of the maximum water capacity, MWC, of the growing medium. The MWC is a benchmark number that is measured in a specific test used in Europe [and available in the United States]. For example, a green roof with an MWC of 1.5 inches will not generate significant runoff until at least 0.5 inches of rainfall has occurred.

Vegetated roof covers are very effective in reducing total runoff volume. A predictor of the percent reduction in total annual runoff volume is:

\[
\text{Pct. Reduction} = 100 \times 0.45 \times \text{MWC}^{1/3}
\]

A typical green roof with about 3 inches of growing media can be designed to reduce annual runoff by more than 50 percent. However, it is very important to keep in mind that this information is based on experience in temperate climates with a rainfall pattern similar to the American Northeast. For instance in the Pacific Northwest, where rainfall tends to occur in steady long-duration events, the reduction in runoff volume may be not be as great.

Another property of interest is field capacity. This is the quantity of water absorbed by the green roof during a rainfall event that will not be later released as runoff. This water will eventually be evapotranspired by the plants. The difference between the field capacity and the MWC determines how effective a green roof will be in suppressing peak rates of runoff during storms. For many types of green roof media, the field capacity is equal to about ½ of the MWC.
Runoff Control Using Thin Vegetated Covers

A critical aspect of using vegetated roof covers is to clearly identify the management goals and develop suitable design criteria. It has been demonstrated in Germany that the 3-inch vegetated roof cover has the highest benefit to cost ratio. A properly designed 3-inch vegetated roof cover will provide a durable, low maintenance system that can achieve the objectives of moderating temperature, reducing runoff, and prolonging the life of the underlying waterproofing materials. Furthermore, these systems can be added to most existing buildings, often without having to reinforce or otherwise alter their structural design.

The value of green roofs in reducing the rate of runoff depends upon the design rainfall events that are considered. For communities where runoff rates are computed using the rational method (which emphasizes the impact of intense short-duration rainfall events), thin vegetated covers can typically satisfy runoff management goals for 10-, 25-, and in some cases even 50-year return design storms. Where design storms are based on 24-hour events, it is generally possible to demonstrate control of runoff to pre-development levels for storms up to several inches in magnitude (i.e., a two-year storm magnitude in southeastern Pennsylvania). It is also helpful to keep in mind that in southeastern Pennsylvania 24-hour storms with magnitudes of less than 1.5 inches contribute more than 90 percent of all rainfall.

In Germany the standard design event for urban runoff management is one inch of rainfall falling in 15 minutes. This would be a 10-year return frequency event in southeastern Pennsylvania. In our opinion, the runoff requirements for urban areas that are undergoing redevelopment should be based on the type of the storm that is linked to chronic runoff-related problems (e.g., nuisance flooding, combined sewer overflow, TMDL exceedances). By-and-large these are summer downpours. Therefore, runoff abatement programs should focus on these storms. Green roofs can be a powerful tool for achieving this benefit.

Deep Vegetated Covers and Zero Discharge Installations

A typical 14-inch deep green roof can be relied on to reduce total annual runoff by 85 to 95 percent in temperate climates. In combination with other water management techniques, zero discharge is a readily attainable goal. The following are excellent examples of the integration of a variety of techniques to eliminate off-site discharge of rainfall runoff. These techniques include green roofs, cisterns, facade planters, reflecting pools, infiltration beds, and utility water recycling systems. Unfortunately, all of the information concerning these systems is in German. However, we have summarized some of these in English. The important points to remember are that: 1) these integrated building systems are a reality in Germany and that 2) a variety of techniques must be deployed in unison to achieve the goal. Although factors such as climate and geologic conditions will influence the design, there will always be a way to achieve the objective.
Cross Savings Bank (Kreissparkasse) in Weilburg

This building occupies a 3,250 square-foot area. The management system utilizes a combination of green roof landscapes, ranging in size from 2 to 6 inches in thickness. Cisterns are used to capture excess runoff for reuse in irrigation during dry periods.

Europe Park (Europapark) in Rust

This project also has a footprint of 3,250 square feet. Green roofs in combination with cisterns and low-head irrigation pumps, powered by photovoltaic panels, characterize this project.

New Convention Center (Neue Messe) in Munich

The Convention Center is a 409,000 (9 acre) square-foot complex. This is a very exciting project that integrates many management techniques. Green roofs are an essential part of the zero-discharge design and are responsible for up to 85% of the reduction in runoff. The remaining runoff reduction is accomplished by recycling runoff for utility uses and by infiltration. The Optigrün RWS computer simulation program was used to estimate the efficiency of the green roofs so that the other practices could be properly sized.

Commercial Center in Bondorf

This is a 40-acre development with zero runoff discharge. This stringent requirement was the result of the inability of the local wastewater treatment plant to absorb additional water from runoff. Fully 70 percent of the total area is covered with impermeable surfaces. In addition to green roofs and water recycling, this project relies on large infiltration galleries and landscape pools to infiltrate water.

[...]The following projects are also noteworthy.

Prisma building in Nurnberg

The water management system for this project incorporates green roofs, cisterns, façade planters, water-curtain climate control, gray water recycling, and infiltration. Water management is made part of an overall artistic statement. This project was described recently in the ASLA Professional Interest Group Water Conservation, Vol. III, No. 1, 1999.

Potsdamer Platz in Berlin

While not strictly an example of zero discharge, this ultra-urban development points the way to the possibilities of integrated runoff design. The design
beautifully integrates extensive green roofs (2 to 3 inches) with reflecting pools, created wetlands, cisterns, and water recycling. The primary limitation of this project was the deliberate decision not to treat runoff from roads and main thoroughfares. Infiltration opportunities were also very limited due to the high water table on the floodplain of the river Sprey.

National Bank of Baden-Würtenberg (Landesbank) in Stuttgart

This is another Optigrün project, which involves covering half of the 43,000 square-foot site with green roofs. A very lovely and diverse roof landscape is used to eliminate all but about 5% of annual runoff. Profiles range from 4 to 16 inches in depth.

[...]

The following table summarizes output from the [empirical Optigrün-]RWS computer simulation program for a 3.25-inch thick prototype installation for the Fencing Academy of Philadelphia. This simulation utilized a one-year, 5-minute digital rainfall record. Two standard design storms were also inserted into the rainfall record. The predictions of the simulation were verified by field observation of the prototype. The output illustrates that this thin green roof is much more effective in controlling brief rainfall events than long-duration storms. However, significant runoff rate suppression was achieved for all storm events. Similar analyses can be conducted as part of the feasibility phase of other projects.
### Selected Storms: RWS Simulation of One-Year Rainfall Record

3.25-inch (8 cm) Deep Extensive Vegetated Roof Cover

Rainfall record for Reading, Pennsylvania (1994)

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<th>Rainfall 15-min</th>
<th>Rainfall 24-hour</th>
<th>15-min Peak</th>
<th>Volume</th>
<th>Discharge</th>
<th>Attenuation</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>in/hr</td>
<td>in</td>
<td>in/hr</td>
<td>in</td>
<td>Comments</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>0.9</td>
<td>negligible</td>
<td>100%</td>
<td>&quot;cloud burst:&quot; peak occurs in first 25 min.</td>
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<td></td>
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<td>0.4</td>
<td>1.1</td>
<td>0.1</td>
<td>63%</td>
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<td>0.4</td>
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<td>72%</td>
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<td>3.2</td>
<td>3.4</td>
<td>1.4</td>
<td>57%</td>
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<tr>
<td>3.5</td>
<td>2.8</td>
<td>1.3</td>
<td>61%</td>
<td>Standard 2-year: type II rainfall distribution</td>
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<td>2.8</td>
<td>47%</td>
<td>Standard 10-year: type II rainfall distribution</td>
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