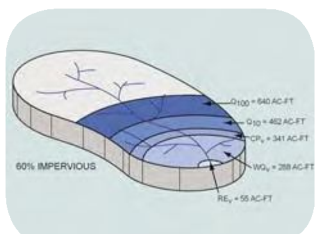
Urban Subwatershed Restoration Manual Series

3

Urban Stormwater Retrofit Practices

Version 1.0

August 2007



CENTER FOR WATERSHED PROTECTION

Manual 3

Urban Subwatershed Restoration Manual No. 3

URBAN STORMWATER RETROFIT PRACTICES

Version 1.0

Prepared by:

Tom Schueler, David Hirschman, Michael Novotney, and Jennifer Zielinski, P.E.
Center for Watershed Protection
8390 Main Street, 2nd Floor
Ellicott City, MD 21043
www.cwp.org
www.stormwatercenter.net

Prepared for:
Office of Wastewater Management
U.S. Environmental Protection Agency
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Foreword

Writing this manual has been a labor of love for many current and former Center staff who have been involved in urban retrofitting in dozens of urban watersheds over the past few decades. The experience we have gained in Sligo Creek, the Kensico Reservoir, Longwell Branch, the Bronx River, Little Lick Creek, Watts Branch, Powhatan Creek, Watershed 263, and many other small watersheds have enabled us to develop and refine better methods to find, design and build retrofits faster and more cost-effectively. This manual outlines our most recent ideas on how retrofits can help restore small urban watersheds.

This manual could not have been written without the help of many retrofit experts. Special thanks are extended to Ted Brown, P.E. (Biohabitats, Inc.), Rich Claytor, P.E. (Horsley Witten Group) and Tim Schueler, P.E. (McKim and Creed) for their ongoing input on the art and science of retrofitting over the past five years. I am also indebted to current Center staff that contributed their hard won experience and knowledge to the effort: Jennifer Zielinski, Dave Hirschman, Mike Novotney and Sally Hoyt. Lisa Fraley-McNeal deserves special thanks for her great retrofit artwork and for updating our national pollutant removal database. Most of all, I am grateful to Tiffany Wright for her tireless work and dedication to quality in producing this manual and seven others in the Urban Subwatershed Restoration Manual Series.

The technical content and readability of the manual were greatly improved due to the insightful comments of Rich Claytor, Tim Schueler, Ted Brown, Dan Harper (Montgomery County DEP), and Dave Hirschman.

Also, since retrofitting is about envisioning the prospects for restoration, we want to credit the many individuals who provided photos to help visualize the process, including Lincoln Kan, City of Mississauga, Ontario; Dr. Bill Hunt, North Carolina State University; Gary Oberts, EOR, Inc.; Tim Schueler, McKim and Creed; Derek Booth, Stillwater Sciences; Roger Bannerman, Wisconsin DNR; Tom Liptan, Portland Bureau of Environmental Services; Rich Claytor, Horsley Witten Group; Martin Covington, Carroll County, MD; Sonal Sanghavi, MD State Highway Administration; Seattle SEA Streets program; and the staff of the Center for Watershed Protection.

Thanks are also due to our EPA project officer, Bryan Rittenhouse, for his support during the two years it took to produce this manual under a cooperative agreement with U.S. EPA Office of Wastewater Management (CP-83276401).

In closing, I hope our readers discover how much fun it can be to embark on the search for storage and build retrofits that improve watershed health. Good hunting!

Sincerely,

Tom Schueler
Director of Watershed Practices

About the Restoration Manual Series

Over the last four years, the Center for Watershed Protection has produced a series of 11 manuals that describes the techniques to restore small urban watersheds. The entire series of manuals was written to organize the enormous amount of information needed to restore small urban watersheds into a format that can easily be accessed by watershed groups, municipal staff, environmental consultants and other users. The contents of the manuals are organized as follows:

Manual 1: An Integrated Framework to Restore Small Urban Watersheds

The first manual, published in 2004, introduces the basic concepts and techniques of urban watershed restoration, and sets forth the overall framework we use to evaluate subwatershed restoration potential. The manual emphasizes how past subwatershed alterations must be understood in order to set realistic expectations for future restoration. Toward this end, the manual presents a simple subwatershed classification system to define expected stream impacts and restoration potential. Next, the manual defines seven broad groups of restoration practices, and describes where to look in the subwatershed to implement them. The manual concludes by presenting a condensed summary of a planning approach to craft effective subwatershed restoration plans.

Manual 2: Methods to Develop Restoration Plans for Small Urban Watersheds

The second manual was published in 2005 and contains detailed guidance on how to put together an effective plan to restore urban subwatersheds. The manual outlines a practical, step-by-step approach to develop, adopt and implement a subwatershed plan in your community. Within each step, the manual describes 32 different desktop analysis, field assessment, and stakeholder involvement methods used to make critical restoration management decisions.

Manual 3: Urban Stormwater Retrofit Practices

This manual, published in 2007, focuses on stormwater retrofit practices that can capture and treat stormwater runoff before it is delivered to the stream. The manual describes both off-site storage and on-site retrofit techniques that can be used to remove stormwater pollutants, minimize channel erosion, and help restore stream hydrology. Guidance on choosing the best locations in a subwatershed for retrofitting is provided in a series of 13 profile sheets. The manual then presents a method to assess retrofit potential at the subwatershed level, including methods to conduct a retrofit inventory, assess candidate sites, screen for priority projects, and evaluate their expected cumulative benefit. The manual concludes by offering tips on retrofit design, permitting, construction, and maintenance considerations.

Manual 4: Urban Stream Repair Practices

The fourth manual was published in 2005 and concentrates on practices used to enhance the appearance, stability, structure, or function of urban streams. The manual offers guidance on three broad approaches to urban stream repair – stream cleanups, simple repairs, and more sophisticated comprehensive repair applications. The manual emphasizes the powerful and relentless forces at work in urban streams, which must always be carefully evaluated in design. Next, the manual presents guidance on how to set appropriate restoration goals for your stream, and how to choose the best combination of stream repair practices to meet them.

The manual also outlines methods to assess stream repair potential at the subwatershed level, including basic stream reach analysis, more detailed project investigations, and priority screenings. The manual concludes by offering practical advice to help design, permit, construct and maintain stream repair practices in a series of more than 30 profile sheets.

Manual 5: Riparian Management Practices

This manual was originally envisioned to provide guidance on how to restore the quality of forests and wetlands in the stream corridor, though it was never officially completed. The Center completed several manuals from 2005 to 2007 that fully address this topic including the three parts of the *Urban Watershed Forestry Manual* and the six *Wetlands and Watersheds* articles produced for USDA and U.S. EPA, respectively.

Manual 6: Discharge Prevention Practices

The sixth manual covers practices used to prevent the entry of sewage and other pollutant discharges into the stream from pipes and spills. The manual describes a variety of techniques to find, fix and prevent these discharges that can be caused by illicit sewage connections, illicit business connections, failing sewage lines, or industrial/transport spills. The manual also briefly presents desktop and field methods to assess the severity of illicit discharge problems in your subwatershed. Lastly, the manual profiles different "forensic" methods to detect and fix illicit discharges. The Center never completed the full manual, but a major portion of the topic is covered in a 2004 manual entitled *Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments* (Brown *et al.*, 2004)

Manual 7: Watershed Forestry Practices

The seventh manual reviews subwatershed practices that can improve the quality of upland pervious areas, which include techniques to improve conditions, revegetate pervious areas, and restore natural area remnants. When broadly applied, these techniques can improve the capacity of these lands to absorb rainfall and sustain healthy plant growth. This manual also outlines methods to assess the potential for these techniques at both the site and subwatershed scale. This manual was published under separate cover as the *Urban Watershed Forestry Manuals.*

Manual 8: Pollution Source Control Practices

Pollution source control practices reduce or prevent pollution from residential neighborhoods or stormwater hotspots. Thus, the topic of the eighth manual is a wide range of stewardship and pollution prevention practices that can be employed in subwatersheds. The manual presents several methods to assess subwatershed pollution sources in order to develop and target education and/or enforcement efforts that can prevent or reduce polluting behaviors and operations. The manual outlines more than 100 different "carrot" and "stick" options that can be used for this purpose. Lastly, the manual presents profile sheets that describe 21 specific stewardship practices for residential neighborhoods, and 15 pollution prevention techniques for control of stormwater hotspots.

Manual 9: Municipal Good Housekeeping Practices

The ninth manual, published in 2007, focuses on how municipal operations can directly support subwatershed restoration efforts. The manual contains a municipal operations analysis to help local stormwater managers target the municipal operations and activities that can improve water quality. The 10 areas include municipal hotspots, municipal construction, road maintenance, street sweeping, storm drain cleanouts, stormwater hotlines, landscaping and park maintenance, residential stewardship, stormwater maintenance, and employee training. The manual presents guidance on how municipalities can modify these 10 programs to promote subwatershed restoration goals. It presents a series of profile sheets that recommends specific techniques to implement effective municipal programs.

Manual 10: The Unified Stream Assessment (USA): A User's Manual

The Unified Stream Assessment (USA) is a rapid technique to locate and evaluate problems and restoration opportunities within the urban stream corridor. The tenth manual is a user's guide that describes how to perform the USA, and interpret the data collected to determine the stream corridor restoration potential for your subwatershed.

Manual 11: The Unified Subwatershed and Site Reconnaissance (USSR): A User's Manual

The last manual examines pollution sources and restoration potential within upland areas of urban subwatersheds. The manual provides detailed guidance on how to perform each of its four components: the Neighborhood Source Assessment (NSA), Hotspot Site Investigation (HSI), Pervious Area Assessment (PAA) and the analysis of Streets and Storm Drains (SSD). Together, these rapid surveys help identify upland restoration projects and source control to consider when devising subwatershed restoration plans.

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Chapter 1: Basics of Stormwater Retrofits

Stormwater retrofits help restore watersheds by providing stormwater treatment in locations where practices previously did not exist or were ineffective. They are typically installed within the stream corridor or upland areas to capture and treat stormwater runoff before it is delivered to receiving waters. Retrofits are the primary practice used to restore subwatersheds since they can remove pollutants, promote more natural hydrology and minimize stream channel erosion. This manual provides detailed guidance on how to effectively retrofit subwatersheds.

This chapter introduces the basics of stormwater retrofits and how they are integrated with other restoration practices to meet subwatershed objectives. Nine sections guide the design team through the search for storage by answering the following questions:

1.1 How is retrofitting different from traditional stormwater design?

1.2 What restoration objectives can be achieved by subwatershed retrofitting?

1.3 How much stormwater storage is needed in the retrofits to meet objectives?

1.4 How much storage can be found in a subwatershed to achieve this target?

1.5 What subwatershed locations are most suited for retrofit sites?

1.6 What stormwater treatment options best meet restoration objectives?

1.7 What desktop and field methods are needed to systematically find them?

1.8 How much does it cost to retrofit an entire subwatershed?

1.9 What are the best strategies to deliver multiple retrofits across a subwatershed?

Chapter 2 describes 13 different locations in a subwatershed where retrofitting may be possible. A profile sheet describes each retrofit location and presents tips on how to find candidate sites using desktop searches and how to assess them in the field. The individual profile sheets provide guidance on permitting, design, construction and delivery issues and outline methods to estimate retrofit construction costs.

Chapter 3 briefly reviews the eight major stormwater treatment options that can be employed in stormwater retrofits and presents a technique to estimate pollutant reduction at individual retrofit sites.

Chapter 4 describes how to systematically assess retrofit potential at the subwatershed level and the individual site. The chapter outlines an eight-step process to guide designers through initial retrofit scoping to final construction. Methods are presented to identify candidate sites in a subwatershed that have the greatest potential for retrofitting. The chapter describes how to perform a Retrofit Reconnaissance Investigation to generate the most feasible sites. Guidance is also provided on how to develop and rank initial concept designs for retrofit projects, and create a subwatershed retrofit inventory. The chapter concludes with general tips to support final retrofit design, construction, maintenance and evaluation.

This manual should be read in the context of several others in the *Urban Subwatershed Restoration Manual Series*, particularly:

- No. 1 An Integrated Framework to Restore Small Watersheds
- No. 2 Methods to Develop Restoration Plans for Small Urban Watersheds
- No. 4 Urban Stream Repair Practices
- No. 7 Watershed Forestry Practices
- No. 8 Pollution Source Control Practices

1.1 Why Retrofitting is Different

Most retrofit designers have some prior experience designing new stormwater practices. It is important, however, to note the many ways that retrofit design differs from the design of new stormwater treatment practices (Table 1.1). Retrofitting requires a different way of thinking; it requires sleuthing skills to determine what can work at highly constrained sites. Designers need to simultaneously envision restoration possibilities and anticipate potential problems. Designers must be extremely creative to find and design effective stormwater solutions within the built environment that produce desired subwatershed results.

The design, permitting and construction of retrofits are almost always more complex, expensive and time consuming than new stormwater practices. Also, since most projects are sponsored by the public sector, they must meet high standards for performance, community benefit and appearance. Designers should seek to maximize restoration objectives and not merely design toward a rule. The ethical bar for retrofit design is also higher – designers must ensure that their proposed retrofit adds to watershed function and does not impair existing wetlands, streams and forests. The goal is not just to get approval for a development project or secure a stormwater permit, but rather to create a project that will look good, perform well for many decades, and have a reasonable maintenance burden.

1.2 Restoration Objectives for Stormwater Retrofits

The retrofit process begins with a diagnosis of how subwatershed development is currently degrading stream quality. The reader should consult Manual 1 for an extended discussion of the Impervious Cover Model and how it can be used to diagnose the severity of problems in a subwatershed and determine restoration potential.

Setting restoration objectives early in the retrofitting process is extremely important. Restoration objectives define the purpose of retrofitting and target the specific subwatershed problems to be solved. A good set of restoration objectives helps identify what pollutants need to be treated, how much storage is needed and where the most cost-effective locations are in the subwatershed. Communities around the country have chosen many different restoration objectives to guide their retrofitting efforts, as described below.

Fix Past Mistakes & Maintenance Problems: Traditionally, communities have used retrofits to improve their existing stormwater infrastructure (e.g., to fix drainage problems, deal with under-sized culverts, protect water and sewer lines threatened by erosion or to address chronic maintenance problems within individual stormwater practices). These infrastructure retrofits are localized to address a specific problem and are seldom done on a subwatershed-wide basis. The type of

Table 1.1: Why Retrofitting is Different from New Stormwater Design	
Urban Retrofit Practices	**New Stormwater Practices**
Construction costs are 1.5 to 4 times greater	Designers seek least costly options
Requires significant data collection	Much of the data may be borrowed from past designs
Assessment and design costs are higher	Focus on low cost design and construction
Sized to meet subwatershed restoration objectives (or best one can do)	Sized to meet local stormwater design standards
Typically installed on public land	Installed at new development projects
Urban soils often cannot support infiltration	Soils may support infiltration
Fingerprinted around existing development and infrastructure	More flexibility on where to locate practices on the site
Must be acceptable to adjacent neighbors and landowners	Aesthetics are not always a major design factor
Most are publicly maintained and the public expects that they will be	Most require private maintenance, which is not frequently performed
Not all candidate sites are feasible	Nearly all sites are made to work
Often tied into existing stormwater conveyance system	Usually creates the new stormwater conveyance system
Integrated with other restoration practices	Stand-alone practice
Public investment in watershed infrastructure	Private investment in stormwater infrastructure
Site visit is prerequisite for design	Design may occur without site visit

storage usually is tailored to solve the specific problem at the site.

Solve Chronic Flooding Problems: Another common retrofit objective is to solve flooding problems at vulnerable locations within a subwatershed. This retrofitting approach focuses on specific reaches or flood prone areas. Upstream storage retrofits may be investigated to reduce flood damage n subwatersheds that were developed prior to local stormwater or floodplain management requirements. These large retrofits are sized to provide storage for extreme flood events (e.g., 25 to 100 year peak discharge control).

Stormwater Demonstration and Education: Many communities embark on retrofitting to demonstrate new stormwater practices on public lands or promote stormwater education and stewardship. As a result, demonstration retrofits are installed on a localized rather than subwatershed-wide basis. Most demonstration retrofits are sized to treat the water quality volume and introduce new stormwater technologies. Well-designed and highly visible demonstration retrofits are a good tactic to garner greater support to finance more widespread retrofitting efforts in the future.

Trap Trash and Floatables: The objective for these retrofits is to keep trash and floatables out of receiving waters. The basic approach combines pollution prevention, storage retrofits and improved catch basins to trap trash and floatables before they enter receiving waters. Since trash is fairly easy to trap, most retrofits are sized based on a fraction of the water quality volume, although they typically require intensive maintenance after every major storm event. Retrofit programs to reduce trash have been conducted in diverse cities such as New York City, Los Angeles, Baltimore, Albuquerque, and the District of Columbia.

Reduced Runoff Volumes to Combined Sewers: In recent years, communities have recognized that on-site retrofits can greatly reduce stormwater inputs to combined sewers, thereby reducing the frequency and size of sewage overflows in urban subwatersheds. This retrofit strategy can greatly reduce the size and cost of traditional combined sewer overflow (CSO) abatement systems such as deep tunnels or storage pipes. In many cases, on-site retrofits only need to reduce a fraction of the water quality volume to become a cost-effective technique to reduce CSOs. Rooftop treatment or disconnection is the most common approach to reduce runoff volumes, and they have been applied in diverse settings such as Philadelphia, Pittsburgh, Portland, Milwaukee, and the District of Columbia.

Renovate the Stream Corridor: This objective focuses on installing retrofits to improve the quality of a stream corridor, whether it is a greenway, stream valley park or chain of wetlands or lakes. The retrofits are located in or near the stream corridor, and are intended to improve water quality, create wetland and wildlife habitat, daylight urban streams, naturalize the stream corridor or demonstrate creative stormwater practices. Some progressive communities that have utilized retrofits to renovate the stream corridor include the Staten Island Bluebelt, Minnehaha Creek in Minneapolis, and the Rouge River in Michigan.

Reduce Pollutants of Concern: Pollutant reduction is often a primary objective of local retrofit programs. The reduction may be driven by a TMDL, a local watershed restoration plan or regional directive to reduce pollutant loads. The pollutant of concern may include sediment, nutrients, bacteria, metals and toxins. Retrofits are then systematically applied across a subwatershed to achieve a pre-designated pollutant reduction goal. Retrofits are typically sized based on a target water quality volume, although individual retrofits may be under or over-sized. Examples of communities that have retrofit subwatersheds to maximize pollutant removal include the Staten Island Bluebelt, communities in Maryland; North Carolina; Austin, TX; Santa Monica, CA; and Burlington, VT.

Systematically Reduce Downstream Channel Erosion: A few communities have sought to reduce downstream channel erosion by installing retrofits in urbanizing subwatersheds. This approach requires systematic installation of channel protection storage retrofits throughout the stream corridor. The strategy works best in impacted subwatersheds where the greater storage volume needed for channel protection can be more easily found. In recent years, this restoration objective has been linked to reduced nutrient loads derived from eroding streambanks. Two notable subwatersheds where channel protection has been a primary restoration objective include Watts Branch and Minebank Run in Maryland.

Support Stream Restoration: This objective uses upstream retrofits to provide hydrologic control to support downstream restoration projects. Individual retrofits are installed above specific stream reaches where stream restoration is planned. The retrofits may provide recharge, water quality and/or channel protection, depending on the specific design needs of the downstream project. The retrofits regulate the volume, duration, frequency, or peak discharge of stormflow, thereby creating a more stable and predictable hydrologic regime for the new stream (see Manual 4). The long-term success of many stream repair restoration projects is contingent on effective upstream retrofits. Notable examples of paired retrofit/stream repair projects on individual streams include Accotink Creek, VA, and Watts Branch, Longwell Branch and Wheaton Branch (MD).

Comprehensive Watershed Restoration: The ideal objective is a comprehensive approach to restore subwatersheds that integrates retrofits in the context of other stream repair, riparian reforestation, discharge prevention, upland reforestation, pollution source control and improved municipal practices (Manual 1).

1.3 Rainfall, Runoff and Retrofits

Once core retrofit objectives are selected, they need to be translated into subwatershed sizing criteria. For this reason, the retrofit team must understand the relationship between rainfall, runoff and retrofits in their community. Retrofitting is fundamentally driven by the distribution of rainfall events. This section introduces the concept of the rainfall frequency spectrum, and how it can be used to define the target runoff volumes for retrofitting.

In the course of a year, many precipitation events occur within a community. Most events are quite small but a few can be several inches deep. A rainfall frequency spectrum describes the average frequency of the depth of rainfall events that occur during a normal year (adjusted for snowfall). Figure 1.1 provides an example of a typical rainfall frequency spectrum that shows the percent of rainfall events that are equal to or less than the indicated rainfall depth. As can be seen, the majority of storms are relatively small but a sharp upward inflection point occurs at about one-inch of rainfall.

The rainfall frequency spectrum outlines five different zones that define targets for different stormwater treatment objectives, as follows:

Recharge: targets rainfall events that create little or no runoff but contribute much of the annual groundwater recharge at a site (denoted as **Rev**)

Water Quality: targets rainfall events that deliver the majority of the stormwater pollutants during the course of a year (denoted as **WQ**v**)**

Channel Protection: targets storms that generate bankfull and sub-bankfull floods that cause stream channel enlargement (denoted as **Cpv**)

Overbank Floods: targets large and infrequent storm events that spill over to the floodplain and cause damage to infrastructure and streamside property (denoted as $\mathbf{Qp_{10}}$).

Extreme Storms: controls the largest, most infrequent and most catastrophic floods that threaten structures and public safety (e.g., commonly known as the 100-year storm; denoted as $\mathbf{Qp_{100}}$).

In general, retrofitting focuses on the lower end of the rainfall frequency spectrum (i.e., managing runoff for recharge, water quality and channel protection). Subwatershed retrofitting to control overbank floods or extreme storms is rarely attempted since it is hard to get enough retrofit storage to manage runoff at this end of the spectrum. As a result, flood mitigation projects are normally installed to prevent problems within a specific flood-prone reach and not on a subwatershed-wide basis.

This manual primarily focuses on water quality treatment, although reference is often made to runoff reduction and channel protection. Table 1.2 illustrates the geographic variability in the rainfall frequency spectrum across the nation. The retrofit team can use the table to develop localized retrofit sizing criteria or they can derive their own rainfall frequency spectrum using the guidance presented in Table 1.3.

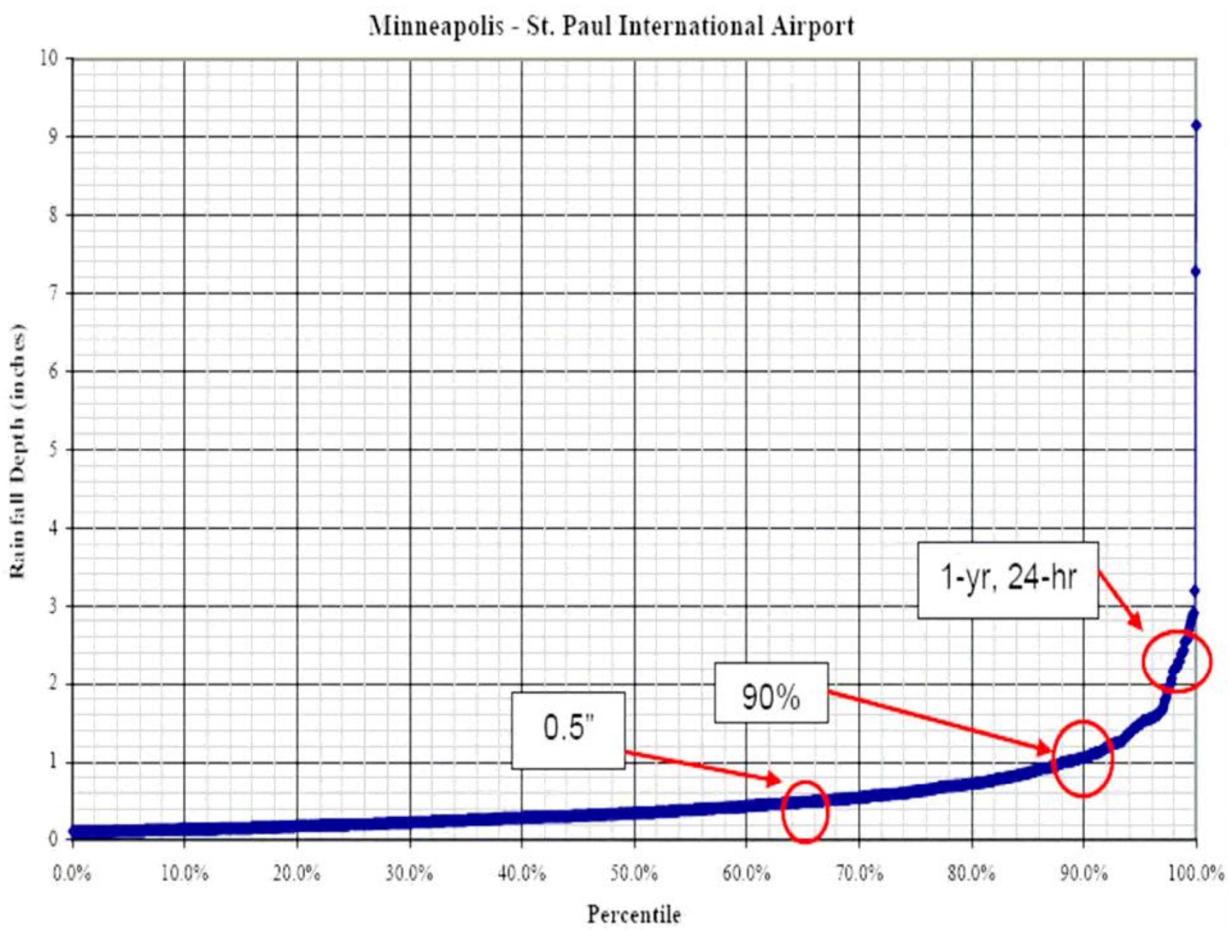


Figure 1.1: Rainfall Frequency Spectrum for Minneapolis-St. Paul Airport, 1971-2000

Table 1.2: Rainfall Statistics and Frequency Spectrum Data for Select US Cities

City	Precipitation		Rainfall event: Depth in inches[1]				
	Annual Inches	Days[2]	50%	75%	90%[3]	95%	99%[4]
Atlanta, GA	50	77	0.5	0.9	1.6	2.1	3.4
Knoxville, TN	48	85	0.4	0.7	1.2	1.5	2.4
New York City, NY	44	74	0.4	0.7	1.2	1.7	2.7
Greensboro, NC	43	73	--	--	1.6	--	2.7
Boston, MA	43	76	0.4	0.6	1.2	1.6	2.6
Baltimore, MD	42	71	0.4	0.8	1.2	1.6	2.5
Buffalo, NY	41	88	0.3	0.5	0.8	1.1	1.8
Washington, DC	39	67	0.4	0.8	1.2	1.7	2.4
Columbus, OH	39	79	0.3	0.6	1.0	1.3	2.1
Kansas City, MO	38	63	0.4	0.7	1.1	1.7	3.2
Seattle, WA	37	90	--	--	1.3	1.6	1.7
Burlington, VT	36	79	0.3	0.5	0.8	1.1	1.7
Dallas, TX	35	32	--	--	1.1	--	3.2
Austin, TX	34	49	--	--	1.4	--	3.2
Minneapolis, MN	29	58	0.3	0.6	1.0	1.4	2.4
Coeur D'Alene, ID	26	88	0.2	0.3	0.5	0.7	1.1
Salt Lake City, UT	17	44	0.2	0.4	0.6	0.8	1.2
Denver, CO	16	37	--	--	0.7	--	--
Los Angeles, CA	13	22	--	--	1.3	--	--
Boise, ID	12	38	--	--	0.5	--	--
Phoenix, AZ	8	29	--	--	0.8	--	1.1
Las Vegas, NV	4	10	--	--	0.7	--	0.8

Notes: Dashed lines indicate no data available to compute.

1. Excludes rainfall depths of 0.1 inches or less
2. Average days per year with measurable precipitation
3. The 90% storm is frequently used to define the water quality volume
4. The 99% storm is equivalent to the one year storm and is used to define the channel protection volume.

Table 1.3: How to Create a Local Rainfall Frequency Spectrum (RFS)

1. Obtain a long-term rainfall record from adjacent weather station (daily precipitation is fine, but try to obtain at least 30 years of daily record). NOAA has several websites with long-term rainfall records (See http://ols.nndc.noaa.gov)

2. Edit out small rainfall events than are 0.1 inch or less (also edit out snowfall events that do not immediately melt)

3. Using a spreadsheet or simple statistical package, analyze the rainfall time series and develop a frequency analysis to determine the percentage of rainfall events greater than or equal to a given numerical value (e.g., 0.2, 0.5, 1.0, 1.5 inches, etc).

4. Construct a curve showing rainfall depth versus frequency, and create a table showing rainfall depths values for 50, 75 90, 95 and 95% frequencies.

5. Use the data to define the recharge (20-50%), water quality event (90%) and one-year storm (99%).

Notes: *If a community is large or has considerable variation in elevation or aspect, the RFS analysis should be conducted at multiple stations. Other regional and national rainfall analysis such as TP-40 (NOAA) or USGS should always be used for rainfall depths or intensity greater than one-year in return frequency (e.g., 2, 5, 10, 25, 50 or 100 year design storm recurrence intervals)*

The rainfall frequency spectrum provides a strong basis to set targets for the desired water quality, runoff reduction or channel protection volume to seek in a subwatershed, as described below:

Setting Water Quality Volume Targets for Retrofitting: The water retrofit goal is to capture and treat the 90% storm, as defined by the local rainfall frequency spectrum. This criterion optimizes runoff capture resulting in high load reduction for many stormwater pollutants. The rainfall depth associated with the 90% storm varies geographically, but typically ranges between 0.8 and 1.2 inches for most parts of the country (see Table 1.2). Once the water quality storm has been selected, it is relatively easy to define the retrofit storage volume needed at both the site and subwatershed scale using the data provided in Table 1.4.

Several practical implications arise when setting the water quality target volume for a subwatershed - particularly when it comes to finding enough retrofit sites to meet it. In general, when the target volume is large, fewer retrofit sites can be found that have adequate space to capture and treat it. An optimization point exists between the target volume and expected number of retrofit locations, as shown in Figure 1.2.

One curve shows how the fraction of subwatershed treatment increases when the capture volume becomes progressively greater. The second curve shows how the number of feasible retrofit sites declines as a function of a higher capture volume. An optimization point exists in most subwatersheds where the two curves intersect. The retrofit optimization point also reflects the degree of subwatershed impervious cover- shifting towards 0.25 inches in highly developed subwatersheds and as much as 1.25 inches in lightly developed ones. This optimization point is an important factor to define early in the retrofit scoping process.

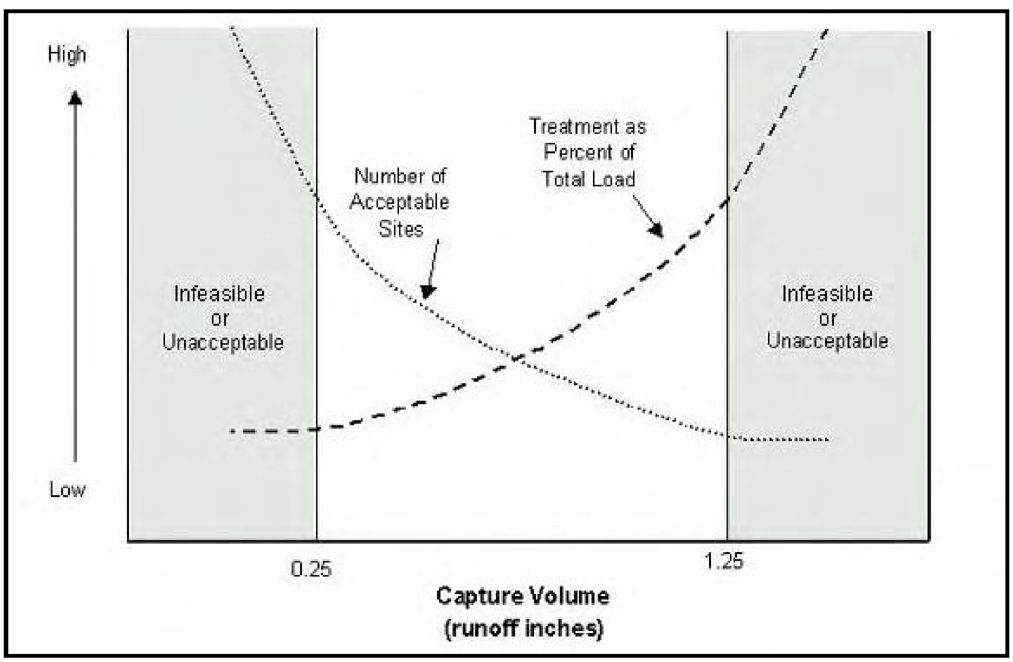


Figure 1.2: Optimization point for retrofit treatment.

Table 1.4: An Estimate of WQv for Select US Cities (in order of descending annual rainfall)

City	90% Rainfall Event (in.)	Subwatershed Imperviousness (%)			
		10%	30%	60%	90%
		WQv (cubic feet/acre)[1]			
Atlanta, GA	1.6	813	1,859	3,427	4,995
Greensboro, NC	1.6	813	1,859	3,427	4,995
Austin, TX	1.4	711	1,626	2,998	4,371
Seattle, WA	1.3	661	1,510	2,784	4,058
Los Angeles, CA	1.3	661	1,510	2,784	4,058
Knoxville, TN	1.2	610	1,394	2,570	3,746
New York City, NY	1.2	610	1,394	2,570	3,746
Boston, MA	1.2	610	1,394	2,570	3,746
Baltimore, MD	1.2	610	1,394	2,570	3,746
Washington, DC	1.2	610	1,394	2,570	3,746
Kansas City, MO	1.1	559	1,278	2,356	3,434
Dallas, TX	1.1	559	1,278	2,356	3,434
Columbus, OH	1.0	508	1,162	2,142	3,122
Minneapolis, MN	1.0	508	1,162	2,142	3,122
Buffalo, NY	0.8	407	929	1,713	2,497
Burlington, VT	0.8	407	929	1,713	2,497
Phoenix, AZ	0.8	407	929	1,713	2,497
Denver, CO	0.7	356	813	1,499	2,185
Las Vegas, NV	0.7	356	813	1,499	2,185
Salt Lake City, UT	0.6	305	697	1,285	1,873
Coeur D'Alene, ID	0.5	254	581	1,071	1,561
Boise, ID	0.5	254	581	1,071	1,561

[1] The WQv values provided above were estimated based on the methodology presented in Table 1.3 and the depth of rainfall associated with the 90% events shown in Table 1.2.

Setting Runoff Reduction Volume Targets: The target storage volume for runoff reduction ranges from 20 to 50% of the target WQv and can be attained through canopy interception, rooftop disconnection, infiltration, rainwater harvesting, evaporation or long-term storage. The specific target volume for runoff reduction is defined based on local subwatershed characteristics, and the desired degree of CSO relief, groundwater recharge or baseflow maintenance. Runoff reduction volumes are deceptively low in comparison to other target volumes. Designers should be aware that most storage retrofits do not reduce much runoff volume, so that dozens or even hundreds of small on-site retrofits may be needed to achieve runoff reduction objectives.

Setting Channel Protection Volume Targets: The recommended channel protection criterion is 24 hours of extended detention for the runoff generated by the 1-year 24-hour design storm. This is generally equivalent to the rainfall depth for the 99% storm depicted in Table 1.2. Runoff is stored and gradually released over a 24-hour period so that critical erosive velocities in downstream channels are not exceeded during the entire storm hydrograph. As a very rough rule, the storage capacity needed to provide channel protection is about 60% of the one-year storm runoff volume. Designers will normally need to define actual channel protection volumes using hydrologic and hydraulic models that simulate specific channel conditions and subwatershed characteristics (See Appendix C for further guidance).

Channel protection storage generally exceeds the water quality storage volume by 20 to 40% in most regions of the country (Figure 1.3). There are some interesting exceptions where Cpv storage is actually less than the WQv storage – most notably in arid and semi-arid regions and the Pacific Northwest where rainfall events are frequent but not particularly intense. It may seem counterintuitive that the Cpv could ever be higher than the WQv, since the rainfall depth associated with the 99% storm must always be greater than the 90% storm. The key difference is in the different way the *treatment volume* is defined for each kind of storage. The WQv is defined as 100% of the runoff volume produced by the 90% rain depth; whereas the Cpv is estimated as 60% of the runoff volume produced for the 99% rain depth.

Both WQv and Cpv storage may be needed to attain certain subwatershed objectives, which effectively doubles the total storage volume needed. The best conditions to find enough channel protection storage are in sensitive or impacted subwatersheds that have a high existing pond density and/or abundant public land in stream corridors. In many cases, channel protection treatment is not possible for the subwatershed as a whole, but may be feasible for individual stream reaches where stream repairs are being proposed.

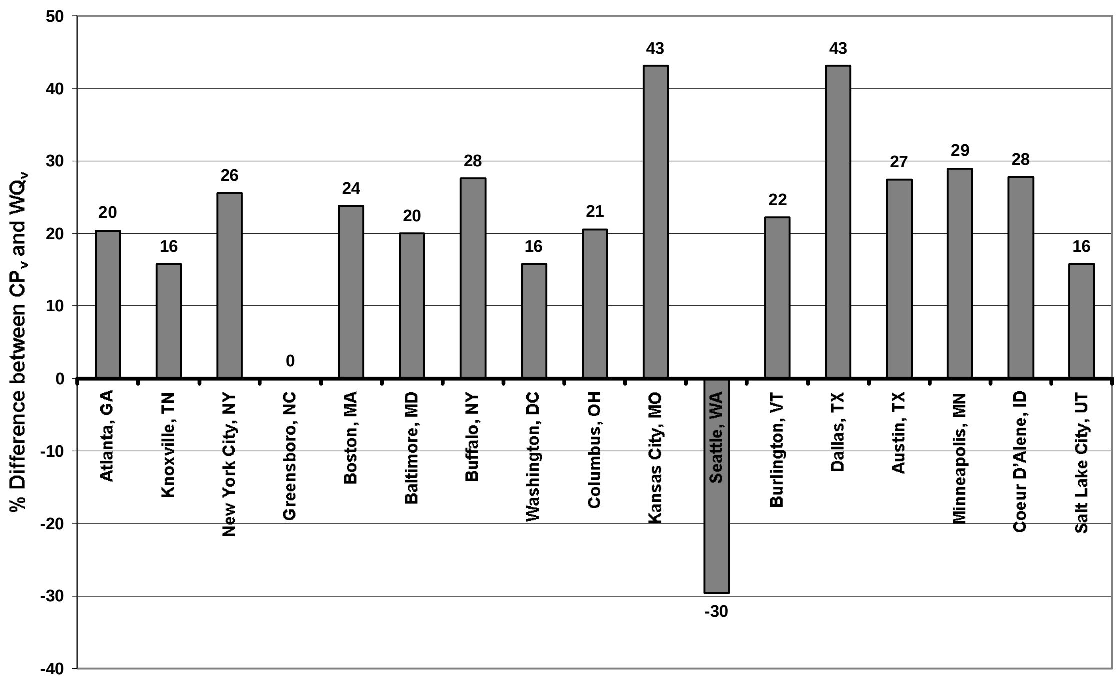


Figure 1.3: Difference in CPv storage and WQv storage for select U.S. cities.

1.4 The Search for Subwatershed Storage

Subwatershed treatment is an important concept when assessing retrofit potential. Designers need to calculate the total water quality treatment volume needed to meet the restoration objectives. The feasibility of capturing and treating this volume will be different in every subwatershed. Conceptually, subwatershed treatment is represented by the following equation:

Total volume = Storage retrofits + on-site retrofit storage + future redevelopment treatment

The redevelopment term reflects future opportunities to provide stormwater treatment within the subwatershed as land is redeveloped. While redevelopment is not an explicit component of the retrofitting process, it is important to update existing stormwater criteria to take advantage of these long-term opportunities to install new treatment.

The challenge of retrofitting is to find enough storage to make a real difference in a subwatershed. The estimated storage needed for a 5,000 acre subwatershed as a fraction of impervious cover can be seen in Figure 1.4. The required storage volume can consume a significant percentage of subwatershed area, particularly when channel protection and flood control storms are being managed.

Retrofitting becomes more and more difficult and costly to pursue as subwatershed imperviousness increases. At lower levels of impervious cover, it is generally possible to find needed storage volumes for water quality and, sometimes, channel protection. Available land to provide water quality and/or channel protection is harder to come by at higher levels of subwatershed impervious cover (45-60%).

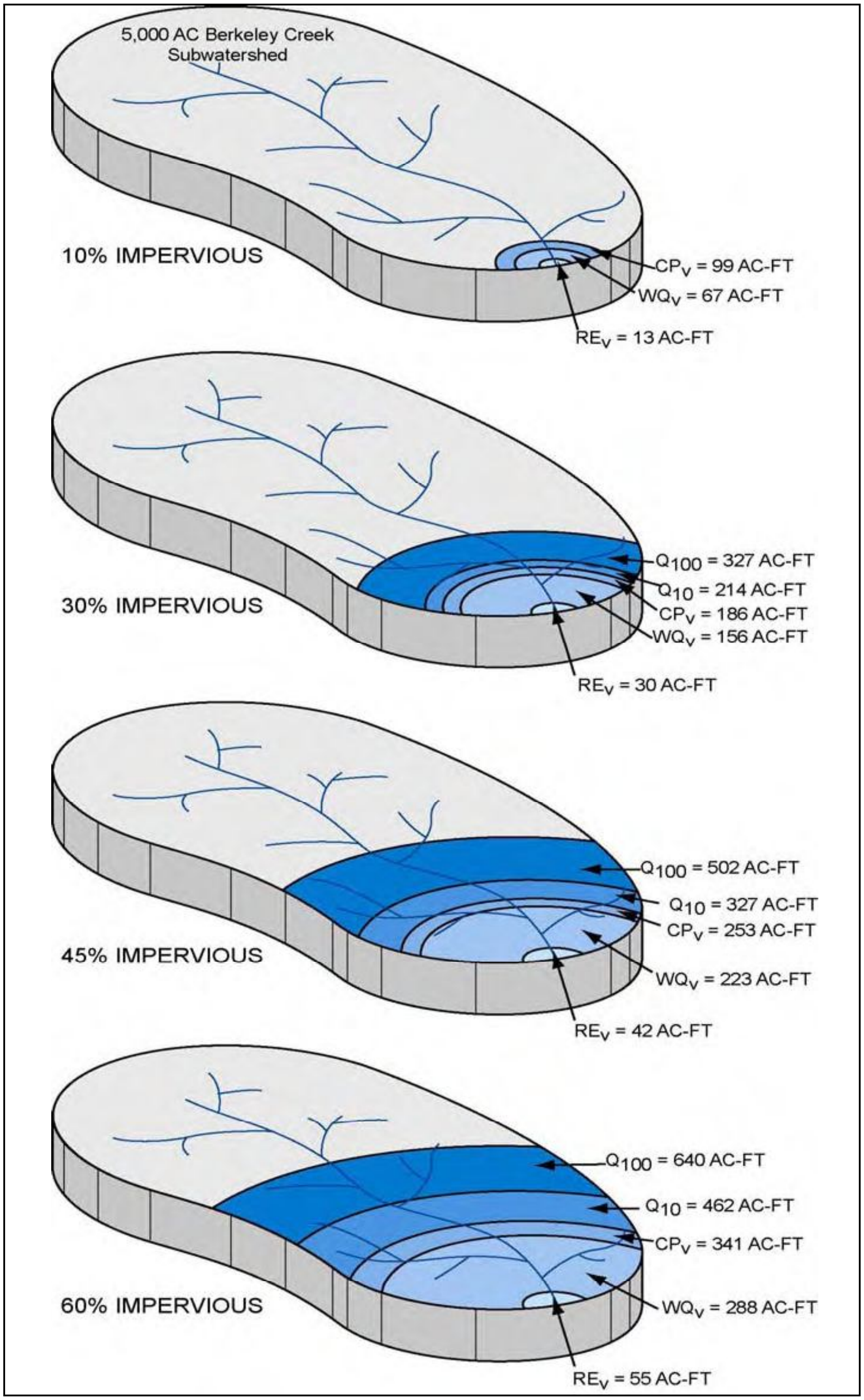


Figure 1.4: The Range of Retrofit Opportunities and Goals as a Function of Impervious Cover
(Note: Areas shown reflect one-foot depth of treatment)

1.5 The Range of Retrofit Practices

Retrofits can be classified by the amount of subwatershed area they treat. *Storage retrofits* treat drainage areas ranging from five to 500 acres. By contrast, *on-site* residential retrofits may individually treat as little as 500 square feet of contributing drainage area. On-site, non-residential retrofits normally treat less than five acres of contributing drainage area, and frequently less than one.

Storage and on-site retrofits represent two different approaches to attain treatment storage and involve different design and assessment methods (Table 1.5). As a general rule, storage retrofits are the most cost-effective approach to meet most subwatershed restoration objectives, although both retrofit approaches may be needed to get the desired level of subwatershed treatment.

Storage Retrofit Classification: Storage retrofits are classified using common locations in a subwatershed where large storage volumes can be found (Figure 1.5). The six major storage retrofit locations are described in detail in Table 1.6. Most storage retrofits are located on publicly owned or controlled land, and rely on some combination of extended detention, wet pond, constructed wetland or bioretention for stormwater treatment.

On-Site Retrofit Classification: On-site retrofits are classified based on the type or location of impervious area they treat, such as individual rooftops, small parking lots, streets, stormwater hotspots and other small impervious areas (Figure 1.6). The seven on-site retrofit locations are described in Table 1.7. On-site retrofits treat the quality and/or reduce the volume of runoff generated by small urban source areas and rely on bioretention, filtering, infiltration, swales or rooftop treatment. On-site retrofits are an effective strategy in ultra-urban subwatersheds that lack space for storage retrofits, and can also provide excellent opportunities to improve public awareness and involvement. Most on-site retrofits are normally installed on private land but involve some form of public delivery.

Table 1.5: Two Different Approaches to Retrofitting

Storage Retrofits	On-site Retrofits
Serve 5 to 500 acres	Serve 0.1 to 5 acres
Generally constructed on public land	Generally constructed on private land
May need dozens in a subwatershed	May need hundreds in subwatershed
Assessed at subwatershed scale	Assessed at catchment/neighborhood scale
Moderate cost per impervious acre treated	High cost per impervious acre treated
Impractical in ultra urban areas	Practical in ultra urban areas
Permitting can be extensive	Few permits are needed
Can provide all stormwater targets	Only provide recharge and water quality
Public construction	Public delivery
Utilize ED, wet pond, and wetlands	Rely on bioretention, filtering, infiltration, swales and other treatment practices

Figure 1.5: Six different storage retrofit options can be used.

Table 1.6: The Six Most Common Storage Retrofit Locations in a Subwatershed	
Where to Look	**How to Get Storage**
SR-1 **Add Storage to Existing Ponds**	Add water quality treatment storage to an existing pond that lacks it by excavating new storage on the pond bottom, raising the height of the embankment, modifying riser elevations/dimensions, converting unneeded quantity control storage into water quality treatment storage and/or installing internal design features to improve performance
SR-2 **Storage Above Roadway Culverts**	Provide water quality storage immediately upstream of an existing road culvert that crosses a low gradient, non-perennial stream without wetlands. Free storage is created by adding wetland and/or extended detention treatment behind a new embankment just upstream of the existing roadway embankment
SR-3 **New Storage Below Outfalls**	Flows are split from an existing storm drain or ditch and are diverted to a stormwater treatment area on public land in the stream corridor. Works best for storm drain outfalls in the 12- to 36- inch diameter range that are located near large open spaces, such as parks, golf courses and floodplains.
SR-4 **Storage in Conveyance System**	Investigate the upper portions of the existing stormwater conveyance system to look for opportunities to improve the performance of existing swales, ditches and non-perennial streams. This can be done either by creating in-line storage cells that filter runoff through swales and wetlands or by splitting flows to off-line treatment areas in the stream corridor
SR-5 **Storage in Road Right of Ways**	Direct runoff to a depression or excavated stormwater treatment area within the right of way of a road, highway, transport or power line corridor. Prominent examples include highway cloverleaf, median and wide right of way areas.
SR-6 **Storage Near Large Parking Lots**	Provide stormwater treatment in open spaces near the downgradient outfall of large parking lots (5 acres plus).

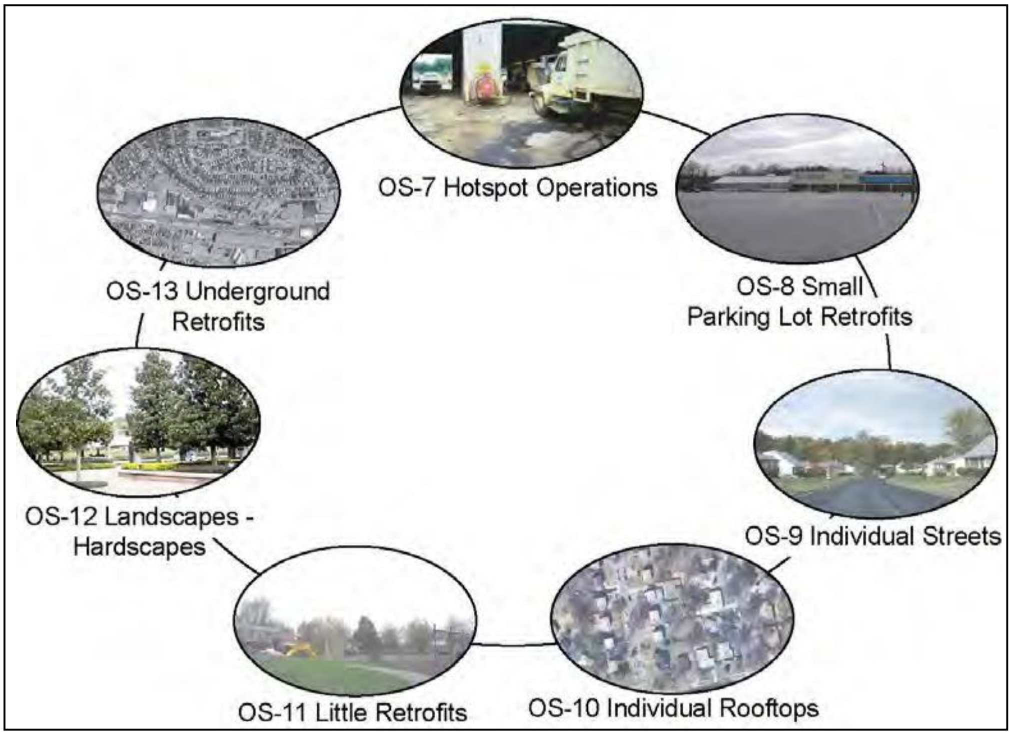


Figure 1.6: These seven retrofit options are available for on-site treatment.

Table 1.7: The Seven Most Common On-Site Retrofit Locations in a Subwatershed	
Where	**How**
OS-7 **Hotspot Operations**	Install filtering or bioretention treatment to remove pollutants from confirmed or severe stormwater hotspots discovered during field investigation
OS-8 **Small Parking Lots**	Insert stormwater treatment within or on the margins of small parking lots (less than five acres). In many cases, the parking lot is delineated into a series of smaller on-site treatment units.
OS-9 **Individual Streets**	Look for opportunities with the street, its right of way, cul-de-sacs and traffic calming devices to treat stormwater runoff before it gets into the street storm drain network
OS-10 **Individual Rooftops**	Disconnect, store and treat stormwater runoff generated from residential and commercial rooftops close to the source.
OS-11 **Little Retrofits**	Convert or disconnect isolated areas of impervious cover and treat runoff in an adjacent pervious area using low tech approaches such as a filter strip
OS-12 **Hardscapes Landscapes**	Reconfigure the plumbing of high visibility urban landscapes, plazas and public spaces to treat stormwater runoff with landscaping and other urban design features.
OS-13 **Underground**	Provide stormwater treatment in an underground location when no surface land is available for surface treatment. Use this as a last resort at dense ultra-urban sites.

1.6 Stormwater Treatment Options for Retrofitting

Eight different stormwater treatment options can be used for retrofitting (Figure 1.7). Each treatment option differs greatly in its pollutant removal capability, hydrologic benefit and retrofit suitability. More detailed information about each stormwater treatment option can be found in Chapter 3 and Appendix I. Some of the basic differences are compared in Table 1.8.

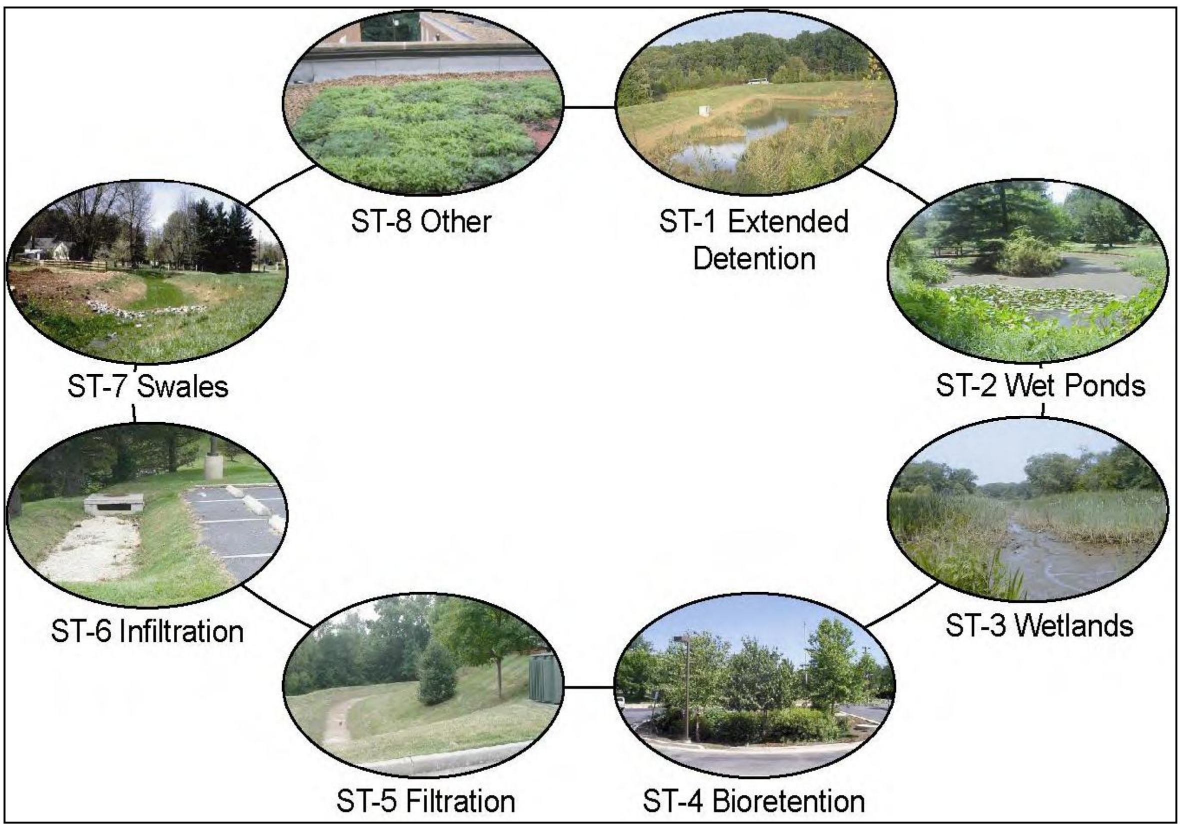


Figure 1.7: Eight stormwater treatment options are available for retrofitting.

Table 1.8: Stormwater Treatment Options for Retrofitting	
Stormwater Treatment Option	**How it Works**
ST-1 **Extended Detention**	This option relies on 12 to 24 hour detention of stormwater runoff after each rain event within a pond, with portions of the pond drying out in between storm events. Extended detention (ED) allows pollutants to settle out, and if enough storage is available, can also provide downstream channel protection.
ST-2 **Wet Ponds**	Wet ponds consist of a permanent pool of standing water. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants removed during prior storms.
ST-3 **Constructed Wetlands**	Constructed wetlands are shallow depressions that receive stormwater for treatment. Runoff from each new storm displaces runoff from previous storms, and the residence time of several days to weeks allows multiple pollutant removal processes to operate.
ST-4 **Bioretention**	Bioretention is an innovative urban stormwater practice that uses native forest ecosystems and landscape processes to enhance stormwater quality. Bioretention areas capture sheet flow from impervious areas and treat the stormwater using a combination of microbial soil processes, infiltration, evapotranspiration, and plants.
ST-5 **Filtering Practices**	Filter practices function by filtering runoff through an engineered media and collecting treated runoff in an underdrain. The media may consist of sand, soil, compost, or a combination of these.
ST-6 **Infiltration Practices**	An infiltration trench is a rock-filled chamber with no outlet that receives stormwater runoff. Stormwater runoff passes through some combination of pretreatment measures, such as a swale or sediment basin, before entering the trench where it infiltrates into the soil.
ST-7 **Swales**	Swales are a series of engineered, vegetated, open channel practices that are designed to treat and attenuate stormwater runoff for a specified water quality volume.
ST-8 **Other Retrofit Treatment**	These on-site practices provide treatment of roof runoff using rain gardens, rain barrels, green roofs, cisterns, stormwater planters, dry wells, or permeable pavers.

1.7 Basic Steps in Stormwater Retrofitting

An eight step process is recommended to systematically search for retrofit storage in a subwatershed (Figure 1.8). The process begins with retrofit scoping and concludes with maintenance of the constructed retrofit. Chapter 4 provides more information on each step of the retrofit process.

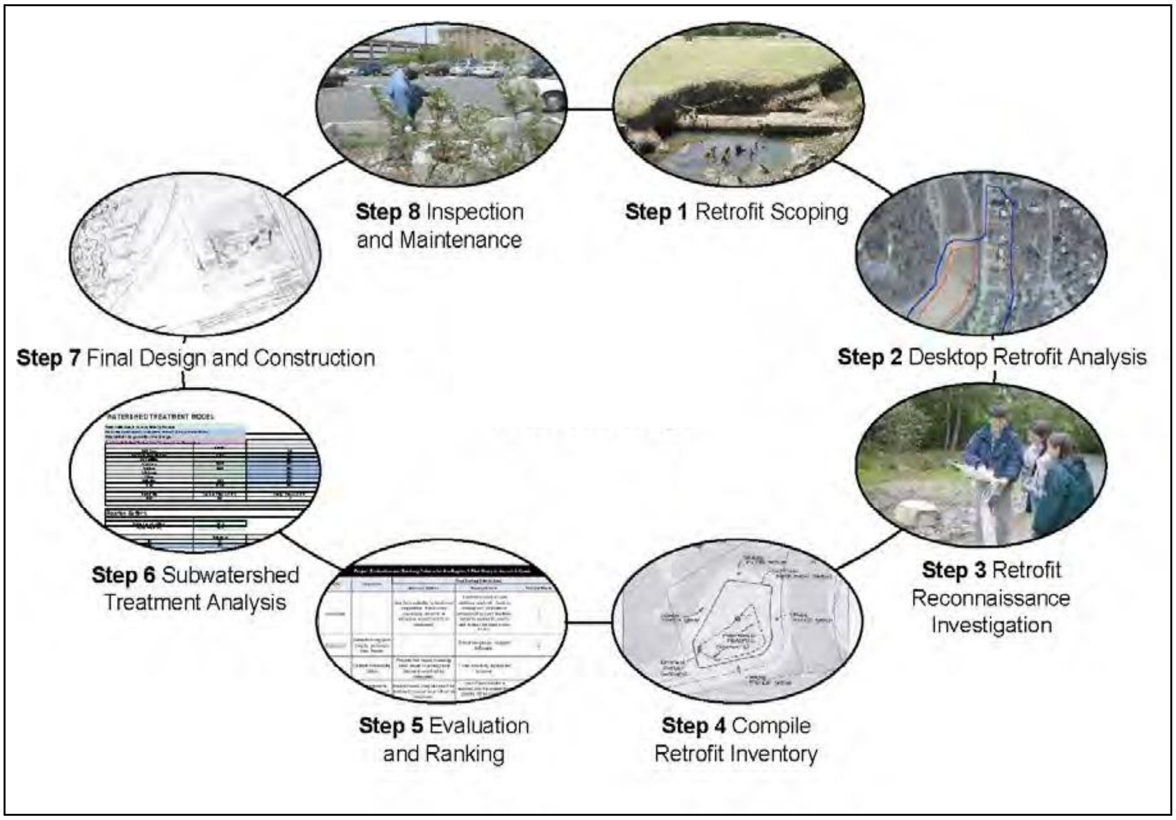


Figure 1.8: The eight basic steps of the stormwater retrofitting process.

1.8 Retrofit Economics

The first generation of retrofits primarily focused on demonstrating that retrofits could achieve restoration objectives, with little attention devoted to finding the least costly restoration solution. The next generation of retrofits, however, will need to demonstrate that they represent the most cost effective solution to the restoration problem they are designed to address. Appendix E contains an analysis of construction cost data from nearly 100 retrofit projects installed around the country. Some key findings on retrofit economics from the 2006 cost survey are shared below.

Retrofitting can be a costly enterprise. The cost to construct retrofits is 1.5 to 4 times greater than the cost to construct stormwater practices at new development sites. The extra costs for retrofits are related to site constraints, higher excavation costs, greater design complexity, more construction contingencies, additional engineering studies, enhanced landscaping and the experimental nature of many designs. Given that many retrofits are prototypes, it is expected that unit costs may decline in the future as contractors gain more familiarity with them.

There may be rare instances when retrofit costs can be based on new practice cost equations, but only when: land is abundant to provide maximum flexibility in site layout, site topography is such that a neutral earth balance can be attained and no major investments are contemplated for special plumbing, environmental permits, utility relocation or major landscaping. Appendix I presents new practice cost equations for retrofit sites that meet these rare conditions.

Figure 1.9 compares the median and quartile range in base construction cost for 18

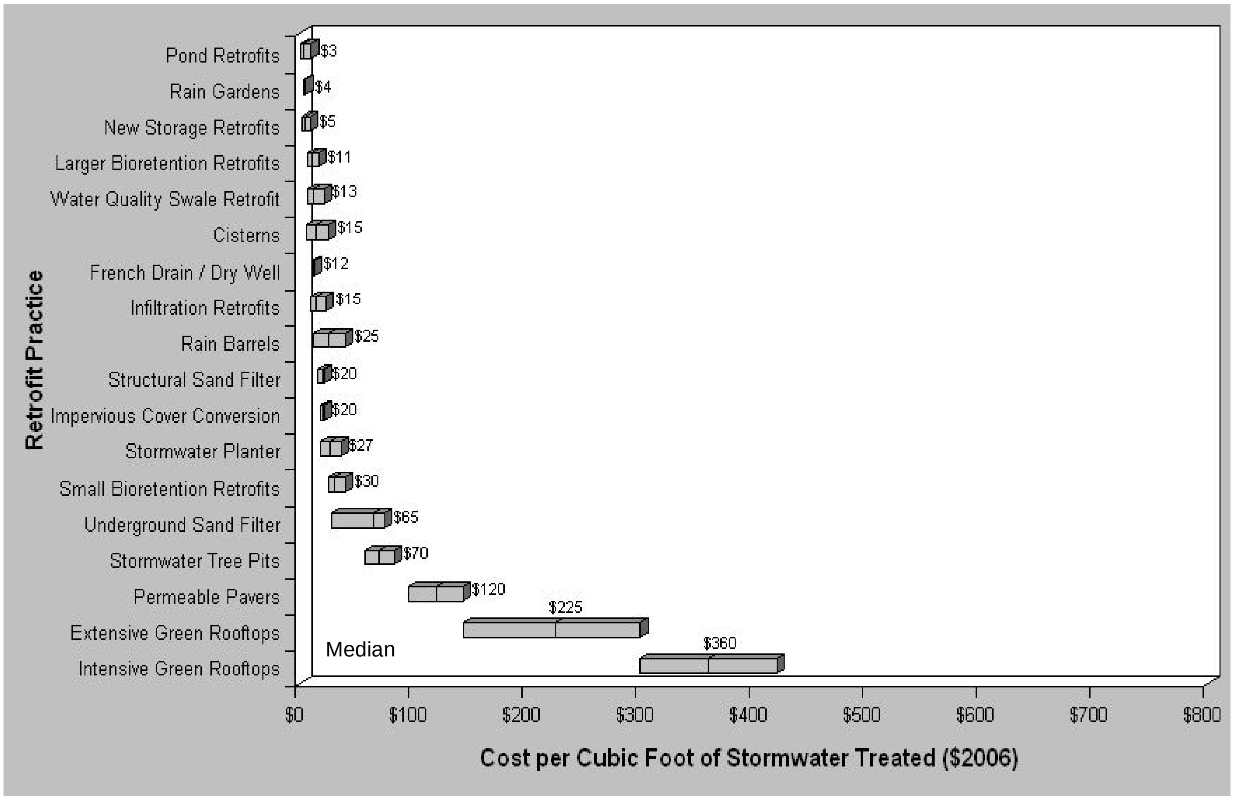


Figure 1.9: Range of base construction costs for various retrofit options.
(Note: Boxes show 25% and 75% quartiles; the line represents the median)

different retrofit techniques. As can be seen, pond retrofits, rain gardens and new storage retrofits are the least expensive to construct, whereas ultra-urban techniques such as underground filters, tree pits, permeable pavers and green rooftops are the most expensive. The design team should carefully review these unit costs during initial scoping to ensure they are targeting the most cost-effective retrofits in a subwatershed.

Storage retrofits are generally more cost-effective than on-site retrofits, primarily due to economies of scale related to the large drainage areas they treat. In general, retrofits serving the smallest drainage areas tend to have the greatest unit cost. This finding suggests that designers should try to exhaust all possibilities for storage retrofits in a subwatershed before they embark on an on-site retrofit approach.

Construction costs for the same retrofit technique can vary by two orders of magnitude. For example, the unit construction cost for the least and most expensive pond retrofits ranged from $1,350 to $107,000 per impervious acre treated. An even wider range was reported for bioretention retrofits ($2,000 to $327,000 per impervious acre). Designers should always look for key factors that can drive up the cost of retrofitting when they evaluate individual retrofit sites. A refined approach to calculate accurate cost estimates for individual retrofit projects is described in Appendix E.

The design and engineering (D&E) costs for both on-site and storage retrofits ranges from 32 to 40% of base construction cost (higher end when environmental permits must be secured). Total D&E costs for retrofits are higher than new stormwater practices, given their higher base construction costs. Land acquisition costs for all storage retrofits are assumed to be zero since they are generally constructed on public land. However, land acquisition costs must be added if land rights or easement need to be secured to build a project. On-site retrofits also have a hidden cost to persuade owners to install them on private land. The program cost to promote and deliver on-site retrofits may rival actual construction costs. Lastly, the retrofit costs shown here do not include the cost to find, assess and rank retrofits at the subwatershed level (see Chapter 4 for unit costs and scoping guidance).

The most important number is the aggregate cost to construct retrofits across an entire subwatershed. Returning to the 5,000 acre subwatershed example, assume that 70% retrofit coverage is desired. If it is further assumed that storage retrofits are used to obtain 80% of the subwatershed treatment and on-sites for the remainder, it is possible to get a sense of the number and cost of retrofits needed for the subwatershed (Table 1.9). At 10% subwatershed impervious cover, the retrofit bill is nearly $7 million and climbs to $20 to 40 million at higher levels of subwatershed impervious cover. While most communities spread out this investment over 5 or 10 years, it clearly underscores the need to devise creative retrofit delivery strategies to get the job done.

Table 1.9: Long Term Costs to Retrofit a 5,000 Acre Subwatershed

Subwatershed Impervious Cover	Impervious Acres Treated	Number of retrofits required	Base Construction Costs	Total Restoration Cost
10%	353	OS = 141 SR = 6	$1,582,500 $3,579,000	$6,700,000
30%	1,088	OS = 435 SR =17	$4,892,500 $10,965,000	$20,600,000
45%	1,650	OS = 660 SR = 26	$7,425,000 $16,740,000	$31,400,500
60%	2,194	OS = 878 SR = 35	$9,900,000 $22,000,000	$41,500,000

Assumptions:
- 50 acres treated per storage retrofits and 0.5 acre treated per on-site retrofit
- 70% of the entire subwatershed area to be retrofit
- 80% of the watershed is treated by storage retrofits; 20% is treated with on-site retrofits
- Storage retrofits are equally split between pond retrofits and new facilities
- 25% of on-sites are on residential land and 75% are non-residential sites.
- Cost per impervious acre treated are: $9,500 for pond retrofits; $15,500 for new storage facilities; $15,000 for residential on-sites; $25,000 for non-residential on-site retrofits
- Total cost includes D&E at 32% of base construction cost

1.9 Strategies to Deliver Retrofit Projects at the Subwatershed Level

Subwatershed retrofitting is a major long-term commitment where dozens or even hundreds of individual retrofit projects are built over a multi-year timeframe. As previously noted, retrofitting can be quite costly and is normally the single largest expense involved in watershed restoration. Given the large number of retrofit projects, their high cost and the long timeframe over which they are built, it is important to discuss the strategies on how retrofits can be delivered in a widespread manner.

This section describes a multi-pronged strategy to sustain public investment in retrofitting over many years. The strategy involves multiple ways to deliver retrofits on both public and private land (Figure 1.10). Many stormwater managers mistakenly believe that retrofitting primarily involves capital construction projects built on public land. Much greater subwatershed coverage, however, can be achieved by a creative combination of financing, education, subsidies, permit coordination and stormwater regulations. To some extent, the retrofit delivery methods are sequential in nature -- the first methods are easier to implement early; whereas, latter methods provide expanded treatment in the future.

Demonstration Retrofits are the usually the first retrofit delivery method. The best sites are located on public land that is highly visible or receives heavy foot traffic, such as community parks, greenway trails, local schools or the city hall. Severe municipal hotspots, such as public works yards, may also be good candidate sites. Demonstration retrofits are normally financed by state or federal water quality grants. Demonstration retrofits can be installed at any stage of the retrofit process, particularly when they can test a new or innovative retrofit technique.

Although demonstration retrofits serve only a small fraction of subwatershed area, they are an excellent early action project for several reasons. First, retrofits can educate residents about urban stream impacts and restoration potential through interpretive signs, tree planting and other stewardship measures. Second, demonstration retrofits show restoration partners and stakeholders what the retrofit "product" looks like, which helps to increase community acceptance for future projects. Third, demonstration projects enable local agency staff to gain valuable retrofit design and construction experience that can be used to deliver other retrofits later.

Retrofits on Public Land: The next retrofit delivery method involves construction of storage retrofit projects on public land in the subwatershed. These retrofits are typically located in stream valleys, parks, public right of way and publicly-owned stormwater infrastructure. Public land retrofits are easier to deliver because they do not require land acquisition and can provide community benefits. Storage retrofits are preferred because they can cost-effectively treat the greatest fraction of subwatershed area. Experience has shown that it is possible to treat as much as 30 to 50% of a subwatershed through public land retrofits, particularly if the community owns land in the stream corridor.

Most public retrofits are financed by long-term capital construction budgets dedicated to retrofits or waterway improvements. Consequently, it may take a decade to construct all of the feasible public land retrofits. This phase of retrofit delivery also requires an agency commitment to efficiently manage construction of multiple retrofit projects over time. Another good retrofit strategy is to integrate retrofits into ongoing municipal stormwater maintenance programs, particularly if the facilities are located on public land. The capital budget for stormwater maintenance can be modified to allocate funds to retrofit older ponds to improve their performance at the same time major maintenance problems are being corrected.

Encourage On-site Retrofits in Neighborhoods: This phase of retrofit delivery educates homeowners to persuade them to install low cost on-site retrofits on their property, such as rooftop disconnections, rain barrels or rain gardens. The most effective campaigns educate the public about need to restore watersheds, provide some simple construction tips, and direct interested residents where they can get more specific information and technical assistance. Local governments may wish to hire local watershed groups to "retail" technical assistance directly to neighborhoods and community associations. While it is doubtful that more than 5% of subwatershed residents will install on-site retrofits though education alone (Manual 8), the relatively low cost of the education program and its outreach and awareness benefits make it a good delivery investment at the outset of the retrofitting process.

Bundle Retrofits into Municipal Construction Projects: The next method incorporates retrofit delivery into other municipal construction capital projects. Communities are constantly investing in streetscaping, transportation projects, school construction, park improvements, water and

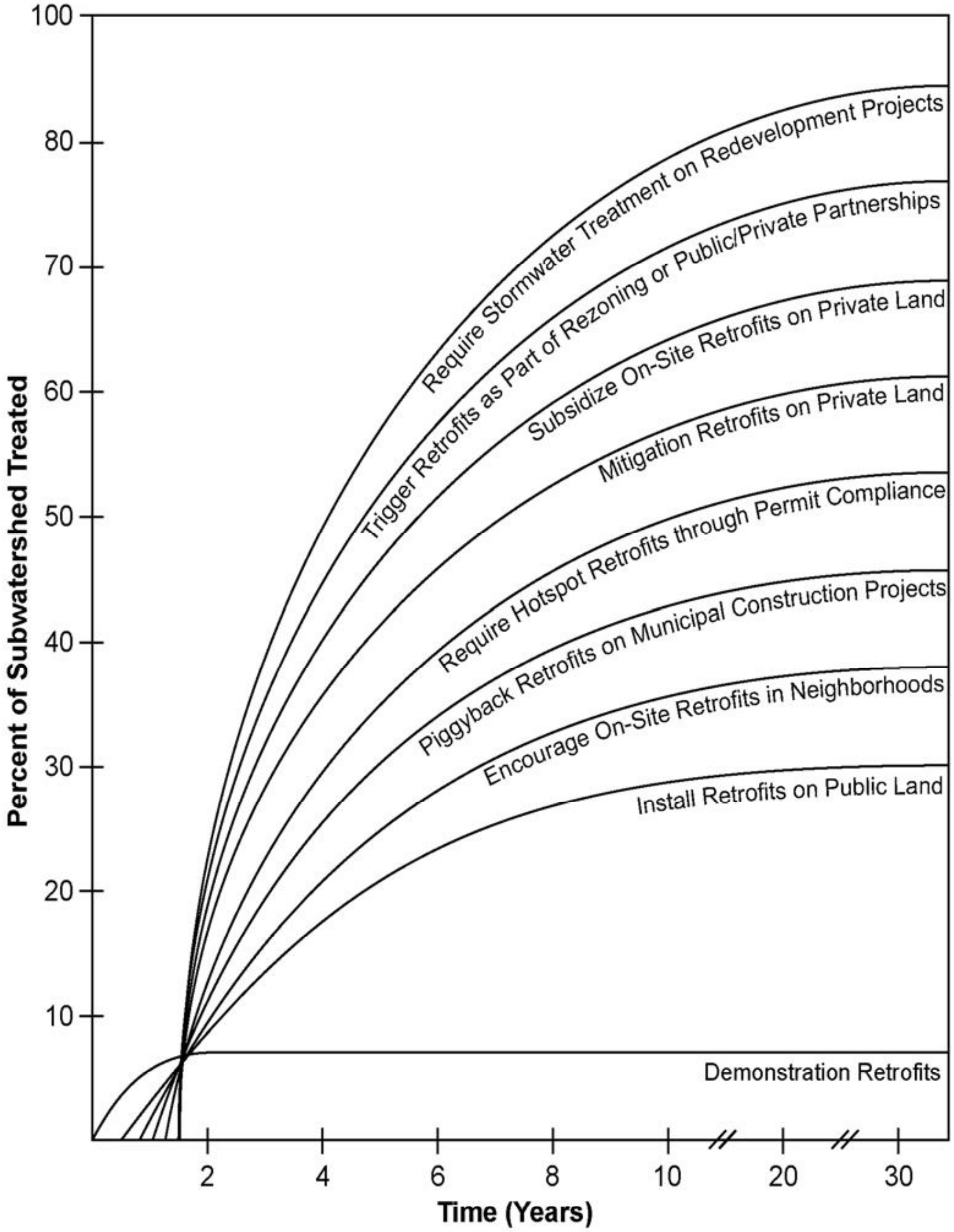


Figure 1.10.Ways to maximize retrofit delivery throughout the watershed

sewer line rehabilitation, drainage improvements and neighborhood revitalization. The strategy is to bundle retrofits into routine capital projects. In some cases, the match is relatively easy, e.g., including a storage retrofit as part of a culvert upgrade or installing water quality features into drainage improvements. Other bundled retrofits require much greater interagency education and coordination efforts since many agencies do not consider watershed restoration as part of their primary mission. The bundling strategy is definitely worth the effort since capital budgets for other municipal construction categories exceed water resource spending by a factor of 100 to 500 (U.S. Census, 2006). The largest municipal construction categories include schools, roads, water supply and wastewater treatment, parks and recreation and municipal building.

While some agencies may initially resist efforts to incorporate retrofits into their capital budgets, several recent trends may make it more appealing. First, many units of local government are now subject to municipal stormwater permits and are no longer exempt from treating the quality of the stormwater produced by their construction projects. Bundling retrofits into existing construction projects makes stormwater compliance easier. Second, municipal project managers are often subject to the same environmental permitting requirements as the private sector, and may find that constructing retrofits conveniently meets their off-site mitigation needs. Third, many communities have formally adopted policies to promote sustainable development and/or low impact design practices in their own municipal construction projects. Several progressive communities, such as Santa Monica, CA and Austin TX, have specified a minimum set-aside for construction of on-site stormwater retrofits in their municipal contracting process (CWP, 2006).

Require Hotspot Retrofits Through Permit Compliance: Stormwater hotspots deserve special attention when it comes to retrofit delivery, given their severe water quality impacts and unique regulatory status. The goal is to construct on-site retrofits to treat the quality of runoff from <u>all</u> severe stormwater hotspots in a subwatershed, using existing authority under industrial and/or municipal stormwater permits (see Retrofit Profile Sheet OS-7). The basic argument is that hotspot runoff violates water quality standards and warrants immediate treatment.

Hotspot retrofits are identified based on two systematic levels of subwatershed field inspection -- a Hotspot Site Investigation to identify severe hotspots (HSI- Manual 11) and a more intensive Hotspot Compliance Inspection to determine whether a structural retrofit is needed to treat hotspot runoff at the site (HCI- Manual 2). In this case, the cost of retrofitting is borne by the hotspot owner, although the locality may also incur costs to find them and enforce compliance.

Stormwater managers should carefully review their existing water quality or illicit discharge ordinances to determine if they actually possess the authority to inspect and enforce compliance over the full range of hotspot sites expected in a subwatershed. If not, local ordinances should be revised to provide for this manner of retrofit delivery. Since many hotspots are small businesses, communities should also consider non-regulatory tools to improve compliance, including employee training, technical assistance and even cost-sharing (see Manual 8).

Mitigation Retrofits on Public or Private Land: This method of retrofit delivery matches the mitigation needs of private and quasi-public entities to specific storage retrofits in the subwatershed. As might be imagined, this retrofit delivery method requires exceptional interagency communication and coordination. Developers, highway agencies, utilities and others often seek opportunities to meet off-site environmental mitigation needs (wetlands, water quality trading, stormwater fees or permit conditions). Existing projects in the subwatershed retrofit inventory can be extremely attractive to permit applicants since the feasibility of the projects is already established and they are located on public land.

Over time, stormwater managers should strive to integrate their retrofit program with any stormwater mitigation, water quality trading or wetland banking efforts that may exist in the community. Most water quality experts predict that water quality trading systems will be common in the future as a cost-effective way to meet TMDLs, wastewater permits or regional nutrient limits. Care should be exercised with mitigation retrofits since they have the potential to be a zero-sum gain, particularly when both the impact and the mitigation occur in the same subwatershed (i.e., the benefit of the mitigation is cancelled out by the impact from the mitigated project). Also, the retrofitting agency may be hesitant about inheriting costly monitoring or maintenance conditions specified in a mitigation permit.

Subsidize On-site Retrofits on Private Land: This retrofit delivery method involves targeted programs to subsidize landowners to install on-site retrofit practices on private land. Such programs go beyond mere education and normally include targeted direct technical assistance and economic incentives to make them happen. The cost of this retrofit delivery method may equal the cost of constructing several large storage retrofits, and may be financed either through grants, operating funds, or a line item in the capital budget.

About a dozen communities have subsidized on-site retrofit delivery at the neighborhood level, primarily to disconnect rooftop runoff from the combined sewer system. Neighborhood adoption rates as high as 15 to 50% have been reported, depending on the extent of the subsidy and the convenience of the retrofit (Profile Sheet OS-10). Economic incentives include direct cash subsidies, tax credits, discounts on water bills or stormwater utility fees, municipal installation, and provision of free rain barrels.

Trigger Retrofits as Part Public/Private Partnership: Local governments are often a major financial partner in redevelopment and rezoning projects designed to promote neighborhood or commercial revitalization. The community may subsidize development by granting payment in lieu of taxes, tax credits, low interest financing or parcel acquisition. Given the taxpayer investment in these development partnerships, the public should expect that these projects will incorporate sustainable stormwater practices and landscaping features to enhance their community benefit. Consequently, stormwater managers should maximize the use of on-site retrofits during urban design to make sure the final projects are compatible with the water quality goals of the subwatershed plan. These retrofit opportunities seldom appear in the retrofit inventory, so stormwater managers will need to frequently coordinate with local urban planners and economic development agencies to find the best targets of opportunity.

Require Stormwater Treatment for Redevelopment Projects: If a subwatershed still has considerable development potential, stormwater managers should make sure they are imposing the most stringent stormwater criteria possible so that increased pollutant loads generated by new development do not offset loads reduced through retrofitting. If existing stormwater quality criteria are outdated, stormwater managers should update local stormwater criteria to maximize pollutant removal performance.

The infill and redevelopment process provides an excellent opportunity to achieve stormwater treatment where it previously did not exist. The amount of subwatershed treatment that can be achieved by imposing redevelopment stormwater criteria is impressive over the long run. The urban landscape is in constant flux, with sites being continually vacated, demolished and redeveloped all the time. The same is true with public infrastructure. The design or service life of most structures and infrastructure is measured in decades, e.g., buildings (50 to 60 years), parking lots (20 to 30 yrs), bridge decks (40 to 50 yrs) and drainage infrastructure (30 to 50 yrs).

Thus, over several decades, it is quite likely that a sizeable fraction of every subwatershed will undergo redevelopment, infill, or infrastructure rehabilitation. Each of these represents an opportunity to retrofit stormwater treatment into the urban landscape. Therefore, an effective retrofit delivery strategy requires redevelopment and infill projects to address stormwater treatment in some manner. Guidance on developing effective and flexible stormwater treatment criteria for redevelopment projects can be found in CWP (2007).

Most communities are reluctant to impose more stringent stormwater criteria because of the small size, sharply higher compliance costs, and physical constraints facing redevelopment projects. While on-site compliance is difficult, it does not imply that stormwater treatment criteria should be waived. Rather, it means that special stormwater criteria need to be developed for redevelopment projects that provide incentives to reduce impervious cover, increase forest cover, or promote the use of smart site practices during redevelopment (CWP, 2004a).

Local stormwater managers may want to consider a fee-in-lieu approach at redevelopment and infill sites. The basic concept is to waive on-site stormwater requirements in exchange for a fee that is used by the local stormwater authority to build retrofit storage elsewhere in the subwatershed. The fee is usually derived based on the cost to retrofit an equivalent acre of impervious cover using a more economical storage retrofit. In other cases, the fee-in-lieu is based on the average cost to remove a pound of nutrients. Several communities have adopted a fee-in-lieu as an equitable and cost-effective way to treat runoff from small urban sites. Guidance on setting an appropriate fee schedule can be found in Winer (2003).

Chapter 2: 13 Subwatershed Locations Near You

This chapter outlines some practical ways to find retrofit storage in 13 different locations in a subwatershed. Thirteen profile sheets describe how to find, assess, design and construct retrofit storage. This locational approach to retrofits helps designers to envision restoration opportunities throughout urban subwatershed. Figure 2.1 illustrates the best locations for both storage and on-site retrofit practices. Each location presents different opportunities and challenges to successfully obtain retrofit

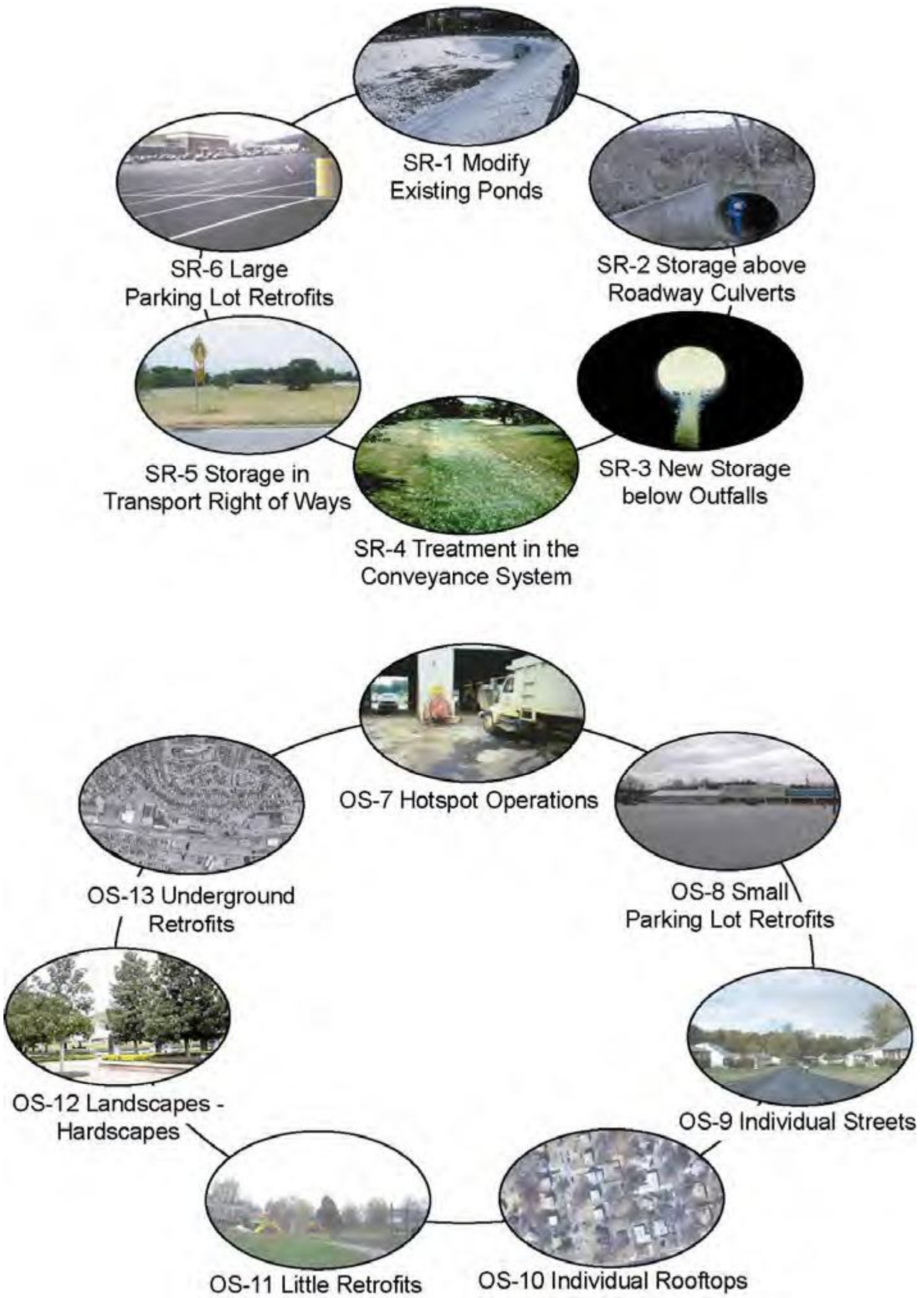


Figure 2.1: Various locations for both storage and on-site retrofits

storage. Table 2.1 compares differences between each retrofit location, in terms of how easy they are found, simplicity of design, ease of permitting/approvals and treatment costs. As can be seen, storage retrofits are generally easier to find and have low treatment costs, although their design and permitting is more complex. By contrast, most on-site retrofits are harder to find and have moderate to high treatment costs, although they are generally easier to design and get permitted.

The retrofit team should carefully choose which subwatershed retrofit locations to investigate when scoping their initial retrofit effort. The general capability of each retrofit location to provide various kinds of stormwater treatment is depicted in Table 2.2.

Table 2.1: Comparison of Retrofit Locations				
Subwatershed Location	Retrofit Design Issue			
	Easy to find from desktop?	Simple to design?	Easy to get permits?	Low treatment cost?
SR-1 Add Storage to Existing Ponds	●	○	◉	●
SR-2 Storage Above Roadway Culverts	●	○	○	●
SR-3 New Storage Below Outfalls	◉	○	◉	◉
SR-4 Storage In the Conveyance System	◉	○	◉	◉
SR-5 Storage in Transport Right-of-ways	●	○	◉	●
SR-6 Storage Near Large Parking Lots	●	○	◉	◉
OS-7 Hotspot Operations	○	◉	●	○
OS-8 Small Parking Lots	◉	◉	●	◉
OS-9 Individual Streets	○	◉	●	○
OS-10 Individual Rooftops	○	R● N◉	R● N◉	R◉ N○
OS-11 Little Retrofits	○	●	●	●
OS-12 Landscapes/Hardscapes	○	●	●	◉
OS-13 Underground	○	○	◉	○
Key: ● Yes ◉ Moderate ○ No R = Residential N = Non-residential				

Table 2.2: Retrofit Options and Stormwater Treatment Provided				
Subwatershed Location	Stormwater Treatment Provided			
	Water Quality	Runoff Reduction	Channel Protection	Flood Control
SR-1 Add Storage to Existing Ponds	●	○	●	○
SR-2 Storage Above Roadway Culverts	●	○	●	◉
SR-3 New Storage Below Outfalls	●	◉	◉	◉
SR-4 Storage In the Conveyance System	●	◉	◉	◉
SR-5 Storage in Transport Rights-of-ways	●	◉	●	◉
SR-6 Storage Near Large Parking Lots	●	◉	●	◉
OS-7 Hotspot Operations	●	○	○	○
OS-8 Small Parking Lots	●	●	◉	○
OS-9 Individual Streets	●	●	◉	○
OS-10 Individual Rooftops	◉	●	○	○
OS-11 Small Impervious Areas	●	●	○	○
OS-12 Landscapes/Hardscapes	●	◉	○	○
OS-13 Underground	●	◉	○	○
Key: ●Full ◉ Partial ○ Rarely				

Each retrofit profile sheet follows a common organization:

Basic Description – This section describes where the retrofit fits into the landscape, how it works, and which stormwater treatment options are most commonly used.

Ideal Conditions for the Retrofit – This section notes the site conditions that lead to a successful retrofit at that location.

Situations Where the Retrofit Is Difficult – This section outlines common site constraints that can indicate a retrofit is difficult or impossible to implement at that location.

Alternative Restoration Projects – This section outlines alternative restoration projects that may be worth pursuing when a retrofit is not feasible at a site.

Desktop Searches for Good Locations- Simple GIS and mapping tricks can help narrow down the list of potential subwatershed retrofit locations to a manageable number. This section presents guidance on how to quickly and efficiently find candidate retrofit sites to investigate in the field.

What to Look For When Investigating Sites – This section provides field crews with step by step guidance on how to investigate retrofit feasibility in the field. Detailed tips are offered on how to determine available treatment area, assess site constraints and develop a concept plan.

Typical Feasibility, Approvals and Permitting – Many hurdles must be overcome to build retrofit projects. This section outlines the most common feasibility, approval and environmental permits that come into play at each location, along with tips and strategies to secure them.

Retrofit Design – This section outlines key issues for the team to consider in the retrofit design process and the range of special studies that are needed to support it. The section concludes with a step by step design process for each retrofit location.

Construction Considerations – Retrofit construction is always challenging. This section helps designers anticipate and address common construction problems at each retrofit location.

Retrofit Delivery Issues – Many on-site retrofits are needed to make a difference in a subwatershed, so this section presents effective strategies to deliver them on a widespread basis. Tips are also given on how to multiply on-site retrofit delivery through education, incentives, and out-sourcing methods.

Construction Cost – Each retrofit location has a unique construction cost, which must be understood to rank and prioritize the most cost-effective retrofits for a subwatershed. This section presents median retrofit construction cost estimates to use for planning purposes during concept design. Cost ranges are also presented, along with site-specific factors that can increase or decrease the cost of individual retrofits to further refine cost estimates.

SR-1 | Storage Retrofits

MODIFY EXISTING PONDS

The first place to look for retrofit storage is within existing ponds. Stormwater ponds are an extremely attractive retrofitting target, particularly when they have existing dry detention or flood control storage. The most common approach is to combine extended detention, wet pond or constructed wetland storage to improve water quality. In other cases, bioretention can be provided in the bottom of dry ponds. Some ponds may have enough capacity to provide Cpv to protect downstream channels from bank erosion. Even modern ponds can be enhanced by retrofits.

Five strategies can be used to retrofit storage into an existing pond:

- Excavate the pond bottom
- Raise the embankment
- Modify the riser
- Steal existing flood control storage
- Fix internal design geometry and/or add forebay

Designers often combine several strategies together to enhance the performance of existing ponds (Figure 1).

Pond retrofits are ideal since land costs are minimal, and construction costs are about 40% less than a new retrofit pond. In addition, since the land is already devoted to stormwater management, most easements are already in place. Pond retrofits also need fewer permits and approvals compared to other storage retrofits. Pond retrofits are often favored by adjacent residents since

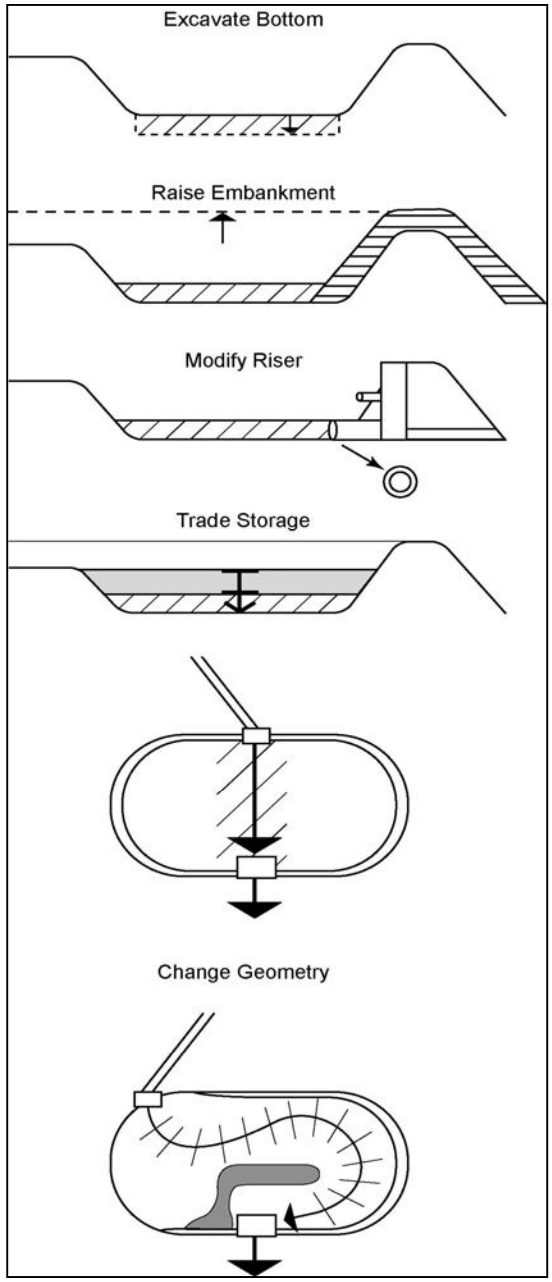


Figure 1: Five strategies to retrofit a pond

they correct maintenance problems and improve pond appearance.

Ideal Conditions for Pond Retrofits

The following types of ponds are ranked in descending order of retrofit potential.

- Regional flood control or detention ponds
- Dry stormwater detention ponds
- Dry extended detention ponds
- Farm and ornamental ponds
- Public golf course ponds
- "Modern" stormwater quality ponds

Another way to analyze pond retrofit potential is to understand the different eras and corresponding design standards under which ponds were built in a community over time. The precise evolution of stormwater pond design differs in each community and should be investigated during the retrofit scoping process. Most communities have followed the following general sequence of stormwater management. Stormwater systems constructed prior to 1970 were primarily comprised of underground pipes, with limited surface land devoted to a few large flood control projects. Between 1970 and 1990, however, many communities built large stormwater detention ponds to control peak flood discharges. Detention ponds in this era often have great retrofit potential for water quality or even channel protection (Figure 2).

Ponds constructed in recent years were designed to treat stormwater quality, and therefore have less retrofit potential. They are still worth investigating, however, since many suffer from basic design flaws that impair their performance (single cells, multiple inlets, short-circuiting, short flow paths and lack of wetland features). Indeed, synoptic studies of recent stormwater ponds constructed in the field suggest that as many as 90% of "modern" ponds have significant design flaws (Figure 3).

Situations Where Pond Retrofits Are Difficult

Several conditions can make it hard to retrofit a pond:

- Older and/or highly urban subwatersheds where development occurred prior to the advent of stormwater pond requirements
- Dry ponds that have utilities running through the pond bottom or are used for dual purposes (e.g., recreational ball fields)
- Older ponds that have lost their original flood storage capacity due to additional upstream development, sediment deposition or both
- Stream corridors with flood prone structures present in the flood plain
- Landlocked ponds that cannot be accessed by construction equipment

Figure 2: Older stormwater detention ponds are an attractive retrofit target

Figure 3: The performance of many “modern” ponds can be improved through retrofitting

Alternative Restoration Practice at Pond Sites

Even when a pond retrofit is not feasible, other restoration practices may be suitable for the site:

- Tree planting within acceptable portions of the pond and its buffer (Cappiella *et al*., 2006a)
- Planting wetland plant species in pond benches
- Notifying owner to perform maintenance tasks to restore pond function
- Including the pond in a local Adopt-a-Pond program (Sturm, 2003)

Desktop Searching for Pond Retrofits

Pond retrofit sites can be quickly found if a community has a good GIS database that shows surface land devoted to stormwater practices. These maps should be closely scrutinized to look for ponds with contributing drainage areas greater than 5 acres. Some communities lack maps or databases of their stormwater infrastructure.

In these situations, pond retrofit sites can be discovered by analyzing recently flown aerial photos (Figure 4).

Dry ponds are among the best retrofit sites, so the presence of water alone is not always a good retrofit indicator. It is helpful to define the age of subwatershed development to find areas built within a particular stormwater design era that is well suited for retrofitting. Some designers go further and analyze topography at potential pond sites to get a first estimate of the contributing drainage area.

Once a subwatershed has been scanned for decent pond sites, the next step is search through local stormwater agency files to see if original as-built drawings or design computations exist. Few communities have digitized pond design review files for older ponds that are best suited for retrofits. Some designers may put off this search until after

Figure 4: Dry ponds are easy to pick up on fine resolution aerial photos

the field reconnaissance to ensure that a pond retrofit is indeed feasible for the site.

What to Look for when Investigating a Pond

The first step during a retrofit reconnaissance is to check out the existing plumbing of the pond and compare it to as-built drawings, if they exist. The crew should quickly check the:

- Condition and elevation of pond inlet(s), internal flow path, outlet, riser and emergency spillway.
- Condition of pond outlet to determine if it is damaged or prone to clogging.
- Changes in the pond since it was originally constructed, such as excessive sediment deposition, maintenance problems or woody growth.
- Physical integrity of the dam or embankment, looking for signs of seepage, settlement, sloughing or animal burrows.

Next, the crew walks above and below the pond to:

- Look at upstream pipes or channels for possible headwater effects
- Look downstream of the pond outfall for possible scour problems to correct
- Quickly verify the contributing drainage area, particularly when multiple inlet pipes are present.

The last step of the pond reconnaissance involves choosing which combination of the five pond retrofit strategies will produce the most cost-effective treatment storage. The crew evaluates the feasibility of each retrofit strategy by looking at:

Excavating the pond bottom – The crew checks the bottom of the pond to see if it can be excavated to provide more storage. The ideal situation is a dry, flat pond bottom with no evidence of standing water. Use a soil auger to check for moisture and presence of hydric soils.

Raising the embankment – The crew looks for available space at the toe of the embankment to determine if there is enough room to support the wider footprint needed to raise embankment height. The crew should also quickly check the proposed new embankment elevation against the invert elevation of pond inlet pipes to assess potential for tailwater problems.

Trading storage – The crew then looks for multiple riser outlets which may indicate detention storage for design storms in the 2 to 25 year range (Figure 5). In many cases, the storage for these design storms can be converted to provide water quality treatment.

Modifying the pond riser - The best situations are dry detention ponds that have a large diameter low flow outlet that can be constricted by attaching an orifice plate, an anti-vortex device and appropriate trash rack. A weir wall can also be used to provide the restriction (Figure 6). If a concrete riser is present, check to see if more weir capacity is needed to pass larger overbank and extreme storms. Try to get a general sense whether the existing detention pond is over-sized.

Modifying internal design – The crew should check to see whether the internal flow path can be extended, wetland elements added, or a forebay installed.

Figure 5: Multiple outlets are a clue that storage trading is a possibility

Figure 6: A dry pond retrofit may include the installation of a weir wall

Feasibility, Permitting and Approvals for Pond Retrofits

Pond retrofits normally involve fewer environmental permits and landowner approvals than other storage retrofits, but may require several analyses.

Since retrofits will modify pond hydraulics, designers often need to secure dam safety permits, particularly if the dam hazard classification changes or the dam was never permitted to begin with. Pond safety standards vary regionally, so check with the appropriate local or state dam safety review authority. In many cases, dam safety criteria may have changed since the pond was originally built, so significant upgrades to the riser, embankment or emergency spillway may be needed to conform to newer and more stringent standards.

Pond retrofits that require conversion of flood storage into water quality storage may result in partial loss of 2, 5 or 10 year peak discharge control. While this may not materially affect the pond's flood control function, designers will need approval from the local stormwater review authority. The authority may require additional hydraulic modeling to ensure that proposed retrofit will not harm downstream property or structures. A dam breach analysis may also be required.

Landowner permission may be needed to retrofit privately-owned ponds. Owners may be willing to grant permission, since the land is already dedicated for stormwater, prior easements may exist, and the retrofit may upgrade the condition of the existing pond.

If the pond retrofit converts dry storage to wet storage, it is important to determine whether an adequate water balance exists to maintain a permanent pool at a constant water elevation. Under-sized pond retrofits that have fluctuating water levels are unsightly and may create nuisance problems. Converting dry storage into wet pond and/or constructed wetlands can also create real or perceived concerns about mosquitoes, drowning, tree loss and resident geese on the part of adjacent residents and landowners.

Some responses to these concerns are provided in Chapter 4.

Designers should not automatically assume that pond retrofits do not require wetland, waterway disturbance or forest conservation permits. Portions of older ponds may have evolved into forest or wetlands, so check with local and/or state permitting agencies to determine their current regulatory status. While utility conflicts are not common in most ponds, sewers may exist underneath (Figure 7).

The feasibility of pond retrofits that rely on excavation is often a matter of earthwork balance. Some designers will prepare a rough grading plan during concept design to determine whether earthwork balance at the proposed retrofit is reasonable by looking at the proposed depth of grading and the required minimum pond side slopes that must be maintained.

Pond Retrofit Design Issues

Pond retrofits have unique design issues compared to new pond construction:

Pond retrofits are challenging when there is limited room to squeeze in the target WQv storage and also include modern pond design features. Forebays, micropools and benches all tend to reduce the already limited treatment volume available at the pond retrofit. As a general rule, designers should compromise on storage before they dispense with design features related to performance, maintenance access or safety. Examples of good pond retrofits that incorporate key design features are shown in Figures 8 and 9.

Figure 7: Conflict with a major sewer was avoided by using a berm and a three cell design in this retrofit.

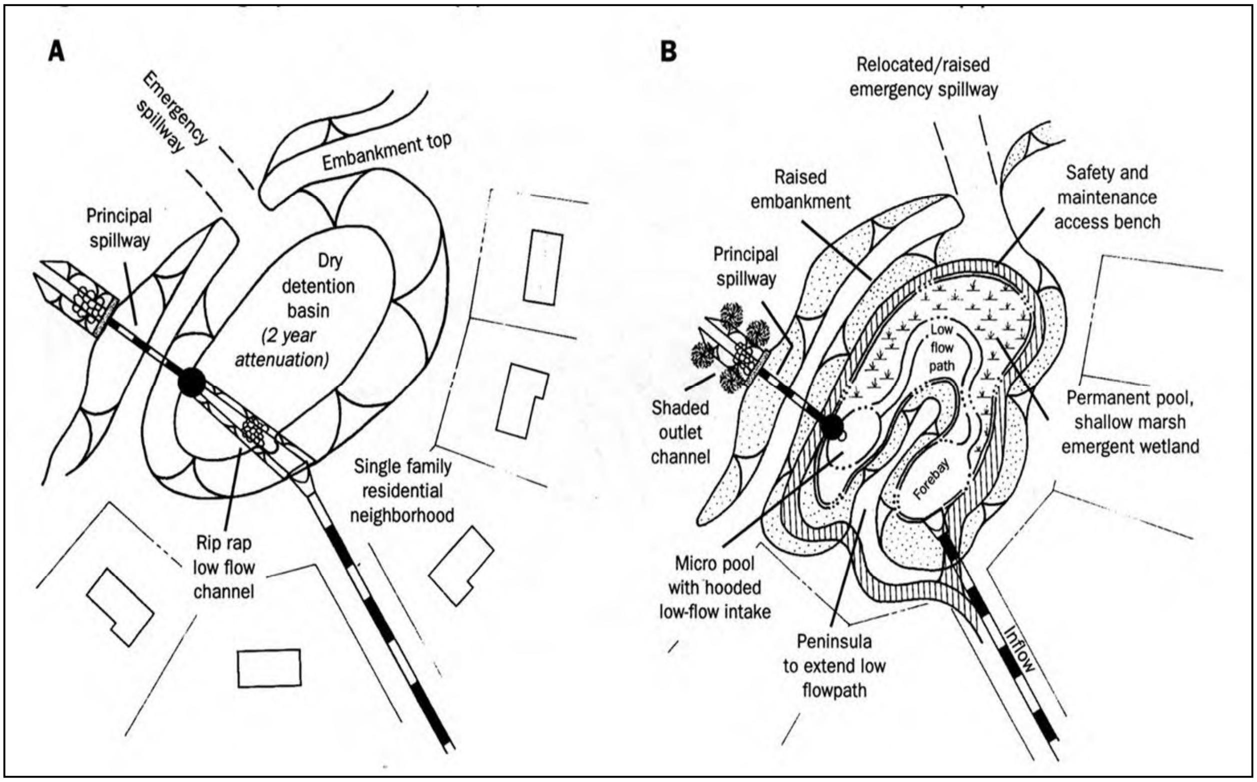


Figure 8: Schematic showing conversion of a dry pond to a shallow marsh

Figure 9: The Rolling Stone retrofit: before and after

Earthwork balance is often tough at pond retrofits since there is little room to spoil excavated material on-site, and soggy soils may not be suitable for embankment fill. Designers need to be creative in keeping material on-site, since off-site hauling of wet sediments can be very expensive. Designers should look for areas at the site where excavated sediments can be de-watered prior to spoiling or hauling. Pond retrofits should include access roads to enable heavy equipment to reach forebays and outlet works to perform maintenance. Designers should avoid using ED as the sole stormwater treatment option at a pond retrofit site. Extensive pond and buffer landscaping should also be a design priority to enhance neighborhood acceptance. Pond retrofits should include signs to educate residents about the stream protection benefits they provide.

Most research suggests that ponds do not cause major mosquito breeding problems and can provide habitats for their predators. Still, designers should include measures that maintain constant outflows, create habitat for predator fish, and provide aquatic benches to support emergent vegetation.

Designers may need to secure temporary or permanent easements for construction and maintenance access, if they were not reserved as part of original pond construction. Pond retrofits can alleviate chronic maintenance problems at failing stormwater practices. Figure 10 shows how a clogged infiltration basin was converted into an extended detention pond with a micropool.

Design Support

Soil borings generally make or break a pond retrofit, and reveal important clues about their feasibility and cost. Soil borings help:

Figure 10: Retrofitting can improve the function of this failed highway practice.

- Ascertain the physical characteristics of excavated material
- Determine its adequacy for use as structural fill or spoil
- Define the depth to groundwater and/or bedrock
- Provide data to develop structural designs for outlet works (e.g., risers and weir walls).
- Determine potential excavation problems and issues with embankment integrity

Several soil borings should be taken along the embankment and the bottom of dry ponds. Soil cores may be needed to ascertain the quality and consistency of bottom sediments in wet ponds.

Other design support needed for modeling pond retrofits includes:

- Updated aerial photos to define the land cover for the contributing drainage area (particularly if it has changed since the pond was first constructed).
- Surveys to define current hydraulic cross-sections of the storm drain network leading to the pond.
- Survey crews may need to establish the current bathymetry, storage and pipe/riser elevations for the pond, if as-built drawings do not exist.

Pond Retrofit Design Process

The retrofit design process analyzes the existing hydrologic and hydraulic characteristics to find opportunities to obtain greater WQv and Cpv storage. Some examples of retrofits created by reallocating storage are shown in Figure 10.

The complexity of the pond retrofit design process depends on the nature of the proposed pond alterations. For example, retrofits that merely install forebays or trash racks, or plant wetland benches do not require detailed retrofit design. Any retrofit that reduces existing flood control storage volume, changes pond storage allocations, alters water elevations, or influences riser performance should undergo the following basic design process:

Step 1: Determine the design objective for the retrofit (e.g., WQv and/or Cpv). Analyze the original design computations/plans to determine the original design objectives for the existing pond (e.g., 2 year, 10 year, 100 year peak discharge control). Check with local review authority to determine whether any existing peak discharge storage can be converted into WQv storage. Existing storage can be reallocated to WQv and Cpv storage as long as it does not create unacceptable downstream flooding conditions. The designer should consult with the local stormwater review authority to determine the hydraulic/hydrologic modeling requirements, as well as the appropriate design storms.

Step 2: Compute the target WQv and/or Cpv storage volume for the proposed retrofit (in acre-feet), based on current drainage area and impervious cover.

Step 3: Determine which combination of the five pond retrofit strategies can be employed at the retrofit to achieve the desired target storage volume. This is done iteratively by analyzing contours of new pond dimensions created by excavation or analyzing the pond's existing stage/storage/discharge curve. Once the designer is confident that the target volume can be obtained, they can begin pond modeling.

Step 4: The designer should analyze existing pond computations to create a new model. Model inputs may need to be updated to reflect changes in contributing drainage area, land use, or storm drain infrastructure leading to the pond. In addition, the original pond dimensions and water surface elevations may need to be revised if topographic or bathymetric surveys indicate they have significantly changed. This is particularly common for older wet ponds where past sediment deposition may have reduced pond capacity.

Step 5: Model the hydrology and hydraulics of the existing pond using the new input deck to determine if it still meets current stormwater and dam safety criteria.

Step 6: Redo pond contours (if re-grading or excavation is anticipated), modify riser dimensions and alter appropriate water surface elevations to conform to the proposed retrofit. Check to make sure they collectively meet target volumes.

Step 7: Route the appropriate design storms through the new pond retrofit and analyze effect on riser performance, water surface elevations, and downstream flooding conditions. This is normally an iterative process.

Step 8: Provide specifications for retrofit design features

Construction Considerations for Pond Retrofits

The construction sequence for pond retrofits can be fairly complex and include the following elements:

- Check construction access routes to the retrofit to determine if any curbs, pavement, manholes, landscaping or other site features will be disturbed during construction and will require repairs.
- Pond retrofits often have limited space for temporary stockpiling and construction staging. In some cases, there may be no alternative but to store equipment within the pond, which may increase the risk that it will be damaged during flood events.
- Clearing/grubbing may be needed for construction access if trees have grown up because the pond has not been regularly mowed.
- Dewatering of bottom sediments and pumping are needed at many pond retrofits to manage groundwater inflow during the excavation process (Figure 11). The proper disposal of these muddy waters must be addressed in the erosion and sediment control plan.
- Temporary diversion of both stormwater runoff and baseflow is generally needed during construction. Cofferdams can be constructed within the pond to isolate construction areas and bypass pond inflows.

Figure 11: Dewatering is needed to excavate bottom sediments.

- A complex construction sequence is needed when embankments are reinforced or outlet structures are replaced. The erosion and sediment control plan will need to be carefully phased to prevent pond sediment from being discharged.

- Fencing and signs should be posted around the limits of disturbance and staging areas to minimize public access during construction.

- If the retrofit forebay is under-sized, accelerate the sediment removal schedule in the maintenance plan (Figure 12).

Typical Costs for Pond Retrofits

Construction cost can be challenging to calculate for pond retrofits, although modifying an existing pond is generally cheaper than constructing a new pond. A planning level cost estimate for converting an existing dry pond into a wet pond or constructed wetland is provided in Table 1. Costs will also vary from region to region based on prevailing labor rates. Several site factors that tend to drive up or reduce construction costs are detailed in Table 2.

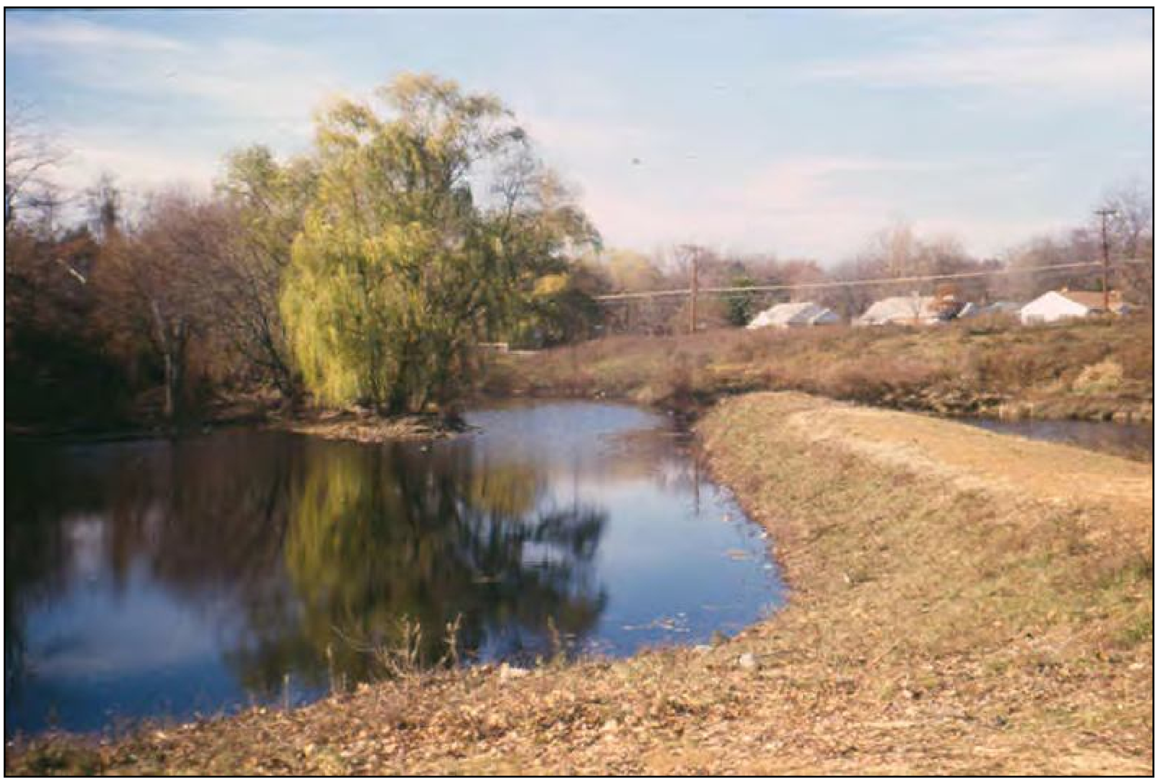


Figure 12: This under-sized forebay filled up with sediment within five years of retrofit construction.

Table 1: Estimated Construction Costs for Pond Retrofits (2006 $/impervious acre treated)			
Retrofit Type	**Median Cost**	**Range**	**Design & Engineering (%)**
Modify Existing Pond [1]	$ 11,150 [2]	$ 3,600 to $37,000	32 [3]

[1] Does not apply to simple changes in pond geometry or enhanced pondscaping
[2] Adjust based on site-specific construction cost inflators/deflators in Table 2
[3] Use a 40% value in major environmental or dam safety permits are needed

Table 2: Site-Specific Factors that Influence the Cost of Pond Retrofits	
Factors that Decrease Cost	**Factors That Increase Cost**
• Available weir space • Neutral earthwork balance • Simple adjustment to low flow pipe in riser • Existing pond is dry • No major changes to riser or embankment • 2 or 10 year storage can be sacrificed • No utility conflicts • Wide setback from pond to structures • No wetland or in-stream permits needed • Existing access is adequate	• Changes to concrete risers or replacement • Need to haul excavated material offsite or import fill to the site • Working in-stream/pond baseflow • Existing pond is wet or has saturated soils; dewatering needed to excavate bottom • Change in dam safety classification • Embankment reinforcement needed • Land-locked ponds with poor access • Wetland mitigation needed for project • New access ramps must be installed

SR-2

Storage Retrofits

STORAGE ABOVE ROADWAY CROSSINGS

Road crossings can be modified to provide temporary water quality storage above an existing road culvert. Storage is obtained by installing a new embankment above the crossing to get "free" storage (Figure 1). The new embankment protects the roadway embankment from seepage effects. Available storage can also be increased by excavating areas adjacent to the upstream channel. In general, crossing retrofits are applied to non-perennial stream channels to avoid permitting problems (i.e., zero and first order streams).

A control structure is normally installed through the new embankment that connects with an upstream micropool (Figure 2). The control structure typically consists of a gabion or concrete weir or a riser/barrel. The micropool has a small permanent pool sized to be at least 10% of the total WQv.

Extended detention, constructed wetlands and wooded stormwater wetlands are recommended treatment options for crossing retrofits (see Figure 3). Road crossings may also contain enough storage to provide channel protection storage. Crossing retrofits are ideal because they take advantage of free upstream storage, which reduces excavation costs. Crossing retrofits are complicated because many environmental permits and landowner approvals are needed to construct them.

Ideal Conditions for Crossing Retrofits

The best situation for a crossing retrofit is when:

- The existing culvert has sufficient hydraulic capacity to pass desired storm flows.
- Upstream land is in public ownership .
- Channel has ephemeral flow (e.g., zero or first order stream).
- Upstream channels are low gradient, are connected to the floodplain, and have short streambanks.
- The retrofit is timed to coincide with scheduled repair/replacement of the existing culvert.
- The retrofit is upstream of a proposed stream restoration or wetland mitigation project.

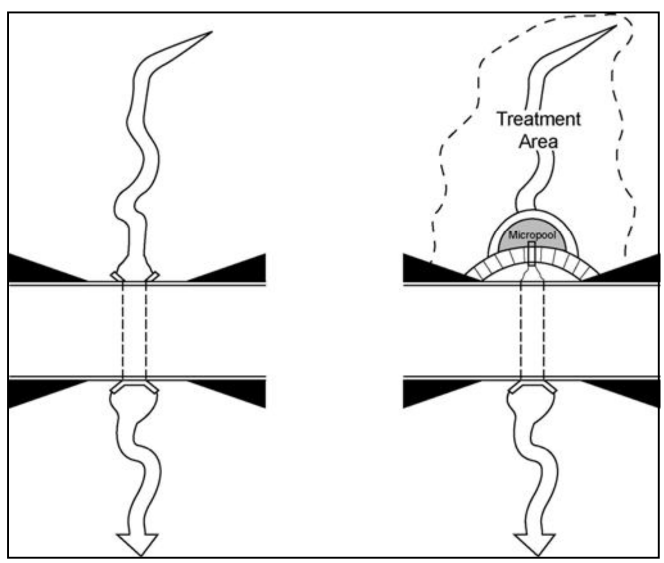


Figure 1: Strategy for getting free storage above a road crossing

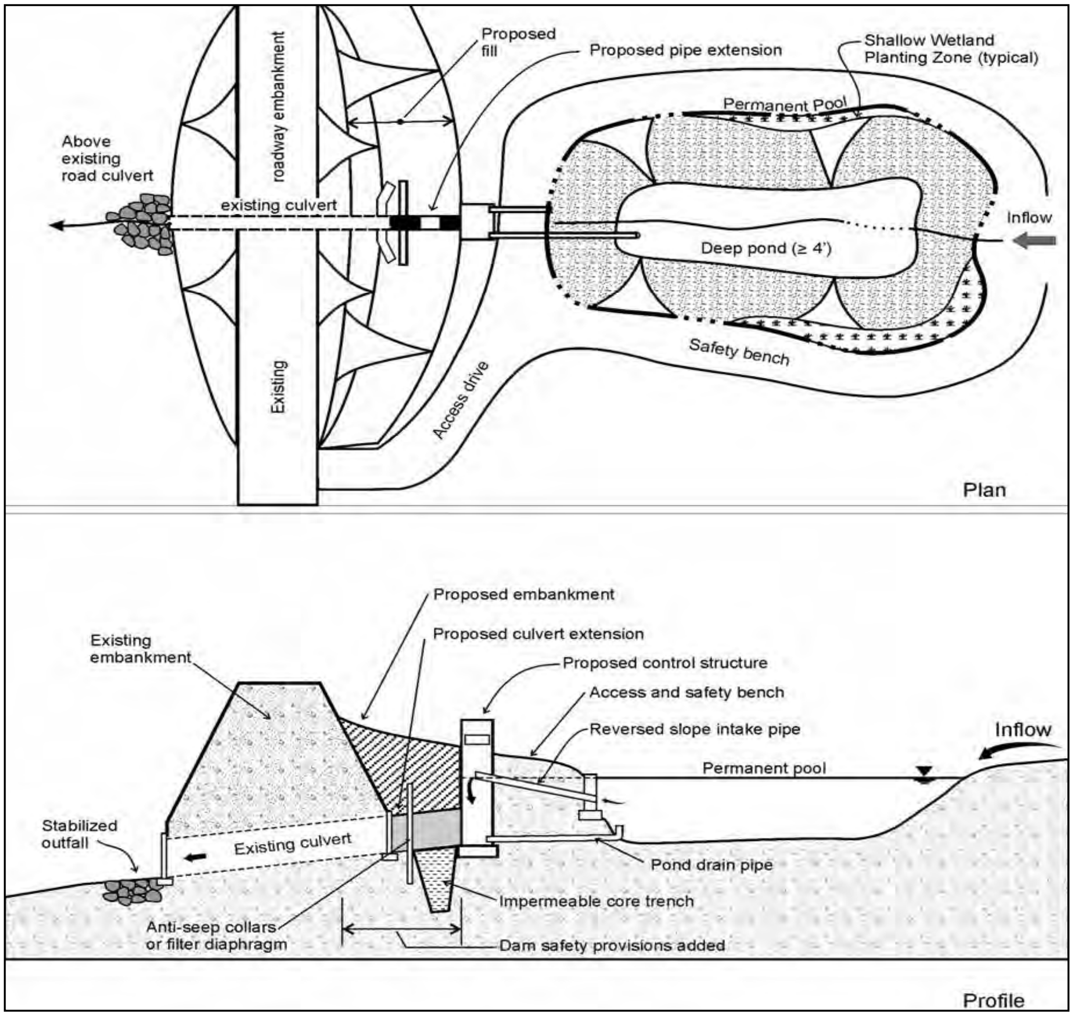


Figure 2: Typical plan and profile of crossing retrofit showing secondary embankment

Situations Where Crossing Retrofits are Difficult

Crossing retrofits are generally not a good option when the:

- Existing culvert lacks hydraulic capacity but is not scheduled for replacement.
- Stream has perennial or intermittent flow (e.g., second order stream or larger) or is used by migratory fish.
- Proposed upstream storage area contains high quality wetlands or mature forests.
- The project storage area contains sewer lines or other utilities that often run adjacent to streams or parallel to the road.
- Contributing drainage area to the crossing is greater than 250 acres
- Upstream channel has a steep gradient, is deeply incised, or has a confined floodplain.
- Existing structures encroach into the floodplain and would be subject to a greater flooding risk.

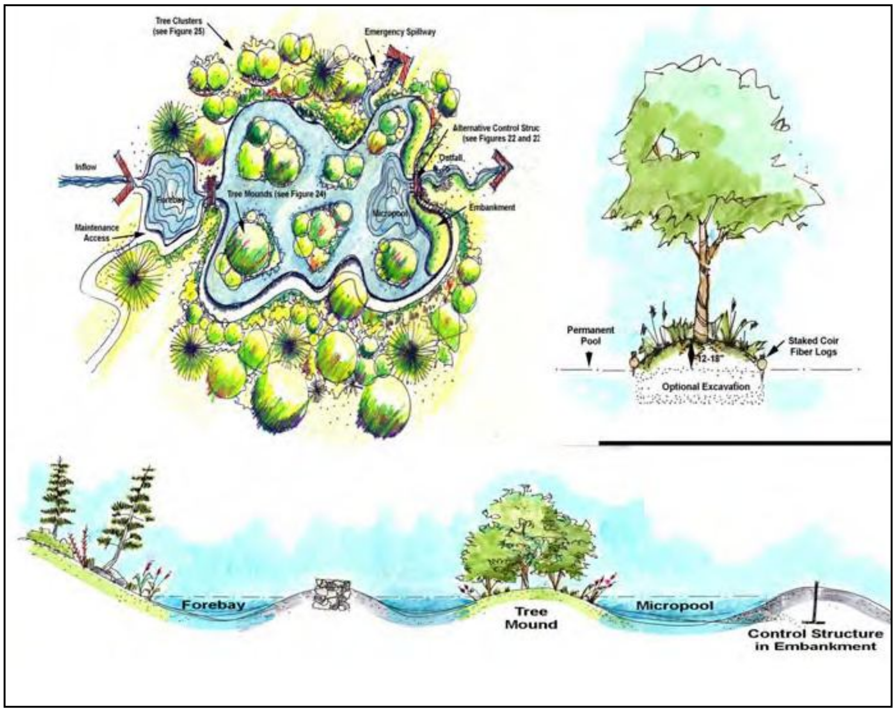


Figure 3: Wooded wetlands are a preferred stormwater treatment option for crossing retrofits.

Alternative Restoration Projects at Crossing Sites

Road crossings are a prime location for many restoration practices, even when a crossing retrofit is not feasible. Designers may wish to consider:

- Upstream wetland restoration
- Culvert repair or replacement (see Profile Sheet R-27 and R-28 in Manual 4)
- Culvert modification to increase tidal flushing in coastal creeks or wetlands
- Fish barrier removal (see Profile Sheet R-30 in Manual 4)
- Downstream stream repair (see Manual 4)
- Riparian reforestation
- Stream adoption (see Profile Sheet C-2 in Manual 4)

Desktop Searching for Crossing Retrofits

Road crossings are generally quite easy to spot on fine-resolution aerial photos or maps (Figure 4). If good GIS data are available to characterize the drainage network, headwater stream layers (zero, first and second order) can be superimposed over the local and state road network to locate

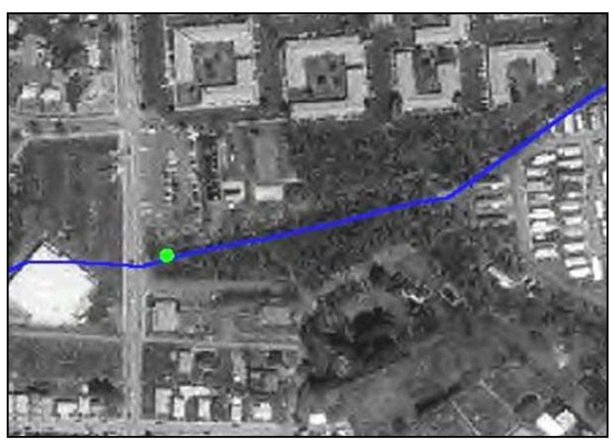


Figure 4: Crossing retrofits are easy to find when road network and drainage layers are superimposed.

potential sites to visit in the field. Ditch lines and headwater streams do not show up well on most maps, so designers may need to define them based on topography above the crossing. If topography is available, it is relatively easy to derive an initial estimate of the contributing drainage area to the proposed retrofit (which some designers may want to know before going out in the field). If a Unified Stream Assessment has already been completed in the stream corridor, the team may want to review the stream crossing (SC) impact forms to find potential sites.

What to Look for When Investigating Crossing Retrofits

The feasibility of crossing retrofits can be quickly determined by assessing the culvert, upstream storage conditions, and downstream conflicts (Figure 5):

1. Evaluate the culvert - The crew should check out the existing plumbing of the culvert to determine its:

- Alignment in relation to the stream
- Invert elevation in relation to the road
- Culvert diameter, material, and condition (including headwalls and endwalls)
- Sediment deposition within the culvert that may reduce its hydraulic capacity.

Next, the crew assesses how easy it will be to get construction equipment down the steep slopes from the roadway embankment to the retrofit. If the elevation difference is minor, it may be possible to construct an access ramp. Many underground utilities often run parallel to the road, so the crew should look for surface utility indicators such as manholes or venting stacks.

2. Evaluate upstream storage potential - The crew then estimate the potential storage volume available upstream. The best way to do so is to envision a triangle with its base parallel to the road crossing and its apex at the point upstream at the same elevation as the roadbed. Walking upstream, the crew paces off the distance to the apex, and then walk in a perpendicular direction to each bank until the roadway elevation is attained. Using this method, the crew can get a rough measure of the boundaries of available surface area (Figure 6). Using a tape measure and lock level, the crew then records the vertical distance from bottom of the culvert pipe to the roadbed. The acre-feet of free storage can then be determined based on the geometry of the prism.

The crew can use a hand auger to get a quick sense of whether the floodplain soils are suitable for excavating additional storage (or whether wetland indicators are present that may cause permitting problems). Lastly, the crew should note any wetlands, mature forest cover or underground utilities that might reduce the available treatment area.

Figure 5: Field crews measure culvert dimensions and examine upstream and downstream conditions.

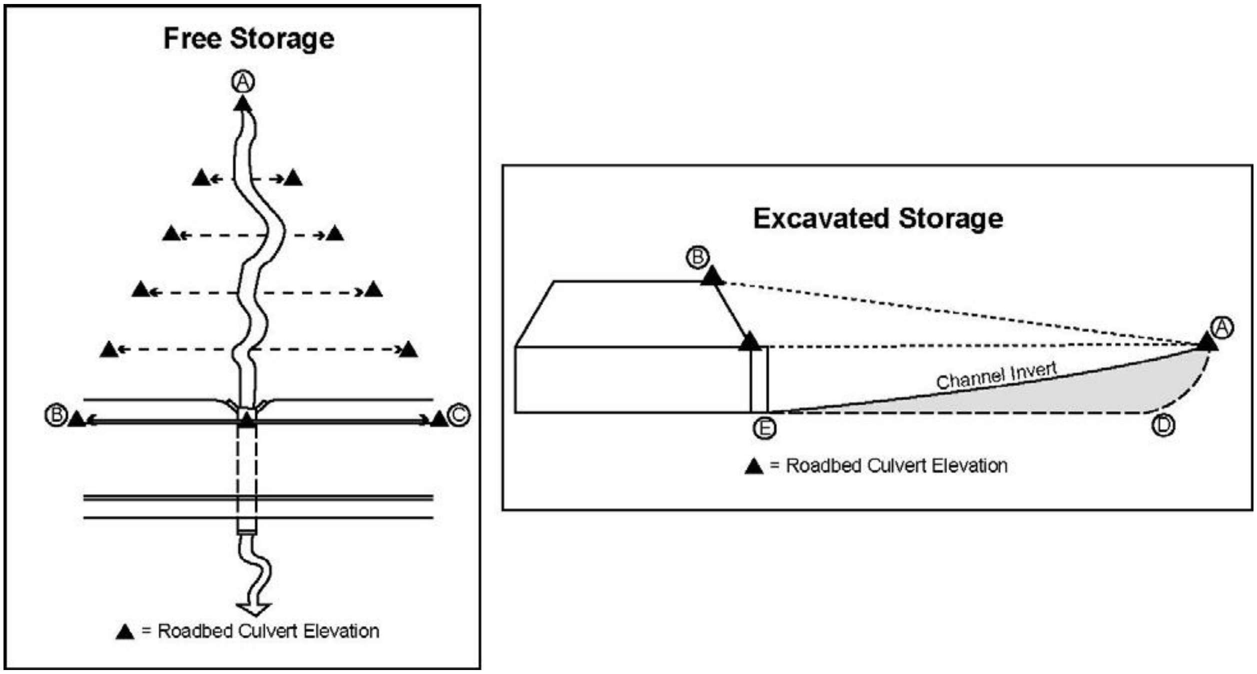


Figure 6: Estimating free storage using the triangle approach

Crews estimate the area of free storage by visualizing an ABC triangle extending with its base parallel to the road and its apex at the upstream elevation as the roadbed (panel a). The depth of free storage is defined by the triangle BEA (panel b) plus any additional excavated storage defined by the EDA triangle.

3. Understand downstream conditions - The crew then turns its attention to the downstream end of the culvert, and measures the vertical distance from the culvert invert to the stream bed, and quickly estimates the rate of flow over the culvert lip (if any). The crew records whether a scour hole exists immediately below the culvert, and whether it is acting as a stream grade control. The crew may need to walk several hundred feet downstream to get a sense of stream morphology and look for any flood prone structures in the stream corridor.

Feasibility, Approvals and Permitting for Crossing Retrofits

Crossing retrofits have many permitting and approval hurdles. The in-stream nature of crossing retrofits triggers numerous environmental permits related to fish passage, forests, floodplains, wetlands and waterway construction. Most permitting agencies are understandably reluctant to allow embankments or other obstructions to be placed across perennial streams. Some agencies may permit crossing retrofits if the existing stream is highly altered or channelized, and does not support aquatic life. The best permitting situation is when the stream is first order or smaller, and has negligible flow. Additional guidance on environmental permits is provided below.

Crossing retrofits nearly always require wetland and waterway disturbance permits as many stream channels are regarded as jurisdictional under Sections 401 and/or 404 of the Clean Water Act. The stream corridor in the proposed retrofit area may contain riparian wetlands that are also subject to the same permits. If stream channels or riparian wetlands are high quality and have functional value, the site should be dropped from consideration. It makes little sense to degrade the function of an existing watershed element in order to restore a new one.

Designers should also consider how future inundation in the proposed retrofit area will affect the quality of existing forests or wetlands (Figure 7). Research has shown that stormwater ponding and water level fluctuations degrade wetland quality (Wright *et al.*, 2007). Similarly, chronic inundation can kill sensitive tree species (Cappiella *et al.*, 2006b). Even though hydrological changes are not technically regulated under most state and federal wetland protection programs, ethical retrofit designers should never degrade the quality of existing forests and wetlands.

Fish passage is a key issue to assess at crossing retrofits. State fishery biologists should be consulted to determine if migratory or resident fish are currently using the upstream segment. The existing culvert often acts as a barrier to upstream fish migration, but if fish are present, the retrofit should be dropped from consideration. Instead, designers should investigate whether culvert repair or replacement is a viable option at the crossing (see Profile Sheets R-27 to R-29 in Manual 4).

Crossing retrofits can potentially increase floodplain elevations above or adjacent to the proposed treatment area. Many zero and first order streams lack a defined or regulatory floodplain, but if one exists, designers may need to secure a permit from the local or state floodplain management authority.

The second key hurdle is getting approval from the local or state highway review authority to modify roadway embankments or culverts and secure easements needed for construction and maintenance access. The highway agency will certainly want to ensure that the proposed design will not saturate existing roadway embankments nor change the condition and flow capacity of

Figure 7: Sedimentation and increased water level fluctuation can harm sensitive forests and wetlands.

the existing culvert. Designers should coordinate closely with highway review staff early in the design process, particularly if the control structure is located outside of their right-of-way or will be maintained by a different party.

The highway agency will want to know who is responsible for maintenance and how it will be paid for. The most common arrangement is a maintenance agreement between the highway agency and the local public works department, although in some cases, a third party landowner might be involved. The highway agency will expect a written maintenance agreement that clearly defines the duties, schedules and contingencies for future maintenance.

Crossing Retrofit Design Issues

The design of crossing retrofits entails the following unique design issues:

Figure 8: Designers should anticipate clogging problems by woody debris at crossing retrofits.

Crossing retrofits are particularly prone to clogging by organic debris, woody vegetation and sediment delivered from upstream sources (Figure 8). Over-sized forebays or micropools are strongly recommended. Trash racks are also needed to protect the control structure and require careful design so that they don't get clogged by woody debris. Reverse slope pipes extending to mid-depth of the micropool are often a good design solution.

Safe and easy access to the micropool or forebay must be provided, as both need to be frequently maintained to remove accumulated sediment and debris. Specialized equipment that can access tight sites may be needed to remove trapped materials.

Another key issue is how to minimize the amount of excavation needed for a crossing retrofit while still achieving the desired water quality volume. Off-site hauling of excavated materials can be very expensive, so designers should try to maximize "free" storage and look for nearby areas where excavated soils can spoiled without losing treatment or floodplain capacity.

The design of each crossing retrofit should always be done in the context of downstream geomorphology. Designers should evaluate whether downstream stabilization and/or grade control are needed to protect the crossing retrofit.

Design support

Crossing retrofits require numerous studies to confirm their feasibility and support final design:

- The contributing drainage area to the crossing retrofit should be accurately delineated using GIS or CAD. If boundaries are questionable, they should be ground-truthed.

- Any forest or wetlands that will be disturbed or inundated by the retrofit should be delineated and their functional value assessed (Figure 9). Designers should consult foresters to determine what upstream tree and wetland species might be harmed by chronic inundation and/or ponding.

- Soil borings should be taken on the embankment, in the vicinity of the proposed control structure and at two points within the proposed treatment area. As a general rule, alluvial material is not useable as structural fill. Soil borings are critical to assess retrofit constructability factors, such as:

  – bearing capacity of risers
  – potential use of fill
  – compaction/composition of embankment
  – depth to groundwater

- Designers should obtain the original culvert design file and review any upstream calculations that exist. If the pipe/channel network has changed since the culvert was installed, designers should survey upstream channel cross-sections and elevations.

Figure 9: Surveys of forest and wetland conditions should always be performed in the proposed treatment area.

- Downstream studies may be needed to assess the impact of the proposed retrofit on fish passage, stream geomorphology or floodplain elevations. Designers should consider whether the retrofit will alter the sediment regime enough to actually increase the potential for downstream channel erosion. If a retrofit effectively captures sediment bed load, it may starve the downstream channel and create a “hungry” stream.

Design Process

The design process for crossing retrofits is generally done in a step-wise process:

Step 1: Check with the appropriate review authority to determine what design storms the culvert is expected to pass.

Step 2: Determine the target WQv or Cpv storage needed at the retrofit based on current drainage area and impervious cover, and compare to the estimated acre-feet of storage that can be obtained behind the secondary embankment (i.e., free storage and excavated storage).

Step 3: Model current upstream hydrology delivered to the culvert based on prior computations. New model input parameters may need to be derived if upstream land use, drainage divides, or storm drain infrastructure has changed since the crossing was originally designed.

Step 4: Run the appropriate design storm flows through the culvert to determine if it has adequate capacity to meet current hydraulic design criteria. If so, proceed with upstream pond design. If not, investigate whether culvert replacement might be integrated into the overall retrofit design.

Step 5: Determine where the control structure will be located and determine the most appropriate material and elevations for the secondary embankment. Evaluate retrofit dimensions to verify that the storage obtained still meets the minimum target volume.

Step 6: Route design storms through the secondary embankment and old culvert to confirm they still meet current standards for design capacity. A dam breach analysis may be needed, depending on the height of the secondary embankment and its proximity to the roadway.

Step 7: Check how proposed water elevations will influence utilities and other structures in the floodplain. Compare manhole elevations to the proposed retrofit surface elevations to avoid the submerging sanitary system.

Step 8: Perform any additional analyses requested by the highway review authority.

Construction Considerations for Crossing Retrofits

Crossing retrofits involve several construction considerations that are not often associated with standard stormwater ponds (Figure 10):

- Staging and access are always challenging at crossing retrofit sites, given steep side-slopes, access through narrow easements on private lands, or confined upstream corridors (Figure 11).

- Designers should meet with contractors frequently during construction.

Figure 10: Two examples of crossing retrofits

- The online nature of crossing retrofits creates an inherent construction risk. Any construction equipment stored in the stream or floodplain will always be at risk from flood damage. Weather forecasts should be frequently consulted during in-stream work.

- Designers should carefully think about how they will work in the stream to address erosion and sediment control. Most sites will need dewatering during excavation and a method to bypass “clean” stream flows and storm runoff around the disturbed area (usually as a temporary diversion and pumping of baseflow around the treatment cell and to the culvert).

- The secondary embankment often needs to be cast in place or formed on-site. Special construction techniques, equipment and experienced contractors are often needed.

- Crossing retrofits constructed near a road require a plan to resolve conflicts between traffic and construction equipment that ensures the safety of motorists, pedestrians, and construction workers. If regular ingress/egress to the road is needed, the highway agency may require a "maintenance of traffic" permit.

- Crossing retrofits should be inspected shortly after construction to check for clogging potential, excessive sediment deposition or changes in vegetative condition.

Crossing Retrofit Costs

Crossing retrofits tend to cost less than new retrofit ponds because they utilize free upstream storage. Their design and permitting costs, however, are often higher than other storage retrofit options. Planning level cost estimates are provided in Table 1, and site-specific factors that increase/ decrease construction costs are outlined in Table 2. More detailed cost estimates will need to be developed as actual concept designs are pursued further.

Figure 11: Construction access and staging is always a challenge for crossing retrofits

Table 1: Estimated Construction Costs for Crossing Retrofits (2006 $/ impervious acre treated)			
Retrofit Type	**Median Cost**	**Range**	**Design & Engineering (%)**
New Storage Retrofit [1]	$ 19,400 [2]	$ 9,000 to $32,000 [3]	40[4]

[1] Use appropriate pond equation in Appendix I if retrofit site satisfies new development site conditions
[2] Construction costs should be reduced based on the proportion of free storage that is available above the crossing. This fraction of storage should be priced using the pond retrofit estimator
[3] Adjust based on site-specific construction cost inflators/deflators in Table 2
[4] Increases to 45% if major environmental permits or highway agency design review is required

Table 2: Site Specific Factors that Influence Crossing Retrofit Project Cost	
Factors that Decrease Construction Cost	**Factors That Increase Construction Cost**
• Free upstream storage (little need to excavate) • Treatment area contains no trees or wetlands • Staging areas available adjacent to floodplain • No access roads are needed to get to site • Useable compactable fill available close by • Existing roadway embankment suitable	• Culvert needs to be replaced • Sewer or utility relocation • Hauling excavated materials off-site • Wetland or forest permits required • Wetland mitigation required

SR-3	Storage Retrofits **NEW STORAGE BELOW OUTFALLS**	

This retrofit creates new treatment adjacent to the stream corridor near the terminus of an existing storm drain outfall. Outfall retrofits are designed off-line by splitting flow from the existing storm drain pipe (or ditch) and diverting it to a stormwater treatment area formed by an existing depression, excavation or constructed berm (Figure 1). A flow splitter allows larger storms to remain in the existing pipe (or ditch) and bypass the retrofit. Typical stormwater treatment options at outfall retrofits are a combination of extended detention, pond or constructed wetland storage (Figure 2). Constructed wetlands are preferred in floodplains where groundwater elevations are high and space is available. Bioretention may also work if the outfall has no dry weather flow and a small contributing drainage area (Figure 3).

Outfall retrofits are ideal because they are close to the stream and maximize the upland drainage area treated. In addition, their off-line location usually means fewer stream permitting problems. Lastly, outfall retrofits only need to be designed to provide the desired storage for water quality and/or channel protection; larger flood flows bypass the retrofit.

Ideal Conditions for Outfall Retrofits

Most communities have hundreds or even thousands of stormwater outfalls discharging to their stream network. Only a fraction of these outfalls are suitable for storage retrofits. The best outfall retrofit sites usually have:

- A 12 to 36 inch diameter outfall discharging above stream or floodplain
- A wide stream corridor in public ownership
- At least 150 feet of unobstructed easement over the buried pipe

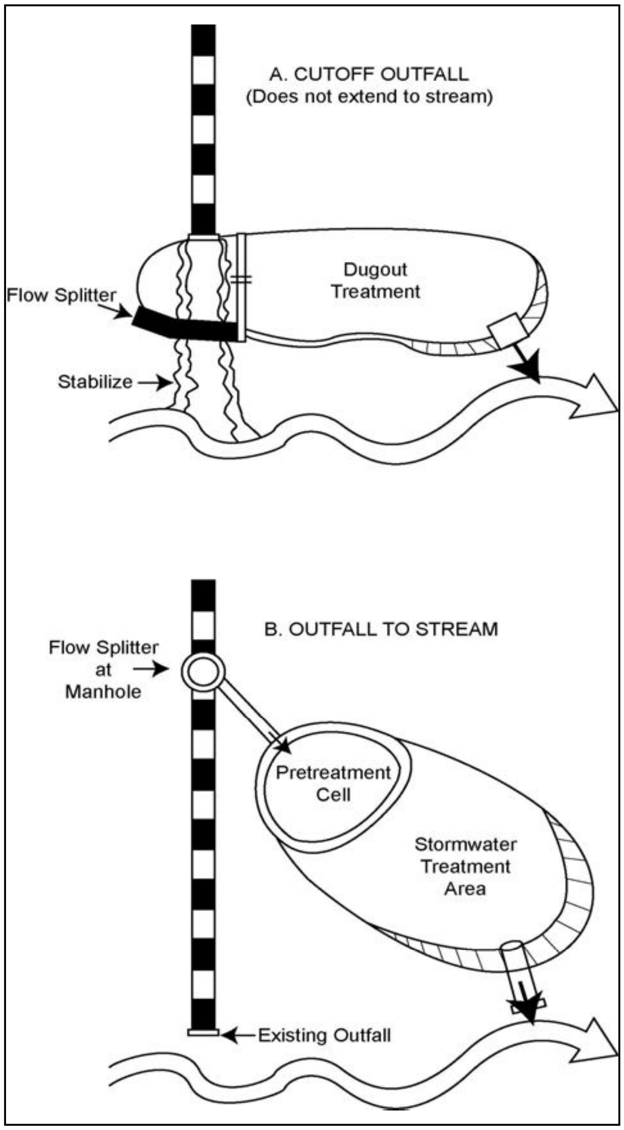
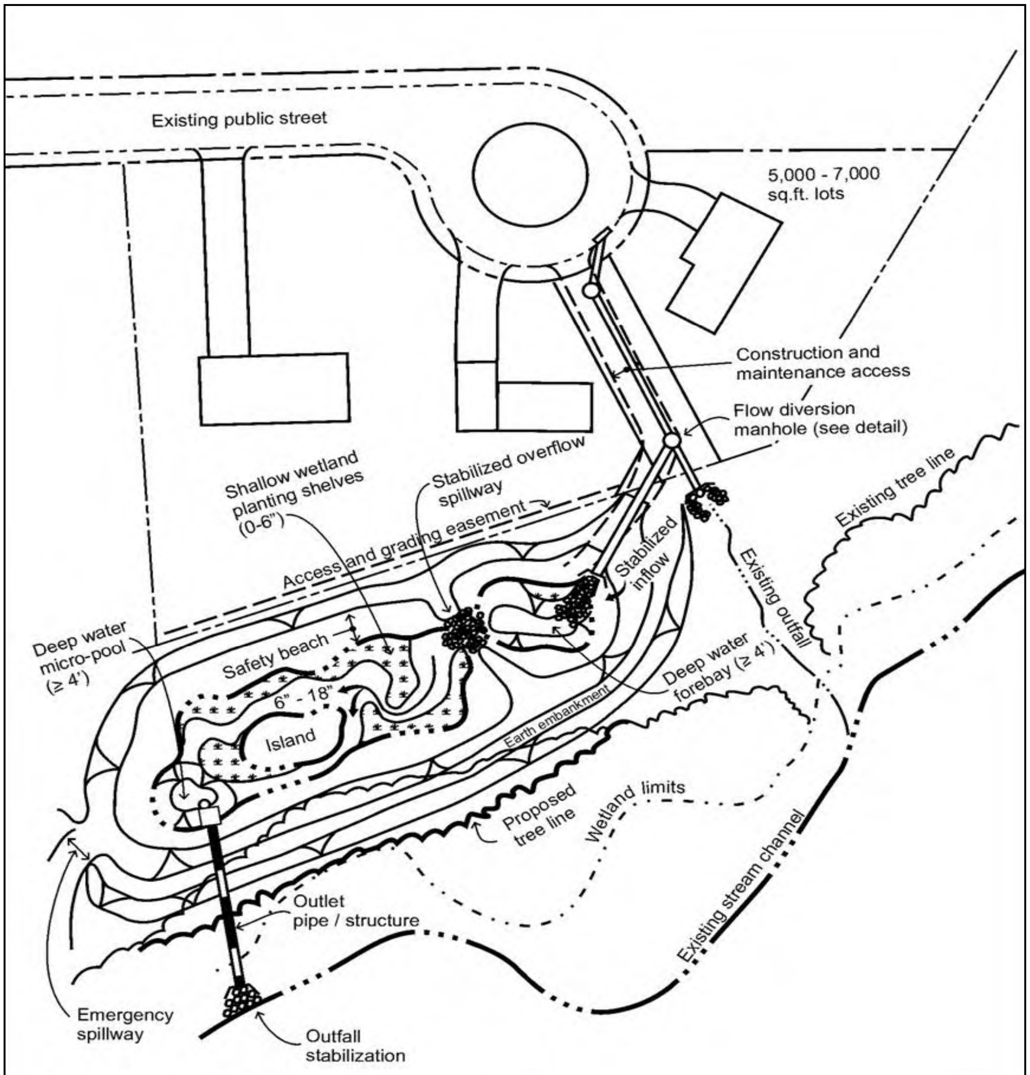


Figure 1: Two strategies for outfall retrofits in the stream corridor

- Enough pipe/channel gradient to divert flows for treatment and return them to the stream via gravity flow
- A good existing manhole to split flows and 5 to 10 feet of head to drive the retrofit
- Unutilized turf available on one or both sides of pipe
- A cutoff outfall (i.e., an outfall that discharges to the floodplain well short of the stream channel; Figure 4)



Off-Line Storage Facility at End of Pipe
(Stormwater Wetland)

Figure 2: Splitting flow from the storm drain pipe to a constructed wetland in the stream corridor.

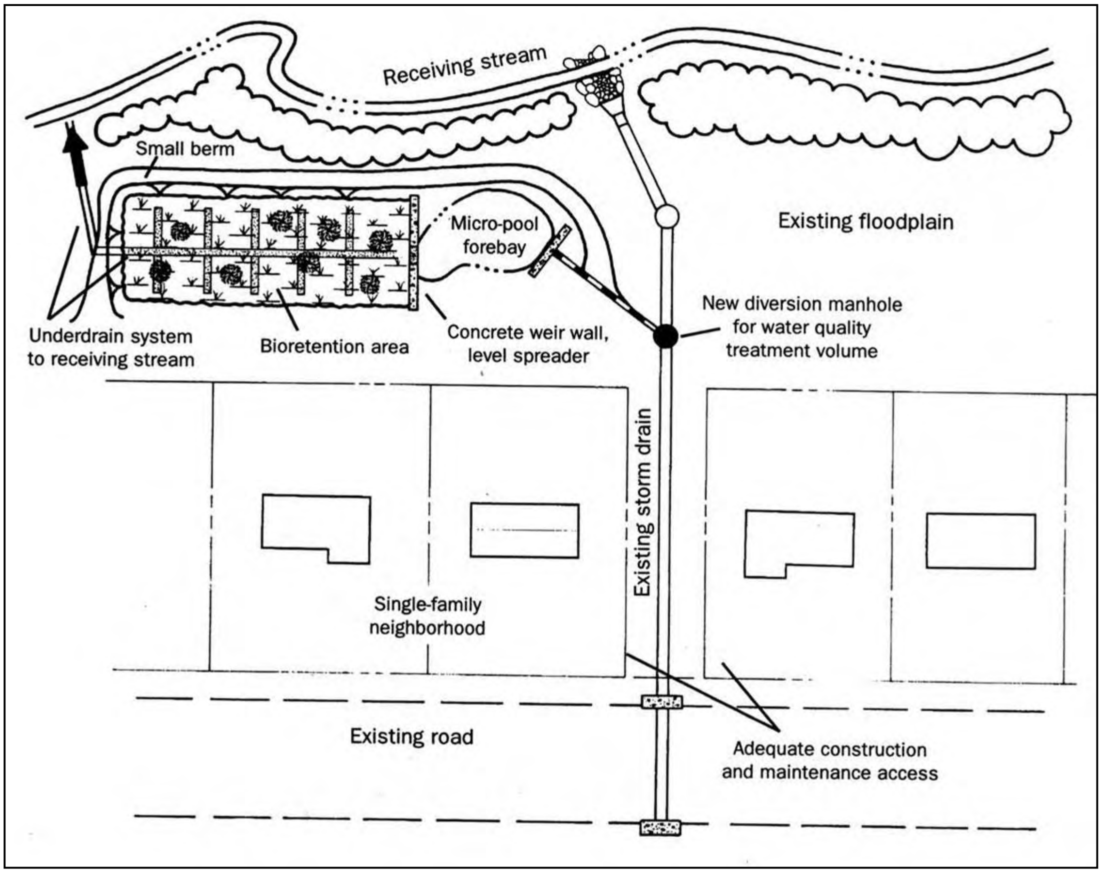


Figure 3: Schematic showing flow being split to an off-line bioretention facility.

Situations Where Outfall Retrofits are Difficult

Several factors make it difficult or impossible to get storage at an outfall, including sites where:

- Private land must be purchased
- Stream corridors are confined and lack land for surface treatment
- Stream valley parks where tree clearing would be controversial
- Very large outfalls (Pipe diameter greater than 60 inches)
- Perennial flow exists in the storm drain pipe or ditch
- Steep gradients or steep stream valley slopes limit available storage volume
- Low gradient causes unacceptable backwater conditions in the pipe system
- Outfall is subject to tidal or storm surges

Figure 4: Example of a "cutoff" outfall discharging well away from the stream

- Fill would need to placed in the floodplain

Restoration Alternatives at Outfall Sites

Other restoration alternatives can be employed when storage retrofits are not feasible, such as:

Outfall Stabilization – Problem outfalls that exhibit excessive scour, head cutting or generate high sediment loads are a good candidate for outfall stabilization. This is common for urban streams where outfalls discharge down steep hill-slopes above stream channels and floodplain terraces (Figure 5). Outfall stabilization may include structural measures such as plunge pools, micropools and other energy dissipation practices. Eroding gullies may also be stabilized with bioengineering techniques that combine soil fill and woody vegetation together.

Stream Daylighting - This may be a good option at sites where a pipe outfalls to a stream and is located too far underground to split. The storm drain pipe can be removed to create a naturalized stream channel. Guidance on designing stream daylighting projects at stormwater outfalls is provided in Profile Sheet R-27 of Manual 4.

Riparian Reforestation – Tree planting is always a preferred option at open spaces in the stream corridor that lack enough room for storage retrofits.

Desktop Search for Outfall Retrofits

The best place to look for outfall retrofits is the transition zone between the upland storm drain network and the stream corridor. Within this narrow zone, there may be many opportunities to install outfall retrofits:

If a community has good GIS coverage of its storm drain and stream network, it is quite easy to superimpose both layers to find points where they coincide with open land adjacent to the stream corridor (Figure 6). If drainage features such as ditch lines are

Figure 5: Reconstruction and/or bioengineering may be needed to stabilize outfalls that discharge down steep slopes.

Figure 6: Outfall retrofit sites can be discovered by overlaying storm drains, streams and adjacent open land.

available on the GIS, they should also be included in the search. The designer should search for publicly owned land parcels at least two acres in size that are associated with storm drain outfalls with a diameter greater than 12 inches and less than 36 inches. Some designers also analyze topography to get an initial estimate of the contributing drainage area to each outfall.

Stormwater outfall data may have been previously assessed during stream corridor surveys such as the Unified Stream Assessment (USA). The key USA impact forms to review include the outfall form (OT) and the impacted buffer (IB) form.

What to Look for During Outfall Investigations

The crew should first determine whether or not a flow splitter is needed to direct runoff for retrofit treatment. If so, the feasibility investigation is done in a step-wise manner, as follows:

1. Confirm the outfall diameter as it gives an indication of probable storm flows and drainage areas (Table 1). Record the shape, diameter, material and condition of the storm drain pipe (Figure 7). Measure the rate of dry-weather flow, if present. If the flow is suspicious, conduct a discharge prevention investigation to determine if it is an illicit discharge, using the methods outlined in Brown *et al.* (2004).

2. Check out the plumbing of the storm drain system in relation to the invert of the stream channel (Figure 8). Record the approximate vertical distance between the elevation of the outfall invert, the stream bottom and the top of bank.

3. Define available treatment area on either side of the proposed split and then establish the point where split flows will enter the proposed treatment area. Use hand auger to get a sense of soil conditions and depth to water table.

4. Determine if further excavation or berms will be needed to obtain more storage in the treatment area, and estimate the probable depth of storage.

5. Look for the best place to bring treated flows back into the stream that minimizes tree loss. It may be possible to install a level spreader to discharge sheet flow across the remaining floodplain at smaller outfall retrofits.

Table 1: Guide for Estimating Drainage Area Based on Outfall Diameter

Pipe Diameter (inches)	Discharge (cfs)	Avg Velocity (fps)	Drainage Area (est. acres)
6	1	4	0.1 to 1
12	3	6	1 to 2
24	25	10	2 to 5
36	90	12	5 to 25
48	150	14	25 to 100
60	350	18	100 to 200
Note: For pipes flowing full, with one percent slope			

6. Locate upgradient manholes that delimit the underground storm drain pipe. Manholes are installed at junctions where storm drain pipes change in size, slope, or direction. The maximum distance between manholes is usually about 200 to 400 feet. Walk off the distance of unobstructed storm drain pipe or ditch contributing to the outfall. Remember that pipe gradient does not always follow surface topography, so pop a few manholes to establish pipe depths and get a general sense of underground pipe gradient.

Figure 7: Crews measure the diameter, condition and invert elevation of the storm drain outfall.

7. Define uppermost manhole or point along the pipe where it is possible to effectively split flows. It is desirable to have at least five to 10 feet of elevation gain from this point to the stream invert. Given standard manhole spacing, this distance may only be one to two manholes up the storm drain system.

8. Record approximate retrofit dimensions and sketch on concept plan.

Feasibility, Approvals and Permitting for Outfall Retrofits

Storage retrofits are only feasible at a limited number of outfalls within a subwatershed. Key feasibility factors include:

Head - Outfall retrofits need enough hydraulic head to drive stormwater flows by gravity from the split to the stream. Outfalls located in flat terrain or tidal areas often lack the five to 10 feet of head needed to make an outfall retrofit work, and may cause

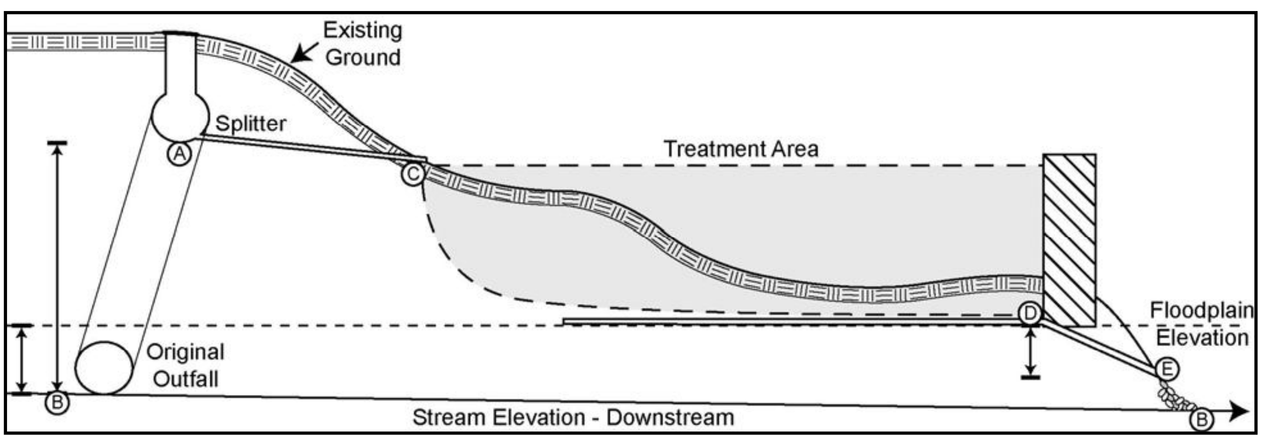


Figure 8: Design points for outfall retrofits

Several design points are of interest for outfall retrofits including (a) the location and elevation of the proposed split (b), the invert elevation of the original outfall, (c) the location and elevation of the discharge to the treatment area (d) the maximum depth of the treatment area and (e) the discharge point back to the stream. Designers need to maximize head through the retrofit, but also account for the influence of floodplain, seasonally high water table and erosive forces working on the stream bank.

tailwater and backwater problems (i.e., ponding backs water up above the split in the storm drain system, or high stream flows back water up into the treatment area).

Space – Since outfall retrofits are located in confined urban stream corridors, they are subject to severe space constraints (Figure 9). The proposed treatment area should be at least 2-5% of the contributing drainage area (depending on the proposed depth of treatment). Look carefully for surface indicators of utilities that reduce available treatment area. Sanitary sewers are a frequent problem as they often run parallel to the stream corridor. The designer should understand utility guidelines with respect to minimum sewer setbacks and the maximum permissible flood elevations to submerge manholes.

Soil Conditions at Proposed Treatment Area. The water table is often close to the surface of the floodplain, and it serves as a practical limit to the depth of excavation (and a clue that a pocket wetland may be ideal for the site). If soils appear to be hydric, designers should undertake a wetland delineation.

Outfall retrofits may require several environmental permits and landowner approvals. Since outfall retrofits are located in the stream corridor, they frequently create impacts to floodplains, wetlands and streamside forests that trigger environmental permits. If either high quality wetlands or mature forest are located within the proposed treatment area, the project should be dropped, unless there is a compelling case that existing habitats are so degraded that the proposed retrofit would restore them.

Easements for construction access or future maintenance may need to be secured at outfall sites that are effectively landlocked or have steep slopes descending to the stream corridor.

Designers should give special consideration to any changes in floodplain elevations, particularly if berms or embankments are needed to increase retrofit storage capacity. A floodplain study may be needed to determine whether any proposed floodplain fill will cause unacceptable changes in floodplain elevations. If the retrofit is located primarily within the floodplain, a

Figure 9: Field crews look for large areas of open land adjacent to the stream corridor.

dam safety permit may be required.

Designers should always model the effects of large flood events on the integrity of the retrofit. Floodplain permits are usually not a problem if the treatment storage is obtained by excavation.

Outfall retrofits are well suited for parks and other public lands. They may also be feasible on private land although designers may need to secure an expanded easement to accommodate the retrofit. In either case, the designer will need to satisfy the local park authority or landowner that the retrofit will:

- Not result in major loss of streamside forest (Figure 10). Any tree clearing should be fully reforested
- Not conflict with stream corridor uses such as footpaths, bike trails and picnic areas (ideally, the designer would incorporate these amenities into the design)
- Not create any new safety risks, particularly if the public has access to the site
- Create an attractive water feature or natural habitat area
- Utilize pondscaping, native plants and interpretive signs to educate the public
- Reduce mowing and other ongoing maintenance operations

Outfall Retrofit Design Issues

The key design element associated with outfall retrofits is the flow splitter that diverts the appropriate runoff volume into the proposed treatment area. Flow splitters use weirs or orifices to divert flows into the retrofit and bypass larger flows around it (Figure 11). The Achilles heel of splitters is clogging, so designers should always incorporate sumps and hoods within the flow splitter to protect the outlet pipe.

Designers need to be aware of backwater effects and hydraulic grade lines when sizing flow splitters to prevent unacceptable up-pipe conditions.

Another key issue involves how to discharge treated runoff back into the stream to prevent scour and erosion at the new outfall

Figure 10: Sensitive layout of outfall retrofit in a park to avoid tree clearing.

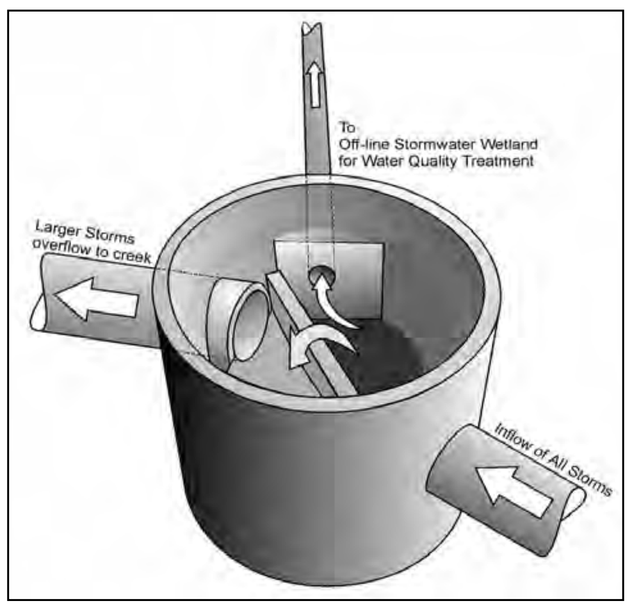


Figure 11: Detail of a flow splitter constructed in a manhole to divert flow for offline treatment.

location. This is a particular concern when there is a considerate drop to an incised urban stream with steep banks (Figure 12). Hard stream stabilization techniques are often needed to protect the new outfall from the erosive energy of the stream during bankfull floods (See Manual 4). Designers should also carefully fingerprint the outfall pipe to protect mature streamside trees and wetland features.

Designers frequently have limited space within the proposed treatment area to include design features such as forebays, benches and micropools. In general, it is better to sacrifice WQv storage than to drop these pond features. Baffles or small berms can be used to extend the flow path within the treatment area and thereby increasing residence time and enhancing pollutant removal performance.

Design Support

Several studies may be needed to support the design of outfall retrofits:

- Search for existing construction drawings of the upstream storm drain network

Figure 12: Designers may need to stabilize retrofit outfalls in incised urban streams.

- Update land cover in the contributing drainage area if it has changed over time
- Survey the invert elevations of the current storm drain system at least three manholes above the proposed split.
- Assess the condition of existing storm drain pipes
- Survey elevations within the proposed treatment area
- Take soil borings to determine depth to groundwater and excavation conditions
- Delineate wetlands and/or forest stand structure, if either is present

Design Process

The following step-wise design approach is recommended for outfall retrofits:

Step 1: Determine the target WQv storage needed at the retrofit site based on current drainage area and impervious cover to the proposed split. Conduct a rough grading analysis to determine the available storage volume (in acre-feet) within the proposed treatment area. If the target volume can be attained, proceed to the next step.

Step 2: Redo the upstream hydrology model for the existing storm drain pipe at the proposed point where flow will be split away from the pipe. Update the model input deck to account for any changes in land use, land cover, drainage divides the drainage network since the pipe system was originally designed.

Step 3: Check to see if the current pipe is flowing full or under pressure. If so, flow splitting may cause back up of flows into the upstream pipe network.

Step 4: Determine the rate and volume to divert for water quality treatment. Select an appropriate flow splitting method; several examples are shown in Figure 13.

Figure 13: Three examples of flow splitters to divert runoff for off-line treatment.

Montgomery County DEP has developed useful flow splitter design guidance which is available at http://permittingservices.montgomerycountymd.gov/permitting/docs/FLOWSPL.pdf

Step 5: Conduct a backwater analysis to determine the extent of the hydraulic grade line under the appropriate design storm scenarios to ensure the practice will not result in nuisance flooding. Good design guidance has been developed by King County, Washington, and is available at http://dnr.metrokc.gov/wlr/dss/kcbwdoc.htm

Step 6: Route the water quality storm through the proposed treatment area, locate and size the new overflow to the stream, and verify that it will be stable under expected stream velocities.

Construction Considerations for Outfall Retrofits

The flow splitter is always a key construction consideration for outfall retrofits. Designers should always make sure they work closely with the contractor to get flow splitter elevations right, ensure joints are water tight and provide easy access for maintenance. The flow splitter should be frequently inspected after construction to ensure it functions properly and does not clog.

The advantage of a flow splitter is that it eliminates the need for a temporary diversion during construction. Storm flows continue to pass through the original storm drain pipe until the treatment area has been constructed. Once the treatment area is stabilized with vegetation, the flow splitter can be "turned on" to direct runoff for treatment.

Some in-stream work may be needed to construct a stable discharge to the stream. Designers should install appropriate in-stream erosion and sediment control practices during this phase of retrofit construction.

If the proposed site has high groundwater levels, construction logistics become very challenging. Soupy soils make excavation more difficult, and may require dewatering devices and specialized construction equipment.

Outfall Retrofit Costs

Construction costs for outfall retrofits are shown in Table 2 for various regions of the country. Table 3 outlines several site-specific factors that can increase or decrease median construction cost. Design and engineering costs for outfall retrofits tend to be higher because of additional studies needed to support the design of the flow splitter. Maintenance costs may be slightly higher at outfall sites to keep the flow splitter from clogging.

Table 2: Estimated Construction Costs for Outfall Retrofits (2006 $/impervious acre treated)

Retrofit Type	Median Cost	Range	Design & Engineering (%)
New Storage Retrofit [1]	$ 19,400 [2]	$ 9,000 to $32,000	40[3]

[1] Use appropriate pond equation in Appendix I if the retrofit site satisfies new development site conditions
[2] Adjust based on site-specific construction cost inflators/deflators in Table 2
[3] Increases to 45% if major environmental permits or highway agency design review is required

Table 3: Site-specific Factors that Influence Outfall Retrofit Project Costs

Decreases Costs	Increases Costs
• Simple pipe daylighting to depression • Limited off-site hauling of soil • Shallow wetland reduce excavation • Short pipe lengths into/out of treatment area • Minimal stabilization is needed at stream	• Bridges needed for trails or pathways • Installing a new manhole to split flows • Existing storm drain pipe needs replacement • Utilities need relocation • High water table makes excavation soupy • Wetland or floodplain permits needed

SR-4	Storage Retrofits **TREATMENT IN THE CONVEYANCE SYSTEM**	

This retrofit obtains storage within altered zero and first order stream channels that comprise about half of the channel network in most subwatersheds. These channels lack perennial flow, have minimal floodplains and typically have a contributing drainage area of 15 to 50 acres in humid regions. Conveyance retrofits create storage, bioretention or wetland cells in an existing ditch, swale or non-perennial stream channel (Figure 1). Conveyance retrofits are particularly appropriate in small headwater channels that have been channelized and/or hardened in the past.

There are two basic design variants for the conveyance retrofit – *in-channel* designs where stormwater treatment storage is obtained within the channel and *off-channel* designs where the treatment storage is provided in cells adjacent to the channel.

In-channel retrofits obtain storage by:

- Installing small weir walls or checkdams in the channel to provide more storage
- Converting a channel or ditch into dry swale or wet swale
- Creating a linear series of wetland or bioretention treatment cells in the channel

Off-channel retrofits split storm flows from the channel to an adjacent depression or excavated treatment area (Figure 1). Off-channel retrofits can be effective when floodplain reconnection or wetland creation

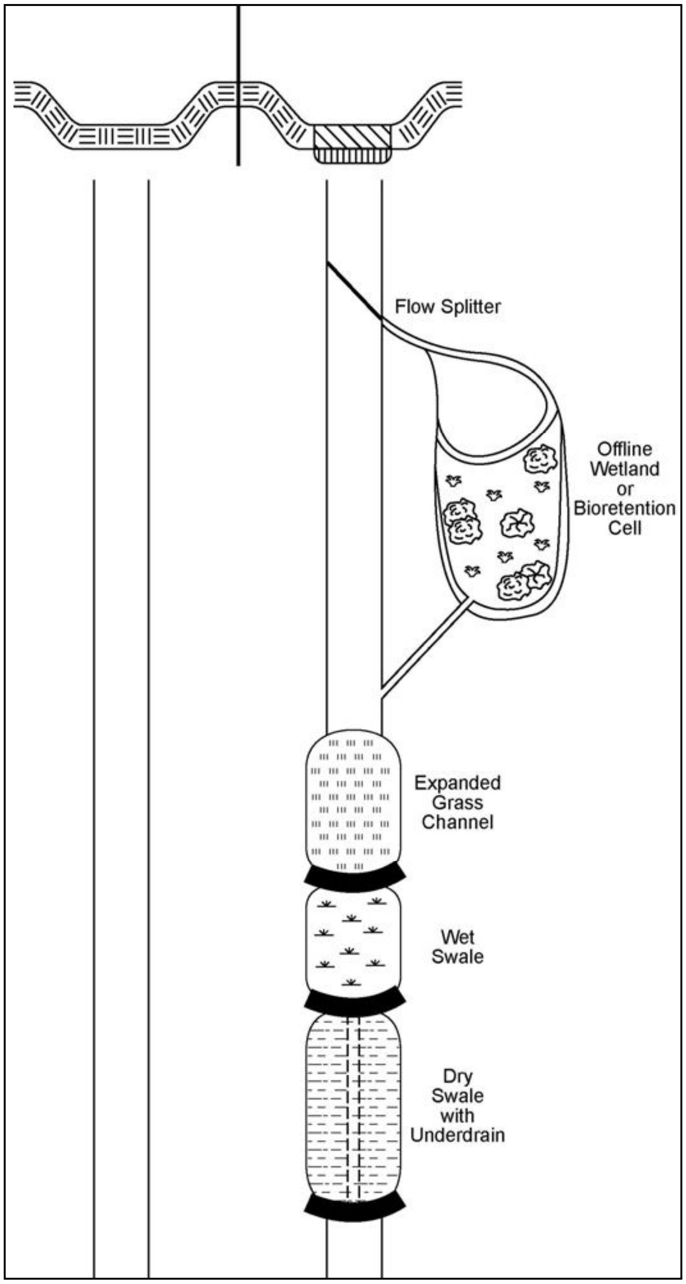


Figure 1: Both in-channel or off-channel treatment are possible in a conveyance.

is a subwatershed restoration objective. Constructed wetlands and bioretention are preferred for off-channel applications since they minimize the need for major excavation and embankments.

The stormwater conveyance system is a good location for storage retrofits since the land is usually located in a dedicated easement or right of way.

Ideal Conditions for Conveyance Retrofits

The ideal conditions for a conveyance retrofit are when the channel has:

- Gradient ranging between 0.5 and 2.0%
- Contributing drainage area of 15 to 30 acres of in humid regions with tight soils. Minimum drainage areas for conveyance retrofits are greater in arid and semi-arid regions with permeable soils.
- Been altered to promote efficient drainage (e.g., ditch, swale or concrete-lined channels; Figure 2)
- Less than three feet of elevation difference between the top of bank and the channel bottom
- Been used for roadway drainage in the right of way
- An unutilized parcel of public land located adjacent to the channel.

Figure 3 illustrates several examples of good candidate sites in the conveyance system for retrofit storage.

Situations Where Conveyance Retrofits are Difficult

Conveyance retrofits are generally not a good idea when the existing channel:

- Is in natural condition and has adjacent mature forests or wetlands
- Is rapidly degrading/incising or has a

Figure 2: Four opportunities within the conveyance system for retrofitting.

Figure 3: De-channelization and other stream repair practices are preferred when the conveyance system has perennial flow.

knickpoint advancing upstream

- Has a channel gradient of 5% or more and/or steep side slopes
- Has perennial flow
- Is located close to a residential neighborhood
- Is privately owned or lacks a drainage easement

Restoration Alternatives for Channels

Even if a storage retrofit is not feasible, several restoration practices can still be employed in the channel:

- Natural channel design or de-channelization (Profile sheets CR-31 to CR-33 in Manual 4)
- Riparian reforestation
- Wetland restoration

Desktop Search for Conveyance Retrofits

Potential sites for conveyance retrofits are found by superimposing the stream and drainage network layers over a land ownership map. The GIS system in most communities, however, seldom shows fine drainage features such as zero-order streams and ditch lines (Figure 4). Alternatively, it may be worth looking at drainage easements recorded on plats or entered into a local stormwater maintenance database. If local mapping is inadequate, potential sites can be found by inspecting high resolution aerial photographs or LIDAR topography (1 foot or better resolution).

If a Unified Stream Assessment (USA) has been conducted in the upper reaches of the subwatershed, potential conveyance retrofit sites can be found by examining the impacted buffer (IB) and channel modification (CM) impact forms.

What to Look for in the Field at Conveyance Sites

The field crew assesses the feasibility of a conveyance retrofit in the field by inspecting the channel reach, adjacent lands and downstream conditions.

1. Evaluate channel conditions

- Quickly estimate channel slope using a tape measure, a simple rod, or a lock-level.
- Measure the distance from the top and bottom of the channel and measure a full cross-section every 100 feet.
- Evaluate soil conditions underneath the channel using a hand auger, and record the presence of wetlands, hydric soils, standing water, erosion or perennial flow.
- Note the condition of vegetation in the existing channel and estimate the roughness of the channel and its floodplain.
- Look for signs that channel is under-capacity due to recent upstream development or past sedimentation (e.g., erosion of channel side slopes, poor vegetative stabilization, out of bank debris).

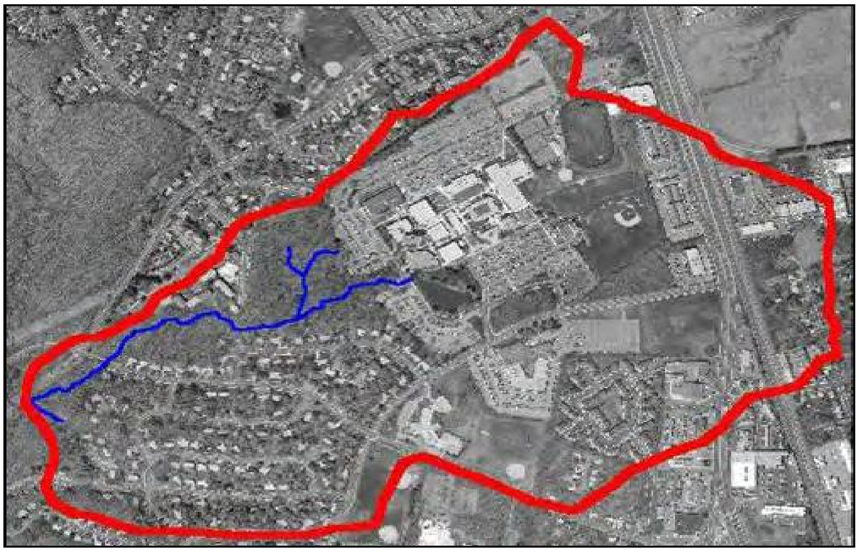


Figure 4: Most ditch lines and zero-order streams do not show up on local GIS maps.

2. Evaluate adjacent treatment potential.

The crew then looks at available land to right or left of the channel to:

- Measure the width available for treatment, such as depressed turf areas
- Look for surface indicators of underground utilities
- Find potential access points to get into the channel and places where construction equipment can be staged and stored
- Note adjacent land uses for any signs of encroachment (e.g., fencing, yard waste, dumping.)

3. Evaluate downstream conditions.

The crew then walks several hundred feet in a downstream direction to get a sense of where the channel becomes a perennial stream. The crew should look for signs of perennial flow, wetlands, and advancing knickpoints.

The site inspection helps to determine whether a conveyance retrofit is feasible and whether it should be located in or off the channel. The crew then sketches the proposed treatment area and indicates the recommended stormwater treatment option(s) on the field sheet. The proposed treatment area may need to be adjusted back in the office based on further research on land ownership, easements and utilities.

Feasibility, Approval and Permitting for Conveyance Retrofits

Conveyance retrofits are subject to many feasibility constraints, permits and approvals. Major feasibility constraints for in-channel and off-channel conveyance retrofits include:

Narrow Easement Width - Most drainage easements are seldom wider than 20 feet and are centered on the drainage feature. As a result, conveyance retrofit sites tend to be extremely tight and linear in nature (Figure 5). Designers will often seek to secure wider easements to increase treatment area or allow construction access.

Figure 5: Not a lot of room to work with - most stormwater easements are very narrow.

Channel Capacity - Most open channels are designed to convey a certain design storm event within a given cross-section. Recent development in the contributing drainage area, however, can produce greater peak flows that exceed the channel's original capacity. If channel geometry is furthered modified by a conveyance retrofit, it could increase flooding risk for adjacent properties and downstream structures. Therefore, designers should maintain the required hydraulic channel capacity established by the local drainage authority, and ensure that in-channel treatment areas can withstand the erosive velocities associated with the maximum design storm.

Available Head – The gradient of the channel is important. For off-channel designs, at least three to four feet of head is needed to divert runoff from channel to the proposed treatment area and then bring it back to the channel. Similarly, several feet of head are needed for in-channel designs to filter runoff and collect it an underdrain. Therefore, extremely low gradient channels are poor candidates for retrofits unless they are designed as wet swales. On the other hand, steep channel gradients often preclude in-channel retrofits.

Adjacent Utilities – Drainage easements are often used as a conduit for water, sewer and other utilities. Therefore, designers should check for possible utility conflicts, particularly for off-channel designs that split flow across the channel.

Conveyance retrofits have a few unique environmental permit issues. For example, zero and first order streams occupy a curious regulatory zone. In humid regions, the regulatory 100-year floodplain only begins when the channel has picked up about 35 to 50 acres of contributing drainage area. The same stream channels lack perennial flow, so they may not be regulated under various local, state or federal environmental permits. If the proposed retrofit is in a regulated floodplain, designers will need to perform floodplain analyses to ensure it does not increase flood elevations. If wetlands and forests are present, designers should pursue the appropriate permit review.

Designers should **never** retrofit a natural channel unless it has been previously altered for drainage purposes (Figure 6). Natural zero- and first-order channels provide major watershed functions, including groundwater recharge and discharge, pollutant removal and aquatic habitat (Meyer *et al.*, 2007; Cappiella and Fraley-McNeal, 2007; Schollen *et al.*, 2006). The destruction of a natural zero-order stream to install a conveyance retrofit simply exchanges one watershed function for another.

Figure 6: Three examples of natural features in zero-order streams that should not be disturbed.

Conveyance Retrofit Design

Conveyance retrofits entail several unique design issues:

The first issue is whether to go with an in-channel or off-channel design. While this decision is dictated by site constraints, off-channel designs are generally preferred, particularly when the contributing drainage area is large. When off-channel areas are treated, designers will need to install an effective flow splitter across the channel that can handle sediment deposition and clogging by trash and woody debris. One technique for flow splitting is shown in Figure 7.

Designers also need to choose whether the channel will be primarily managed as a man-made treatment system or as a natural stream corridor feature. The choice is generally made based on the condition of the existing channel and the aesthetic preferences of adjacent landowners. Natural landscaping and bio-engineering techniques should always be considered to soften its appearance.

If designers need to expand existing stormwater easements, they will need to negotiate with multiple landowners bordering the channel. Most property

Figure 7: One technique for splitting flow from the conveyance channel for off-channel treatment.

owners may grant an expanded easement if the proposed retrofit also solves an existing drainage or maintenance problem. It is also important to check to see if the easement is dedicated to the public or just to the private owner.

Designers need to calculate the erosive velocity and/or shear stress that channel soils will be exposed to over a wide range of design storms. Designers may need to reinforce the channel with geotextile fabric to prevent erosion and practice failure.

Since conveyance retrofits occur in the headwaters of the urban stream network, designers should anticipate the long term stability of the future channel. Designers should make sure the downstream end of the retrofit is protected by a fixed grade control structure to prevent an upwardly migrating knickpoint from undermining it (Figure 8). In addition, any flow splitters, weirs or checkdam installed across the existing channel should be fully armored with rock above and below the structure to prevent undercutting. The wingwalls should also extend several feet into each bank to prevent outflanking.

Since conveyance retrofits rely on vegetation for stability, designers should carefully choose grass or wetland plant species and devise a realistic plan to manage vegetation growth in future years.

Design Support

Conveyance retrofits may require several studies to support design, including:

- Legal research on drainage and stormwater easements. Few communities routinely record these in their GIS, so designers may need to analyze original development plans or even individual property deeds to confirm their boundaries
- Original design capacity computations for the existing channel
- Delineation of the contributing drainage area and land cover if either has substantially changed since the channel was originally designed
- Soil borings or test pits to determine underlying soil conditions in the channel, as well as the depth to bedrock or water table
- Surveys of current channel cross-sections and elevations and to confirm

Figure 8: Crews should look downstream for advancing knickpoints that could undermine in-channel treatments.

locations and depths of any suspected utilities.

Design Process

The design process for a conveyance retrofit depends on whether it is an in-channel or off-channel design. In both cases, hydrologic and hydraulic models are used to assess proposed water elevations with respect to channel capacity, property impacts, and potential utility submergence. The following step-wise design process is recommended for in-channel retrofits:

Step 1: Compute the desired target water quality volume for the retrofit site (in acre-feet), given its current drainage area and impervious cover. Compare this to the estimated WQv available within in-channel treatment cells. Water quality storage can be created above or below the existing channel. Storage below the channel is obtained by dry swales, bioretention swales, or excavated wetland cells, none of which alter the hydraulic capacity of the channel. Storage above the channel is obtained using weirs, berms or checkdams that do alter channel hydraulic capacity (Figure 9). If the target volume can be achieved, proceed to the next step.

Step 2: Check with the local review authority to confirm which hydraulic capacity design standards apply to (e.g., conveyance of 10-year design storm). Roadway conveyance design standards may vary based on road classification.

Step 3: Revise the existing hydrologic model for the existing open channel section (or create new one). The model input deck may need to be modified if the upstream channel or its contributing drainage area has changed since it was originally constructed. Verify that the existing channel has adequate hydraulic capacity to pass the design storm.

Step 4: Repeat the modeling process for the final retrofit channel dimensions to determine whether proposed changes in slope, channel geometry or roughness can still accommodate the local design storm for safe conveyance.

Step 5: Use Manning equation to ensure that minimum residence time is achieved for the water quality design storm within the channel treatment area. A minimum target is 10 to 20 minutes of residence time for the channel, not accounting for any infiltration into the treatment cells. Evaluate the channel geometry to ensure that flow spreads evenly over the bottom of the channel.

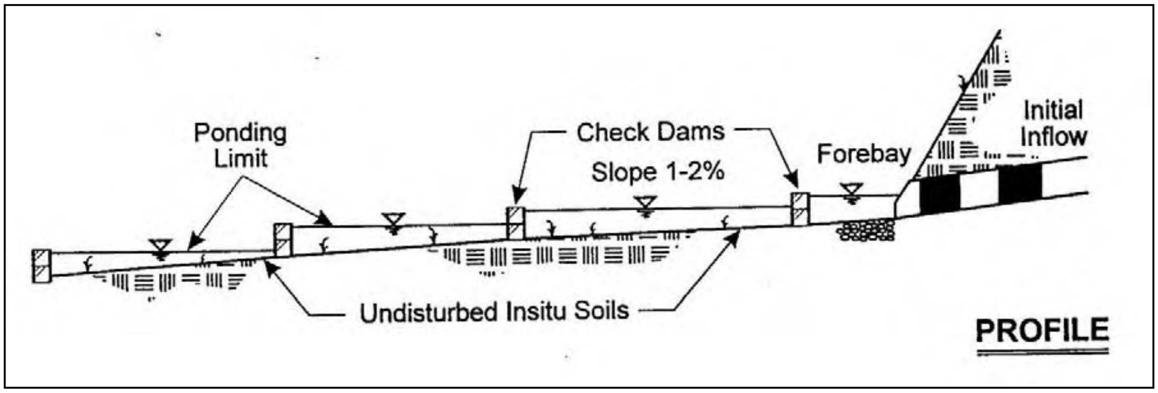


Figure 9: Getting storage on the surface of a conveyance channel using checkdams.

Step 6: Velocity control is a significant design consideration with in-channel retrofits to minimize sediment re-suspension and prevent erosion. Velocity may be reduced by further reducing channel slope, increasing the channel width, increasing roughness, or using geotextile reinforcement. Scour analysis may be needed to size the diameter of stone needed to stabilize checkdams, biologs or weir walls.

Step 7: Employ a grade control to fix the downstream elevation of the retrofit in larger naturalized channels. A rock vortex weir may be appropriate to fix the retrofit (See Profile Sheets R-18 to R-21 in Manual 4). An entrenched stone checkdam should suffice for smaller conveyance channels. The design process for off-channel retrofits is very similar to outfall retrofits (See Profile Sheet SR-3). Several examples of conveyance retrofits are presented in Figure 10.

Construction Considerations for Conveyance Retrofits

Conveyance retrofits can be challenging to construct for several reasons. Construction access and staging areas are always at a premium given that most drainage easements are very narrow (10 to 50 feet). Designers often need to get temporary easements to store construction equipment and materials (Figure 11). Bid documents should specify specialized construction equipment that can work in tight and narrow spaces (such as bobcats).

Even though most conveyance retrofits lack perennial flow, designers should consider the effect of storm flow when it comes to erosion and sediment control. In particular, erosion control fabrics are recommended to anchor the bottom of the channel (see Profile Sheet R-10 in Manual 4). Sod may be needed to anchor steeper channel side-slopes.

Designers will need to find a way to bypass or pump around storm flows during retrofit construction. The construction schedule should be compressed to complete work as soon as possible and rapidly stabilize the channel so the retrofit is not washed out by an early storm. Contractors should consult weather forecasts before commencing work, and contingency items should be included in contracts to allow for replacement of plant material and temporary channel repairs.

Conveyance Retrofit Costs

A planning level cost for conveyance retrofits can be developed based on the stormwater treatment options employed (Table 1). In general, off-channel designs are more costly than in-channel designs due to the need to construct a flow splitter. Construction costs for conveyance retrofits are extremely variable, and designers should always look at site-specific factors shown in Table 2 to adjust their final cost estimate.

Figure 10: Four examples of conveyance retrofits.

Figure 11: Specialized equipment is needed to work within tight project boundaries.

Table 1: Estimated Construction Costs for Conveyance Retrofits (2006 $ per impervious acre treated)			
Retrofit Type	**Median Cost**[3]	**Range**	**Design & Engineering (%)**[4]
In-channel treatment [1]	$ 45,400	$ 25,400 to $62,600	32
Off-channel treatment [2]	$ 68,100	$38,100 to $93,900	32

[1] Based on average cost for water quality retrofit which may be high if the existing channel requires little surface grading
[2] Costs for off-channel treatment assumed to be 1.5 times more expensive due to need for flow splitters and channel reconnections
[3] Adjust the median cost to account for site-specific construction cost inflators/deflators shown in Table 2
[4] May increase to 40% if zero order streams are regulated under section 404 or if deed research is needed for multiple landowners

Table 2: Site-specific Factors that Influence Conveyance Retrofit Construction Cost	
Factors that Decrease Costs	**Factors That Increase Cost**
• Wide drainage easement available • Public land available for off-channel treatment • Existing channel is over-capacity • Single property owner • Ability to construct with small equipment • Surface treatment in swale (wet swales)	• Need to negotiate additional access easements • Poor construction access • Wetland permitting • Legal research on easements • Multiple property owners to notify • Flow splitter needed

SR-5	Storage Retrofits STORAGE IN TRANSPORT RIGHTS-OF-WAY	

Highways contain un-used land within their right-of-way where storage can be obtained by diverting highway runoff into a depression or excavated area. Highways frequently cross local drainage divides, which reduces contributing drainage area and makes the corresponding WQv storage more manageable. In most cases the contributing drainage area to a highway retrofit is less than 10 acres.

The most common stormwater treatment options for highway retrofits are ponds and constructed wetlands, although linear bioretention and swales may also be feasible in wider medians and rights-of-way (Figure 1). In general, infiltration is not recommended as a stormwater treatment option, unless they contain enough pretreatment to fully capture and contain a 10,000 gallon spill.

Highway retrofits are ideal because their runoff pollutant concentration is high. Land costs are negligible since the retrofit is located in the dedicated right of way. Highway agencies have stronger incentives to retrofit to comply with emerging stormwater permit requirements, watershed mitigation needs and hazardous material spill liability. Lastly, highway agencies are often "good maintainers" and may see retrofits as a means of reducing their ongoing maintenance operations.

Ideal Conditions for Highway Retrofits

The best conditions to shoehorn storage retrofits into the highway system occur at:

- Cloverleaf interchanges (Figure 2)
- Depressions created by approach ramps
- Open section drainage within a right-of-way that is wider than 30 feet and located down-gradient from the road and free of utilities
- Drainage leading to bridges that cross streams with extensive floodplains
- Highway drainage that can be diverted to adjacent public land
- Targets of opportunity in highway widening/realignment construction projects

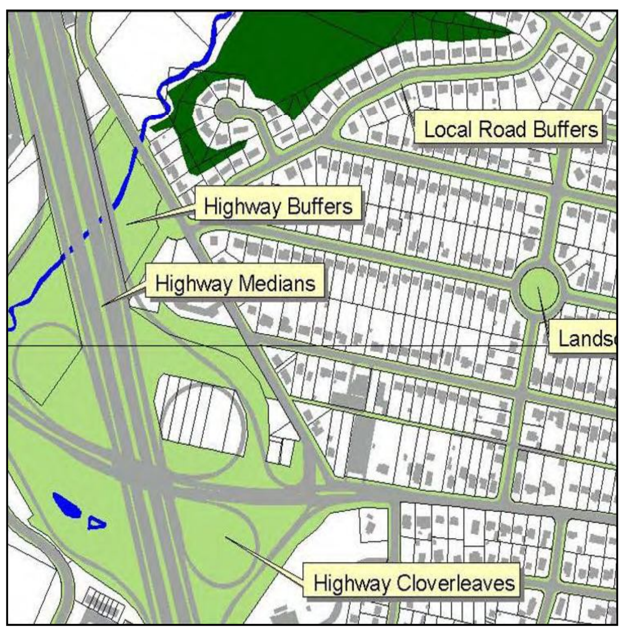


Figure 1: Highway corridors present numerous retrofitting opportunities.

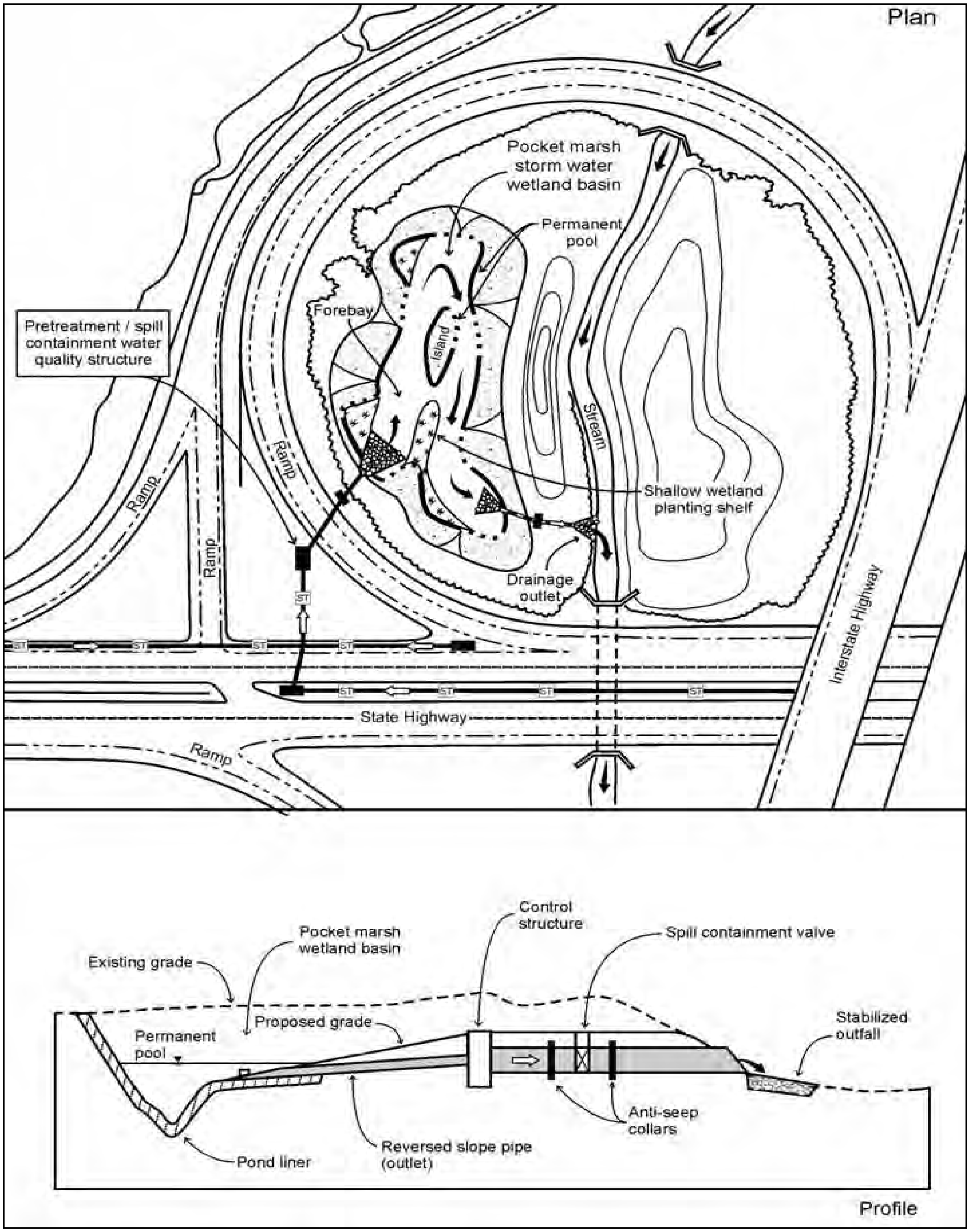


Figure 2: Plan and profile of wetland retrofit within cloverleaf interchange.

Situations Where Highway Retrofits are Difficult

Retrofitting is not a good idea at highway sites that:

- Are likely to be widened or expanded in the future to handle increased traffic flow
- Have guard rails, steep side-slopes or limited sight distance
- Require lane closures to provide construction or maintenance access
- Are slated to be used as a staging area for future road construction projects

Restoration Alternatives at Highway Sites

If a storage retrofit is not feasible, the site may still be suitable for reforestation (Figure 3) using the highway tree planting methods outlined in Cappiella *et al.* (2006a).

Desktop Search for Highway Retrofits

Potential highway retrofit sites can be found using several methods. The quickest is to visually examine aerial photos, since major highway features tend to really standout (Figure 4). A more systematic method is search existing local, state or federal highway right-of-way GIS layers against open land and the stream network. The combined land area in open space and right of way should generally meet a minimum acreage threshold of one acre. Most highway agencies have good maps of their road drainage, so try to get copies to take into the field (Figure 5). These maps should be analyzed to find any existing highway stormwater treatment practices that might be suitable for retrofitting.

Figure 3: Reforestation may be a viable option if a retrofit is not feasible.

Figure 4: Highway retrofits really standout in aerial photos, although highway drainage does not.

Figure 5: Many highway agencies have good GIS data on their stormwater infrastructure.

Highway drainage maps are a great help since highways often define (and frequently alter) the topographic boundaries of the contributing drainage area. Some designers may want to analyze these maps to initially estimate drainage area to potential highway retrofit sites before they go out in the field. Designers should also coordinate with highway planners about future road construction plans that could influence proposed retrofit sites. For example, an otherwise fine treatment area might be slated for construction staging in a future road construction project.

What to Look for During Field Investigations at Highway Retrofits

Highway retrofit sites can be dangerous, so safety is paramount. Crews should wear blaze orange safety vests, don hardhats, and look for safe places to park vehicles and cross traffic lanes to access the site. Crews should always get authorization from the highway agency to access potential retrofit sites. Better yet, highway engineers should be invited to share their knowledge about road safety, drainage and history. It is advisable to get highway drainage maps before going out in the field, since highway drainage can be complex and confusing to determine in the field. As a general rule, sites that are hazardous to access will be poor retrofit candidates. Assuming a site is reasonably safe, the crew should:

Check to see whether the highway has open or closed drainage and try to delimit the upstream drainage divide. The actual drainage can be difficult to ascertain because of subtle grades, or pipes that buck grade, so the crew may need to consult as-built drawings to solve the drainage puzzle.

Sketch out the contributing drainage area and flow path and compare against highway design drawings. Most highway retrofits have fairly small drainage areas, so several retrofits may be needed for full treatment. As a rule, keep in mind that each 100 feet of a 10 foot travel lane equates to about 0.022 acres of drainage area. Look for obvious depressions in a down gradient direction that can provide treatment without major excavation.

Remember that available treatment area needs to be adjusted to account for standard highway safety setbacks. For example, a 15 to 50 foot setback from edge of pavement is normally required for sight distance and traffic safety. Similarly, many highway agencies insist that road side-slopes be maintained at a grade of 6:1 (h:v) or better in the absence of guard rails.

The crew should measure available head, which is usually fixed by the invert of the receiving highway drainage system. In most cases, at least six feet of head is needed to drive pond or wetland retrofits.

Feasibility, Approvals and Permitting for Highway Retrofits

The greatest hurdle is getting approval from the local/state or federal highway agency that owns the retrofit site.

Early coordination with the appropriate highway agency is essential. Designers should thoroughly understand all agency road design requirements such as setbacks from pavement, sight lines, pool depths, minimum freeboard, access and drainage capacity, and treat them as a given during retrofit assessment and design. The highway agency will want to ensure that the proposed design will not saturate existing roadway embankments nor diminish the flow capacity of existing highway drainage.

In most cases, retrofit construction will temporarily interrupt traffic flow, so the reviewing agency will want to know how traffic flow will be maintained, and may require a separate permit known as a "maintenance of traffic" plan.

Highway agencies are keenly interested in the maintenance implications of the retrofit and who will pay for it. The highway agency maintaining the right-of-way will normally maintain the new retrofit, and will expect that safe access and spill control be addressed. The approving agency will expect a written maintenance agreement that clearly defines the duties, schedules and contingencies for future maintenance operations. The reviewing agency will want assurances that the proposed retrofit will not interfere with routine highway maintenance operations such as pulling ditches or mowing.

Most highway retrofits do not involve environmental permits, although it is good practice to minimize any major tree loss or wetland impact. In some regions, the wetland permitting authority may regulate wetlands that were unintentionally created by original highway construction, so be sure to consult them about their jurisdictional status. Highway agencies usually have numerous wetland mitigation needs, so designers may want to utilize constructed wetlands as the stormwater treatment option to make the retrofit more attractive.

If trees are cleared during construction that remove an existing visual screen or noise barrier, expect significant concerns from adjacent residents about the loss of trees.

Design of Highway Retrofits

Highway retrofits involve several unique design considerations, including:

Road design criteria - Designers need to fully understand and satisfy all highway design criteria relating to safety and maintenance to have any chance of getting the retrofit approved by the review agency. For example, most agencies will require a minimum 30 foot "clear zone" from the road shoulder to allow vehicles to recover when they run off the road.

Design for higher pollutant loadings - Highway runoff can be a significant source for sediment, hydrocarbons, heavy metals and other pollutants, so designers should select the best stormwater treatment option that maximize removal of the pollutant of concern. Highway runoff also contains high inputs of litter and debris that can cause clogging, reduce treatment capacity and increase retrofit maintenance burdens.

Pretreatment - Over-sized pretreatment is recommended for most highway retrofits. The pretreatment cell should comprise at least 25% of the entire WQv storage.

Safe and direct maintenance access - Highway agencies will always insist on safe and direct access for heavy equipment to the retrofit. Operationally, this means a retrofit design that avoids steep slopes, reduces the need for lane closures, allows for safe highway ingress/egress and enables vehicles to turnaround easily.

Compatibility with ongoing highway maintenance - Highway crews need to efficiently maintain hundreds of miles of ditch, shoulder and right of way every year. Designers should consult them to determine how the proposed retrofit will influence their routine maintenance operations, and be prepared to adjust the design accordingly.

Maintenance of traffic - Temporary lane closures are often needed at critical points in retrofit construction to ensure the safety of both construction workers and motorists. A detailed construction sequence must be formulated to safely segregate traffic and construction equipment. The retrofit maintenance plan should also specify how traffic will be managed to permit maintenance access.

Wintertime operation **-** Designers in northern climates should always consider how snow management will impact the proposed retrofit. For example, high chloride inputs can harm vegetation, so landscaping plans should specify salt tolerant plant species. If road sanding loads are high, designers should incorporate additional storage and/or pretreatment. Lastly, designers should anticipate the direct impact of snow plowing, dumping and melting on the retrofit and its vegetation, as well as the risk of damage to inlets and curbs from snow plows.

Spill Containment - Accidents and spills are a common occurrence along highways, so it is wise to incorporate spill containment features into highway retrofits. Ponds, wetlands and pretreatment cells should contain a butterfly shut-off valve so that spills can be rapidly contained within the retrofit. If underlying soils are permeable, it may be advisable to install liners to prevent downward migration of polluted stormwater. Figure 6 shows a large surface sand filter in Austin, Texas that has a hazardous material diversion chamber located prior to the filtering treatment area.

Sediment Disposal **-** Sediments that accumulate in highway retrofits have a small but higher risk of being classified as hazardous waste due to stormwater runoff and spills. Visual inspections are recommended prior to sediment removal operations to determine if further testing is needed. If the visual inspection indicates sediments are discolored or malodorous, sediment testing can determine whether they need to be disposed in a conventional landfill or special hazardous waste facility.

Figure 6: Spill containment should be a feature in highway retrofit designs.

Design Support

Highway retrofits require several special studies to support design, including:

- Interview highway planners about future uses at the proposed site.
- Review as-built surveys to delineate the contributing drainage area and drainage network. If these are not available, surveys may be needed to confirm drainage areas and elevations.
- Take soil borings at the proposed treatment area since the original soils have been severely altered and compacted by mass grading during initial road construction.
- If the proposed retrofit is located close to the right-of-way boundary, conduct plat research to define ownership and establish easements.

Design Process

The highway review agency will dictate the design process for each retrofit site. The design process will also depend heavily on the type of stormwater treatment selected (Figure 7).

Construction Considerations for Highway Retrofits

Construction of highway retrofits are challenging given the volume and speed of nearby traffic.

- Contractors should diligently follow the maintenance of traffic plan to ensure worker and motorist safety.
- Highway retrofits tend to be quite tight for material and equipment staging.
- Erosion and sediment controls should be scrupulously maintained since these retrofits are visible to passing motorists

Highway Retrofit Costs

Cost data are fairly sparse for highway retrofits. For planning purposes, construction costs can be assumed to be equivalent to the cost to construct a new retrofit facility, as shown in Table 1. Construction cost estimates should be adjusted to account for site-specific factors that can influence highway retrofit construction, as shown in Table 2.

Figure 7: Two examples of retrofits located in the highway right of way.

Table 1: Estimated Construction Costs for Highway Retrofits (2006 $ per impervious acre treated)			
Retrofit Type	**Median Cost**	**Range** [2]	**Design & Engineering**
New storage retrofit [1]	$19,400	$9,000 to $32,000	32% [3]

[1] Use appropriate pond equation in Appendix I if retrofit site satisfies new development site conditions
[2] Adjust based on site-specific construction cost inflators/deflators in Table 2
[3] Increases to 40% if extensive highway agency design review approval is needed

Table 2: Site Specific Factors that Influence Highway Retrofit Projects	
Factors that increase costs	**Factors that decrease costs**
• Need to excavate to get storage • Off-site hauling • Need new maintenance access • Gates and fencing • Erection of temporary construction barrier • Spill controls	• Existing depression • Open section roads • Gentle side slopes • Low traffic volumes • Cooperative highway review agency • Retrofit contributes to mitigation needs

SR-6	Storage Retrofits **LARGE PARKING LOT RETROFITS**	

Large parking lots are a good retrofit opportunity to treat runoff quality. Large parking lots are defined as five acres or greater in size (including any connected rooftops – Figure 1). Common examples include lots serving municipal buildings, high schools, regional shopping malls, stadiums, auto dealerships, airports, commuter lots, hospitals and big box retail stores. Larger parking lots are normally served by extensive storm drain systems and contain numerous inlets, underground pipes and outfalls.

This retrofit strategy excavates centralized treatment storage in unutilized land located downgradient of the lot (Figure 2). Common stormwater treatment options include extended detention, ponds, constructed wetlands or a large bioretention area.

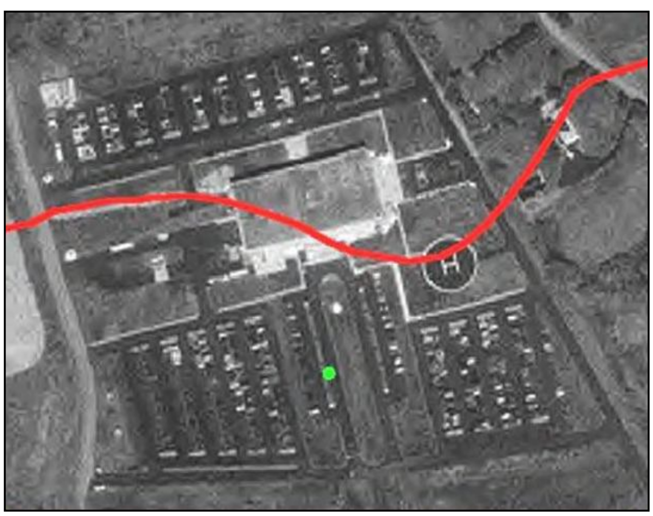


Figure 1: Large parking lots are a key retrofit target.

Centralized retrofits are not the only retrofit strategy for parking lots; an on-site retrofit strategy for small parking lots is described in Profile Sheets OS-8 and OS-13. The centralized retrofit strategy is generally more cost-effective on a per acre treated basis than an on-site strategy.

Large parking lots are an ideal retrofit because they generate more stormwater runoff and pollutants on a unit area basis than any other land use in a subwatershed.

Ideal Conditions for Parking Lot Retrofits

Parking lots built in the last few decades are good retrofit opportunities since local codes often require more generous setbacks for screening, landscaping and noise reduction. Recently developed suburban commercial zones are only about 70% impervious, suggesting that a decent fraction of the site may be available for surface treatment (Cappiella and Brown, 2001). Other good retrofit situations are:

- Parking lots serving large institutions, corporate campuses and colleges that tend to have even lower percentage of impervious cover for the whole site.
- Municipally-owned parking lots such as commuter lots, park access, and schools adjacent to open areas
- Industrial parking lots designated as stormwater hotspots
- Any parking lot served by an existing stormwater detention pond (use SR-1)

Figure 2: Down gradient open land reserved in setbacks is ideal for treatment.

Situations Where Parking Lot Retrofits Are Difficult

Several conditions make it difficult to retrofit a large parking lot:

- Parking lot is smaller than five acres in size (but try on-site parking lot retrofits described in Profile Sheet OS-8)
- Older lots located in highly urban areas, such as downtown central business districts
- Parking lots that discharge directly to waterfronts or waterways
- Open space adjacent to the parking lot is designated as a jurisdictional wetland, stream buffer or forest reserve.

Restoration Alternatives at Large Parking Lots

Even if a storage retrofit is not feasible, it may still be possible to install other restoration practices inside the parking lot or along its margins, such as:

Reforestation - in open spaces, parking lot islands and setbacks using the planting methods outlined in Cappiella *et al.* (2006a).

Pollution prevention practices - particularly when the lot is used for vehicle storage or is frequently resealed (see Profile Sheets H-4 and H-11 in Manual 8).

Regular vacuum sweeping and litter control - to keep gross solids and trash from entering the storm drain system.

Desktop Searching for Parking Lot Retrofits

It is fairly easy to find large parking lots since they stand out on aerial photographs or recent land use maps (Figure 3). Alternatively, a GIS search can match large contiguous parking areas/rooftops greater than 5 acres in size with adjacent open land in public or institutional ownerships. Some topographic analysis may be useful to confirm that the open land is actually downgradient from the lot.

The contributing drainage area is defined as the sum of the lot area and the footprint of the buildings it serves. It is helpful to estimate the contributing drainage area before investigating the lot in the field.

Figure 3: Large parking lots and potential off-site treatment area are easy to find on aerial photos.

What to Look for When Investigating Parking Lot Retrofits

The retrofit recon for a large parking lot is fairly straightforward, and is best done when parking demand is lowest (e.g., weekends, daytime or evening, depending on the use), and while it is raining.

1. *Confirm the size and use of the parking lot* - The crew should walk the entire lot to get a sense of its total area and whether it is connected to rooftop drainage. A simple rule of thumb is that 400 square feet of impervious cover are associated with each individual parking stall (Schueler, 1994) so that one acre of impervious cover is created for every 100 parking spaces (rooftop drainage not included). The crew can get a good sense of the acreage of the parking lot by quickly estimating the number of parking spaces in the lot, and multiplying it by 400 (Figure 4).

2. *Assess parking lot grade* - While most parking lots seem to be flat, they have subtle grading to key curb or drop inlets. If stormwater plans exist for the lot, they should be taken out in the field. The crew should sketch the existing plumbing by tracing the storm drain inlets toward the low point of site and looking for obvious points of discharge into adjacent open space (Figure 5). The crew should look for additional stormwater outfalls and pull a manhole or two to see how deep the pipes are underground. The crew may also want to see if there are good locations to cut the curb to divert surface runoff to a treatment area.

3. *Estimate the boundaries of the treatment area* – The crew should pace the approximate boundaries of the proposed treatment area, taking care to look for surface indicators of underground utilities that may reduce it. The size of the proposed treatment area can then be compared to the contributing drainage area estimated in Step 1. As a general rule, the proposed treatment area needs to be at least 3 to 5% of the contributing drainage area. Alternatively, the crew can directly compute the target WQv using the 3600 cubic feet per impervious acre rule, assuming that the contributing drainage area is 100% impervious.

4. *Evaluate head* - The crew then visually estimates the elevation difference between the invert of the storm drain outfall from the parking lot and the elevation at the proposed treatment area. Like most other storage retrofits, hydraulic head is needed to accommodate the depth of treatment and drive the retrofit by gravity flow. A

Figure 4: Stall counting is a quick way to estimate parking lot area.

Figure 5: The crew should check out the internal plumbing of the lot to see where runoff goes.

minimum of four to six feet of head is needed to make storage retrofits feasible at most parking lots (Figure 6). The crew may want to inspect soil conditions in the proposed treatment area using a soil auger to determine how deeply the retrofit could be excavated.

5. Sketch out the proposed design - Based on the foregoing information, the crew should have a good sense of the best stormwater treatment option for the site and whether a flow splitter is needed to direct stormwater into the proposed treatment area. The preliminary concept should then be sketched on the RRI field form.

6. Consider on-site parking lot options. If the recon indicates a storage retrofit cannot work, the crew should break up the lot into smaller drainage units to determine if some or all of it can be served by on-site retrofits located within the lot or along its margins (see Profile Sheet OS-8).

Feasibility, Approvals and Permitting for Large Parking Lot Retrofits

The biggest hurdle is getting permission to retrofit the open space parcel without having to acquire the land. The problem is pronounced when the adjacent land is not owned by the same landowner. Just because a parcel is open today doesn't mean that it is not slated for future development. Some initial research is needed to determine the development status of the open parcel. The best situation is when the parcel cannot be developed because it is contained within a required easement, open space, or setback.

Underground utilities are another common hurdle for parking lot retrofits. Sewer, water, gas and other utilities can be challenging obstacles to design around or relocate. Above-ground lighting, signs and overhead wires can also be a problem, but are somewhat easier and cheaper to relocate. If the parking lot outfall discharges to a floodplain or stream corridor, designers should check to see if the flows will impact wetlands, floodplains or forests.

Figure 6: The invert elevation of the storm drain pipe underneath the lot is a critical design factors.

Parking Lot Retrofit Design

The basic design of parking lot retrofits is fairly standard, but there are a few issues worth noting:

Designers may need to install flow splitters within the parking lot to divert runoff from the storm drain pipe to a more desirable area for water quality treatment (see Profile Sheet SR-3)

Large parking lots generate a lot of trash, litter and debris and can have high sediment loadings due to winter sand applications. Consequently, designers should provide over-sized and accessible pretreatment (e.g., forebays) and plan on a more frequent sediment removal schedule (Figure 7).

Designers should consult with the facility manager to gain a better understanding of temporary or seasonal parking lot maintenance practices that can influence retrofit design, such as deicing applications, snow storage, sweeping, and vehicle washing (Figure 8). Designers should landscape the retrofit to improve its appearance, particularly when it is located in a highly visible area.

Figure 7: While ponds are most common, larger bioretention areas can provide effective treatment.

Note: a two-cell design with forebay would have worked better for this site

Figure 8: Designers should check to see if the proposed treatment area can be used for winter snow storage.

Design Support

Design support for parking lot retrofits may include several tasks:

- Secure as-built drawings of the original parking lot design from the local review authority. If they are not available, drainage area may need to be re-delineated and surveyors may need to take spot elevations of parking lot plumbing.
- Research zoning, easement and plat records to determine the future development potential of the proposed treatment area
- Take standard soil test pits in the proposed treatment area
- Conduct parking demand studies to confirm that the existing lot has enough capacity to meet current and reasonable future parking needs
- Delineate any forests or wetlands that may be present in the proposed treatment area (or any other wetlands or forests

that may receive stormwater discharges from the new retrofit).

Design Process

The basic design process for large parking lot retrofits is essentially the same as a new stormwater facility, unless flow splitters or curb cuts are used to divert stormwater runoff to an off-line treatment area.

Construction Considerations for Parking Lot Retrofits

Large parking lot retrofits involve the same basic construction sequence as new stormwater ponds, although a few logistical issues arise if the lot is being actively used:

A small portion of the lot may need to be closed for construction access, staging and storage. Both construction and staging areas should be temporarily fenced to keep the public out. Traffic management plans may be needed to segregate construction ingress and egress traffic from existing motorists. Construction should be scheduled to avoid obvious spikes in parking demand such as the holiday shopping season.

Parking Lot Retrofit Costs

The cost to construct parking lot retrofits is generally assumed to be equal to the cost to construct a new retrofit facility (Table 1). Cost equations for specific stormwater treatment options may also be used to get a more accurate estimate (See Appendix J). The cost estimate should be adjusted to account for numerous site-specific factors that can influence retrofit construction costs shown in Table 2.

Table 1: Estimated Construction Costs for Large Parking Lot Retrofits (2006 $ per acre of impervious cover treated)

Retrofit Type	Median Cost	Range [2]	Design & Engineering (%)
New storage retrofit [1]	$19,400	$9,000 to $32,000	32

[1] Use appropriate pond equation in Appendix I if the retrofit site satisfies new development site conditions
[2] Adjust based on site-specific construction cost inflators/deflators in Table 2

Table 2: Site-specific Factors that Influence Large Parking Lot Retrofit Project Costs

Factors that Decrease Cost	Factors that Increase Cost
• Public land or cooperative landowner • Storage via embankment rather than excavation • Off-line design • Existing storm drain discharges near surface • Use of ED wetland as treatment option • No environmental permits needed • Staging and stockpiling areas away from lot	• Off-site hauling • Need to secure stormwater easements • Pavement repair due to construction equipment • Reworking the storm drain system underneath the parking lot • Relocating downstream storm drain or channel • Flow splitting • Land acquisition

OS-7	On-site Retrofits	
	HOTSPOT OPERATIONS	

These retrofits provide on-site water quality treatment at confirmed stormwater hotspots, defined as any operation that generates higher concentrations of stormwater pollutants and/or has a higher risk of spills, leaks or illicit discharges. Pollution prevention practices such as covering, secondary containment, and employee training should always be considered first. However, when prevention practices are not sufficient to provide full treatment, on-site retrofits are needed to treat the quality of runoff from the stormwater hotspot (Figure 1).

The preferred stormwater treatment option at hotspot operations are filtering practices (Figure 2 and Profile Sheet ST-5). Alternatively, bioretention without exfiltration may be used (Profile Sheet ST-4). The use of infiltration is strongly discouraged due to the risk of groundwater contamination.

Hotspots are good locations for on-site retrofits since they contribute higher stormwater pollutant loads than any other urban source area. Second, many communities have the regulatory authority to compel private landowners to install onsite retrofits to comply with municipal or industrial stormwater requirements.

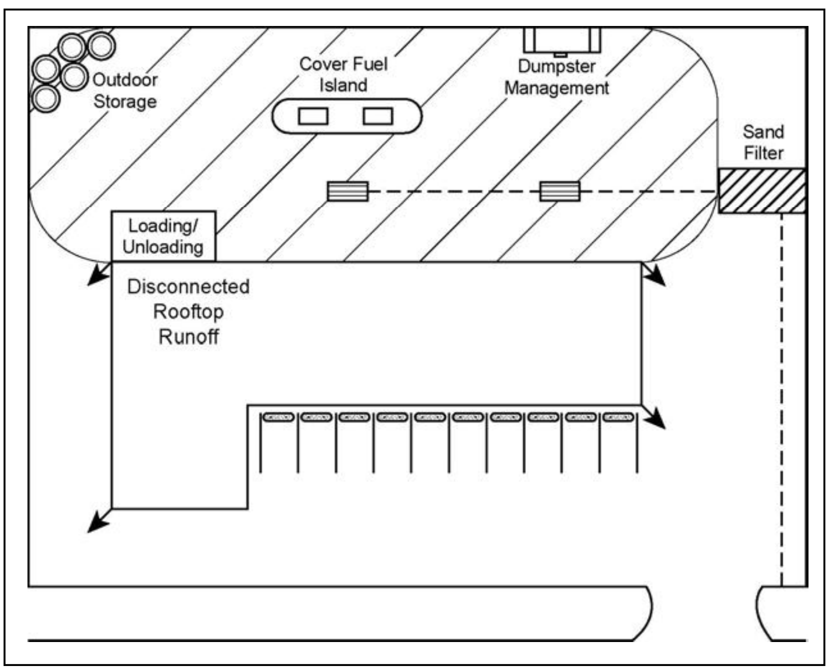


Figure 1: Schematic showing typical treatment at hotspot generating areas.

Figure 2: Sand filters are the preferred stormwater treatment option for hotspot retrofits.

Ideal Conditions for Hotspot Retrofits

Retrofits should always be considered for any operation:

- Found to be a severe hotspot during a hotspot site investigation
- Covered by an existing industrial stormwater permit or specifically designated as a stormwater hotspot in the local water quality ordinance
- Where site investigation shows that pollution prevention practices alone are not sufficient to remove pollutants in stormwater runoff

Situations Where Hotspot Retrofits are Difficult

Most subwatersheds contain dozens or even hundreds of potential stormwater hotspots, but only a fraction of them require on-site stormwater treatment. Hotspots do not need retrofits when:

- Field investigations indicate that the hotspot is not severe
- Legal responsibility to manage the property is unclear (e.g. operator leases the space from property owner)
- Community does not offer technical assistance to help operators install low cost stormwater treatment options
- Site is severely constrained by a lack of head or space

Alternative Restoration Projects at Stormwater Hotspots

A nonstructural approach can effectively prevent pollution from many stormwater hotspot operations. Manual 8 contains 15 different profile sheets that describe pollution prevention practices that can be applied to stormwater hotspots:

H-1 Vehicle Maintenance and Repair
H-2 Vehicle Fueling
H-3 Vehicle Washing
H-4 Vehicle Storage
H-5 Loading and Unloading
H-6 Outdoor Storage
H-7 Spill Prevention and Response
H-8 Dumpster Management
H-9 Building Repair and Remodeling
H-10 Building Maintenance
H-11 Parking Lot Maintenance
H-12 Turf Management
H-13 Landscaping/Grounds Care
H-14 Swimming Pool Discharges
H-15 Unique Hotspot Operations

Desktop Searching for Stormwater Hotspots

The team can isolate areas to search for hotspots in the field by reviewing maps depicting commercial, industrial or municipal land use (Figure 3). Local knowledge can also be helpful. A more systematic approach for finding hotspot sites involves searching local business databases using standard industrial codes (SIC). Methods for conducting an SIC database search can be found in Appendix A of Manual 8. Another approach to find potential stormwater hotspots is to search databases of industrial operations that hold stormwater permits.

What to Look for When Investigating Hotspots

Procedures to inspect and rank stormwater hotspots are described in the Hotspot Site Investigation (HSI) component of the Unified Subwatershed and Site Reconnaissance (see Manual 11). The HSI involves a rapid visual assessment to inspect site operations that may cause a stormwater hotspot. If a site is ranked as a confirmed or severe hotspot, then the crew looks into the "plumbing" at the site to determine whether additional stormwater treatment is needed beyond standard pollution prevention practices.

Five steps are used to assess the feasibility of on-site treatment at a stormwater hotspot:

1. Define hotspot generating area – In the first step, the crew defines the approximate area of the hotspot generating area (HGA) which is defined as the actual area at the site that is generating higher levels of pollutants (Figure 4). The HGA is usually associated with:

- Vehicle Operations
- Outdoor Materials
- Waste Management
- Physical Plant Maintenance
- Intensive Turf/Landscaping

The HGA often comprises only a fraction of total site area, although more than one may be present at larger sites. The crew should sketch the approximate boundaries of the HGA on the site map.

Figure 3: Hotspots are too small to find on aerial photos but can be found by searching business databases.

2. Evaluate pollution prevention practices - The crew then evaluates whether the HGA can be fully treated by non-structural practices such as covering, secondary containment, or employee training. Full treatment is operationally defined as no exposure of the polluting operation to rainfall or runoff. If full treatment cannot be obtained, the crew moves to the next step.

3. Evaluate hotspot connection to public storm drain system - The crew walks the site to understand how the plumbing of the private storm drain system connects to the public storm drain system (Figure 5). In simple terms, this means tracing the path of runoff from the HGA as it crosses the site and enters offsite drainage. The crew should look for all connections to the storm drain system to determine if they are illegal or illicit. Some connections to the storm drain

Figure 4: Common hotspot generating areas to look for during a site investigation: vehicle service/fueling (a); bulk outdoor storage(b); dumpsters (c); truck washouts (d) irrigation/fertilization (e); and chemical drums (f).

system may be located inside a building or under a roof (e.g., shop drains). The existing plumbing then sketched on the site map.

4. Select stormwater treatment option - The crew then evaluates the feasibility of a sand filter or bioretention to treat the hotspot. Head is usually the key feasibility constraint and is defined as the vertical distance between the elevation of the stormwater inlet and the bottom elevation of the existing storm drain system to which it discharges. Most stormwater filter and bioretention designs require three to 10 feet of head. If the entry point is not feasible for a retrofit, the crew moves down-gradient in the storm drain system to look for a more suitable treatment area.

5. Get retrofit design information - Once a suitable treatment area is found, the crew records details to assist in future design efforts, such as the adjusted drainage area, surface and pipe slopes, and notes on soil and subsurface conditions.

Figure 5: A crew member checks for a connection between the HGA and the storm drain system (sometimes it's obvious).

Feasibility and Permitting for Hotspot Retrofits

The major feasibility issue for hotspot retrofits is whether a community has legal authority to enforce on-site treatment of stormwater quality at existing hotspots (i.e., without having to wait until stormwater requirements are triggered by new development or redevelopment applications).

The review of hotspot retrofit designs is fairly straightforward, assuming the local stormwater review authority has experience with filtering and bioretention practices. The review authority may wish to add conditions to maintenance agreements that require testing sediments to ensure trapped sediments are safe for landfill disposal (i.e., are not considered hazardous waste). Communities may obtain greater compliance if they offer direct technical assistance to owners/operators on how to implement stormwater treatment and pollution prevention practices.

Hotspot Retrofit Design

Several key design issues arise when dealing with hotspot retrofits:

The design of each retrofit should control the specific pollutants generated at the stormwater hotspot (e.g., oil, sediment, metals). Manual 8 provides guidance on the types of pollutants generated by different hotspot operations. The designer should also interview the owner/operator to fully understand the operations that routinely occur at the site throughout the year (Figure 6). For example, an otherwise ideal retrofit location may interfere with business operations or impede traffic. In other cases, the hotspot generating area may change with the season of the year (particularly for outdoor storage).

Pretreatment is essential for hotspot retrofits. Sand filters or bioretention areas should have a two-cell design that enables the first cell to capture and contain spills or transitory flows. If the site experiences chronic flows, the crew should conduct a discharge prevention investigation to determine whether the source of the flow constitutes an illicit discharge (for methods, consult Brown *et al.* 2004). Continuous or chronic dry weather flows should never be discharged into a hotspot retrofit.

Hotspot retrofits require more frequent routine maintenance compared to storage retrofits. Designers should develop a clear plan with specific maintenance tasks, schedules, costs and vendors. Hotspot retrofits should be located on the surface (or just below it) to allow direct access for maintenance and sediment removal. Hotspot retrofits must be clearly marked or posted so they can be easily recognized as a stormwater treatment practice during routine inspections.

Some hotspot sites are so confined that only underground treatment can work (see Profile Sheet OS-13). Designers should avoid infiltration or any other practice that connects to groundwater (e.g., swales and exfiltrating bioretention).

Figure 6: Designers should interview operators to understand seasonal operations

Design Support

Designers may need key information to support the design of hotspot retrofits:

- Secure original as-built drawings of site drainage.
- Mark the location and elevation of existing utilities.
- Survey the pipe system to determine permissible pipe invert elevations.
- Survey the site to at least a tenth of a foot to determine the precise grade and contributing drainage area to the proposed retrofit. The designer may also want to check these boundaries during an actual storm event.
- Extend soil borings to a depth two feet below the bottom of the proposed retrofit.
- Conduct a discharge prevention investigation if chronic or continuous dry-weather flows are observed.

Design Process

The design process of most hotspot retrofits is fairly straightforward, and involves six steps:

Step 1: The pollutant(s) of concern discovered during the site inspection should be the focus of design.

Step 2: Disconnect or divert any rooftop runoff that "runs on" to the HGA (which helps reduce the water quality storage volume needed for the retrofit)

Step 3: Further minimize the size of the HGA by covering and secondary containment measures.

Step 4: Choose the most effective stormwater treatment option for the retrofit based on site conditions and the pollutant of concern (normally a sand filter or bioretention with an underdrain).

Step 5: Size the retrofit to capture the entire runoff volume from the locally required WQv storm event. Hotspot retrofits should provide extensive pretreatment storage.

Step 6: If the retrofit will bear loads, perform computations to determine if structural reinforcement is needed to withstand expected vehicle loads.

Delivery Considerations for Hotspot Retrofits

Many communities have authority to require on-site retrofits as part of municipal or industrial stormwater permit compliance (although relatively few have exercised it). Widespread compliance, however, can seldom be achieved by permitting alone - technical assistance, employee training, business recognition and even cost-sharing may be needed to encourage small businesses to retrofit their hotspots. Manual 8 describes a carrot and stick approach to obtain greater hotspot compliance.

Construction Considerations for Hotspot Retrofits

Several considerations are important when constructing hotspot retrofits:

- Construction phases should be compressed to minimize interference with existing operations or parking.
- Inspectors should ensure that the top of the filter bed is completely level, the retrofit is water tight, and the connection between private and public storm drains is secure.
- Runoff should be diverted around the retrofit during construction.
- Retrofit maintenance tasks, costs, schedules and vendors should be clearly outlined in the Stormwater Pollution Prevention Plan developed for the site. Employees and facility managers should review the plan annually to schedule maintenance work.

Hotspot Retrofit Costs

The cost to construct hotspot retrofits is primarily based on the stormwater treatment option selected and the specific design variant employed (see Table 1). Other site-specific factors that can drive up the cost of a hotspot retrofit are described in Table 2.

Table 1: Estimated Construction Costs for Stormwater Hotspot Retrofits (2006 $ per cubic foot treated)			
Stormwater Treatment Option	**Median Cost**	**Range**	**Design & Engineering (%)[6]**
Surface Sand Filter [1]	$ 5.00	$ 3.00 to $ 8.00	35
Structural Sand Filter [2]	$ 20.00	$ 16.00 to $ 22.00	35
Underground Sand Filter [3]	$ 65.00	$ 28.00 to $ 75.00	35
Multi-chamber Treatment Train	$ 80.00	$ 66.00 to $ 94.00	35
Large Bioretention [4]	$ 10.50	$ 7.50 to $ 17.25	35
Small Bioretention [5]	$ 30.00	$ 25.00 to $ 40.00	35

[1] Surface filter in pervious area with minimal concrete or structural features
[2] Two cell surface or perimeter sand filter with concrete structures
[3] Underground filter that can bear traffic loads
[4] Retrofit serving more than 0.5 acres of CDA with underdrain and bottom liner
[5] Retrofit serving less that 0.5 acres of CDA with connection to storm drain system
[6] Higher design & engineering for employee training in pollution prevention and maintenance

Table 2: Factors that Influence Construction Costs for Hotspot Retrofit Projects	
Factors that Decrease Cost	**Factors that Increase Cost**
• Ability to cover or contain runoff from HGA • Redirecting runoff passing thru HGA • No major changes to existing plumbing • Treatment available on turf or landscaping area • HGA can be reduced through non-structural practices	• Filter needs to bear traffic loads • Grates or bollards needed to protect it • Underground treatment • Pavement repairs needed after construction • Full treatment of the water quality storm

OS-8	On-site Retrofits **SMALL PARKING LOT RETROFITS**	

This on-site retrofit strategy treats the quality of runoff from existing parking lots less than five acres in area. Surface retrofits can be installed within the parking lot, along its perimeter, or in adjacent pervious areas (Figure 1). A wide range of stormwater treatment options can be adapted for this retrofit, including:

- Impervious Cover Reduction
- Permeable Pavers
- Bioretention Islands
- Perimeter Bioretention
- Perimeter Sand Filter
- Filter Strips
- Infiltration
- Dry Swales

Parking lots are an ideal location for on-site retrofits since they generate extremely high unit area runoff volumes, pollutant loads and temperature spikes. Parking lot retrofits also have great demonstration value due to their high visibility. Figure 2 presents numerous examples of small parking lot retrofit techniques, and a design schematic is shown in Figure 3.

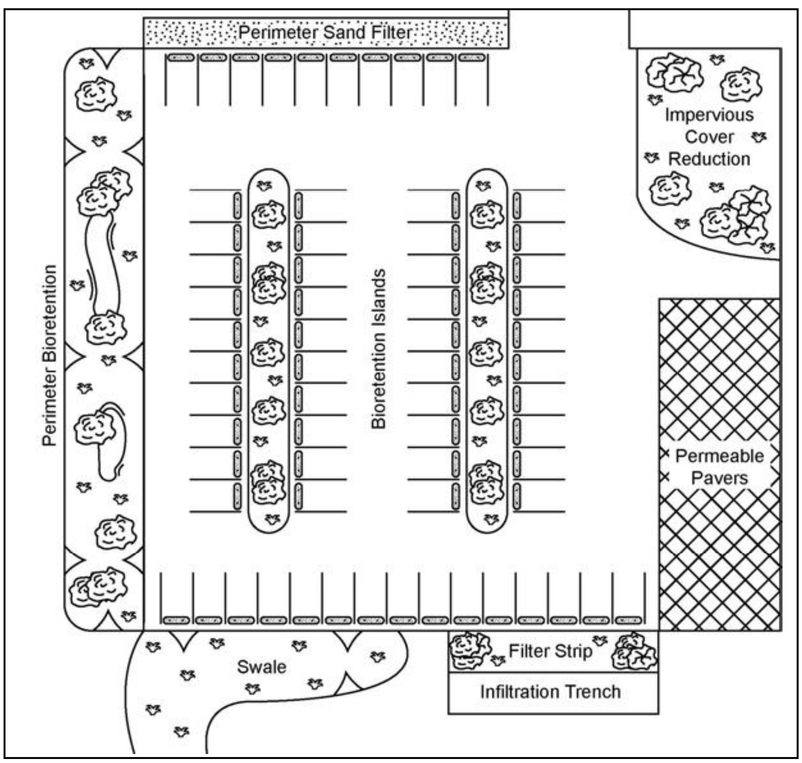


Figure 1: Many different retrofit strategies can be employed to retrofit parts of a smaller lot.

Figure 2: Examples of retrofits employed at small parking lots: permeable pavers (a); dry swale (b); perimeter sand filter (c); grass filter//infiltration trench (d;) filter strip (e); internal bioretention (f); underground infiltration (g) and island bioretention (h).

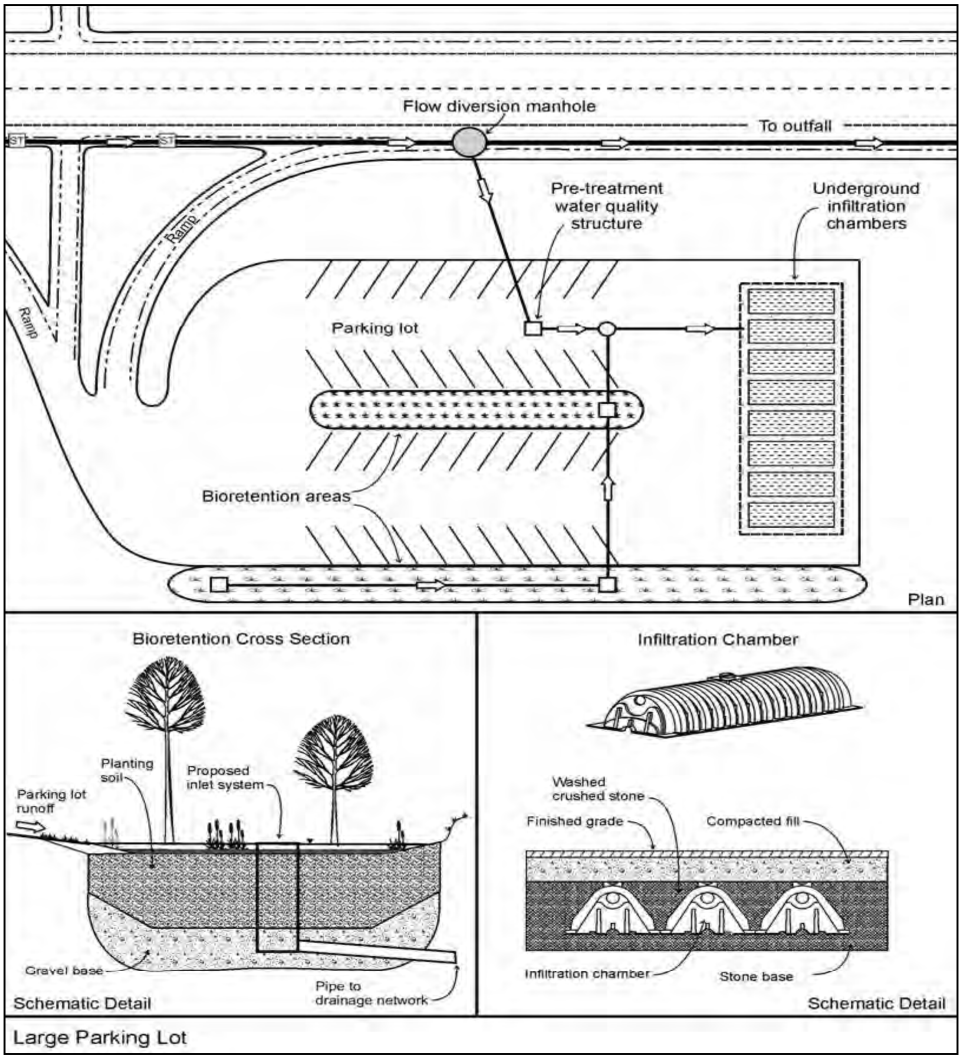


Figure 3: Schematic showing multiple practices treating small parking lot.

Ideal Conditions for Small Parking Lot Retrofits

The best conditions to retrofit small parking lots are when:

- Communities retrofit a municipally-owned parking lot as a demonstration project
- New parking lots are constructed as part of redevelopment or infill projects
- Existing parking lots are slated for resurfacing, reconfiguration or renovation (their normal design life is about 15 to 25 years)
- Local stormwater regulations trigger water quality control at time of lot renovation or rehabilitation
- Parking lots were built with generous landscaping, open space, screening or frontage setbacks
- Parking lots are not fully utilized because they were designed using excessive parking demand ratios (Figure 4)

Situations Where Small Parking Lot Retrofits are Difficult

Small parking lot retrofits can potentially reduce available parking area, so they are generally not a great option in the following situations:

- Over-crowded parking lots
- Older parking lots built prior to modern design standards for screening, drainage, and landscaping
- Owners are reluctant to sacrifice parking spaces and/or are unwilling to perform future maintenance
- Dry or wet utilities run underneath the parking lot
- The parking lot is located in flat terrain and lacks adequate head
- The parking lot is already served by an effective stormwater treatment practice.

Alternative Restoration Practices for Small Parking Lots

Even if an on-site retrofit is not feasible, the following restoration practices may still be viable:

- *Tree planting* in parking islands, lot margins and setbacks.
- *Vacuum sweeping and litter control* in the parking lot (Figure 5).
- *Parking lot pollution prevention practices*, especially for vehicle storage and parking lot maintenance (see Profile Sheets H-4 and H-11 in Manual 8).

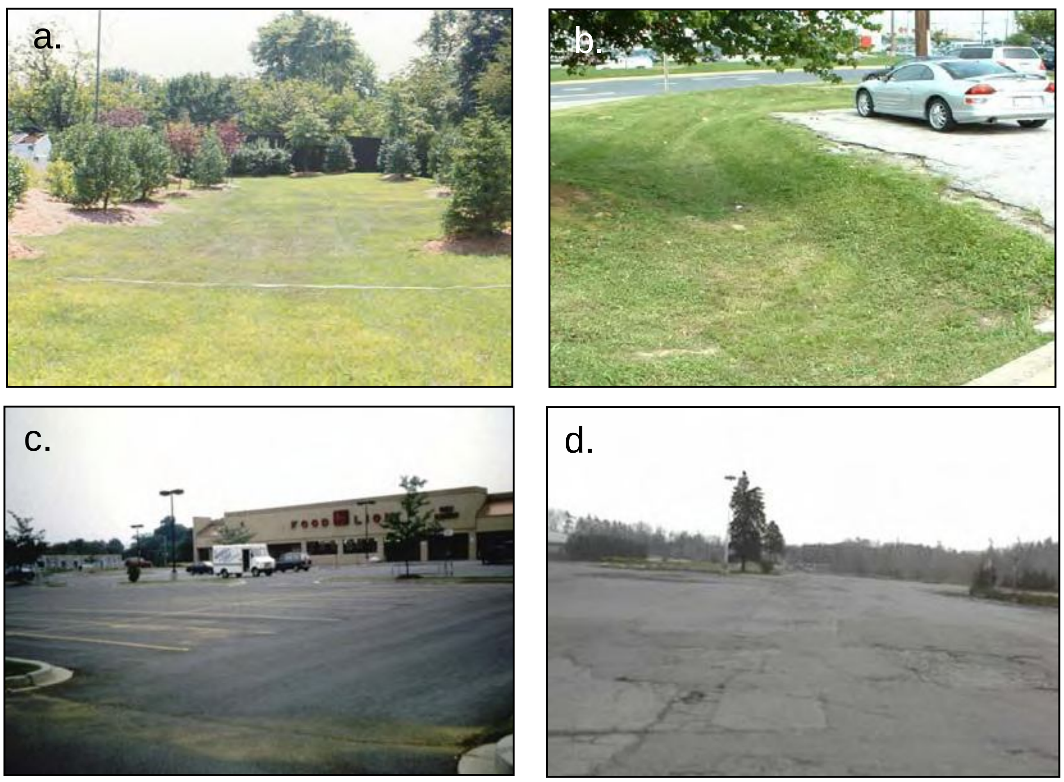


Figure 4: Ideal conditions for retrofitting small parking lots include: adjacent open land (a); unutilized setbacks along margins (b); under-utilized lots (c); and lots needing repair or rehabilitation (d).

Desktop Searching for Small Parking Lots

Small parking lots are generally quite easy to spot on aerial photographs or GIS data layers (Figure 6). A more systematic approach may restrict the search to parking lots in municipal or institutional ownership where permission to retrofit may be easier to get. Otherwise, the feasibility small parking lot retrofits is normally determined in the field.

Figure 5: Routine parking lot sweeping can reduce litter collection in storm drains.

Figure 6: Orthophotos can help find small parking lots and for concept sketches.

What to Look for When Investigating Small Parking Lots

1. *Confirm the size and use of the parking lot* - The crew should estimate the total lot area and any connection with rooftop drainage. Many parking lots are merely a continuation of rooftop drainage, so the crew should check whether rooftop leaders are connected to the parking lot. The size of the parking lot can be estimated using the stall-counting method described in Profile Sheet SR-6. The crew should evaluate parking lot use/capacity to see if some spaces can be sacrificed for stormwater treatment without reducing existing parking needs.

2. *Eyeball parking lot grade and subdivide into smaller drainage units* - This is the tricky part of retrofitting small parking lots. While they appear to be flat, lots have subtle grading to promote drainage to drop inlets or curb cuts. Crews should walk the entire parking lot and trace the surface flow path draining toward the low point(s). The crew can then break up the parking lot into smaller drainage units where flow can be directed to different on-site treatment areas. Curb cuts can also be used to split flows from smaller drainage units to on-site treatment areas.

3. *Evaluate each on-site treatment area for available space* - Potential treatment areas include any unutilized turf, landscaping or paved areas located downgradient from the lot. This may include parking lot islands, the perimeter or margins of the lot, landscaping areas, frontage setbacks and other open space. An on-site retrofit is normally feasible if the proposed treatment area is five to 10 percent of the size of its contributing drainage area.

The crew may want to use a hand auger at the proposed treatment area to get a sense of underground soil quality and infiltration rates. As always, the crew should look for surface indicators of underground utilities that might reduce available area. The crew should carefully review parking lot grading again to get an accurate estimate of the actual contributing area to each on-site retrofit treatment area (and note whether the lot must be regraded during construction).

4. Determine how the treatment area can be reconnected to the existing storm drain system and measure the bottom invert of the downstream storm drain. The crew should measure the elevation of pipe inverts of the storm drain pipe closest to the treatment area. These inverts establish what elevation is needed to tie the underdrain from the proposed retrofit area into the storm drain system (Figure 7). In general, four to five feet of elevation above this invert is needed to drive storm water through the proposed retrofit. Designers can avoid the head problem by disconnecting the contributing drainage area from the storm drain system through filter strips, curb cuts, infiltration or permeable pavers.

Figure 7: Understanding the plumbing: measuring pipe inverts at drop inlets.

5. Sketch the proposed treatment area(s) and indicate the recommended stormwater treatment option on the RRI field form.

Feasibility, Approvals and Permitting for Small Parking Lot Retrofits

Small parking lots are subject to normal retrofit feasibility constraints. Given the wide range of available stormwater treatment options, however, it is usually possible to find an on-site retrofit option that can treat at least a portion of the lot.

The biggest hurdle is getting permission from the parking lot owner to install the retrofit, which usually means the best sites are located on municipal or institutional land. A stormwater easement may be needed to connect to the downstream storm drain system.

Small parking lot retrofits seldom require many environmental permits. It is advisable to interview the facility manager to understand seasonal uses and pollutant loadings (Figure 8). A grading permit and stormwater design approval may be required by the local stormwater review authority.

Small Parking Lot Retrofit Design

Design Support

- Original drawings from the development plan that show the storm drain profile and inverts.
- Soil borings or test pits to determine soil quality and infiltration rates.

Figure 8: Interview property managers to anticipate seasonal uses and pollutant loads.

- Survey data to get accurate delineation of contributing drainage area (e.g., to a tenth of a foot).
- Spot elevations of the storm drain inverts if original drawings do not exist.
- Marking the location and depth of any underground utilities
- Parking demand studies during peak use (daytime, evening, weekend) to document lot capacity.

Design Process

The design of small parking lot retrofits is fairly straightforward, and depends on the type of stormwater treatment option. In general, the design process is the same as a new stormwater practice. Specific design considerations include:

- Hydraulic analyses may be needed on the existing storm drain system to ensure nuisance ponding will not occur, particularly in situations where head is limited
- The location of the retrofit may be dictated by the space needed for construction access
- It may be possible to direct sheet flow over to a parking lot filter strip as shown in Figure 9.

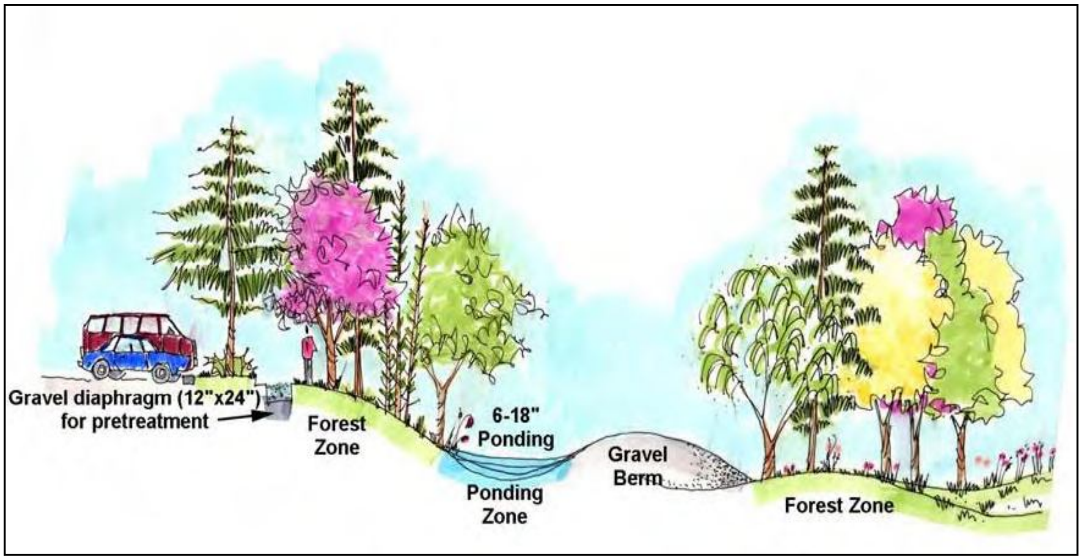
Construction Considerations for Small Parking Lot Retrofits

Retrofit construction may result in temporary closure of portions of the parking lot, so designers should sequence construction to occur quickly during periods of minimal parking use. Other construction considerations include:

- Install temporary fencing to prevent public access to the construction site.
- Specify smaller construction equipment to minimize damage to the parking surface and avoid soil compaction.
- Make provisions for temporary parking during construction, if needed.
- Make sure the construction budget includes contingency costs to repair existing pavement, curbs, pavement markings, trees or landscaping that might be damaged during construction.
- Include care and replacement warranties to ensure landscaping material survives beyond the first growing season.

Costs for Small Parking Lot Retrofits

The cost to construct small parking lot retrofits depends on the stormwater treatment option selected (Table 1). Retrofit costs will be higher, if any of the site-specific factors outlined in Table 2 occur at the project site.



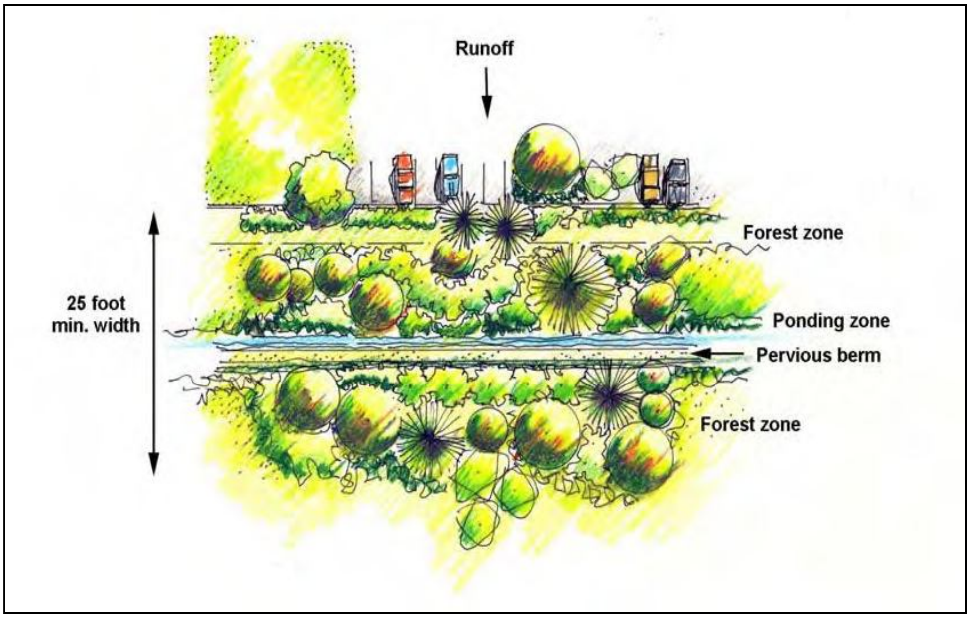


Figure 9: Plan and profile view of simple forested filter strip design for a parking lot.

Table 1: Estimated Construction Costs for Small Parking Lot Retrofits (2006 $ per cubic foot treated)			
Stormwater Treatment Option	**Median Cost**	**Range**	**Design & Engineering (%)**
External Bioretention [1]	$ 10.50	$ 7.50 to $ 17.25	32
Internal Bioretention [2]	$ 30.00	$ 25.00 to $ 40.00	32
Surface Sand Filter [3]	$ 5.00	$ 3.00 to $ 8.00	32
Perimeter Sand Filter [4]	$ 20.00	$16.00 to $ 22.00	32
Filter Strip [5]	$ 5.00	$ 3.50 to $ 10.00	15
Parking Lot Swales [6]	$ 12.50	$ 7.00 to $ 22.00	15
Perimeter Infiltration [7]	$ 15.00	$ 10.00 to $ 23.00	32
Permeable Pavers [8]	$ 120.00	$ 96.00 to $ 144.00	15
IC Conversion [9]	$ 20.00	$ 18.50 to $ 21.50	15

[1] Located outside of the parking lot
[2] Bioretention installed within parking lot islands or elsewhere on the lot
[3] Non-structural surface sand filter located on the perimeter of parking lot
[4] Structural sand filter within the parking lot that bears load
[5] Grading, level spreader and re-vegetation at perimeter of parking lot
[6] Water quality swale draining a portion of the parking lot
[7] Infiltration with pretreatment at perimeter of parking lot
[8] Permeable paver blocks within lot, along with subgrade preparation
[9] Demolition and removal of IC with soil and grass replacement

Table 2: Factors that Influence Construction Cost of Small Parking Lot Retrofits	
Factors that Decrease Cost	**Factors that Increase Cost**
• Parking lot is under-capacity • High soil infiltration rates • Use of filter strips, swales or infiltration • Lot is scheduled for rehabilitation • Wide setbacks along lot perimeter	• Design to bear traffic loads • Additional landscaping and tree planting • Complicated construction sequence • Need to repave lot • Need for underdrains

OS-9

On-site Retrofits

INDIVIDUAL STREETS

This group of on-site retrofits provides stormwater treatment within the roadbed or right of way of individual streets. A wide range of retrofit strategies can be employed depending on whether the street has open or closed drainage:

- Install stormwater treatment within open section drainage
- Convert enclosed drainage into open section and install stormwater treatment practices
- Divert stormwater for surface treatment before it enters the storm drain
- Make storm drain pipes less efficient at delivering stormwater by promoting infiltration in the storm drain pipe.

Stormwater treatment options for open section street retrofits include dry swales, grass channels, bioretention cells and wet swales. Streets with closed drainage may utilize street bioretention, expanded tree pits, cul-de-sac bioretention, catch basin inserts or perforated storm drain pipes. Figure 1 illustrates the many different ways stormwater treatment can be applied to street retrofits.

Streets are a significant urban pollutant source area and act as the primary conduit to move stormwater runoff from rooftops, lawn and driveways. Street retrofits treat stormwater near the source, improve neighborhood appearance, calm traffic and act as a focal point to educate adjacent residents about stormwater quality. Creative techniques to retrofit streets are shown in Figures 2 through 4.

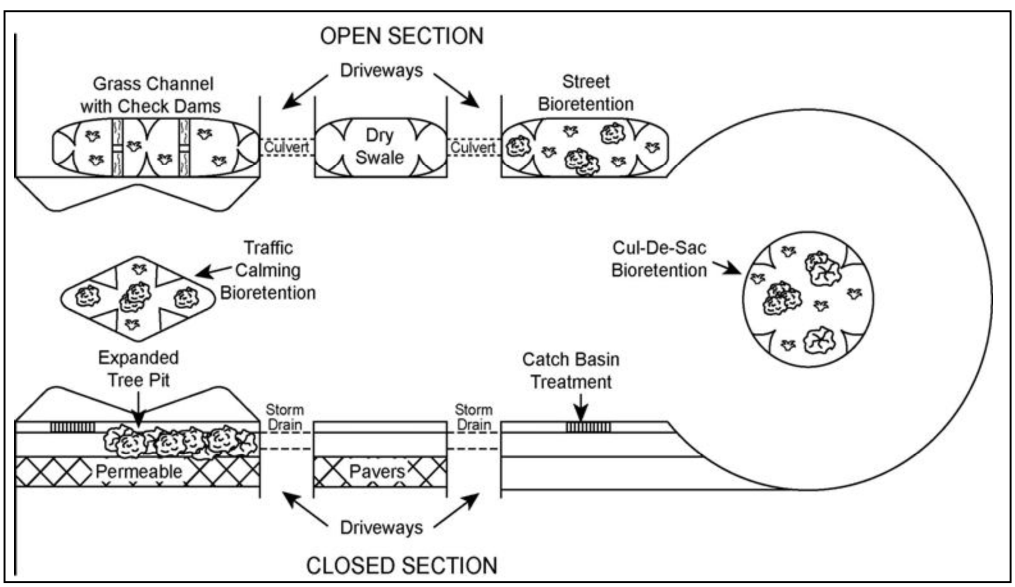


Figure 1: Retrofit strategies depend on whether the street has open of enclosed drainage.

Figure 3: Innovative street retrofits include: curb cuts to rain gardens (a), surface bioretention in traffic calming measures (b), larger bioretention pocket in multi-family residential (c), and curb cuts to cascading bioretention cells (d).

Figure 4: More street retrofit ideas: SEA streets swale (a); close-up of Portland street bioretention (b) and bioretention in street medians (c/d).

Ideal Conditions for Street Retrofits

Most communities maintain hundreds or even thousands of residential street miles (Law, 2006). Key suitability factors for street retrofits are shown in Figure 5 and include:

- Streets classified as having a moderate to severe pollution severity, as measured by field surveys.
- Neighborhoods that request traffic calming devices to slow residential speeding
- Streetscaping projects or neighborhood revitalization efforts where street drainage can be modified
- Bundling retrofits as part of upcoming water and/or sewer rehabilitation projects
- Wider streets that serve large lots (1/2 acre lots and up)
- Wide street right of ways that provide room for stormwater treatment options
- Streets where utilities are located underneath the pavement or on only one side of the street

Figure 5: Ideal conditions for street retrofits include a wide right of way (a), excessively wide streets (b), open section drainage channels (c), and large cul-de-sacs (d).

Situations Where Street Retrofits are Difficult

Only a fraction of residential streets are good candidates for retrofits (Figure 6). Retrofits are not a good idea for streets that:

- Are not currently scheduled for streetscaping or renovation
- Have longitudinal slopes greater than 5%
- Are classified as arterial or connector roads
- Have extensive upland contributing drainage area
- Are slated to be widened to accommodate future traffic capacity
- Have mature street trees or intensive residential landscaping
- Have a narrow right of way or heavy on-street parking demand
- Have very small lot sizes (i.e., the driveway effect)
- Lack an active homeowners association
- Have wide sidewalks on both sides of the street

Figure 6: Conditions that make street retrofits difficult include: small lots and multiple driveways (a), on-street parking demand (b), underground and overhead utilities (c), and mature street trees (d).

Alternative Restoration Projects for Streets

Alternative restoration projects that can be applied to streets include:

- Street Sweeping
- Storm Drain Cleanouts
- Storm Drain Marking (see Profile Sheet N-21 in Manual 8)
- Watershed Education and Stewardship
- Neighborhood Pollution Source Controls (Manual 8)
  - Natural Landscaping
  - Soil Erosion Repair
  - Safe Car Washing
  - Driveway Sweeping
  - Car Fluid Recycling

Desktop Searching for Street Retrofits

The first place to look for potential street retrofits is the municipal capital improvement budget, which indicates future street or sewer improvements scheduled in a subwatershed where retrofits might be bundled. In addition, the team may want to focus on neighborhoods with a history of drainage or basement flooding problems. An advanced GIS query can narrow down the number of streets by looking at street feasibility criteria such as slope, right of way width, open section drainage, presence/absence of sidewalks, parking lanes and adjacent lot size.

If a USSR has been conducted, Street and Storm Drain (SSD) or Neighborhood Source Assessment (NSA) forms should be reviewed. These forms calculate a pollution severity index for streets, and help rank potential street retrofit sites. The forms and associated photos also provide insights into the condition of the sidewalk zone and street pavement.

What to Look for when Investigating Streets

The crew investigates the general condition of the street and its right-of-way in three areas:

1. The crew observes the following conditions at the street:

- Pavement width
- Longitudinal and lateral slope
- On-street parking demand
- Traffic volume
- Pavement condition
- Pollutant accumulation in curbs or gutters
- Distance between driveways

2. Next the crew inspects the right-of-way and front yards to ascertain the:

- Condition of sidewalk zone
- Setback distance of houses
- Homeowner encroachment
- Density of vegetative cover
- Presence/absence of street trees

3. The crew then notes the location and elevation of the downstream discharge point or its entry into the storm drain system.

If a street has open section drainage, the retrofit crew should record:

- Existing channel cross-section and sideslope dimensions
- Grade/head available, using a 100 foot tape measure
- Available width free of underground or overhead utilities (one or both sides of street)
- General condition of the ditch line (e.g., vegetative cover and density, evidence of erosion, standing water)
- Average distance between driveway culverts

The crew records different retrofit feasibility factors for streets with enclosed storm drains:

- Location of all storm drain inlets, recording size and type (curb vs. grate).

- The crew should pull manholes or inlet grates at proposed retrofit locations and measure the depth, invert and gradient of underground storm drain pipes (Figure 7).

- If catch basins are present in the inlet, crews should measure the depth of pool water, trapped sediment or organic debris

- The crew should look for street covers and markings that indicate the presence of underground utilities that might interfere with construction.

- Locations on the street where treatment could be provided before runoff enters a storm drain inlet (e.g., cul-de-sacs, sidewalk zone, expanded tree planters, etc). Normally, the best locations are just upstream from inlets where curb cuts can divert runoff for treatment.

Figure 7: Crews check storm drains, grate inlets or manholes to determine depth of enclosed storm drainage.

The crew then sketches a preliminary concept design for the proposed street retrofit on the RRI field form.

Feasibility and Permitting for Street Retrofits

Street retrofits require extensive consultation and community relations, since they are located in the front yards of residents. These retrofits can only proceed if they are strongly endorsed by the entire neighborhood. Street retrofits should always reinforce other neighborhood concerns, such as traffic calming, street trees, improved drainage, enhanced landscaping and pedestrian safety. In addition, designers should anticipate resident concerns about trash accumulation, mowing, on-street parking, standing water and nuisance conditions.

Since street retrofits are a new concept, designers may need approval or support from multiple agencies (e.g., water, sewer and dry utilities, and forestry, public safety and road maintenance agencies). Each of these parties has a strong interest in what happens in the street right of way, so designers will need to coordinate with each to satisfy their concerns.

Street Retrofit Design

Street retrofits have several unique design issues.

Since street retrofits affect many adjacent residents, designers should place a premium on enhancing neighborhood appearance and landscaping. Mature street trees should be considered sacred and never be cleared.

Retrofit designs should always try to separate sidewalks from the street edge to promote greater pedestrian safety. Other street design standards that influence retrofitting include minimum turning radius, curb height, and handicapped access requirements. Some reviewers may want to see calculations of gutter spread to ensure street ponding is kept to an acceptable level.

Designers should choose plant species that can be realistically maintained by adjacent owners. For example, turf and herbaceous plants may require more ongoing maintenance than trees and shrubs.

The high compaction of the road corridor often makes infiltration an unsuitable stormwater treatment option. If soils are limiting, the retrofit will need an underdrain that ties into the existing storm drain system.

Utilities constrain the location of street retrofits, so designers should become familiar with the minimum vertical and horizontal setback requirements for underground and overhead utilities.

Third pipe or in-pipe storage are an alternative design for enclosed street sections. In a third pipe system, a perforated pipe with gravel bedding carries low flows (OME, 2002). Higher flows fill the low flow pipe and are conveyed through the traditional storm drain pipe. In-pipe storage requires oversized storm drain pipes and orifice plates to restrict the storm flow rate.

The responsibility for routine landscaping and structural repairs should be legally established when individual homeowners are expected to maintain a retrofit located in the street right of way.

Design Support

Several studies are needed to support the design of street retrofits:

- As-built drawings and design computations for the street, storm drains and sewers.
- Door to door notification of residents about the project
- Road, pipe, channel, curb and catch basin elevations and locations.
- Soil borings or test pits to determine soil quality and infiltration rate
- Depth and location of underground utilities. Many dry utilities (e.g., phone, cable, gas, and electric) are installed well after initial construction and may not be drawn on original engineering plans. In addition, water and sewer laterals from the house to the street are seldom shown on development plans. Each type of utility must be located prior to street retrofit design.

Design Process

The retrofit design process depends on whether the street has open or closed drainage, and what stormwater treatment option is employed. The design process for open section street retrofits is similar to that described for conveyance retrofits (Profile Sheet SR-4) and consists of four steps:

Step 1: Delineate the drainage area to each proposed street retrofit and compute target WQv storage needed. Confirm that available storage in the proposed retrofit can meet the target volume

Step 2: Model the existing hydraulic capacity of the open channel based on the design storm established by the local review authority.

Step 3: Determine whether water quality treatment cells will be created by checkdams, constrictions at driveway culverts, expanded channel cross-sections or replacement of existing soils with a more permeable media. The designer should also carefully consider how runoff will pass under driveways and sidewalks (Figure 8).

Step 4: If channel dimensions change due to the street retrofit, designers should redo the hydraulic analysis for the two-year design storm (to ensure conditions are non-erosive) and that the channel can still safely accommodate the 10-year storm.

The design process for closed section retrofits depends on whether runoff is treated at the surface or within the pipe. If runoff is diverted at the road surface prior to entry to the storm drain pipe, no hydraulic modeling is needed. The design of surface retrofits is generally dictated by the design guidelines for the specific stormwater treatment option employed. Several additional retrofit design considerations may also apply:

- Some reviewers may want to see evidence that the surface retrofit will not saturate the roadbed
- Since surface retrofits parallel the road, designers should examine how any changes in longitudinal slope will influence temporary street ponding.
- Designers should show how runoff rates in excess of the treatment volume will bypass the retrofit and return to the storm drain system.

Figure 8: Designers need to find creative ways to pass runoff across driveways and sidewalks.

A hydraulic analysis is needed when an enclosed pipe is converted into an open channel. Designers should follow the design process for stream daylighting described in Profile Sheet R-27 in Manual 4.

Street Retrofit Delivery Considerations

A community should consider developing a comprehensive program to coordinate the delivery of neighborhood street retrofit, education and municipal stewardship services. Since street retrofits are a new concept, communities may want to construct demonstration projects to convince local skeptics. Seattle's SEA Streets program is an excellent example of how street retrofits can be delivered on a widespread basis (Figure 9). Neighborhoods across Seattle now compete for the privilege of getting a street retrofit, and their popularity has greatly expanded funding for streetscaping projects. Over time, communities should look for creative ways to incorporate street retrofits into the design of all municipal streetscaping, water and sewer rehabilitation, and neighborhood revitalization projects.

Construction Considerations for Street Retrofits

The high neighborhood visibility of street retrofits requires a very sensitive construction approach that responds to neighborhood concerns. Some key considerations include:

- Every neighborhood tree seems to have its own advocate, so remove as few mature trees as possible.
- Construction crews should have an on-site supervisor experienced in community relations who can quickly respond to resident complaints and resolve them.
- The construction sequence should strive to provide continuous driveway and sidewalk access for local residents (Figure 10).
- A maintenance of traffic plan will be needed on busier residential streets.
- Erosion and sediment control needs to be taken extremely seriously throughout retrofit construction.
- Street retrofit inspections should focus on getting the correct elevations, grades and cross sections for the pipe or channel, assuring proper connection of underdrains to the storm drain system, and rapidly stabilizing areas with vegetation and landscaping.

Street Retrofit Costs

Construction costs for street retrofits largely depend on the stormwater treatment option used (Table 1). It is generally less expensive to retrofit open-section streets than closed-section streets. Some street-specific factors that influence the cost of street retrofits are outlined in Table 2.

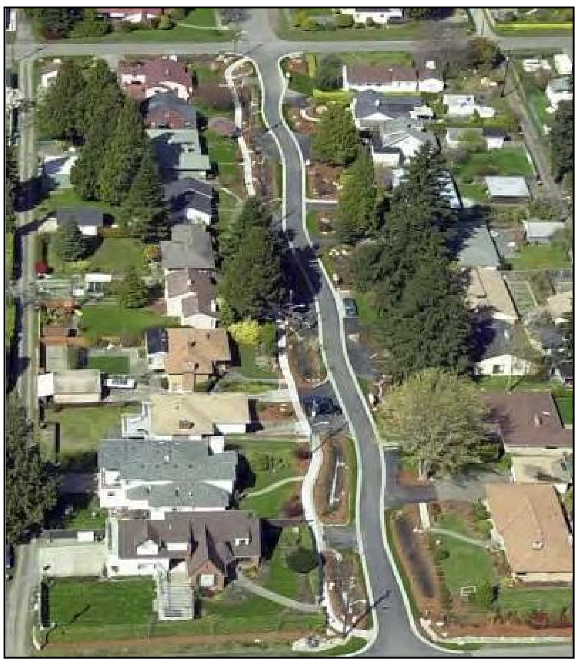


Figure 9: Aerial shot of Seattle SEA Streets retrofit.

Figure 10: Construction sequencing is critical to maintain driveway access and minimize disruption to homeowners.

Table 1: Estimated Construction Costs for Various Street Retrofits (2006 $ per cubic foot treated)			
Stormwater Treatment Option	**Median Cost**	**Range**	**Design & Engineering[7] (%)**
Water Quality Swale [1]	$ 12.50	$7.00 to $22.00	35
Dry Swale [2]	$ 23.00	$ 13.00 to 31.50	35
Bioretention Cells [3]	$ 30.00	$ 25.00 to $40.00	35
Street Bioretention [4]	$ 18.00	$15.00 to $24.00	35
Stormwater Tree Pits [5]	$ 70.00	$ 58.00 to $83.00	35
Daylight Enclosed Pipes [6]	$ 46.00	$ 26.00 to 63.00	40

[1] Conversion of existing grass channel into water quality swale
[2] Channel conversion, using urban bioswale costs reported by Hoyt (2007)
[3] Construction of new bioretention in street right of way
[4] Surface bioretention using curb extensions and other methods
[5] Expanded tree pits to treat stormwater on more urban streets
[6] Conversion of enclosed drainage to dry swale or bioretention. No cost data available; assumed to be twice the cost of dry swale
[7] Higher design & engineering for neighborhood consultation and utility negotiations

Table 2: Site-specific Factors that Reduce the Cost of Street Retrofit Projects	
Factors that Reduce Costs	**Factors that Increase Costs**
• Open section retrofits • No modification of road surface • Wide street right of way • Active civic or neighborhood group • Utilities located under pavement	• Closed section retrofits • Multiple driveways • Utility relocation • Legal resources to define right-of-way or easements • Additional landscaping

OS-10	On-site Retrofits
	INDIVIDUAL ROOFTOPS

This group of onsite retrofits captures, stores, treats and then gradually releases runoff from individual rooftops. The goal is to systematically retrofit as many residential and non-residential rooftops as possible within a given subwatershed. The many different ways that rooftops can be retrofit are portrayed in Figure 1. A variety of stormwater treatment options can be employed for rooftop retrofits as shown below:

Residential rooftops

- Simple Disconnection
- Rain Barrels
- Rain Gardens
- French Drain/Dry Wells

Non-residential rooftops

- Simple Disconnection
- Rain Gardens
- Stormwater Planters
- Cisterns
- Green Rooftops

Examples of rooftop retrofit techniques are shown in Figures 2 through 4. Additional details on each technique can be found in the Rooftop Retrofit Design Sheets provided in Appendix F. Rooftop retrofits are ideal when a comprehensive delivery system is developed to implement them on a widespread basis. From a cost-benefit standpoint, it makes more sense to target residential rooftops first since they comprise a greater fraction of subwatershed area and are less expensive on a unit-area treated basis.

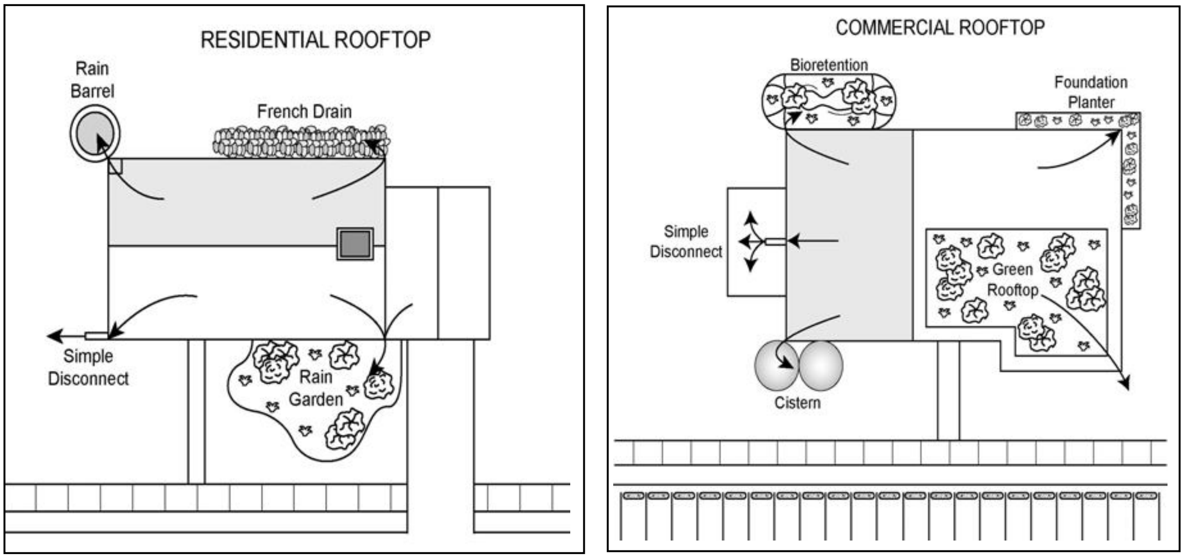


Figure 1: A variety of retrofit strategies can be applied to treat the quality of runoff from residential and commercial rooftops.

Figure 2: Residential rooftops can be treated by french drains (a), rain barrels (b), or rain gardens (c&d).

Figure 3: Runoff from larger rooftops can be treated in cisterns (a), infiltration areas (b), or bioretention planting beds (c).

Rooftop retrofits are particularly well-suited in subwatersheds where runoff reduction is a major restoration goal (e.g., to reduce the volume of stormwater runoff entering a combined sewer system). Retrofitting rooftops for water quality purposes is less effective since rooftop runoff tends to be cleaner than other urban source areas (with the possible exception of metals). On the other hand, incremental rooftop retrofitting can be an effective long range strategy to control runoff in highly urban subwatersheds.

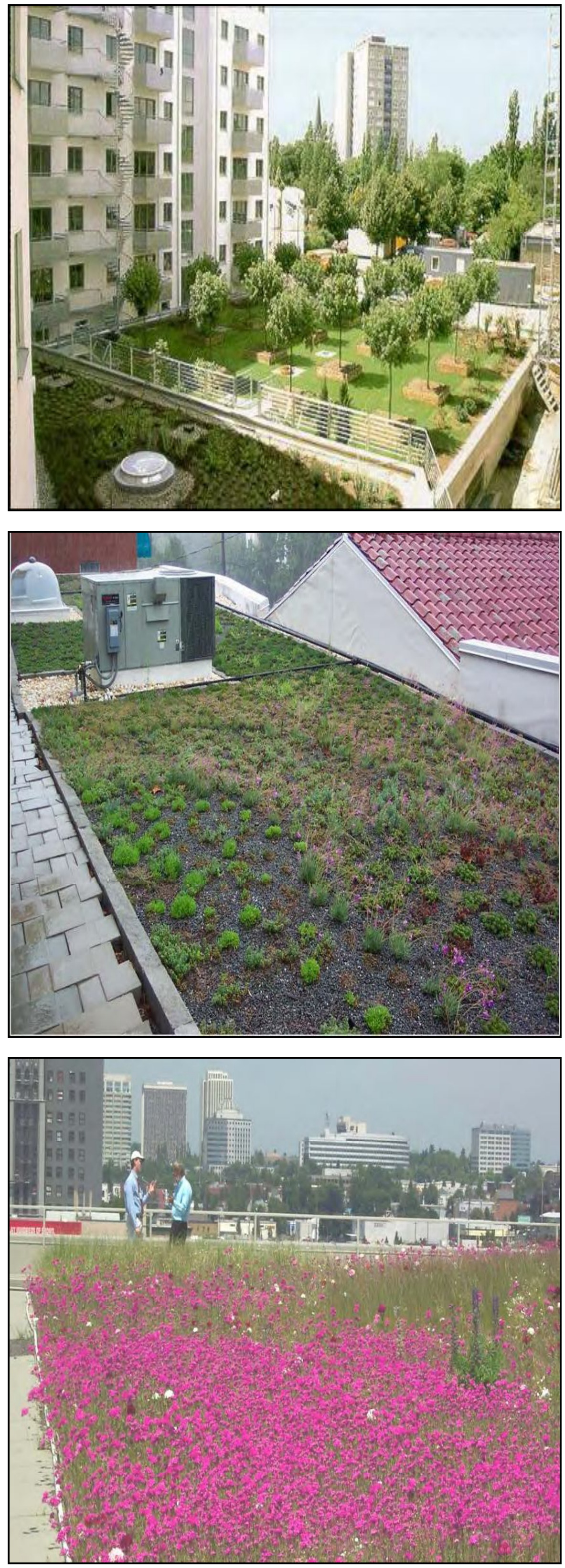


Figure 4: Green rooftops can also treat the quality of runoff from flat rooftops.

Ideal Conditions for Rooftop Retrofits

The ideal conditions to retrofit residential rooftops are when a neighborhood:

- Has no basements (if infiltration is used)
- Has homes where roof leaders are directly connected to storm drain system
- Is located in a subwatershed where stormwater reductions can reduce combined sewer overflows
- Has a strong neighborhood association, environmental concern or community activism
- Has medium density residential lot sizes in the 0.25 to 1.0 acre range.

Rooftop retrofits work best in non-residential settings when the rooftop:

- Is being built as part of redevelopment or infill project
- Is owned or being built by a municipality or a cooperative institution
- Can discharge to landscaping or open space adjacent to the building
- Has reached the end of its design life and needs replacement.
- Is large, flat and directly connected to the storm drain system
- Owner is interested in green building certification

- Retrofit can provide supplemental irrigation to existing landscaping arid climates)

Situations Where Rooftop Retrofits are Difficult

Most communities have thousands of rooftops but not all of them can be retrofit. Some common situations where residential rooftops are not feasible include:

- Neighborhoods with basements and sump pumps
- Large residential lots where most roof leaders are already disconnected (<1 acre lots)
- Small residential lots (less than 4,000 square feet) that lack room for a retrofit
- Neighborhoods that lack environmental awareness or community organization
- Lots that lack yards or have poor vegetative cover
- Lawns with extremely compacted or tight soils

There are also situations where non-residential rooftops are difficult to retrofit:

- No open space or landscaping areas are present near building
- Rooftop has internal building drains (i.e., no downspouts)
- Building has a basement or its foundation lacks waterproofing

Alternative Restoration Methods for Rooftops

If rooftop retrofits are impractical, it is still possible to educate their occupants to adopt neighborhood stewardship or pollution prevention practices (Manual 8).

Desktop Searching for Rooftop Retrofits

A search is not very helpful in finding individual rooftop retrofit sites, although the average age and lot size in a neighborhood are worth assessing, since homes built to the same drainage standards tend to have similar retrofit potential (Figure 5). Rooftop retrofit potential can also be assessed using the Neighborhood Source Assessment of the USSR (Figure 6). Another GIS search option is to look for specific neighborhoods that deliver stormwater into combined sewers or have historic flooding or drainage problems. Rooftop retrofits alone may not solve these problems, but can play a role in a larger package of retrofit solutions.

A GIS search that defines older commercial, industrial or institutional zones that are near the end of their design life may help find good candidates for non-residential rooftop retrofits. A search of all municipal buildings in a subwatershed may also be warranted to assess their suitability for demonstration retrofits.

Figure 5: Desktop searches should emphasize neighborhood age to define rooftops built in the same design era.

Figure 6: The Neighborhood Source Assessment (NSA) of the USSR is a useful method to determine the extent of downspout connections in a neighborhood.

What to Look for When Investigating Rooftops

Rooftop retrofit potential can be discovered through a simple neighborhood investigation:

1. Interview homeowners to gauge their willingness and preferences for retrofitting and understand their home drainage issues
2. Evaluate general rooftop conditions in the neighborhood (e.g., pitch, gutters, overhead tree canopy)
3. Pace the width and depth of the average home and estimate the contributing roof area to each roof leader (Figure 7)
4. Trace the pathway of the roof leader to the storm drain system in the street. If the roof leader is plumbed directly to the storm drain, note the depth and location of the pipe connection.
5. Measure the length of the flow path from the roof across pervious areas such as lawn and landscaping that may be suitable for disconnection
6. Use screwdriver or soil auger to get a sense of lawn compaction and soil quality
7. Determine the most suitable retrofit technique for each roof leader using the flow chart in Figure 8. Note that more than one retrofit technique may be needed for each residential roof.

The investigation for non-residential rooftops is much the same, although roof drainage area is larger and more complex (Figure 9). The crew should first look at more cost-effective options such as bioretention, cisterns and disconnection. If the owner is interested in green rooftops, the crew will need access the roof to assess its age, condition and structural capacity.

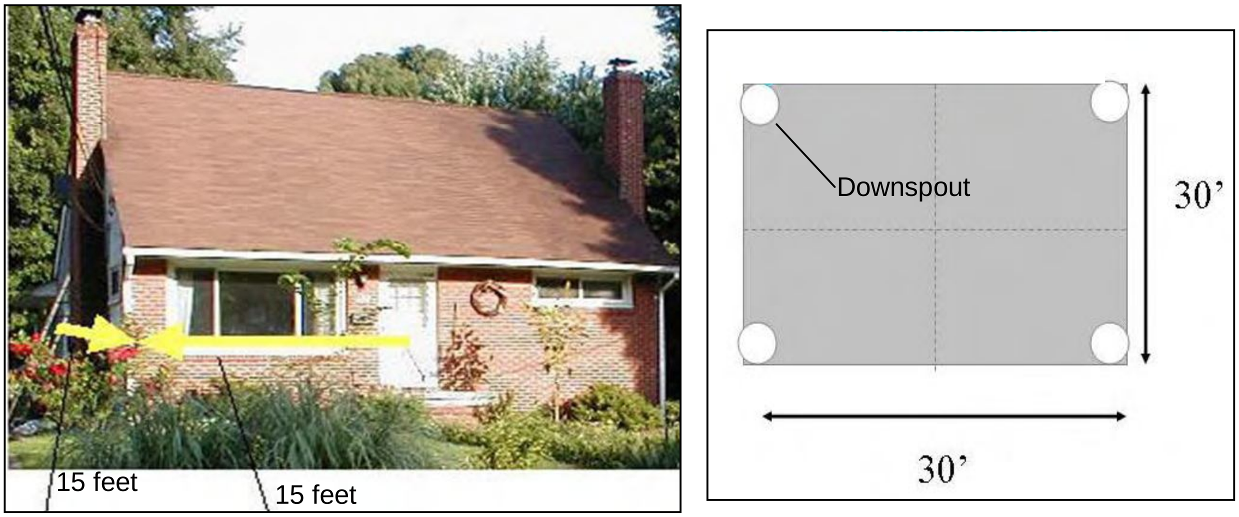


Figure 7: Sizing of residential retrofits is based on simple measurements of roof area draining to each downspout.

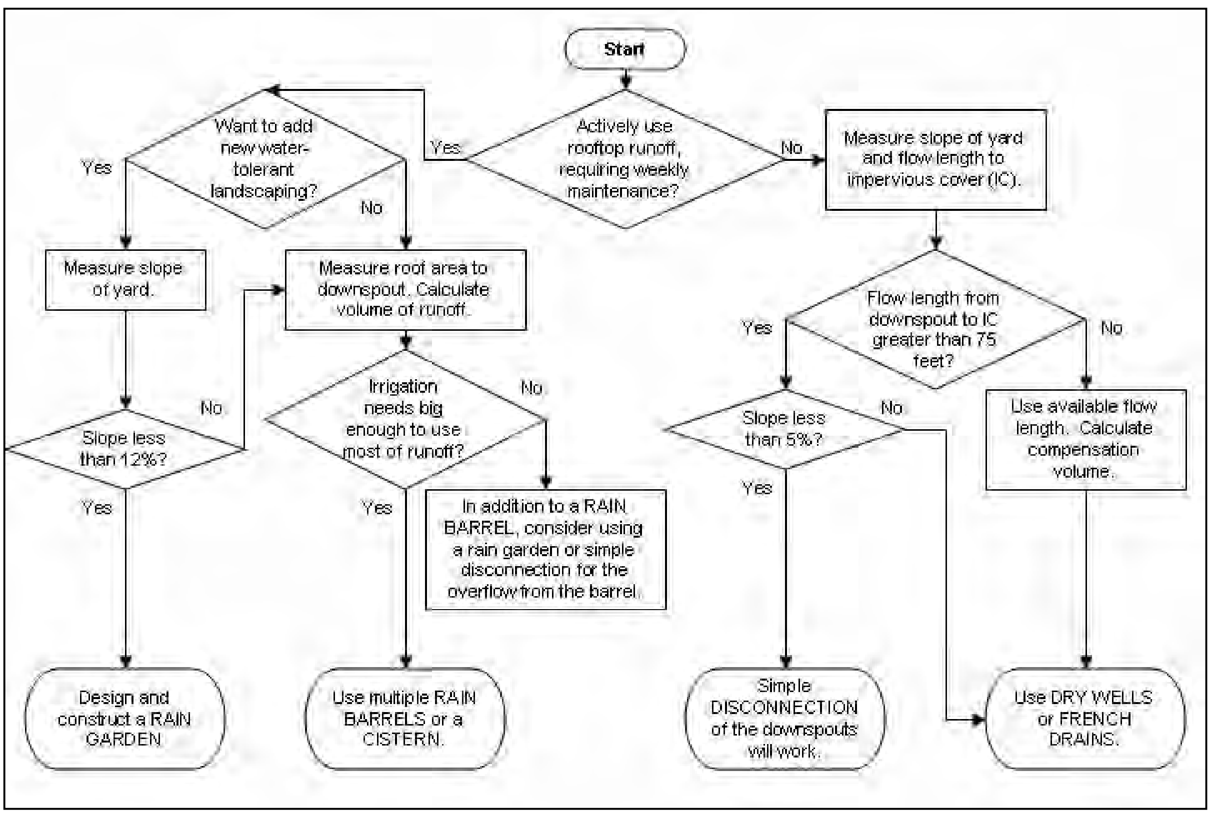


Figure 8: This simple flow chart helps homeowners decide whether simple disconnection, rain barrels, french drains or rain gardens are most appropriate for their lot.

Feasibility and Permits for Rooftop Retrofits

Since residential rooftop retrofits are installed and maintained by private landowners, the real hurdle is convincing them to do so. Some excellent publications exist on how to address perceived concerns about maintenance, algae and mosquito control (see Appendix F). Few environmental permits or approvals are needed, unless a stormwater plan is required under the redevelopment process. Designers may need to submit documentation about the retrofit to qualify for green building certification.

Rooftop Retrofit Design

The design requirements and level of engineering support are different for each rooftop retrofit. Some are exceedingly simple, while others involve complex structural engineering. The designer should consult the individual rooftop retrofit design sheets in Appendix F for the relevant design process.

Rooftop Retrofit Delivery Considerations

Because each rooftop retrofit treats a small area, dozens or hundreds are needed to make a measurable difference in a subwatershed. Consequently, an effective delivery system is needed to make rooftop retrofits happen, which normally involves a combination of targeted education, technical assistance and financial subsidies to individual homeowners or business community (Figure 10). In some cases, communities may need to modify their current building codes to permit green rooftops and cisterns. Several excellent examples of effective local rooftop retrofit delivery programs are presented in Table 1. These innovative programs have achieved a residential adoption rates ranging from 13 to 55%. Many of their educational and program materials are a good starting point to craft a local retrofit delivery system.

Figure 9: Retrofitting of non-residential rooftops is more complex.

Figure 10: Education and public involvement are key tools to maximize delivery of rooftop retrofits.

Table 1: Case Studies of Rooftop Retrofit Delivery

Municipal Program	Delivery Mechanisms and Financial Incentives
City of Bremerton, WA *Cooperative Approach to CSO Reduction* CSO reduction. Disconnection of downspouts became mandatory in the City's combined sewer area. 33% of notified properties were assessed. Of these, the 16% that were contacted were disconnected.	Outreach campaign through by utility bill inserts, billboards, radio, buses and newspaper ads, workshops, direct mail, instructional videos, cable TV, and website. Free downspout assessments by 4 City staff, disconnections done by private contractor or homeowner. $25 to $500 mini-grants to support residential disconnection
Pittsburgh, PA *Nine Mile Run Rain Barrel Initiative* CSO reduction, water quality improvement and inflow & infiltration reduction in pilot subwatershed. 13% of contacted owners participated.	Local watershed association, directed outreach campaign via direct mail, door-to-door canvassing and newspaper, posters and radio ads. Free rain barrel assessment and installation by trained student volunteers (Student Conservation Association and AmeriCorps)
City of Portland, OR *BES Downspout Disconnection Program* CSO reduction in targeted combined sewer sheds. 40%-55% disconnection achieved in many sewer sheds	Direct outreach by door-to-door canvass, direct mail, and community events. Churches, youth and civic groups promote disconnection as a fundraising activity (get a finders fee of $13 per downspout). 9 AmeriCorps volunteers coordinate program and outreach. City provides free disconnections and gives a $53 credit per disconnection on sewer bill

Table 1: Case Studies of Rooftop Retrofit Delivery	
Municipal Program	**Delivery Mechanisms and Financial Incentives**
City of Austin, TX *Rainwater Harvesting Programs* Water conservation and stream protection	Outreach by utility bill inserts, website, and seminars. Installation is the responsibility of the owner. Rebates for installation (up to $500 for residential, $40,000 for commercial). Discounted Rain Barrels ($60/each; maximum 4). State of Texas sales tax exemption for rainwater harvesting equipment.
Minneapolis, MN *Landscaping for Rainwater Management* Reduce flooding and improve water quality at the neighborhood scale	Outreach via neighborhood association, website, and workshops. Downspout assessment by specific consultant. Homeowner installation. Subsidized assessment. Matching grants ($50-$400) for rain gardens, rain barrels, gutter redirection.
Milwaukee, WI *Every Drop Counts* CSO reduction and water quality improvement	Outreach by website, newsletters, garden class, and farmers market. Homeowner installation of discounted rain barrels ($23/each; maximum 5)
Montgomery County, MD *Rainscapes* Enhance water quality and stream habitat	Outreach by website and workshops. Free "make your own rain barrel" workshops. Homeowner installation
Bremerton, WA http://www.cityofbremerton.com/content/downspoutdisconnections.html Fulton, MN http://www.fultonneighborhood.org/lfrwm.htm Pittsburgh, PA http://www.ninemilerun.org/programs/stewardship/rainbarrel/ Portland, OR http://www.portlandonline.com/bes/index.cfm?c=32144 Austin, TX http://www.ci.austin.tx.us/watercon/default.htm Milwaukee http://www.mmsd.com/programs/every_drop_counts1.cfm Montgomery Co http://www.rainscapes.org	

Rooftop Retrofit Construction Considerations

Construction considerations vary for each rooftop retrofit technique; specific guidance can be found in the rooftop retrofit design sheets provided in Appendix F.

Rooftop Retrofit Costs

The cost to construct rooftop retrofits varies from virtually nothing at all to more than a million dollars per impervious acre treated, depending on the rooftop retrofit technique employed. Table 2 presents some planning level estimates for the different rooftop retrofit techniques. Appendix F presents more detailed data construction and maintenance costs. Stormwater managers should also account for program administration costs to deliver rooftop retrofits.

Table 2: Estimated Construction Costs for Rooftop Retrofit Techniques (2006 $ per cubic foot treated)			
Rooftop Retrofit Technique	**Median Cost**	**Range**	**Design & Engineering (%)**
Simple Disconnection [1]	$ 2.00	$1.00 to $3.00	5
Rain Barrel [2]	$ 25.00	$ 12.50 to $ 40.00	5
French Drain/Drywell [3]	$ 12.00	$ 10.50 to $13.50	5
Rain Garden [4]	$ 4.00	$ 3.00 to $ 5.00	5
Installed Rain Garden [5]	$ 10.00	$ 5.00 to $ 10.00	32
Bioretention Cell [6]	$ 30.00	$ 25.00 to $40.00	32
Stormwater Planters [7]	$ 27.00	$ 18.00 to $36.00	15
Cistern [7]	$ 15.00	$ 6.00 to $ 25.00	15
Extensive Green Rooftop [8]	$225.00	$ 144.00 to $300.00	32
Intensive Green Rooftop [9]	$360.00	$300.00 to $420.00	32

[1] Surface diversion of downspout over appropriate pervious area using flexible pipes
[2] Average cost for eight cubic foot barrel serving one typical roof leader
[3] Three foot deep stone trench serving two roof leaders
[4] Volunteer homeowner installation (materials cost only with minimal landscaping)
[5] Residential, but professionally designed/installed with extensive landscaping treatment
[6] Larger commercial application, treats up to ½ acre of rooftop in existing landscaping area.
[7] Commercial application, see rooftop retrofit design sheets in
[8] Commercial rooftop with shallow soil media, see
[9] Commercial rooftop with deeper soil media and need to structurally reinforce roof

OS-11	On-site Retrofits	
	LITTLE RETROFITS	

Little retrofits are simple on-site practices that treat runoff from directly connected impervious areas less than one acre in size (Figure 1). Examples include sidewalks, bike paths, driveways, basketball and tennis courts, vacant lots, compacted ball fields, paved play areas, and other surfaces that are impermeable to rainfall. Recommended stormwater treatment options for little retrofits include swales, infiltration, filter strips, impervious cover conversion, impervious cover disconnection and soil compost amendments.

Collectively, small impervious areas comprise less than 5% of total impervious area in a subwatershed. So why bother with little retrofits? The reason is that small impervious areas are easy to retrofit because they are isolated within larger pervious areas. Many small impervious areas fall below minimum area thresholds that trigger stormwater management requirement and were therefore built without consideration for engineered drainage or stormwater practice.

Figure 1: Examples of little retrofits serving small impervious areas: a rain garden treating runoff from a trail (a); surface sand filter treating tennis court (b); and bioretention treating a small courtyard (c).

Little retrofits are ideal because they are low cost, require less sophisticated design and can solve localized drainage and erosion problems. In many cases, they can be constructed by watershed groups, homeowners associations or property managers with minimal engineering background.

Ideal Conditions for Little Retrofits

The best conditions for little retrofits are when the retrofit:

- Is located on publicly-owned land such as a park or school
- Would serve an educational or demonstration function
- Is in close proximity to a large pervious area
- Would alleviate an existing drainage or erosion problem
- Can take advantage of soils with a high infiltration rate
- Can be linked with a planned reforestation project for the site (Figure 2)

Other Restoration Alternatives

If a little retrofit doesn't work at a site, reforestation is always a restoration option.

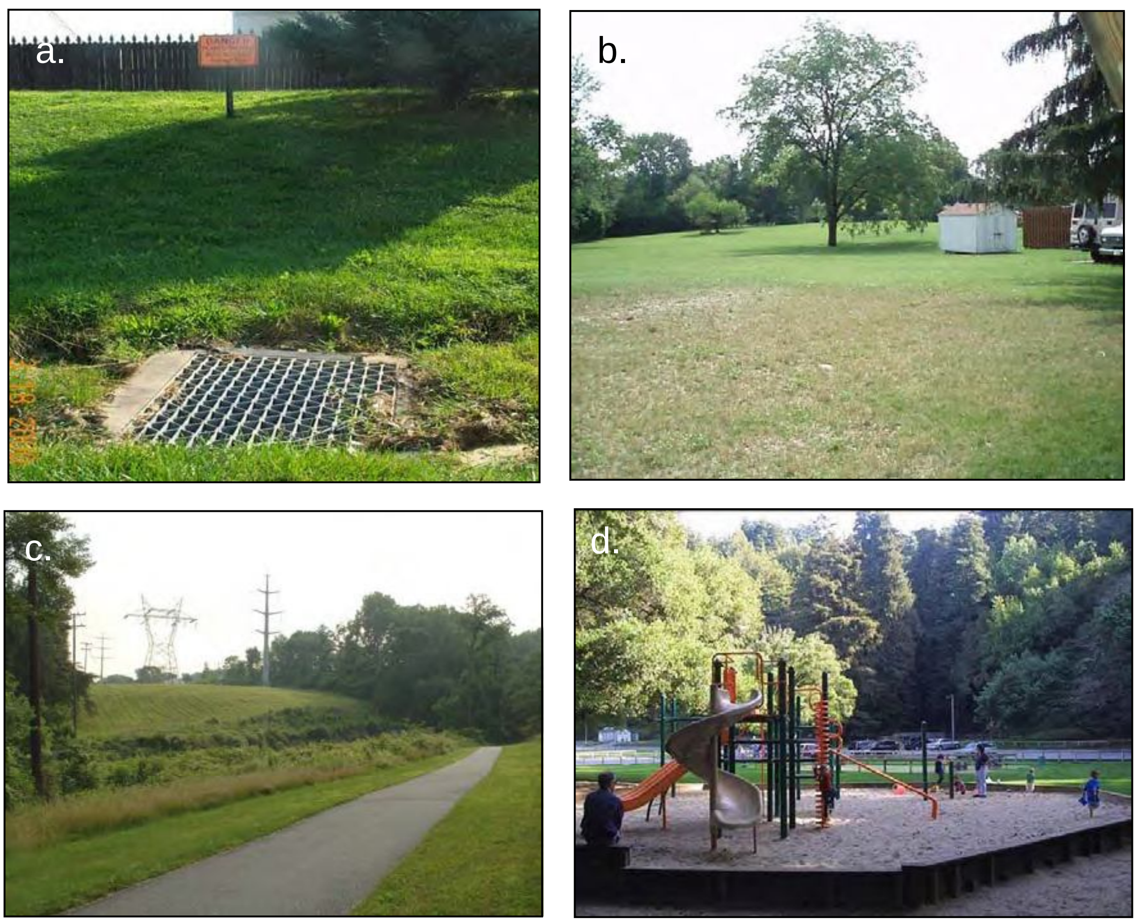
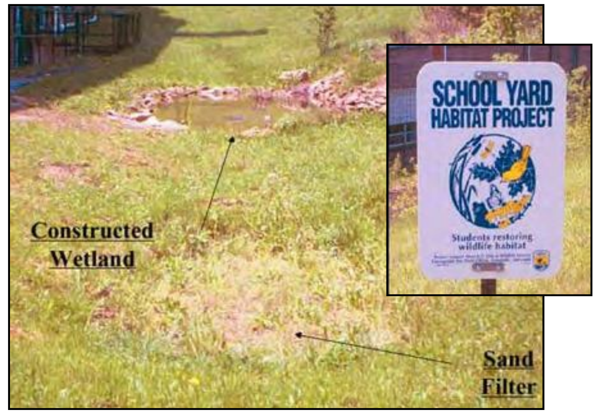


Figure 2: Common areas for little retrofits include pervious areas with drainage problems (a); parks and open space (b); bike trails (c); and playgrounds (d).

Desktop Searching for Little Retrofits

Little retrofits are simply too small to be worth a desktop GIS search or even an analysis of fine resolution aerial photos. They are generally found during field investigations of larger sites. The team may want to look for school properties and tax reverted vacant lots before going out in the field (Figures 3 and 4).



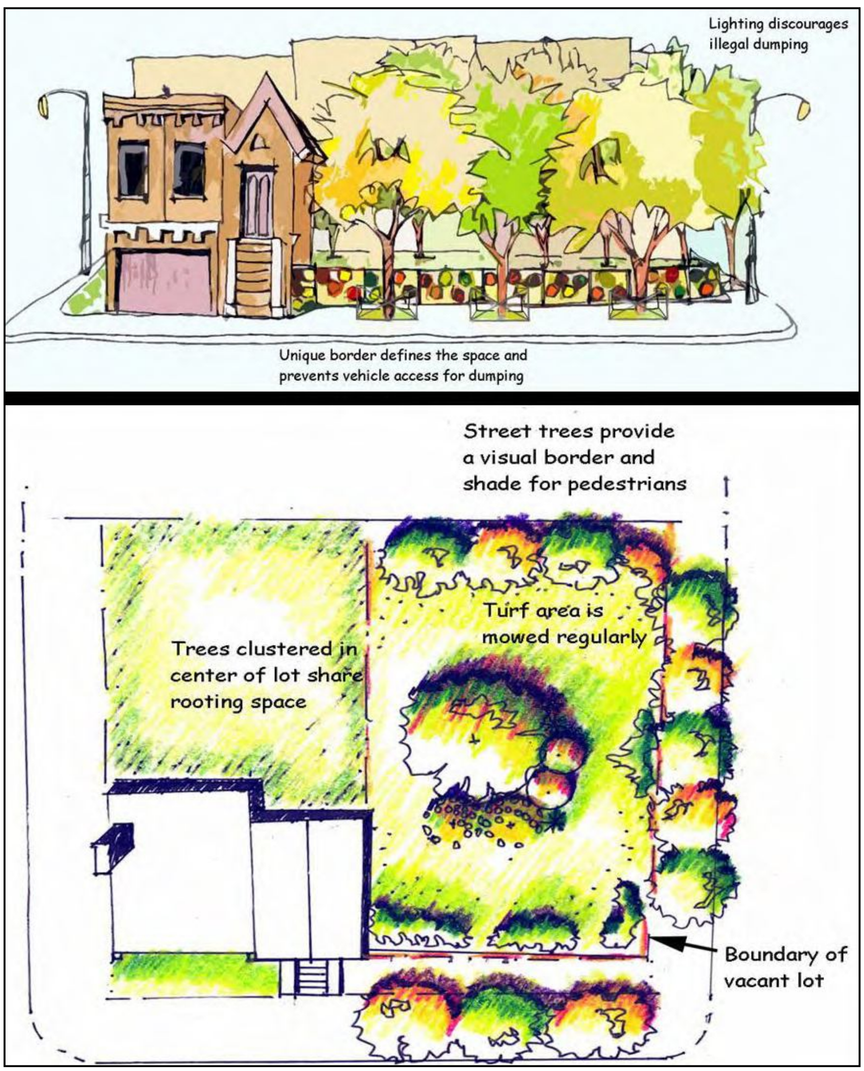


Figure 4: Compost amendments and tree planting are a good little retrofit strategy for vacant lots.

What to Look for During the Investigation

The feasibility of little retrofits is assessed by examining how stormwater works on the site. Crews can diagnose runoff problems by looking for signs of erosion, gullies or sediment deposition in the flow path.

1. The crew should first check to see if the impervious cover is really needed. If not, replace the impervious cover with soil, compost amendments and vegetation.
2. The crew then walks in a down-gradient direction to follow the flow path from the impervious area to the storm drain or channel system
3. If a direct connection exists, find the best place where sheetflow can be split or diverted into a pervious area for treatment. Next, choose the most appropriate and cost-effective stormwater treatment option
4. If no storm drain exists, check to see if runoff flows to an adjacent impervious area.
5. If there is no direct connection to the storm drain system, no retrofit is needed but consider reforestation as an alternative.

Feasibility and Permitting for Little Retrofits

Few environmental permits are needed for little retrofits, although it is a good idea to prepare an erosion and sediment control plan for construction. Landowner approval may need to be secured, although permission is not hard to get if it solves an existing drainage or erosion problem. Most communities will not require a stormwater design plan, although it may be helpful to get technical advice from an engineer or landscape architect. Indeed, little retrofits can be a good opportunity to involve civil engineering and landscape architecture students from local colleges.

Little Retrofit Design

This class of retrofits is largely sized based on simple design rules and seldom require modeling or engineering to support design (Figure 5). Little retrofits rely on the common-sense knowledge of park managers, site superintendents or watershed group staff.

Soil Investigation - Soil properties often dictate whether or not infiltration will work for a little retrofit. The crew may choose one of the following methods to determine soil infiltration rates:

- Observe how the site responds to rainfall during a storm to see if water ponds or infiltrates and discover the flow path through the site.
- Local cooperative extension offices can provide low cost or free tests to establish soil drainage qualities

Figure 5: While little retrofits require minor engineering, it is advisable to get some technical help.

- A low-tech infiltration test can be performed by digging a hole, filling it with water, and timing how long it takes to disappear. Dig below the topsoil to the proposed ponding depth (e.g., 6 inches). If the water infiltrates in the hole within 24 hours, the site may be suitable for an infiltration practice, although 12 hours or less is preferred.
- A soil auger can bore down below the bottom of the retrofit to determine if clay layers exist that would impede infiltration.

Plant Selection and Layout – To choose the right plants for the little retrofit, it is advisable to consult with a local partner, such as a master gardener, cooperative extension agent, landscape architect, or community forester. Most states also recommend native species. Where possible, ask the plant expert to do an on-site visit. In some cases, soil amendments that incorporate two inches of compost into the top six inches of soil can improve both infiltration and plant survival.

Flow paths - Learning the flow path helps determine the location and the drainage area of a little retrofit. Some simple field observations and measurements can define the flow path and drainage:

- Visit during a rain storm to see where water flows.
- Spray the area with a hose or dump a bucket of water to simulate rain.
- Roll a tennis ball to see which direction it travels over a smooth impervious surface.
- Use two stakes, a string, and a hanging level to measure elevation difference. Pound a stake into the ground or have someone hold it on an impervious surface. Tie the string to each stake, and hang the level on the taut string. Adjust the string on the stakes until the string is level. Measure from the string to the ground and compare the distances. Use this method to determine the slope of a proposed site.

Sizing - Some simple rules can be applied to size the little retrofit once the location and drainage area are known. For example, the following guidance can be used to disconnect impervious areas over a vegetated filter strip:

- The contributing flow path from impervious cover should not exceed 75 feet.
- The pervious area disconnection length must exceed the contributing flow path. The recommended minimum length over which runoff is spread is 75 feet. Make sure that the runoff cannot "reconnect" by flowing back onto an impervious surface within 75 feet.
- Pervious areas used for disconnection, including swales and filter strips, should have a slope no greater than 5%.
- The total impervious area draining to a single point shall not exceed 1,000 square feet.

Rain gardens and infiltration practices can be sized as a fraction of the impervious surface that drains to them. In general, the surface area of the practice should be about 10 to 20% of the impervious drainage area. Additional guidance on these practices can be found in Appendix F.

Stabilizing the Retrofit Site – Silt fences should be installed for little retrofits that involve more than a few hundred square feet of soil disturbance. Apply grass seed and soil amendments immediately after digging and use a seeding mix that grows well during the season when construction is scheduled.

Little Retrofit Delivery Considerations

The best delivery mechanism for little retrofits is to establish a mini-grant program for local watershed groups, community associations, garden clubs or service organizations who can provide volunteer labor for construction (Figure 6). Local watershed groups or municipal staff can also provide technical assistance to develop little retrofits project plans. Municipal agencies may want to develop short and simple specifications for little retrofits; excellent examples have been developed by Hoyt and Zielinski (2006). It is also a good idea to install interpretive signs to describe how the little retrofit works (Figure 7).

Little Retrofit Costs

The costs to construct little retrofits are generally quite low, as shown in Table 1.

Figure 6: Example of interpretative signage with a little retrofit.

Figure 7: Little retrofits are a great way to involve volunteers in watershed restoration.

Table 1: Estimated Construction Costs for Little Retrofits (2006 $ /cubic foot treated)			
Retrofit Option	**Median Cost**	**Range**	**Design & Engineering (%)**
IC Conversion [1]	$ 20.00	$ 18.50 to 21.50	5
Soil Compost Amendments [2]	$ 8.00	$ 3.15 to $11.40	5
Filter Strip [3]	$ 5.00	$ 3.50 to $ 10.00	5
Simple Infiltration [4]	$ 7.50	$ 5.00 to $ 11.50	5
Rain Garden (volunteer) [5]	$ 4.00	$ 3.00 to $ 5.00	5
Rain Garden (contractor) [6]	$ 7.50	$ 5.00 to $ 15.00	15
Bioretention [7]	$ 10.50	$ 7.50 to $ 17.25	32

[1] Demolition and removal of existing concrete or asphalt, and applying topsoil and hydroseed to establish vegetation
[2] Simple redirection of flow from impervious area to a pervious area using flow spreader, curb cut or checkdam split
[3] Deep tilling, mixing of nine inches of compost, and reseeding
[4] Re-grading, level spreader and reseeding to establish vegetation
[5] Directing runoff into shallow infiltration trench
[6] Volunteer installation, materials and equipment rental only
[7] Professionally installed with more extensive landscaping
[8] Professionally designed and installed bioretention cell serving more than 0.5 acres of CDA

OS-12 On-site Retrofits — LANDSCAPES-HARDSCAPES

This class of retrofits relies on landscaping to treat stormwater in highly urban settings. Examples include commercial landscaping areas, plazas, waterfronts, urban streetscapes, and pocket parks (Figure 1). While these urban landscapes occupy a trivial amount of total subwatershed area, they are included here because they represent a great opportunity to demonstrate retrofits in highly visible locations. The basic strategy is to treat stormwater as a landscaping resource and design amenity using innovative practices such as rain gardens, stormwater planters, expanded tree pits or permeable pavers (Figure 2).

Scaping retrofits are ideal because they have strong demonstration and education value, are frequently maintained, and may lower landscaping maintenance costs through reduced mowing, greater tree survival, or less irrigation.

Ideal Conditions for Scaping Retrofits

- Commercial, municipal, institutional and urban park settings
- Redevelopment and infill projects
- Public spaces with high exposure
- Area where urban water features are being designed as an amenity
- Downtown central business districts
- Waterfront developments
- Development constructed through public/private partnerships
- Neighborhood beautification and revitalization projects

Figure 2: Landscape architects can creatively use stormwater as a resource in foundation planters (a); permeable pavers (b); bioretention (c); and stormwater tree pits (d).

Situations Where Scaping Retrofits Don't Work

- No party is willing to undertake routine maintenance
- Retrofit would need to be shut down in winter to avoid ice problems

Alternative Restoration Practices

Even if a retrofit is not possible, other restoration projects may apply including:

- Reduced fertilizer and pesticide use (see Profile Sheet H-13 in Manual 8)
- Planting native plants
- Urban forestry practices
- Smart Site practices for redevelopment and infill that minimize impervious cover (CWP, 2004a)

Desktop Searching for Scaping Retrofits

A GIS search for scaping retrofits is probably overkill. It is much more effective to work with community planners and urban designers to discover public projects where scaping retrofits could be incorporated into the early planning stage. Local city planners, park designers, landscape architects or arborists may also know about opportunities for scaping retrofits in upcoming projects. They should be encouraged to view stormwater as a resource and landscaping as a water quality solution.

What to Look for During the Investigation

There really is no field investigation for scaping retrofits. Designers simply participate in the urban design process to look for opportunities to insert scaping retrofits. The following concepts should be kept in mind when designing scaping retrofits:

Hydrology - Keep in mind that scaping retrofits will receive more runoff to the planting area than would otherwise be supplied by rainfall. Designers should compare the surface area delivering runoff to the surface area of the planting area itself. If the ration is more than 5:1, the scaping retrofit should have an underdrain so that plants don't become water logged. If the ratio is greater than 10:1, the design should include a surface overflow.

Plants - The real trick in scaping retrofits is to match the right plant materials to the expected moisture conditions created by the retrofit. Depending on the seasonal rainfall regime, plants may be exposed to long periods of drought followed by short periods of full saturation. At the same time, landscape architects want to select plants that meet their design objectives for form, function and color. Designers may want to consult regional plant and tree lists developed for stormwater or urban forestry that outline their tolerance for inundation, drought, chlorides, shade and other factors (Cappiella *et al.*, 2007).

Soil Media - Scaping retrofits require the creation of special soil media to meet both stormwater and landscaping needs. From a stormwater standpoint, the media should promote rapid drainage through the bed, but also have a layer of organic material to bind pollutants. A common soil mixture contains 50% sand, 30% non-clayey topsoil, and 20% well-aged compost. From a landscaping perspective, the soil media needs to be dense enough to support trees and shrubs, and retain enough moisture and nutrients to ensure growth during dry periods. The surface of the planting bed is also a key design consideration. Designers may want to use native rock, river stone or bank run gravel to provide a more durable surface than mulch and create a more artistic impression.

Water Features - Scaping retrofits are an opportunity to combine functional landscape treatment with art (Echols and Pennypacker, 2007). The aesthetic possibilities are endless, but frequently involve a cascading flow of water through chutes and ladders, much as it does in a natural stream.

Plaza and Sidewalk Drainage - This approach reduces stormwater runoff by connecting impervious areas with landscaped areas. Permeable pavers or porous concrete can further limit runoff generation from hard surfaces. These pavers come in a variety of textures and patterns, and are durable enough to hold up to pedestrian traffic. Sidewalks and plazas should be sloped toward the landscaping areas.

Rooftop Drainage - External downspouts of buildings can be designed to feed into landscaped areas or foundation planters so rooftop runoff becomes a source of supplemental irrigation. The drop from the roof to the ground can also create mini-waterfalls, drive water wheels and rain chimes, or create a cascade effect.

Expanded Tree Pits - Expanded street tree pits capture and treat stormwater and provide better growing conditions for street trees (Figure 3 and Cappiella *et al.*, 2006a). The basic design provides additional root volume for individual trees and links the soil media so that trees can share root volume. Runoff is graded into the pits through curb cuts or grate inlets and an underdrain ties into the existing storm drain system to promote rapid drainage. Pollutant removal is achieved by filtering through the soil media. A plan and profile view of the expanded tree pit design is illustrated in Figures 4 and 5. The expanded tree pit design was originally developed for urban street trees, but can be adapted for any situation where trees are desired in an urban hardscape.

Figure 3: Urban areas are a harsh environment and trees often get too little or too much runoff.

Feasibility and Permitting of Scaping Retrofits

No major permits and approvals are needed for scaping retrofits, beyond those required for the larger construction project of which they are a part.

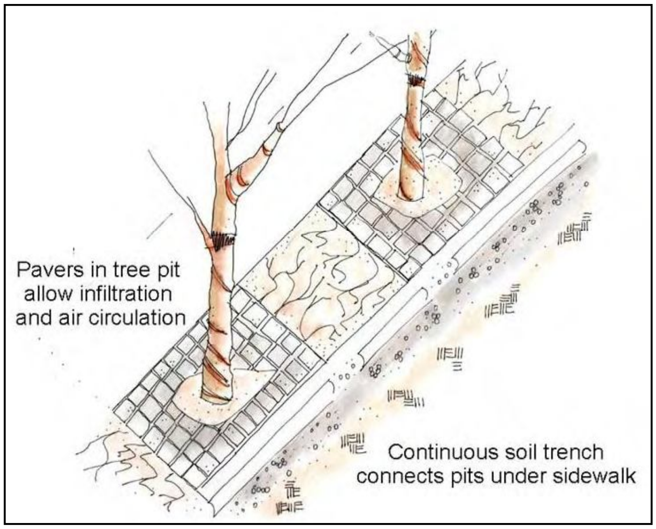
Scaping Retrofit Design

Urban landscapes are intensely used and require frequent maintenance, so designers may want to consider the following design elements:

- *Heavy pedestrian traffic* – Scaping retrofits should include a barrier to pedestrian entry to prevent soil compaction and plant damage, such as bollards or iron fences.

Figure 4: Urban foresters can treat stormwater using creative street tree planters.

- *Potential vandalism* - Scaping retrofit materials should be durable enough to withstand vandalism.
- *Trash and litter* – Scaping retrofits will collect litter that previously washed into the storm drain system. Designers may need to create a maintenance plan that includes daily or weekly trash clean outs. If the retrofit is located in a public space, maintenance crews will need training on how to access the retrofit to remove trash.



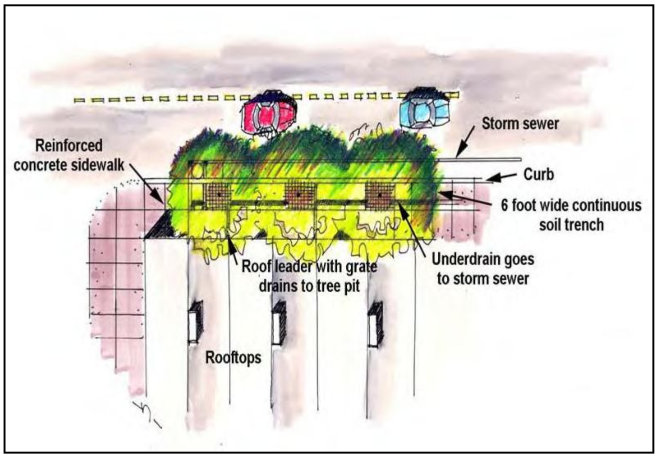


Figure 5: Plan and profile detail on stormwater tree pit design with shared rooting space.

- *Public safety* – Providing adequate lighting and avoiding dense vegetation can address concerns about crime and personal safety
- *Need for supplemental irrigation* – Even plants accustomed the wet/dry cycles of stormwater may require watering for the first year or two to become established.

Scaping Retrofit Delivery Considerations

The primary delivery mechanism is to train landscape architects on water-sensitive design (France, 2003). Education of urban foresters, arborists, urban designers, park managers, maintenance crews and architects can also encourage widespread adoption of scaping retrofits.

Scaping Retrofit Costs

The costs for scaping retrofits depend on the nature of the urban design project. The best way is to generate an initial construction cost estimate is to look at the cost for individual scaping retrofit techniques as shown in Table 1.

Table 1: Estimated Construction Costs for Scaping Retrofits (2006 $/cubic foot treated)			
Stormwater Treatment Option	**Median Cost**	**Range**	**Design & Engineering (%)**
Small Bioretention [1]	$ 30.00	$ 25.00 to $ 40.00	32
Permeable Pavers [2]	$ 120.00	$ 96.00 to $ 144.00	32
Stormwater Planters [3]	$ 27.00	$ 18.00 to $ 36.00	32
Water Quality Swale [4]	$ 12.50	$ 7.00 to $ 22.00	32
Stormwater Tree Pits [5]	$ 70.00	$ 58.00 to $ 73.00	32
IC Conversion [6]	$ 20.00	$ 18.50 to $ 21.50	15

[1] Designed bioretention cell in highly urban area serving less than 0.5 acre CDA with a landscape architect doing planting plan
[2] Replacement pavers for courtyard or plaza with some subgrade preparation
[3] Foundation planters capture rooftop runoff in an enclosed landscape box – see Appendix F
[4] Conversion of existing surface flow path to a more effective water quality swale
[5] Expanded tree pits with shared rooting space to treat stormwater in highly urban streets
[6] Breakup and removal of existing impervious area followed by revegetation with turf

OS-13

On-site Retrofits

UNDERGROUND RETROFITS

Underground retrofits are the on-site retrofit of last resort due to their high cost. They make sense when other on-site retrofits cannot fit on the surface, or land acquisition costs are too high. Underground retrofits are normally restricted to small sites that generate high pollutant loadings discharging to sensitive waters. Common methods of underground treatment are shown in Figure 1 and include:

- Infiltration galleries
- Underground sand filter
- Underground detention pipes
- Multi-chamber treatment train (MCTT)
- Proprietary stormwater treatment devices

This class of retrofits applies to ultra-urban subwatersheds that lack surface area for stormwater treatment (Figure 2). The most common form of treatment is the underground sand filter which provides effective pollutant removal. Underground sand filters make sense when water quality and public health issues are paramount.

Ideal Conditions for Underground Retrofits

The most ideal situations for underground retrofits are in:

- Ultra-urban areas that lack available space on the surface for treatment
- Redevelopment or infill projects where stormwater treatment requirements are triggered
- Severe stormwater hotspots or central business districts
- Sites where untreated direct stormwater discharges to extremely sensitive waters (e.g., intake for drinking water supply, swimming beaches, harbors, shellfish beds, waterfronts; Figure 3)
- Sites where pretreatment is needed prior to another retrofit
- Regions that have underlying soils with exceptionally good infiltration rates (e.g., glacial till, outwash plains, sandy plains)
- Parking lots that cannot be served by a surface retrofit
- Public works yards where crews can perform frequent maintenance

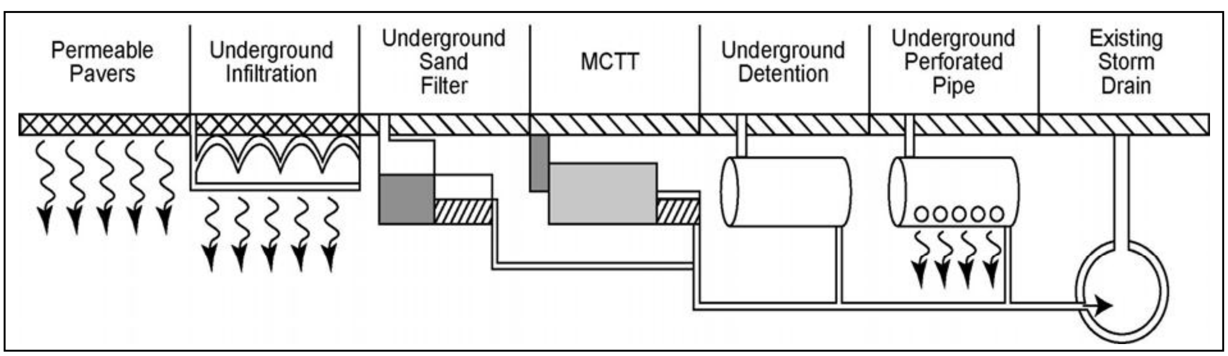


Figure 1: Numerous strategies can be used for underground retrofits.

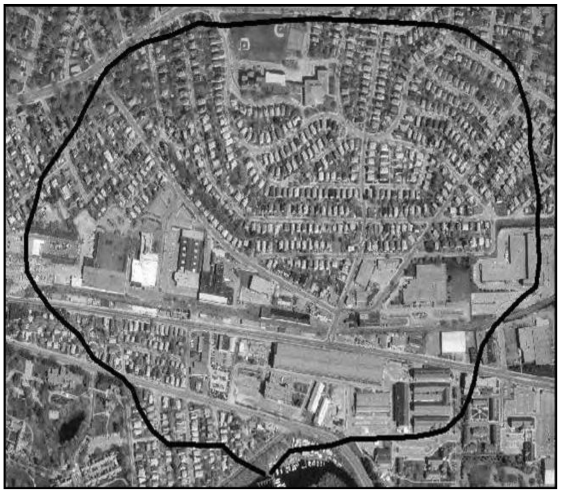


Figure 2: Underground retrofits are typically used in ultra-urban watersheds that lack surface area for other retrofits.

Figure 3: Large underground sand filter under construction to treat runoff near a drinking water intake.

Situations Where Underground Retrofits Are Difficult

Underground retrofits are problematic when:

- Excavation is limited by bedrock or a high water table
- Multiple utilities run underneath the site
- Terrain is flat and/or adequate head is lacking to drive the retrofit
- The receiving storm drain system is only a few feet below ground level
- Owner/operator is unwilling or unable to frequently maintain it

Restoration Alternatives in Ultra Urban Areas

It can be extremely expensive to retrofit ultra-urban subwatersheds using underground retrofits. Alternatives for improving stormwater quality in these subwatersheds include non-structural practices, such as:

- Intensive street sweeping (Manual 9)
- Regular cleanouts of storm drain inlets (Manual 9)
- Pollution prevention practices (see Manual 8)
- Detection and elimination of illicit discharges (see Brown *et al.*, 2004)
- Municipal housekeeping practices (Manual 9)

Desktop Searching for Underground Retrofits

There is generally no reason to conduct a desktop search to find underground retrofit sites. It may be helpful to consult a soils map to assess potential infiltration rates, but keep in mind that most urban soils are highly altered and compacted due to prior construction and no longer retain their original soil properties.

What to Look for when Investigating Underground Retrofits

Crews should consider underground retrofits only when all other surface retrofit options have been exhausted. Underground retrofits are extremely difficult to assess in the field since it is often hard to understand what is happening underground. The crew should look for indicators of underground utilities and pop any manholes or grates to determine the invert elevation and diameter of the storm drain pipe that will accept runoff from an underground retrofit.

Feasibility and Permitting for Underground Retrofits

Available head is the primary feasibility factor restricting underground retrofits. The difference in the surface elevation and the pipe elevation defines the head available, which in turn sets the maximum depth of underground treatment. Anywhere from four to 12 feet of head are needed depending on the retrofit design variant.

Underground retrofits require approval by the local stormwater review authority who may lack experience with this class of retrofits. The review and inspection of underground retrofits is more complex than other stormwater practices, and may involve:

- Underground injection permits (if the retrofit infiltrates)
- Confined space safety issues and other OSHA requirements
- Certification that the retrofit is water-tight (if the retrofit does not infiltrate)
- Maintenance contracts to ensure that trapped pollutants are routinely removed

Underground Retrofit Design

Several key design issues are involved in underground retrofits:

To infiltrate or not - The designer should be very clear on the retrofitting objective for the site. If runoff reduction is the goal, infiltration is desirable (Figure 4). On the other hand, filtering is recommended to remove stormwater pollutants to improve water quality. Infiltration should never be considered at stormwater hotspots to minimize the potential for groundwater contamination. Most urban soils have been severely altered and compacted by past earthmoving, so several borings and infiltration tests are essential for underground retrofits.

Structural reinforcement - Most underground retrofits are installed underneath parking lots and roads, so designers may need to perform a structural analysis to determine whether the retrofit has adequate load bearing capacity or needs structural reinforcement.

Visibility - Underground retrofits are out of sight and out of mind, so designers should include observation wells to monitor retrofit water levels and clearly mark the location of all access points on the ground, in pollution prevention plans and in maintenance records (Figure 5).

Easy sediment removal - Designers should provide multiple access points to maintain the retrofit and carefully think through how crews can safely remove trapped sediments. Designers should look at manhole diameters, grates, ladders and other features to make it

Figure 4: Where soils permit, infiltration galleries can be used to treat stormwater underground.

easy for crews to access the retrofit. It is preferable if sediment removal can be done with specialized equipment such as a vactor truck or hydraulic suction, as opposed to manual removal (Figure 6). Many underground retrofits will require confined space entry training to access the site.

Two cell design - Pretreatment is needed to handle high loads of sediment, trash, and organic debris and to contain spills and transitory illicit discharges. Underground retrofits should have a two cell design. The first pretreatment cell can be wet or dry, and should comprise at least 25% of the target WQv.

Use of proprietary treatment devices - The cost and complexity of underground retrofits can be reduced when proprietary stormwater treatment practices are specified. Designers, however, should clearly understand the capabilities and limitations of these practices when it comes to actual pollutant removal.

Construction Considerations for Underground Retrofits

Underground retrofits involve several unique construction considerations:

- Worker safety is important during excavation or trenching, particularly if the retrofit will be more than four feet deep.
- Workers should be trained in confined space entry procedures.
- Designers should be present when contractors are pouring concrete and should carefully inspect all work since it is not easy to remedy problems once the retrofit is paved over.
- Inspectors should make sure underground retrofits are water tight unless they are expected to infiltrate stormwater.
- Inspectors should make sure the connection to the accepting storm drain pipe is at the proper elevation.

Figure 5: Out of sight means out of mind – make sure inspectors can access underground retrofits.

Figure 6: Mechanized rather than manual sediment removal is always preferred.

Costs for Underground Retrofits

Underground retrofits normally cost at least an order of magnitude more to construct than surface retrofits (Table 1). The higher cost is attributed to:

- Greater need for excavation and off-site hauling
- Underground storage materials
- Structural reinforcement to bear traffic loads
- Poor urban soils
- Need to provide excellent maintenance access
- Cast-in-place construction

In addition, underground retrofits tend to be more expensive to maintain**.** The cost differential for underground retrofits can narrow if land acquisition is needed for surface retrofits, or if effective proprietary stormwater practices are employed.

Table 1: Estimated Construction Costs for Underground Retrofits (2006 $ /cubic foot treated)

Stormwater Treatment Option	Median Cost	Range	Design & Engineering (%)
Underground Infiltration [1]	$ 180.00	$ 144.00 to $ 216.00	32
Underground Sand Filter [2]	$ 65.00	$ 28.00 to $ 75.00	32
Multi-Chamber Treatment Train	$ 80.00	$ 66.00 to $ 94.00	32
Porous Concrete [3]	$ 65.00	$ 50.00 to $ 85.00	32
Proprietary Practices	$ 5.00	$ 3.00 to $ 20.00	15

[1] Removal of existing impervious cover, 12 inch stone subgrade or plastic arches and installation of pervious surface (permeable pavers, porous asphalt/concrete)
[2] Two cell underground watertight concrete vault with sand filter
[3] Removal of existing impervious cover, six inch stone and typical porous concrete application

Chapter 3: Stormwater Treatment Options For Retrofitting

Retrofitting involves choosing the most appropriate and effective stormwater treatment option at the individual retrofit site that can achieve local restoration objectives. Designers can choose from among as many as eight different stormwater treatment options when retrofitting (Figure 3.1). Each stormwater treatment option differs greatly in its pollutant removal capability, stormwater benefits and retrofit suitability. In many cases, more than one stormwater treatment option can be used at a retrofit site. This chapter provides general guidance to help designers choose the best options for their particular retrofit situation.

This chapter is not intended to be a treatise on stormwater design, as many stormwater design manuals already exist. Rather, it outlines how each stormwater option is modified in the context of retrofitting.

The ensuing series of profile sheets describes how each stormwater option can be adapted for retrofitting, and are organized as follows:

- **How They Operate -** How does the stormwater treatment option work to improve the quality of stormwater runoff?
- **Typical Retrofit Applications -** Which retrofit locations in a subwatershed are best for using the stormwater treatment options?

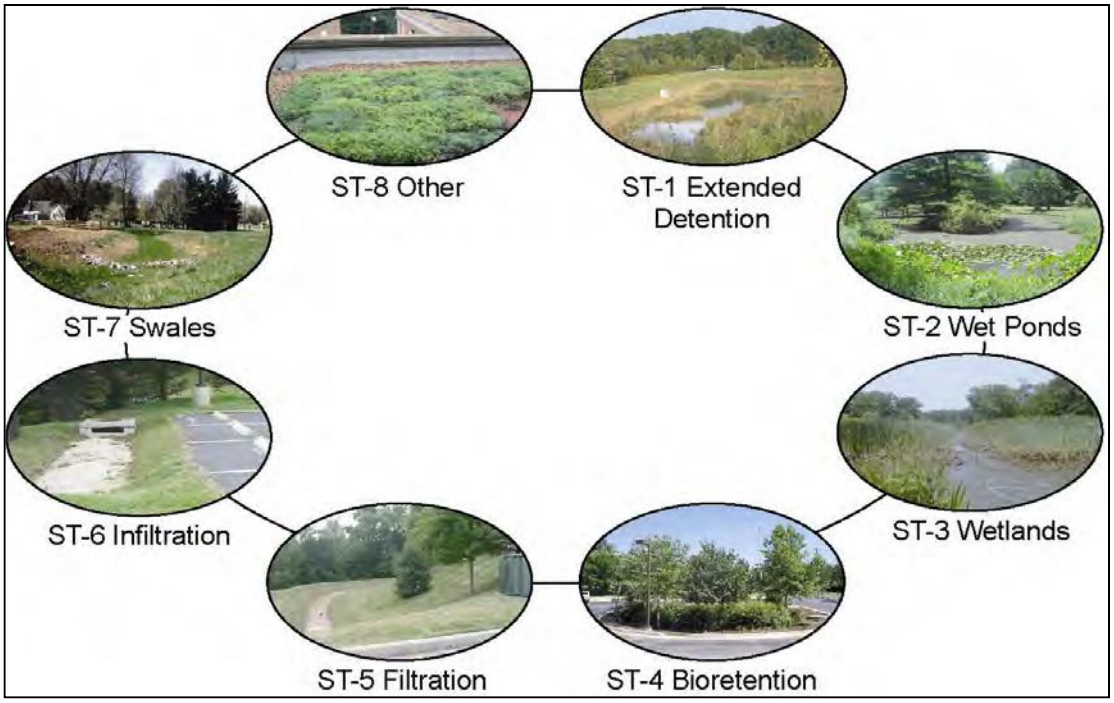


Figure 3.1: Eight stormwater treatment options are available for retrofitting.

- **Pollutant Removal Capability -** What are the primary pollutant removal mechanism(s) and the expected pollutant removal rates for each stormwater treatment options?

- **Other Stormwater Benefits Provided –** Can the stormwater treatment options provide additional stormwater management objectives such as groundwater recharge or channel protection?

Several matrices are provided to help designers choose the most appropriate stormwater treatment option for their retrofit site (Tables 3.1 to 3.3). The first matrix indicates which stormwater treatment options are preferred at each retrofit location, the second compares their ability to meet various restoration objectives, and the last rates their capability to remove different pollutants of concern.

These profile sheets can be used in conjunction with the retrofit location profile sheets contained in Chapter 3 to build a retrofit concept at a given site.

Designers may also wish to consult Appendix I to learn more about how each stormwater treatment option can be adapted for retrofitting. Each design sheet provides further information on the following topics:

- Typical Feasibility Constraints in Developed Watersheds
- Common Community and Environmental Concerns
- Retrofit Design Issues
- Retrofit Maintenance Issues
- Adaptations for Special Climates and Terrain
- Installation Costs
- Internet Design Resources

Table 3.1: Stormwater Treatment Options Used in Different Retrofit Locations

Subwatershed Location	Stormwater Treatment Option							
	ST-1 Extended Detention	ST-2 Wet ponds	ST-3 Wetlands	ST-4 Bio-retention	ST-5 Filters	ST-6 Infiltration	ST-7 Swales	ST-8 Other
SR-1 Existing Ponds	●	●	●	◉	◉	○	○	○
SR-2 Roadway Culverts	●	◉	●	○	○	○	○	○
SR-3 Below Outfalls	●	●	●	◉	◉	○	○	○
SR-4 Conveyance	◉	○	●	●	○	○	●	○
SR-5 Transport ROW	●	●	●	●	◉	○	◉	○
SR-6 Large Parking Lots	●	●	●	◉	◉	◉	○	○
OS-7 Hotspots	○	○	○	●	●	X	○	○
OS-8 Small Parking Lots	○	○	○	●	●	●	●	●
OS-9 Individual Streets	○	○	○	●	◉	◉	●	○
OS-10 Rooftops	○	○	○	●	○	◉	○	●
OS-11 Little Retrofits	○	○	○	●	◉	●	●	●
OS-12 Hard/Landscape	○	○	◉	●	◉	◉	◉	●
OS-13 Underground	◉	○	○	◉	●	◉	○	○

KEY
● = Preferred stormwater treatment option
◉ = Feasible in some circumstances
○ = Seldom used for the retrofit
X = Not recommended under any circumstances

Table 3.2: Ability of Stormwater Treatment Options to Address Retrofit Objectives

Retrofit Objective	Stormwater Treatment Options							
	Extended Detention	Wet Ponds	Wetlands	Bio-retention	Filtering	Infiltration	Swales	Other
Correct Past Mistakes	●	●	●	●	◉	●	●	◉
Reduce Flood Damage	●	●	●	○	○	◉	○	○
Education/ Demonstration	◉	◉	●	●	●	●	●	●
Trap Trash and Floatables	●	●	●	◉	●	○	○	○
Reduce Flows to Combined Sewer	◉	○	◉	●	○	●	◉	●
Renovate Stream Corridor	◉	●	●	●	○	◉	◉	○
Remove Pollutant of Concern	*Varies depending on pollutant, see Table 3.3*							
Reduce Bank Erosion	●	◉	◉	◉	○	◉	◉	◉
Support Stream Repair	●	◉	●	◉	◉	●	◉	○
Full Watershed Restoration	●	●	●	●	●	●	●	●

KEY
● = Primary stormwater treatment option to address objective
◉ = Secondary stormwater treatment option
○ = Supplemental stormwater treatment option

Table 3.3: Comparison of Pollutant Removal Capability

Stormwater Treatment Option	Stormwater Pollutant						
	TSS	TP	TN	Metals	Bacteria	Organic Carbon	Oil & Grease
Extended Detention	◉	X	○	○	○	X	◉
Wet Ponds	●	◉	○	◉	◉	○	◉
Wetlands	◉	◉	○	○	◉	X	●
Bioretention	◉	X	○	●	●	◉	●
Filtering	●	◉	○	◉	◉	◉	●
Infiltration	●	◉	○	●	?	●	●
Swales	●	X	○	◉	X	◉	●
Rooftop	*Varies*						

KEY
● = Excellent Removal (76 to 100%)
◉ = Good Removal (51 to 75%)
○ = Fair Removal (26 to 51%)
X = Low Removal (0 to 25%)
? = Unknown Removal

NOTES
See Profile Sheets in Chapter 2 for precise removal rates and ranges and Appendix B for documentation on derivation of removal rates

ST-1	Stormwater Treatment Options **EXTENDED DETENTION**	

This option relies on 12 to 24 hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow so it backs up and is stored within a pond or wetland. The temporary ponding enables particulate pollutants to settle out and reduces the effective shear stress on downstream banks. Extended Detention (ED) differs from stormwater detention, which is used for peak discharge or flood control purposes and often detains flows for just a few minutes or hours. ED is normally combined with other stormwater treatment options such as wet ponds and constructed wetlands to enhance retrofit performance and appearance (Figure 1). The most common design variations for ED retrofits include:

- Micropool Extended Detention (Water Quality)
- Micropool Extended Detention (Channel Protection)
- Wet Extended Detention Pond
- ED Wetlands

Schematics of each ED retrofit design variation are provided in Figure 2. ED is an ideal stormwater treatment option because it is cost-effective, versatile and safe, and is also the preferred stormwater treatment option for providing downstream channel protection.

Typical ED Retrofit Applications

ED is an attractive option to retrofit existing ponds (SR-1), and can also be utilized for other storage retrofits with the possible exception of the conveyance system (SR-4). ED is generally not suited for on-site retrofit applications. Dry ED ponds should seldom be considered as a standalone retrofit strategy, unless downstream channel protection is a priority.

Figure 1: This shallow wetland was designed with extended detention. (Rolling Stone retrofit, Montgomery County, MD)

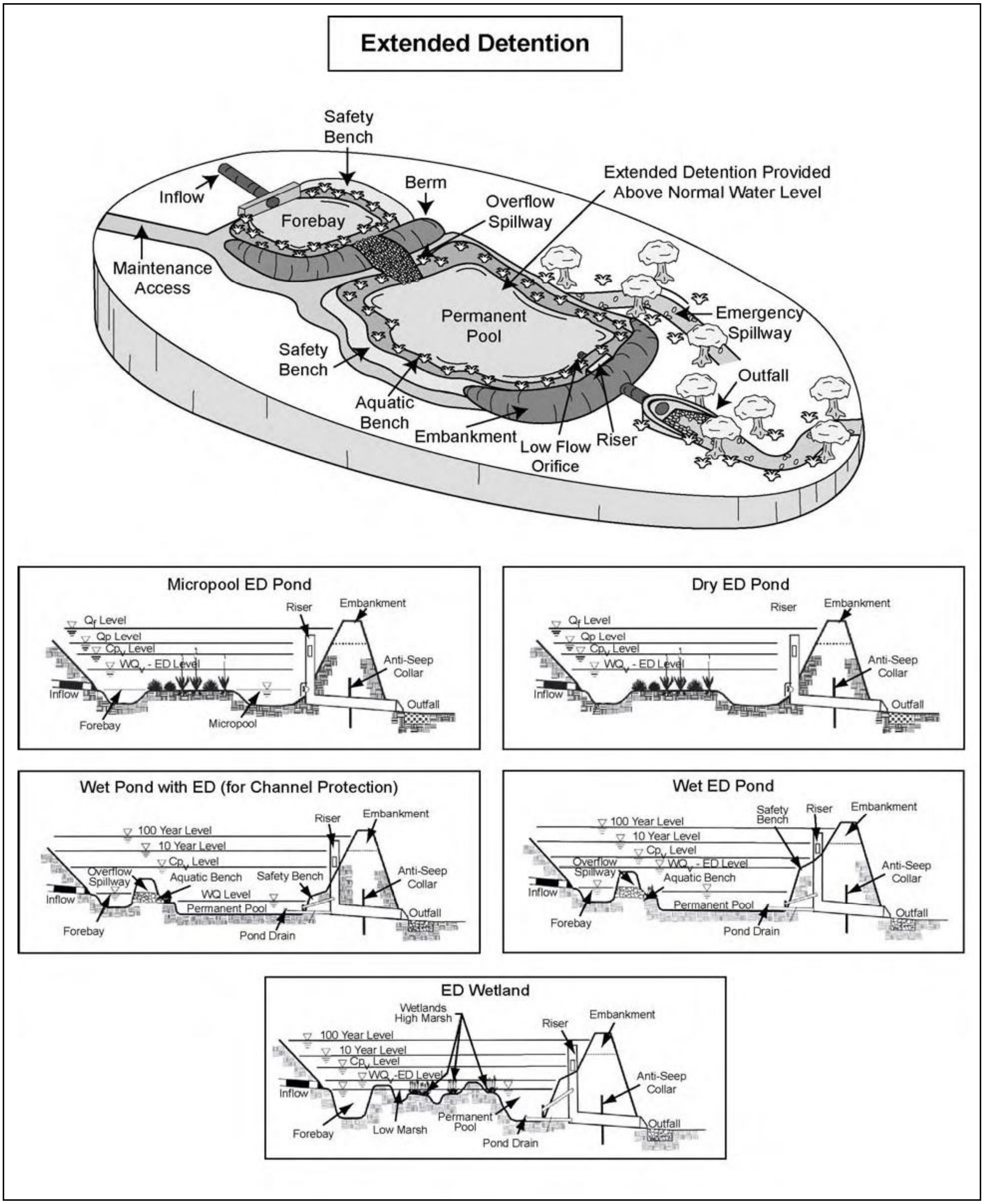


Figure 2: Extended Detention Schematics

ED Pollutant Removal Capability

ED ponds rely on gravitational settling as their primary pollutant removal mechanism. Consequently, they generally provide fair to good removal for particulate pollutants but low or negligible removal for soluble pollutants, such as nitrate and soluble phosphorus (Table 1). ED generally has the lowest overall pollutant removal rate of any stormwater treatment option. As a result, ED is normally combined with wet ponds or constructed wetlands to maximize pollutant removal rates.

Several site-specific factors can have a strong influence on ED pollutant removal rates. Designers should review the design factors in Table 2 to compute the expected pollutant removal rates for the individual retrofit using the design point method.

Table 1: Range of Reported Removal Rates for Dry Extended Detention Ponds			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	50	70	80
Total Phosphorus	15	20	30
Soluble Phosphorus	-10	-10	40
Total Nitrogen	25	25	35
Organic Carbon	15	25	35
Total Zinc	25	30	60
Total Copper	30	30	50
Bacteria	0	40	90
Hydrocarbons	40	70	80
Chloride	0	0	0
Trash/Debris	65	80	85
See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25th and 75th quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for ED Retrofits		
Design Factors	**X**	**Points**
Wet ED or Multiple Cell Design		+ 2
Exceeds target WQv by more than 25%		+ 1
Exceeds target WQv by more than 50%		+ 2
Off-line design		+ 1
Flow path greater than 1.5 to 1		+ 1
Sediment forebay		+ 1
Constructed wetland elements included in design		+ 1
On-line design		- 1
Flow path less than 1:1		- 1
Pond SA/CDA ratio less than 2%		- 2
Does not provide full WQv volume		- 2
Pond intersects with groundwater		- 2
NET DESIGN SCORE (max. of 5 points)		

An important factor influencing pollutant removal rates is whether ED is combined with another treatment option, such as a wet pond or stormwater wetland. As a general rule, if more than 50% of the target WQv is provided by a wet pond or constructed wetland, then the higher pollutant removal rate for the treatment option should be applied (see Profile Sheets ST-2 and ST-3).

Other Stormwater Benefits Provided by ED

ED retrofits can provide other stormwater benefits to address other restoration objectives:

Recharge: Dry ED pond retrofits can provide modest groundwater recharge benefits. Strecker *et al.* (2004) reported up to 30% runoff reduction for a large population of monitored dry ED ponds, presumably due to infiltration through the bottom soils of the basin. Recharge benefits will be reduced if the ED pond has impermeable or compacted soils, a liner, or a permanent pool of water.

Channel Protection: ED ponds are the primary means to protect downstream channels if full channel protection storage can be provided at the retrofit site. It should be noted, however, that channel protection normally requires about 20-40% more storage volume than that needed for water quality treatment (see Figure 1.3 in Chapter 1). Consequently, designers may have difficulty finding adequate space to retrofit channel protection storage at tight sites. Guidance on estimating channel protection storage volume for individual retrofit sites can be found in Appendix C.

ST-2	Stormwater Treatment Options	
	WET PONDS	

Wet ponds consist of a permanent pool of standing water that promotes a better environment for gravitational settling, biological uptake and microbial activity (Figure 1). Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during prior storms. When sized properly, wet ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate.

Wet pond retrofits can be employed in several different design configurations:

- Wet Pond
- Wet ED Pond
- Wet Pond with ED for Channel Protection
- Pond Wetland System

Figure 2 illustrates each wet pond design variation. Wet ponds are an ideal retrofit treatment option due to their high and reliable pollutant removal performance, community acceptance and amenity value. Wet ponds can also provide channel protection above the permanent pool in some retrofit situations.

Figure 1: Wet ponds can provide additional pollutant removal through settling

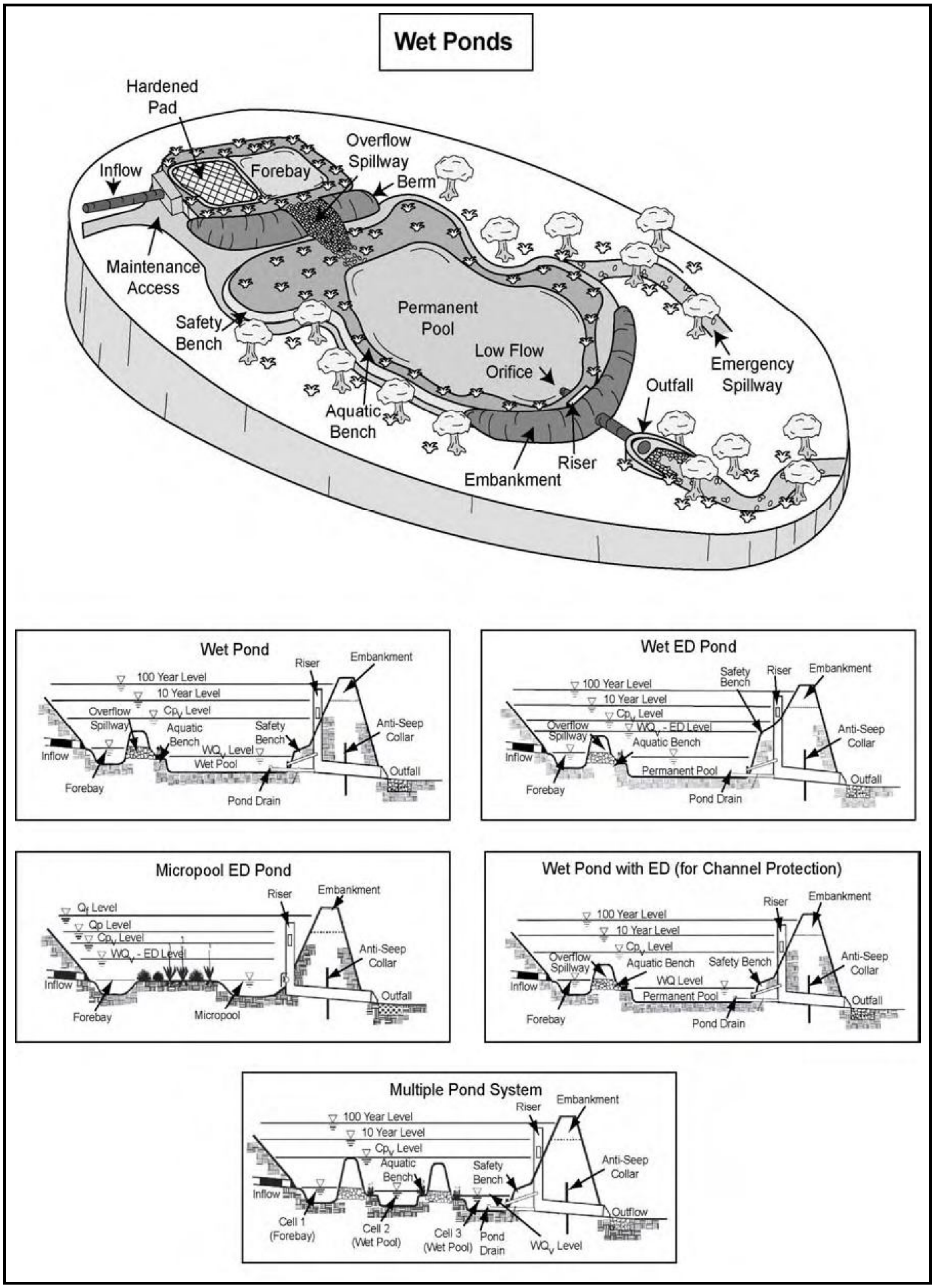


Figure 2: Schematics for various wet pond variations

Typical Retrofit Applications

Wet ponds can be used as either a primary or secondary treatment option in most storage retrofit situations. Wet ponds are not recommended for conveyance retrofits (SR-4) and most on-site retrofit applications.

Wet Pond Pollutant Removal Capability

Many pollutant removal mechanisms operate in the water column and bottom sediments of wet ponds including gravitational settling, algal uptake, adsorption, ultra-violet radiation and microbial processes. Many wet ponds have been intensively monitored in the past three decades and researchers consistently report moderate to high removal rates across the full range of stormwater pollutants (Table 1). Wet ponds generally have higher pollutant removal rates than other stormwater treatment options reviewed in this chapter.

Wet pond research has revealed many site-specific conditions and design factors than can enhance or detract from the median removal rates (Table 2). In general, the walkaway volume of a retrofit is when it cannot provide at least 35% of the target WQv. In addition, if more than 50% of the target water quality volume is provided by ED, the lower removal rates outlined in Profile Sheet ST-1 should be applied. Designers can review the design factors and site conditions in Table 2 to evaluate whether their individual retrofit design will perform better or worse than normal, using the design point method.

Other Stormwater Benefits Provided by Wet Ponds

Wet pond retrofits have limited potential to provide other stormwater benefits:

Groundwater Recharge: Due to their standing water and sealed bottoms, wet ponds do not offer much benefit in terms of groundwater recharge.

According to Strecker *et al.* (2004), wet ponds reduce incoming runoff volumes by less than 5%, most of which is accomplished by evaporation rather than soil infiltration.

Channel Protection: When site topography permits, extended detention can be stacked above the permanent pool to provide downstream channel protection. Designers should note that the CPv storage is typically 20 to 40% greater than the WQv storage so it is often hard to provide full channel protection at tight retrofit sites. Guidance on estimating the channel protection volume needed at individual retrofit sites can be found in Appendix C.

Table 1: Range of Reported Removal Rates for Wet Ponds			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	60	80	90
Total Phosphorus	40	50	75
Soluble Phosphorus	40	65	75
Total Nitrogen	15	30	40
Organic Carbon	25	45	65
Total Zinc	40	65	70
Total Copper	45	60	75
Bacteria	50	70	95
Hydrocarbons	60	80	90
Chloride	0	0	0
Trash/Debris	75	90	95
See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25^{th} and 75^{th} quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for Wet Pond Retrofits		
Design Factors	**X**	**Points**
Wet ED or Multiple Pond Design		+ 2
Exceeds target WQv by more than 50%		+ 2
Exceeds target WQv by more than 25%		+ 1
Off-line design		+ 1
Flow path greater than 1.5 to 1		+ 1
Sediment forebay at major outfalls		+ 1
Wetland elements cover at least 10% of surface area		+ 1
Single cell pond		- 1
Flow path less than 1:1		- 1
On-line design		- 1
Pond SA/CDA ratio less than 2%		- 2
Does not provide full WQv volume		- 2
Pond intersects with groundwater		- 2
NET DESIGN SCORE (max of 5 points)		

ST-3

Stormwater Treatment Options

CONSTRUCTED WETLANDS

How Constructed Wetlands Work

Constructed wetlands are shallow depressions that receive stormwater inputs for treatment. Wetlands are typically less than one foot deep (although they have deeper pools at the forebay and micropool) and possess variable microtopography to promote dense and diverse wetland cover (Figure 1). Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity.

Constructed wetlands can be a stand-alone treatment option, or be combined with other stormwater treatment options in several configurations:

- Shallow Marsh
- ED Wetland
- Pond Wetland
- Wet Swales

Each constructed wetland design variation is illustrated in Figure 2.

Constructed wetlands are ideal because they replicate natural wetland ecosystems, provide efficient and reliable pollutant removal and have low construction costs (if ample space is available at the retrofit site). Well-designed stormwater wetlands enjoy widespread community acceptance, and possess high amenity and habitat value. Depending on site topography, constructed wetlands can also provide downstream channel protection when ED storage is stacked above the normal water level of the wetland.

Figure 1: This wetland was constructed to treat stormwater from a nearby commercial area.

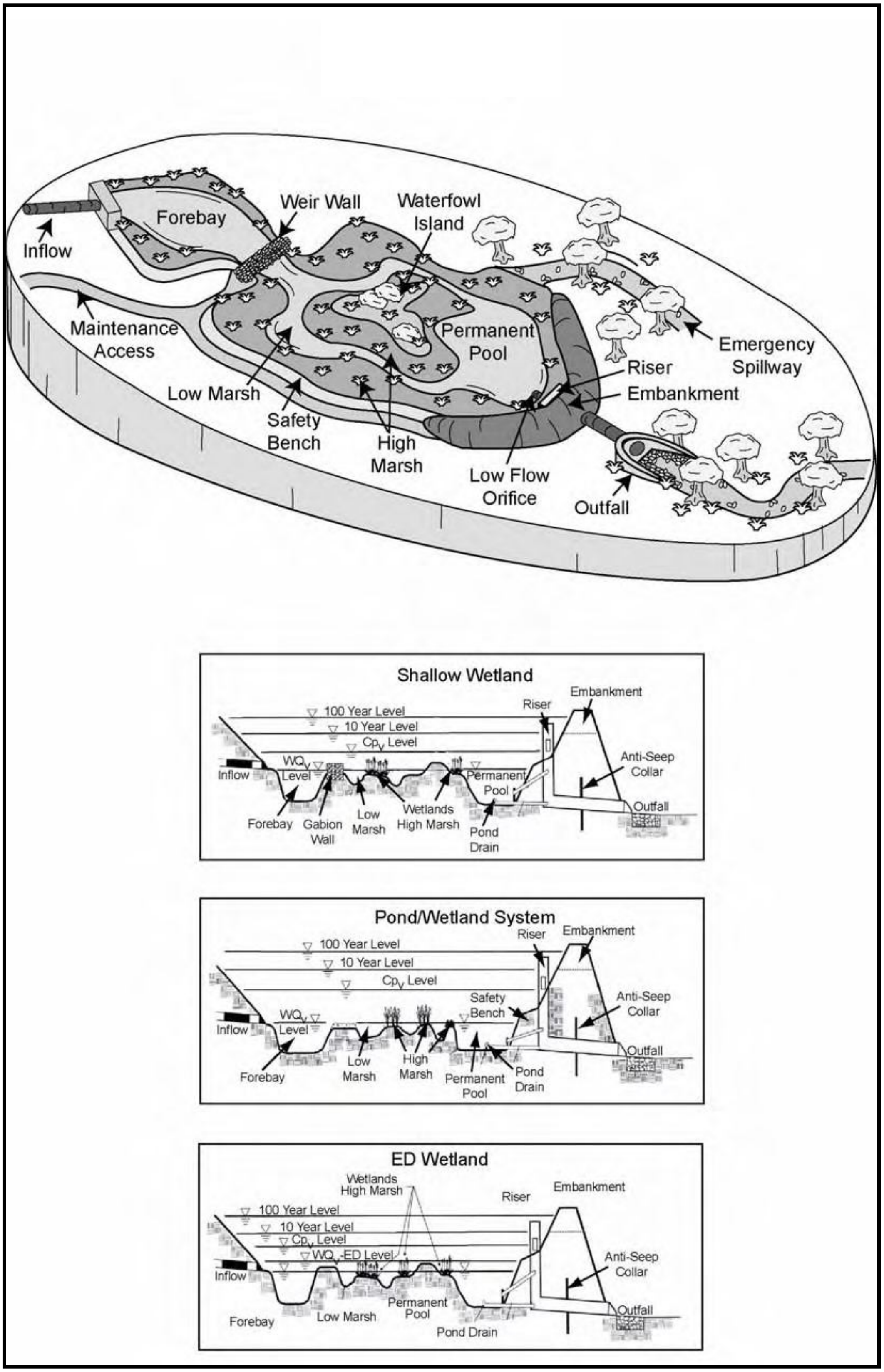


Figure 2: Schematics of three wetland variations

Typical Retrofit Applications for Constructed Wetlands

Constructed wetlands can be the primary or secondary form of stormwater treatment in the following storage retrofit applications:

- **SR-1** Excavate shallow wetland in bottom of pond or add aquatic benches to wet pond
- **SR-2** Create wooded wetlands above road crossings (often with ED)
- **SR-3** Divert runoff from pipe to shallow wetland treatment cells in floodplain
- **SR-4** Install offline shallow wetland cells or in-line wet swales in the conveyance system
- **SR-5** Install wetland cells in highway cloverleaf or create wet swales in highway right of way
- **SR-6** Create wetland treatment cell adjacent to large parking lots

Constructed wetlands are seldom used for on-site retrofit applications, although several may incorporate some wetland elements.

Pollutant Removal Capability of Constructed Wetlands

Constructed wetlands utilize a range of physical, chemical, microbial and biological mechanisms to remove pollutants. Wetland vegetation and sediments provide a growth media for microbes and filter and settle pollutants attached to sediments. Researchers have studied a large population of stormwater wetlands, and have concluded their removal rates are similar to wet ponds, but are somewhat more variable, especially for nutrients and organic carbon (Table 1).

Key design factors and site conditions that increase or decrease pollutant removal rates within constructed wetland retrofits are outlined in Table 2. The recommended walkaway volume for wetland retrofits is when they provide less than 35% of the target WQv. Constructed wetlands that allocate more than 50% of their storage for ED should use the lower removal rates for ED ponds shown in Profile Sheet ST-1. The median pollutant removal rates at individual retrofit sites can be adjusted to account for runoff capture volume and other site factors using the design point method (Table 2).

Other Stormwater Benefits Provided by Constructed Wetlands

Constructed wetlands can offer additional stormwater benefits:

Runoff Reduction: Constructed wetlands are capable of reducing 5 to 10% of the incoming runoff volume through evaporation and seepage losses, according to Strecker *et al* (2004). This minor reduction is not likely to provide a meaningful groundwater recharge benefit.

Channel Protection: Designers can stack ED above constructed wetlands to provide channel protection storage, although the frequent changes in water levels will degrade the quality and density of wetland cover. Designers can avoid the “bounce” problem by limiting the vertical depth of extended detention. Guidance on estimating the channel protection volume needed at an individual retrofit site is provided in Appendix C.

Table 1: Range of Reported Removal Rates for Constructed Wetlands			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	45	70	85
Total Phosphorus	15	50	75
Soluble Phosphorus	5	25	55
Total Nitrogen	0	25	55
Organic Carbon	0	20	45
Total Zinc	30	40	70
Total Copper	20	50	65
Bacteria	40	60	85
Hydrocarbons	50	75	90
Chloride	0	0	0
Trash/Debris	75	90	95
See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25th and 75th quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for Wetland Retrofits		
Design Factors	**X**	***Points***
Pond-Wetland or Multiple Cell Design		+ 2
Pond-Wetland or Multiple Cell Design		+ 2
Exceeds target WQv by more than 50%		+ 2
Complex wetland microtopography		+ 2
Exceeds target WQv by more than 25%		+ 1
Flow path greater than 1.5 to 1		+ 1
Wooded wetland design		+ 1
Off-line design		+ 1
No forebay or pretreatment features		- 1
Wetland intersects with groundwater		- 1
Flow path is less than 1:1		- 1
No wetland planting plan specified		- 2
Wetland SA to CDA ratio is less than 1.5%		- 2
Does not provide full WQv volume		- 2
NET DESIGN SCORE (max of 5 points)		

ST-4	Stormwater Treatment Options	
	BIORETENTION	

Bioretention is a landscaping feature adapted to treat stormwater runoff at retrofit sites (Figure 1). Individual bioretention areas serve drainage areas of one acre or less. Surface runoff is directed into a shallow landscaped depression that incorporates many of the pollutant removal mechanisms that operate in forested ecosystems. The filter is composed of an 18 to 48 inch deep sand/soil bed with a surface mulch layer. During storms, runoff temporarily ponds six to nine inches above the mulch layer and then rapidly filters through the bed. Normally, the filtered runoff is collected in an underdrain and returned to the storm drain system (Figure 2). The underdrain consists of a perforated pipe in a gravel jacket installed along the bottom of the filter bed.

In other cases, bioretention can be designed to infiltrate runoff into native soils. This can occur at sites with highly permeable soils, a low groundwater table, and a low risk of groundwater contamination. This design features the use of a "partial exfiltration" system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed or are eliminated altogether, thereby increasing stormwater infiltration.

Figure 1: Bioretention created in a parking lot turn-around

Bioretention creates an ideal environment for filtration, biological uptake, and microbial activity, and provides moderate to high pollutant removal. Bioretention can become an attractive landscaping feature with high amenity value and community acceptance. In the right landscape setting, bioretention can be a cost effective and flexible retrofit option.

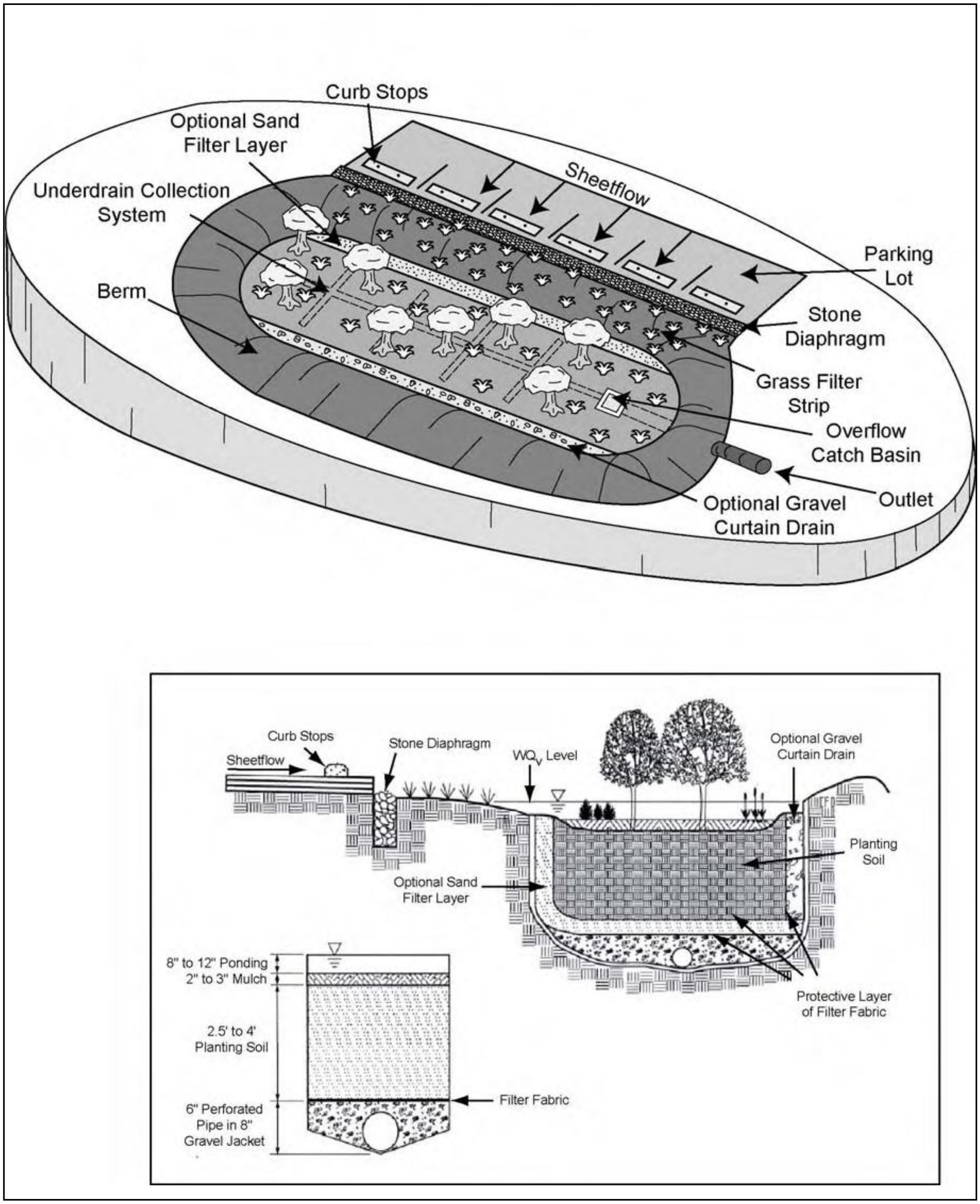


Figure 2: Bioretention schematic with underdrain

Typical Retrofit Applications for Bioretention

Bioretention is an extremely versatile stormwater treatment option for both storage and on-site retrofits that can fit within unused land at a variety of different sites. Common bioretention retrofit opportunities include:

- **SR-1** Install bioretention in bottom of dry pond
- **SR-3** Split flows from smaller pipes to a large bioretention area
- **SR-4** Create series of on-line or off-line bioretention cells
- **SR-5** Install two-cell bioretention area
- **SR-6** Divert flow to two-cell bioretention area
- **OS-7** Install bioretention w/ underdrain to treat hotspot
- **OS-8** Install bioretention within parking lot islands or perimeter
- **OS-9** Incorporate bioretention in streetscapes, tree pits, cul-de-sacs or traffic calming measures
- **OS-10** Install rain-garden to treat residential or commercial rooftop runoff
- **OS-12** Utilize bioretention as a landscape feature

Estimated Pollutant Removal by Bioretention

Until recently, only a handful of monitoring studies had measured the pollutant removal performance of bioretention areas. The most recent studies indicate that bioretention provides effective pollutant removal for many pollutants as a result of sedimentation, filtering, plant uptake, soil adsorption, and microbial processes. Table 1 summarizes bioretention pollutant removal rates for a variety of common stormwater pollutants.

The recommended walkaway volume for bioretention is about 50% of the target water quality volume. Another notable factor is whether the underlying soils have enough permeability to dispense with an underdrain. If an underdrain is not needed, pollutant removal will be enhanced by the greater infiltration of runoff into the soil and may approach the higher pollutant removal rates achieved by infiltration practices (see Profile Sheet ST-6). From the standpoint of nutrient removal, it is strongly recommended that the phosphorus index of topsoil mixed into the bioretention media be tested.

Table 2 can be used to adjust the median removal rates for individual retrofit projects by using the design point method.

Other Stormwater Benefits Provided by Bioretention

Bioretention retrofits can provide important stormwater benefits under certain site conditions.

Recharge: Bioretention has been shown to reduce runoff volume by 35 to 50% through evapotranspiration and infiltration of runoff, according to Hunt *et al.* (2006) and Traver (2006). Runoff reduction exceeding 90% has been reported for deeper filter beds that lack underdrains and are situated on permeable soils (Horner *et al.*, 2003).

Channel Protection: The feasibility of storing the channel protection volume within bioretention areas has not yet been demonstrated, although the impressive runoff reduction rates suggests that widespread use of bioretention could be an effective element of a larger strategy to protect downstream channels from erosion.

Table 1: Range of Reported Removal Rates for Bioretention Areas			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	15*	60*	75*
Total Phosphorus	-75	5	30
Soluble Phosphorus	-10	0	50
Total Nitrogen	40	45	55
Total Zinc	40	80	95
Total Copper	40	80	100
Bacteria	20	50	80
Hydrocarbons	80	90	95
Chloride	0	0	0
Trash/Debris	80*	90*	95*
* Adequate pretreatment must be provided to reduce sediment loads to bioretention areas or clogging and practice failure may result See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25th and 75th quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for Bioretention Retrofits		
Design Factors	**X**	**Points**
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Tested filter media soil P Index less than 30 (phosphorus only)		+ 3
Filter bed deeper than 30 inches		+ 1
Two cell design with pretreatment		+ 1
Permeable soils; no underdrain needed		+ 2
Upflow pipe on underdrain		+1
Impermeable soils; underdrain needed		- 1
Filter bed less than 18 inches deep		- 1
Single cell design		- 1
Bioretention cell is less than 5% of CDA		-1
Does not provide full water quality storage volume		- 2
Filter media not tested for P Index (phosphorus only)		- 3
NET DESIGN SCORE (max of 5 points)		
NET PHOSPHORUS SCORE (max of 5 points)		

ST-5	Stormwater Treatment Options	
	FILTRATION	

Stormwater filters are a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting it in an underdrain and then returning it back to the storm drain system (Figure 1). The filter consists of two chambers; the first is devoted to settling, and the second serves as a filter bed (with sand or an organic filtering media).

Stormwater filters are a versatile retrofit option that offers moderate pollutant removal performance. They are especially attractive for on-site retrofits where space is limited, because they consume very little surface land and have few site restrictions. Filters are the preferred option to treat runoff from
stormwater hotspot sites.

There are several design variations of the basic sand filter that enable designers to retrofit challenging sites or improve pollutant removal rates. The most common design variants include:

- Surface Sand Filters
- Surface Organic Media Filters
- Underground Sand Filters
- Perimeter Sand Filters
- Multi-Chamber Treatment Train (MCTT) Filter

Surface Sand Filter
The surface sand filter is designed with both the filter bed and sediment chamber located at ground level (Figure 2). Surface sand filters are designed off-line so that only the desired WQv is directed to the filter for treatment. The surface sand filter is the least expensive filter option, and has been the most widely used.

Organic Media Filter
Organic media filters are essentially the same as surface filters, with the sand replaced with an organic filtering medium (Figure 3). Two notable examples are the peat/sand filter (Galli, 1990a) and the compost filter system. Organic filters achieve higher pollutant removal for metals and hydrocarbons due to the increased cation exchange capacity of the organic media.

Figure 1: Surface Sand Filter

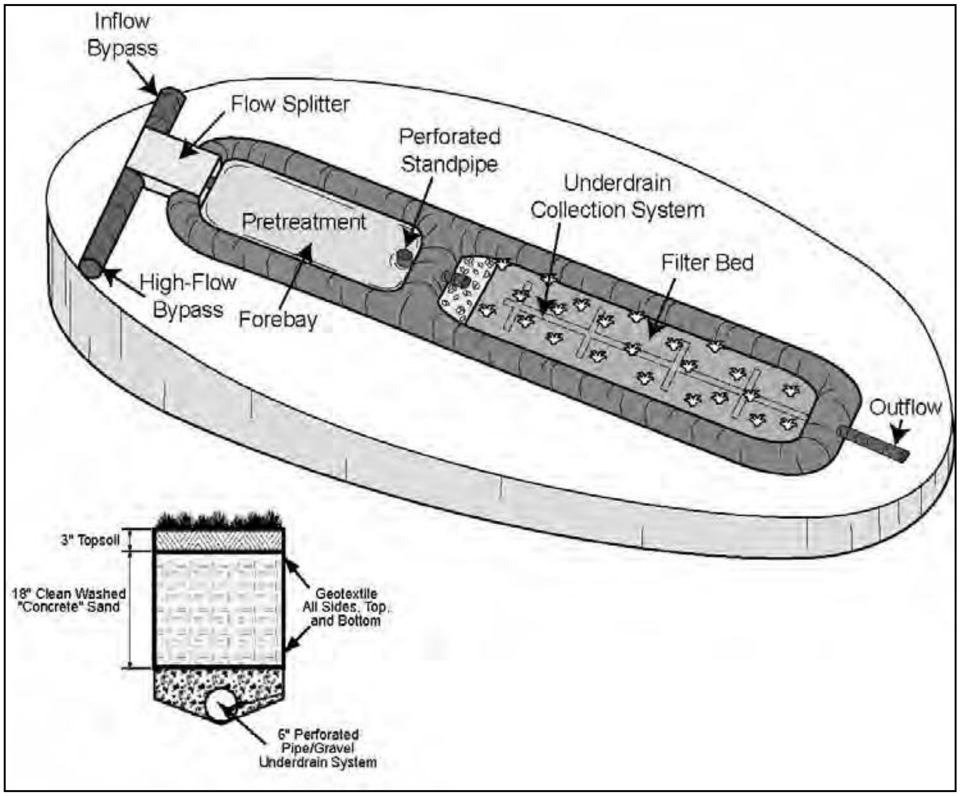


Figure 2: Schematic of a surface sand filter

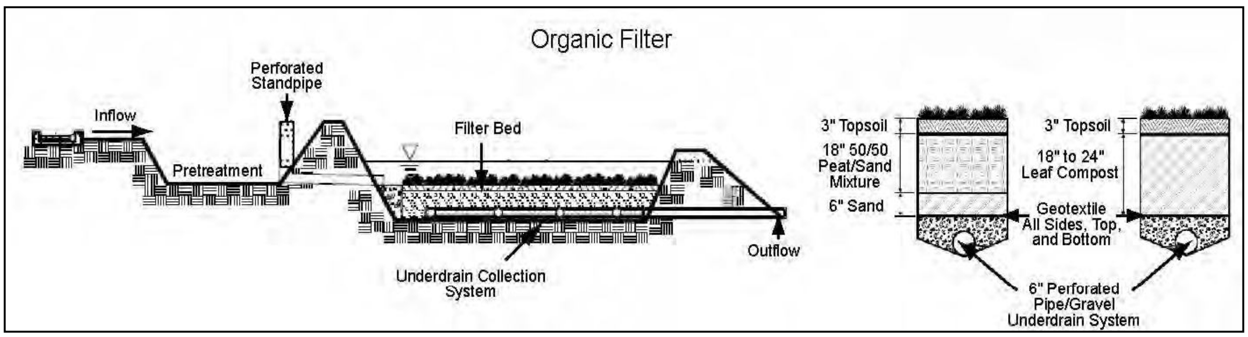


Figure 3: Schematic of an organic filter

Underground Sand Filter
The underground sand filter is modified to install the filtering components underground and is often designed with an internal flow splitter or overflow device that bypasses runoff from larger stormwater events around the filter (Figure 4). Underground sand filters are expensive to construct, but consume very little space and are well suited to ultra-urban areas.

Perimeter Sand Filter
The perimeter sand filter also includes the basic design elements of a sediment chamber and a filter bed. In this design, however, flow enters the system through grates, usually at the edge of a parking lot. The perimeter sand filter is usually located on-line, with all flows entering the system, but larger events bypass treatment by entering an overflow chamber. One major advantage to the perimeter sand filter design

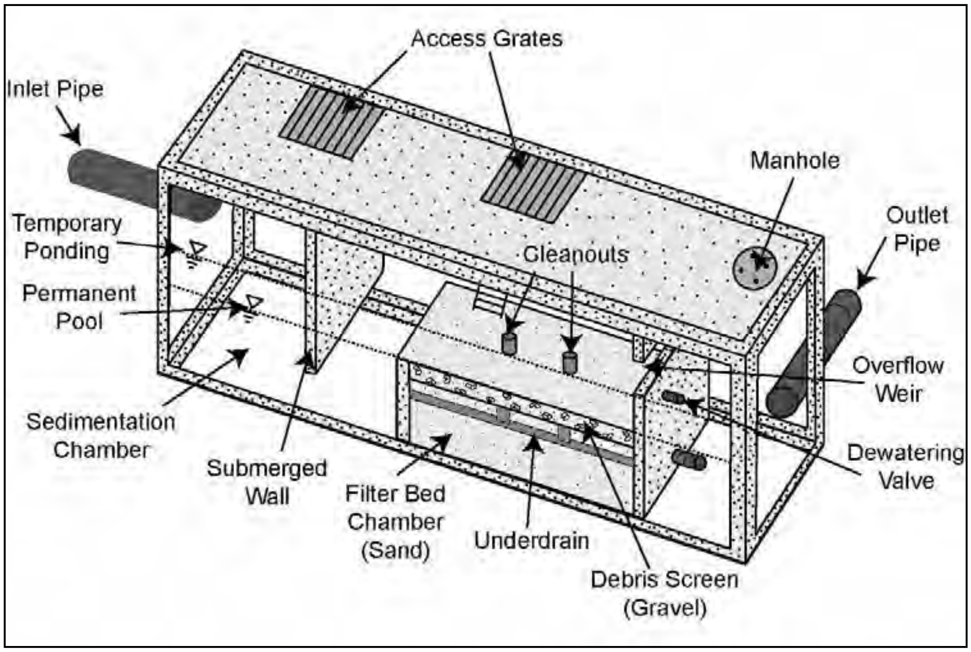


Figure 4: Underground filter schematic

is that it requires little hydraulic head and is therefore a good option for retrofit sites with low relief.

Multi-Chamber Treatment Train (MCTT)
The MCTT is an advanced underground sand filter developed by Pitt *et al*. (1997) that consists of three chambers (Figure 5). Stormwater enters into the first screening chamber where large sediment particles are trapped and highly volatile compounds are removed. The second chamber promotes settling of finer sediments and further removal of volatile compounds and floatable hydrocarbons using fine bubble diffusers and sorbent pads. The final chamber provides filtration using a peat sand filter to remove remaining metals and toxicants. The top of the filter bed is covered by a filter fabric to evenly distribute flow. Monitoring has shown the MCTT can achieve very high pollutant removal rates. Due to its high cost, it is best applied to severe stormwater hotspots.

Typical Retrofit Application for Stormwater Filters

Filter retrofits are particularly well suited to treat runoff from stormwater hotspots and smaller parking lots. Other retrofit opportunities may occur during redevelopment of commercial sites or when existing parking lots are renovated or expanded. While stormwater filters are seldom used as a storage retrofit in humid climates, they may be a more attractive option in arid and semi-arid climates. Some typical retrofit applications for stormwater filters include:

- **SR-3** Split flow from storm drain pipe to a surface sand filter
- **SR-6** Treat flow from large parking lot to a surface sand filter

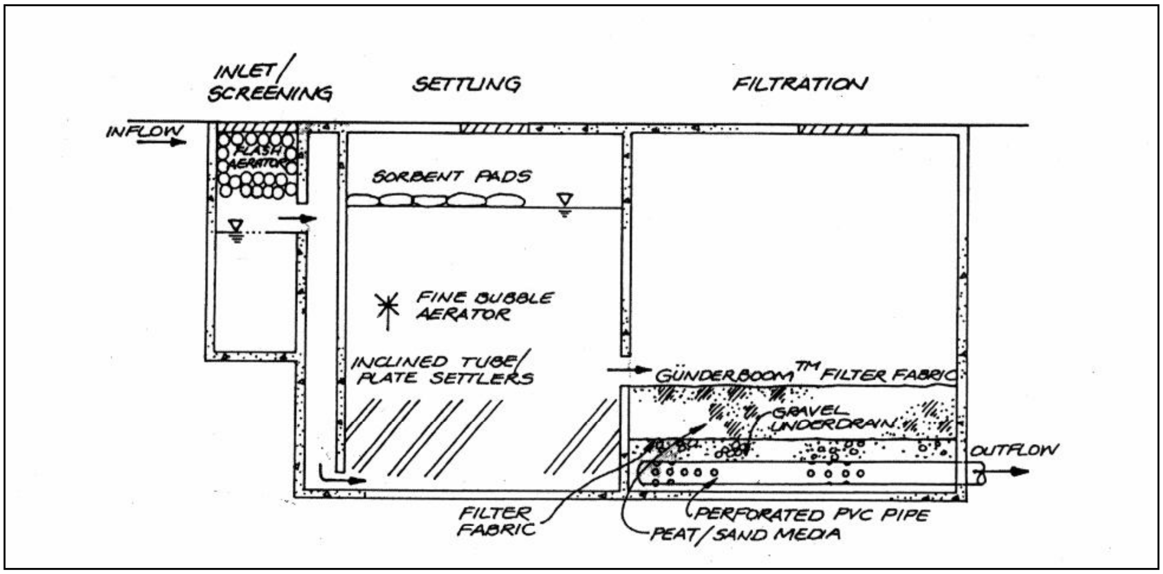


Figure 5: Drawing of a Multi-Chamber Treatment Train

- **OS-7** Treat flow from a hotspot operation using various sand filter designs
- **OS-8** Treat flow from small parking lot using surface or perimeter sand filter
- **OS-13** Treat runoff in an underground sand filter or MCTT

Filters can work on most commercial, industrial, institutional or municipal sites and can be located underground if surface area is not available. Filters are usually designed only for water quality treatment.

Stormwater Filter Pollutant Removal

Stormwater filters depend mainly on physical treatment mechanisms to remove pollutants from stormwater runoff including gravitational settling in the sedimentation chamber, straining at the top of the filter bed, and filtering and adsorption onto the filter media. Microbial films often form on the surface of the filter bed which can also enhance biological removal.

Table 1 reports the range in reported removal rates for 15 sand and organic filters reviewed in the CWP national pollutant removal database (excluding vertical sand filters and the MCTT). As a group, stormwater filters provide consistent removal of most pollutants, with the exception of soluble nutrients, such as soluble phosphorus and nitrate-nitrogen.

Several site-specific conditions and design factors have a strong influence on stormwater filter pollutant removal rates. Table 2 outlines how these factors can be used to adjust median removal rates using the design point method for individual retrofit projects.

If the retrofit is under-sized, pollutant removal rates will be near the lower end of the range. The recommended walkaway volume for stormwater filters is 50% of the target WQv. Another important factor is whether organic material is included in the filter bed media, which can enhance performance with respect to hydrocarbons and metals.

Other Stormwater Benefits Provided by Stormwater Filters

Stormwater filter retrofits can seldom address other stormwater management objectives beyond water quality treatment. Since they have an impermeable liner and underdrain, they cannot recharge groundwater. They usually lack enough storage capacity to provide meaningful channel protection.

Table 1: Range of Reported Removal Rates for Stormwater Filters			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	80	85	90
Total Phosphorus	40	60	65
Soluble Phosphorus	-10	5	65
Total Nitrogen	30	30	50
Organic Carbon	40	55	70
Total Zinc	70	90	95
Total Copper	35	40	70
Bacteria	35	40	70
Hydrocarbons	80	85	95
Chloride	0	0	0
Trash/Debris	85*	90*	95*
See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25th and 75th quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for Filtering Retrofits		
Design Factors	**X**	**Points**
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Site is a severe or confirmed hotspot		+ 2
Organic media used within filter bed (all pollutants except N/P)		+ 2
Two cells with at least 25% WQv allocated to pretreatment		+ 1
Filter bed SA is at least 2.5% of CDA		+ 1
Filter bed exposed to sunlight		+ 1
Off-line design w/ storm bypass		+ 1
Dry pretreatment		- 1
On-line design, w/o storm bypass		- 1
Underground design (except MCTT)		- 1
Filter design is hard to access for maintenance		- 2
Does not provide full WQv volume		- 3
NET DESIGN SCORE (max of 5 points)		

ST-6	Stormwater Treatment Options	
	INFILTRATION	

Infiltration practices capture and temporarily store stormwater runoff before infiltrating it into underlying soils where most pollutants are trapped. Infiltration can be an ideal on-site retrofit to treat stormwater runoff as long as minimum geotechnical requirements are met. Infiltration retrofits consists of a rock-filled chamber with no outlet. Stormwater runoff must first pass through some form of pretreatment, such as a swale or sediment basin. Runoff is then stored in the voids between the stones, where it slowly infiltrates into the soil matrix over a few days (Figure 1). Alternatively, proprietary materials such as perforated corrugated metal pipe, plastic arch pipe, or plastic lattice trays can be substituted for stone to increase storage capacity. A schematic of a typical infiltration trench is provided in Figure 2**.**

Where favorable soil conditions exist, infiltration can improve water quality, increase groundwater recharge and reduce runoff volumes. Infiltration practices are particularly desirable in subwatersheds that seek to reduce runoff volumes to prevent combined sewer overflows.

Figure 1: Infiltration Trench

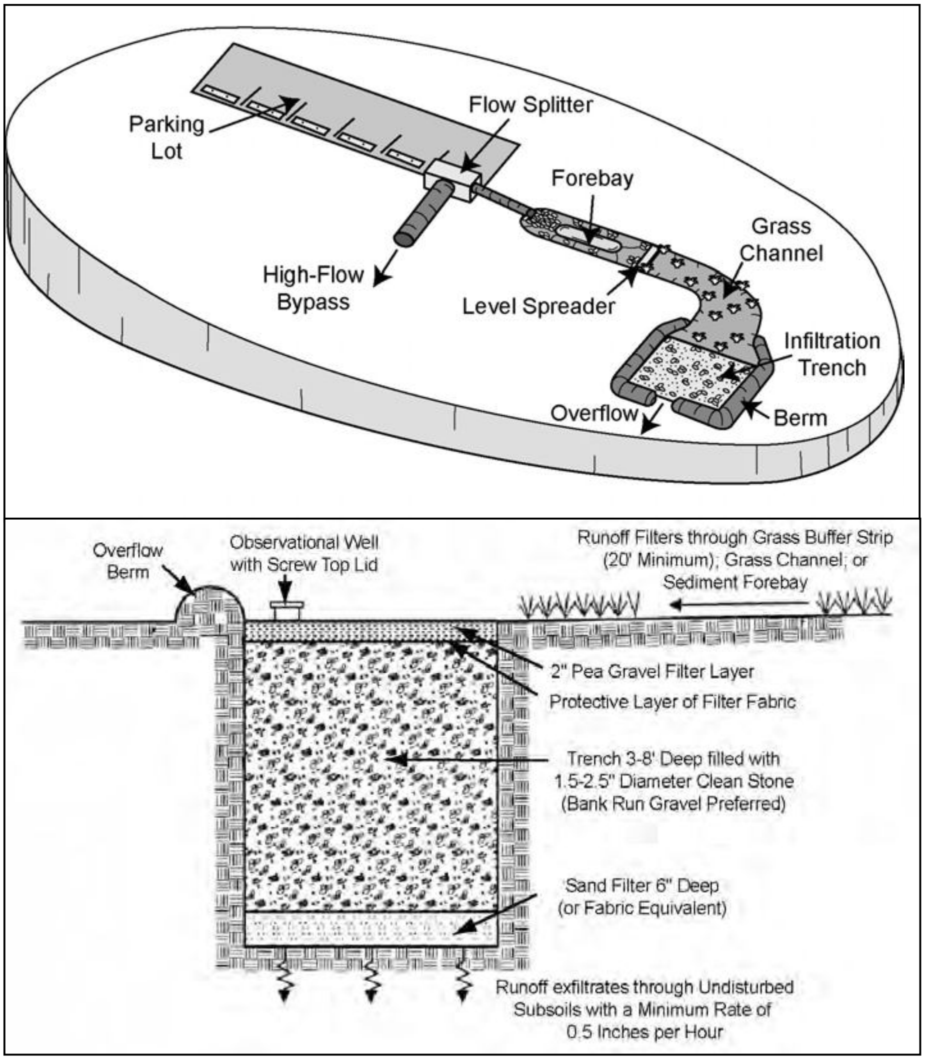


Figure 2: Schematic of an infiltration trench

Other Stormwater Benefits Provided by Stormwater Filters

Stormwater filter retrofits can seldom address other stormwater management objectives beyond water quality treatment. Since they have an impermeable liner and underdrain, they cannot recharge groundwater. They usually lack enough storage capacity to provide meaningful channel protection.

Typical Retrofit Application

Infiltration retrofits can be located on small, unused portions of a site and consume as little as 2-5% of site area. They are effectively used in narrow linear areas along setbacks or property boundaries. Where soils are acceptable, infiltration can treat runoff in the following retrofit locations:

- **OS-8** Infiltration trenches along margins of small parking lot or use of permeable pavers
- **OS-9** Perforated storm drain pipes to infiltrate street runoff
- **OS-10** Simple disconnection of roof leaders over appropriate soils or use of french drains/dry wells to infiltrate rooftop runoff

- **OS-11** Disconnection of small impervious surfaces
- **OS-12** Permeable pavers in urban hardscapes
- **OS-13** Underground infiltration galleries

Infiltration is seldom used for storage retrofits unless underlying soils have exceptional infiltration capability. It is important to confirm that retrofit soils can support adequate infiltration, since past grading, filling, disturbance, and compaction can greatly alter original soil infiltration qualities. The greatest opportunity for infiltration retrofits exists in sensitive or impacted subwatersheds, where some of the original soil structure may still exist. By contrast, most soils in non-supporting subwatersheds are not likely to be suitable for infiltration. Some regions of the country still have excellent soils that allow for widespread implementation of infiltration retrofits (e.g., glacial tills, sand).

Pollutant Removal by Infiltration Retrofits

Infiltration retrofits utilize several pollutant removal mechanisms including filtering, soil adsorption and transfer to groundwater. Theoretically, nearly all the pollutants that enter an infiltration practice should be removed except for soluble pollutants that travel through groundwater and return downstream. It is important to note that infiltration retrofits **are not** intended to treat sites with high sediment or trash/debris loads, as they will cause the practice to clog and fail.

Very few infiltration practices have been monitored, so only limited pollutant removal data has been published. Designers should therefore regard the infiltration pollutant removal rates shown in Table 1 as an initial estimate until more performance monitoring data becomes available.

Several site-specific and design factors can have a strong influence on infiltration pollutant removal rates (Table 2). As always, removal rates for individual retrofit projects should be adjusted to account for site-specific design factors that can enhance or diminish pollutant removal using the design point method. The most important design factor is the size of the individual retrofit in relation to the target WQv treatment. Pollutant removal rates diminish for under-sized infiltration retrofits; the recommended walkaway volume is about 50% of the target WQv.

Other Stormwater Benefits Provided by Infiltration

Infiltration retrofits are desirable because they confer other stormwater benefits:

Groundwater Recharge: Infiltration of stormwater runoff is the preferred means to provide groundwater recharge within a subwatershed. When designed properly, they can infiltrate the entire runoff reduction or WQv to keep stormwater runoff out of combined sewers.

Channel Protection: While infiltration practices are not specifically designed to store the channel protection volume, their ability to reduce runoff volumes should help protect downstream channels from erosion. If suitable soils are present across a subwatershed, infiltration may be an effective channel protection strategy.

Table 1: Range of Reported Removal Rates for Infiltration Practices			
Pollutant	Low End	Median	High End
Total Suspended Solids	60*	90*	95*
Total Phosphorus	50	65	95
Soluble Phosphorus	55	85	100
Total Nitrogen	0	40	65
Organic Carbon	80	90	95
Total Zinc	65	65	85
Total Copper	60	85	90
Bacteria	25	90	95
Hydrocarbons	85	90	95
Chloride	0	0	0
Trash/Debris	90*	95*	99*
* Adequate pretreatment must be provided to reduce sediment loads to infiltration practices or clogging and practice failure may result See Appendix D for data sources and assumptions used to derive these removal rates Low End and High End are the 25th and 75th quartiles			

Table 2: Design Point Calculation to Estimate Pollutant Removal for Infiltration Retrofits		
Design Factors	X	Points
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Tested infiltration rates between 1.0 and 4.0 in/hr		+ 2
At least two forms of pretreatment prior to infiltration		+ 2
CDA is nearly 100% impervious		+ 1
Off-line design w/ cleanout pipe		+ 1
Underdrain utilized		- 1
Filter fabric used on trench bottom		- 1
CDA more than 1.0 acre		- 1
Soil infiltration rates < 1.0 in/hr or > 4.0 in/hr		- 2
Pervious areas or construction clearing in CDA		- 2
Does not provide full WQv volume		- 3
NET DESIGN SCORE (max of 5 points)		

ST-7	Stormwater Treatment Options	
	SWALES	

Swales utilize the stormwater conveyance system to provide treatment in either storage or on-site retrofit applications. Swales have moderate pollutant removal capability, can reduce runoff volume and increase groundwater recharge. Swales are designed to treat the WQv within an open channel. The three design variants are the dry swale, wet swale, and grass channel.

Dry swales are a linear soil filter system that temporarily stores and then filters the desired WQv (Figure 1). Dry swales are similar to bioretention areas in that they rely on a fabricated soil bed on the bottom of the channel. Existing soils are replaced with a sand/soil mix that meets minimum permeability requirements. Dry swales provide a good environment for filtration, biological uptake, and microbial activity. Stormwater treated by the soil bed flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system is typically created by encasing a perforated pipe within a gravel layer on the bottom of the swale.

Wet swales are linear wetland cells that intercept shallow groundwater to maintain a wetland plant community (Figure 2). Saturated soils support wetland vegetation, which provides an ideal environment for gravitational settling, biological uptake, and microbial activity.

Grass channels are open channels that provide limited water quality treatment using rate-based design criteria. Grass channels reduce flow velocities and increase filtration capacity. Grass channels generally cannot provide the same degree of pollutant removal as dry or wet swales.

All three swale designs provide significantly better water quality treatment than the conventional roadside ditch. Schematics of the dry and wet swale designs are illustrated in Figure 3.

Figure 1: Dry Swale

Figure 2: Wet Swale

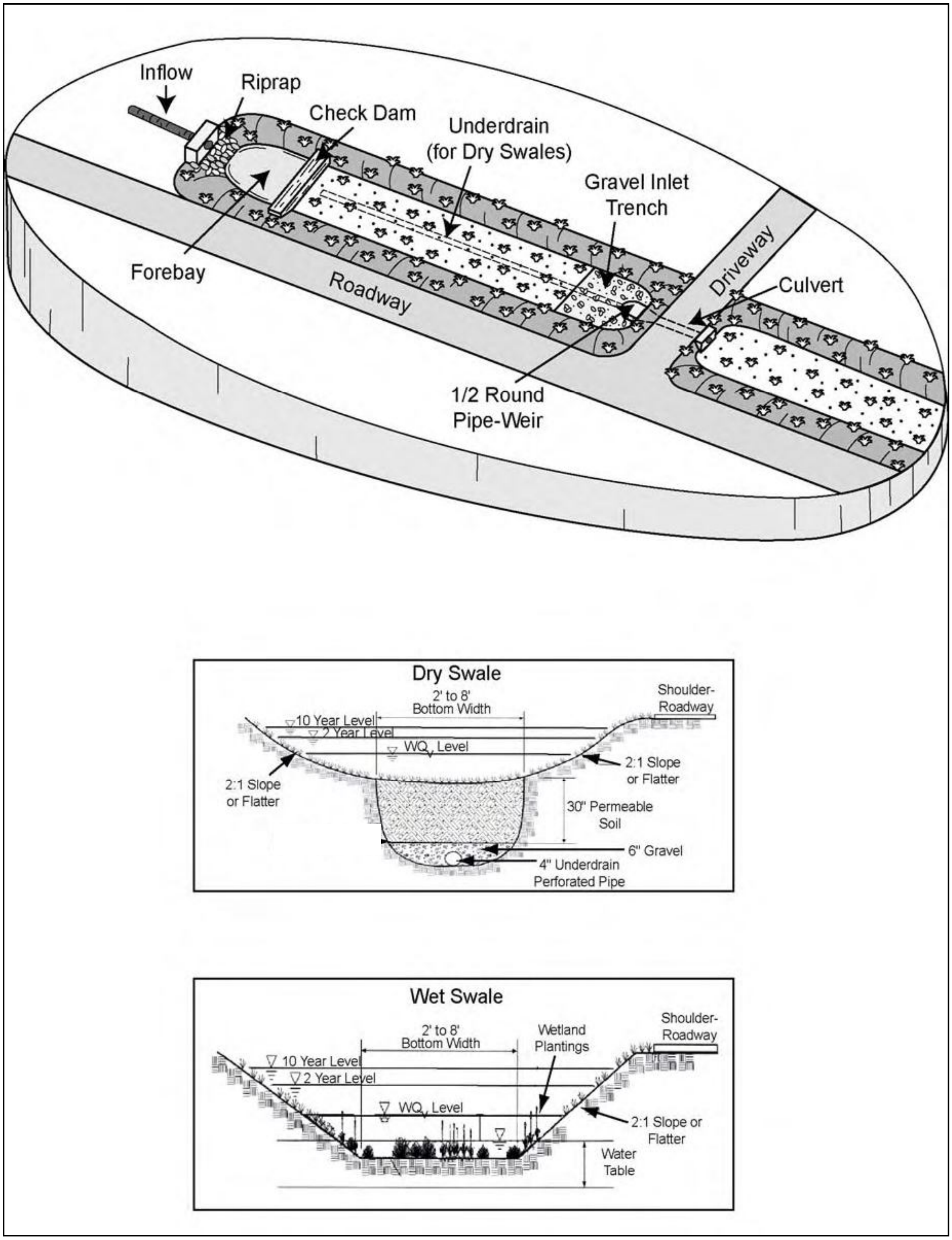


Figure 3: Schematic of a dry and wet swale

Typical Swale Retrofit Application

Most swale retrofits require that an existing open channel be widened, deepened, reduced in gradient, or some combination of all three. Swales are particularly well suited to treat runoff from low and medium density residential streets and small parking lots. Typical retrofit situations where swales can be applied include:

- **SR-4** Install dry swale or grass channel within existing conveyance system
- **OS-8** Install swales along margins of small parking lots
- **OS-9** Install swale retrofit along open section street or convert closed section street into dry swale
- **OS-11** Direct runoff to swale as means to disconnect a small impervious area

Estimating Pollutant Removal Capability of Swale Retrofits

The primary pollutant removal mechanisms operating in swales are settling, filtering infiltration and plant uptake. The reported pollutant removal rates for swales are highly variable. Table 1 shows the range in removal rates for swales that have been specifically designed for stormwater treatment (e.g., dry swales, wet swales and biofilters). Please note that the median removal rates should be cut in half if the proposed retrofit is a grass channel.

Designers may find it difficult to define the expected removal rate for a swale retrofit. Many site conditions and design factors can enhance or diminish their pollutant removal rates (Table 2). A reasonable estimate for each individual swale retrofit can be developed using the design point method. A primary factor influencing swale removal rates is the proportion of the WQv that is actually infiltrated or stored within retrofit treatment cells. A second influential factor is how the retrofit is sized in relation to the target WQv-- the recommended walkaway volume is about 50% of the target WQv.

Table 1: Range of Reported Removal Rates for Swales

Pollutant	Low End	Median	High End
Total Suspended Solids	70	80	90
Total Phosphorus	-15	25	45
Soluble Phosphorus	-95	-40	25
Total Nitrogen	40	55	75
Organic Carbon	55	70	85
Total Zinc	60	70	80
Total Copper	45	65	80
Bacteria	-65	0	25
Hydrocarbons	70	80	90
Chloride	0	0	0
Trash/Debris	0	0	50

See Appendix D for data sources and assumptions used to derive these removal rates
Low End and High End are the 25th and 75th quartiles

Table 2: Design Point Calculation to Estimate Pollutant Removal for Swale Retrofits		
Design Factors	***X***	***Points***
Exceeds target WQv by more than 50%		+ 3
Dry or wet swale design		+ 2
Exceeds target WQv by more than 25%		+ 2
Longitudinal swale slope between 0.5 to 2.0%		+ 1
Velocity within swale < 1 fps during WQ storm		+ 1
Measured soil infiltration rates exceed 1.0 in/hr		+ 1
Multiple cells with pretreatment		+ 1
Off-line design w/ storm bypass		+ 1
Longitudinal swale slope < 0.5% or > 2%		- 1
Measured soil infiltration rates less than 1.0 in/hr		- 1
Swale sideslopes more than 5:1 h:v		- 1
Swale intersects groundwater (except wet swale)		- 1
No pretreatment to the swale or channel		- 1
Swales conveys stormflows up to 10 year storm		- 2
Does not provide full WQv volume		- 2
Grass channel		- 3
NET DESIGN SCORE (max of 5 points)		

Other Stormwater Benefits Provided by Swales

Swales retrofits can provide other stormwater benefits, including:

Groundwater Recharge: Swales can reduce runoff volumes by an average of 40% through infiltration on the swale bottom and across side-slopes, according to Strecker *et al*. (2004). Some research studies have reported as much as 80 to 90% runoff reduction for dry swales that are heavily landscaped with trees and shrubs to promote greater evapotranspiration (Horner *et al.*, 2003).

Channel Protection: While most swales are not designed to provide channel protection storage, the high degree of runoff reduction suggests that they have some potential to protect downstream channels from erosion. It may be possible to capture and detain the entire channel protection volume at small sites.

ST-8	Stormwater Treatment Options **Other Retrofit Treatment**	

This stormwater treatment option includes a diverse group of on-site techniques that capture, store and partially treat rooftop runoff in residential areas and highly urban landscapes, including:

Residential Rooftops

- Rainbarrels
- Rain Gardens
- French Drains/Drywells

Non-Residential Settings

- Cisterns
- Green Rooftops
- Permeable Pavers
- Stormwater Planters

Each rooftop technique has a unique ability to reduce runoff, remove pollutants or recharge groundwater and differs greatly in its design, installation cost and maintenance needs. A full description of each treatment option is provided in the series of fact sheets provided in Appendix F.

Typical Retrofit Applications

Many of these practices are primarily used to treat runoff from individual rooftops (OS-10), but stormwater planters and permeable pavers can also be applied to retrofit small parking lots (OS-8) and urban landscapes/hardscapes (OS-12).

Pollutant Removal Capability

These techniques can provide partial or full treatment of the target WQv, depending on site conditions. The pollutant removal rate for each technique varies greatly, so designers should consult the appropriate fact sheet in Appendix F to get an accurate estimate.

Benefits, Constraints, Concerns and Design, Construction and Maintenance Issues

Taken as a group, these stormwater treatment techniques are suitable for use in small, on-site retrofits and have few site constraints. Individually, each technique has numerous siting, design, and maintenance issues which are described in Appendix F.

Installation Costs for Other Stormwater Retrofits

The installation costs for this group of retrofits are compared in Table 1.

Table 1: Installation Costs for Other Stormwater Retrofits (per cubic foot treated)		
Retrofit Type	**Median Cost**	**Cost Range**
Residential Settings		
Rain Barrels	$ 25.00	$ 12.50 to $ 40.00
Rain Gardens:		
Volunteer Installation	$ 4.00	$ 3.00 to $ 5.00
Professional Installation	$ 7.00	$ 5.00 to $ 10.00
Professional Landscaping	$ 12.00	$ 10.00 to $ 15.00
French Drains/Drywells	$ 12.00	$ 10.50 to $ 13.50
Non-Residential Settings		
Cisterns	$ 15.00	$ 6.00 to $ 25.00
Intensive Green Rooftops	$ 360.00	$ 300.00 to $ 420.00
Extensive Green Rooftops	$ 225.00	$ 144.00 to $ 300.00
Permeable Pavers	$ 120.00	$ 96.00 to $ 144.00
Stormwater Planters	$ 27.00	$ 18.00 to $ 36.00
Rain Gardens	$ 12.00	$ 10.00 to $ 15.00
Note: See Appendix E for documentation and cost assumptions		

Chapter 4: The Search For Storage - Finding Retrofit Opportunities at the Subwatershed Level

The search for storage requires considerable creativity by the retrofit team. The team should possess a practical understanding of hydrology, hydraulics, and stormwater engineering and a knack for sleuthing current infrastructure to envision possibilities for better stormwater treatment. This chapter presents the methods developed by the Center to investigate retrofit potential at the subwatershed level. The basic eight step retrofit process is portrayed in Figure 4.1. This systematic approach is cost effective and can be used for both larger storage retrofits and smaller on-site retrofits. The purpose and tasks associated with each retrofit step are described in Table 4.1.

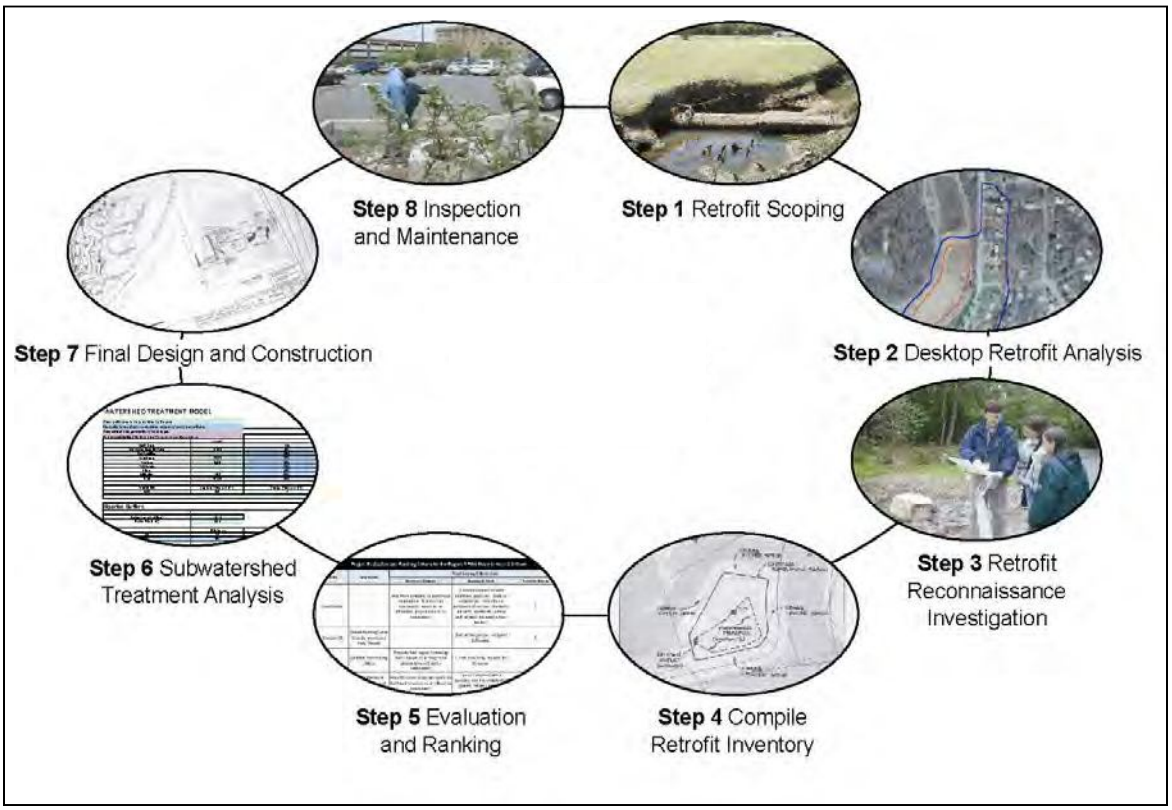


Figure 4.1: The eight steps of stormwater retrofitting

Table 4.1: Purpose of the Eight Steps in the Stormwater Retrofitting Process	
Step and Purpose	**Key Tasks**
Step 1: Retrofit Scoping Refine the retrofit strategy to meet local restoration objectives	• Screen for subwatershed retrofit potential • Review past, current and future stormwater • Define core retrofitting objectives • Translate into minimum performance criteria • Define preferred retrofit treatment options • Scope out retrofit effort needed
Step 2: Desktop Retrofit Analysis Search for potential retrofit sites across the subwatershed	• Secure GIS and other mapping • Conduct desktop search for retrofit sites • Prepare base maps for RRI
Step 3 : Retrofit Reconnaissance Investigation Investigate feasibility of retrofit sites in the field	• Advanced preparation • Evaluate individual sites during RRI • Finalize RRI sheets back in office
Step 4: Compile Retrofit Inventory Develop initial concepts for best retrofit sites	• Complete storage retrofit concept designs • Finalize on-site retrofit delivery methods • Assemble retrofit inventory
Step 5: Retrofit Evaluation and Ranking Choose the most feasible and cost-effective sites	• Neighborhood consultation • Develop retrofit screening criteria • Create retrofit project priority list
Step 6: Subwatershed Treatment Analysis Determine if retrofits can achieve subwatershed restoration objective	• Compute pollutant removal by storage retrofits • Compute pollutant removal by on-site retrofits • Compare against restoration objective
Step 7: Final Design and Construction Assemble design package to lead to successful retrofit construction	• Secure environmental permits • Obtain landowner approval and easements • Perform special engineering studies • Put together final design package • Contract and project management
Step 8: Inspection, Maintenance & Evaluation Ensure retrofits are working properly and achieving subwatershed objectives	• Construction inspection • Retrofit maintenance • Project tracking and monitoring

Step 1: Retrofit Scoping Process

Retrofitting should be fundamentally guided by the specific restoration goals chosen for the subwatershed, so the team should carefully scope out what they want to achieve at the outset. The retrofit scoping process involves six basic tasks:

Task 1. Screen for subwatershed retrofit potential (Optional)
Task 2. Review past, current and future stormwater management
Task 3. Define the core retrofitting objective
Task 4. Translate objectives into minimum retrofit treatment performance criteria

Task 5. Define the preferred methods of stormwater treatment

Task 6. Estimate retrofitting effort needed in the subwatershed

Task 1 Screen Subwatersheds for Retrofit Potential (Optional)

In some cases, the team needs to analyze a large group of subwatersheds to identify the ones with greatest retrofit potential. The team can perform a modified Comparative Subwatershed Analysis (CSA) to screen subwatershed retrofit potential across a larger watershed (see Manual 2). It is relatively easy to screen the most promising subwatersheds with stormwater retrofit potential from a desktop, assuming basic GIS layers are available. Once the watershed has been subdivided into subwatersheds, retrofit screening metrics can be derived to discriminate among all of the subwatersheds. These simple metrics provide important clues about the comparative potential to find either storage or on-site retrofits within a subwatershed (Tables 4.2 and 4.3).

Each screening metric can be weighted and analyzed in a simple spreadsheet to determine the comparative retrofit potential of a group of subwatersheds. Both the screening factors selected and their relative weight will be unique for each watershed, and should be customized to reflect local retrofit objectives. Priority subwatersheds can then be selected based on their individual total scores.

Table 4.2: Subwatershed Metrics to Evaluate Storage Retrofit Potential

Screening Metric	What It Says About Retrofit Potential
Current Impervious Cover	Subwatersheds with moderate IC have greater retrofit potential since they offer a greater range of candidate sites and require less total stormwater storage to meet subwatershed objectives. (% of subwatershed)
Density of Stormwater Ponds	A high pond density indicates strong retrofit potential given the large number of possible sites to employ pond retrofits. (# of ponds per square mile)
Headwater Road Crossings	A high number of headwater road crossings increases potential for installing storage retrofits upstream of road crossings. (# of crossings per stream mile)
Available Area in Stream Corridor	Subwatersheds with more available open area in the stream corridor possess a greater number of potential sites for many types of storage retrofits, including new storage facilities split from outfalls. (acres per stream mile)
Density of Stormwater Outfalls	A high density of stormwater outfalls within a subwatershed indicates greater retrofit potential since every outfall represents a possible storage retrofit site, if flows can be split from the pipe to a down gradient treatment area. (number of mapped outfalls per stream mile)
Publicly Owned Land	Subwatersheds with a high percentage of publicly owned land have greater retrofit potential because publicly owned lands are the preferred location for storage retrofits. (% of subwatershed)
Subwatershed Stream Density	High stream density generally indicates greater retrofit potential since it suggests that more stream corridor is available to locate retrofit practices. (stream miles per square mile)
Large Area of Contiguous Impervious Cover	A high number of large parking lots or other contiguous impervious areas in a subwatershed present more opportunities for storage retrofits. (number of commercial parcels >5 acres per subwatershed)

Table 4.3: Subwatershed Metrics to Evaluate On-site Retrofit Potential	
Screening Metric	**What It Says About Retrofit Potential**
Average Age of Development	The age of development helps to determine the potential for on-site retrofits, since the nature of rooftop connections is associated with the building codes and practices of different eras. (decades)
Publicly Owned Land	Subwatersheds with a high percentage of publicly owned land have greater retrofit potential because publicly owned lands are the preferred location for on-site retrofits. (% of subwatershed)
Medium and Large Lot Residential Land	Subwatersheds with a high proportion of residential land have greater on-site retrofit potential, although this frequently needs to be confirmed by field assessments. (% of subwatershed)
Stormwater Hotspot Density	Subwatersheds with a greater hotspot density are expected to generate higher stormwater pollution loads, and may be targeted for on-site retrofits and pollution prevention practices. (no. of hotspots / square mile)
Industrial Land	Subwatersheds with a high % of industrial land have high on-site retrofit potential, since many industrial operations are already regulated and may need to install on-site retrofits to comply with stormwater permits. (% of subwatershed)
Presence of Combined Sewers	Subwatersheds that are served by combined sewers have greater on-site retrofit potential, since local utilities have a strong interest in reducing the runoff volumes delivered to the system that cause overflows. (presence or absence)
Subwatershed Redevelopment Potential	Subwatersheds undergoing redevelopment present great opportunities to cost effectively incorporate stormwater retrofits as a component of the overall site design and construction. (% of subwatershed)
Active Homeowner Assocation or Watershed Group	Subwatersheds with active groups have an existing network to promote on-site retrofit delivery.

Task 2 Review Past, Current and Future Stormwater Management

The team should understand past, current and future stormwater practices and design criteria within the community to identify retrofit possibilities. The following questions help the team find the best opportunities to treat runoff quality.

- What types of stormwater practices were installed in the subwatershed in the past? Can their performance or function be improved?
- Could ongoing flooding problems or drainage complaints be resolved through retrofitting?
- Are maintenance inspections performed on stormwater infrastructure in the subwatershed? If so, could the effectiveness of existing practices be upgraded through retrofits or maintenance repairs?
- What, if any, municipal stormwater permit requirements could support retrofitting?
- What is the future development potential within the subwatershed? Will future development projects be designed to more stringent stormwater management criteria?
- Are current stormwater sizing criteria and design standards for new development capable of meeting restoration or pollutant reduction goals?

- What are the prospects for achieving additional retrofit coverage through redevelopment and infill development?
- What opportunities exist to incorporate retrofits into future capital projects in the subwatershed?

The answers to these questions help the team understand how to deliver retrofit projects at the subwatershed level.

Task 3 Define Core Retrofitting Objectives for Subwatershed

The team should carefully define their core retrofitting objectives and designate a primary pollutant of concern. In some cases, the objective may have already been developed in the process of preparing a local subwatershed plan. If not, the team may want to:

- Analyze existing stormwater quality monitoring data to identify the pollutant(s) of concern.
- Consult with state water quality agencies to find out which pollutants are causing local water quality impairment.
- Review any pollutant load reduction goals contained in a Total Maximum Daily Loads (TMDL) for the subwatershed, watershed or basin.
- Consult with aquatic ecologists to determine if fishery restoration is a realistic objective.
- Evaluate current and future Impervious Cover Model predictions to set achievable subwatershed restoration objectives, as subwatershed impervious cover can fundamentally constrain retrofitting objectives (Appendix A of Manual 1).
- Assess whether runoff reduction is needed to reduce combined sewer or sanitary sewer overflows. Determine whether retrofits are needed to complement planned stream restoration projects in the subwatershed.
- Review past stream assessments to evaluate stream habitat quality and the possible need for channel protection.

The outcome from this task may be a narrative or numeric description of the restoration objectives chosen for the subwatershed (Table 4.4). The team also designates a pollutant of concern and identifies the type of retrofit storage needed to meet the core subwatershed restoration objective (Table 4.5).

Table 4.4: Examples of Subwatershed Restoration Objectives	
Subwatershed Objective	**Action Required**
Correct Past Mistakes	Address 50% of chronic drainage complaints
Reduce Flood Damage	Reduce incidence of events that inundate structures and roadways. Ensure "no damage" conditions for 50-year storm.
Trap Trash, Debris and Floatables	Capture 90% of trash and debris delivered to storm inlets
Create Wetland/Wildlife Habitat	Create or restore 100 acres of habitat in the subwatershed
Recharge Groundwater	Ensure 70% recharge rate for the first one inch of rainfall across the subwatershed
Reduce Bank Erosion	Reduce Q of channel-forming flow to acceptable shear stress levels
Support Downstream Repairs	Ensure that Q of channel-forming flow does not exceed stream repair design levels at build-out
Reduce Nutrient Loads	Reduce phosphorus load by 25% or to 0.30 pounds/acre/year across the subwatershed
Reduce Bacteria Loads	Reduce bacteria load to allocated levels for stormwater in TMDL
Reduce Metal/Toxin Loads	Provide treatment for 90% of confirmed hotspots

Table 4.5: Stormwater Treatment Needed to Meet Common Retrofit Objectives				
Retrofit Objective	**Stormwater Treatment Model**			
	Water Quality	**Runoff Reduction**	**Channel Protection**	**Flood Control**
Correct Past Mistakes	○	○	◉	●
Reduce Flood Damage	○	○	○	●
Education/Demonstration	●	●	◉	○
Trap Trash and Floatables	◉	●	○	○
Reduce Flows to CSOs	◉	●	○	○
Renovate Stream Corridor	●	○	◉	X
Reduce Pollutant of Concern	●	X	●	X
Reduce Bank Erosion	○	◉	●	○
Support Stream Restoration	●	◉	●	X
Full Watershed Restoration	●	●	◉	X
KEY ● Always ◉ Usually ○ Sometimes X Never				

Table 4.6: Ability to Meet Retrofit Objectives at Various Levels of Impervious Cover

Retrofit Objective	Subwatershed Impervious Cover			
	10 to 25%	25 to 40%	41 to 60%	61 to 100%
Correct Past Mistakes	●	●	⦿	○
Reduce Flood Damage	●	●	⦿	○
Education/Demonstration	●	●	●	●
Trap Trash and Floatables	●	●	⦿	○
Reduce Flows to CSOs	●	●	⦿	⦿
Renovate Stream Corridor	●	●	⦿	○
Reduce Pollutant of Concern	●	●	●	⦿
Reduce Bank Erosion	●	⦿	○	×
Support Stream Restoration	●	⦿	○	×
Full Watershed Restoration	●	⦿	○	×

KEY
● Objective can normally be widely achieved across a subwatershed
⦿ Objective may be feasible, depending on individual reach characteristics
○ Objective can only be achieved in isolated reaches in the subwatershed
× Objective is generally not achievable in the subwatershed

Task 4 Translate Objectives into Minimum Retrofit Treatment Performance Criteria

This task translates restoration objectives into performance criteria to guide future retrofitting efforts. Typically, this means defining a minimum level of treatment needed across a subwatershed to reduce the pollutant of concern to an acceptable level. This may be quantified either as a desired level of pollutant reduction (e.g., 25% total phosphorus reduction) or a target percentage of the subwatershed that will be treated by effective retrofits (e.g., 50% of subwatershed area). The maximum treatment area is often constrained by subwatershed impervious cover (Table 4.6). In most subwatersheds, it is hard to find enough feasible storage retrofits to treat more than 50% of subwatershed area. If the design team seeks a higher treatment percentage, they will need to consider on-site retrofits. The retrofit team may want to consult Table 4.7 to estimate the aggregate WQv storage needed in their subwatershed.

The retrofit team should also establish a minimum WQv storage needed for individual retrofit projects that achieve a minimum removal rate for the pollutant of concern. This is needed to eliminate retrofits that are so under-sized they cannot perform their primary pollutant removal function. The team would "walkaway" from a site when a retrofit falls below this volume or consider an alternative restoration practice. The walkaway volume for most stormwater treatment options ranges from 35 to 50% of the target WQv (see Chapter 3).

Task 5 Define the Preferred Methods of Retrofit Treatment

In this task, the team chooses the preferred stormwater treatment option(s) and retrofit locations for a subwatershed. This is also when the team decides whether to focus on storage retrofits, on-site retrofits, or both. Decisions on which stormwater treatment

Table 4.7: Steps to Determine The Retrofit Water Quality Volume
1. Define Area and Impervious Cover The area and impervious cover for the retrofit site or the subwatershed as a whole can be directly measured. For operational purposes, impervious cover (I) is defined as any area of the site/subwatershed that is not covered by vegetation, and is expressed as a percentage.
2. Compute Subwatershed Runoff Coefficient The volumetric runoff coefficient is defined based on the following equation: Rv = 0.05 + 0.009 (I)
3. Choose Appropriate Water Quality Storm (S) Choose the depth of rainfall associated with the 90% storm from the appropriate rainfall frequency spectrum.   The depth in inches can be converted into a unit area retrofit treatment scaling factor (X) by multiplying the depth (S) by 12, and then multiplying 43,560 square feet. The team may also want to define a smaller minimum walk-away volume for individual sites.
4. Compute Water Quality Volume (WQv) The Water Quality Volume (WQv) expresses the acre feet of runoff that must be treated in an acceptable stormwater retrofit practice, and is computed as: WQv = (Rv)(S)(A) (X)   Where = A = site or subwatershed area in acres
5. Compute Treatment Area Needed Divide the WQv by an assumed depth of retrofit treatment to determine the estimated surface area (in acres) needed for retrofit treatment (usually ranges between 3 and 6 feet).

options to employ are usually based on their comparative ability to remove the pollutant of concern. For example, if the primary restoration objective is to reopen a public beach closed due to high fecal coliform levels, then the team would rely on stormwater practices with high and reliable bacteria removal rates. The team can analyze the more detailed pollutant removal tables provided in Chapter 3 to make an informed choice. Keep in mind that this task is only intended to justify using one treatment option over another when more than one could be used at the site.

Stormwater treatment options also differ in their ability to meet restoration objectives, such as channel protection or runoff reduction. Other key factors in choosing the preferred stormwater treatment options are construction cost, hydrologic benefits and community acceptance. Chapter 3 and Appendix I provided comparative data on stormwater treatment options.

Next, the team must decide whether to search for storage retrofits or a combination of storage and on-site retrofits in the subwatershed. A storage retrofit approach is quicker, less expensive and usually more cost-effective, but may not achieve adequate treatment throughout the subwatershed or meet all restoration objectives. If the team elects to go with a storage retrofit approach, then they should decide which subwatershed locations are worth concentrating on during their field investigations (Chapter 2).
If on-site retrofits are employed, the team will need to choose which general land uses

to target for widespread delivery (e.g., individual neighborhoods, municipal land, stormwater hotspots). Thousands of on-site retrofit opportunities are available in most subwatersheds, so the team needs to focus on areas with the greatest potential project delivery. Publicly owned lands such as municipal buildings, public works yards, schools and parks are often the first target for on-site retrofits, followed by privately owned stormwater hotspots, cooperating institutions or individual neighborhoods.

Task 6 Estimate Retrofitting Effort Needed in the Subwatershed

Once the team agrees on key retrofit scoping issues, it can estimate the staff effort needed to complete a retrofit investigation across the subwatershed. Generally, the effort needed to conduct the desktop analysis steps is driven by subwatershed size, whereas the field and design tasks are driven by the number of retrofit sites assessed. Table 4.8 presents guidance to estimate staff time to conduct various retrofit assessments for a 10-square mile subwatershed.

Step 2: Desktop Retrofit Analysis

In this step, the team searches for potential retrofit locations by completing three office tasks:

- Secure GIS layers and other mapping data
- Conduct a desktop search for retrofit sites
- Prepare the base field maps for the RRI

Task 1 Secure GIS Data and Other Mapping

A watershed-based Geographic Information System (GIS) can be employed in every step of the retrofitting process (Table 4.9). While a GIS is an ideal way to store, organize and evaluate retrofit data, aerial photos or existing paper maps can also be used. Table 4.10 outlines the essential and optional mapping layers needed to support the retrofit process and if they are needed in GIS format. Guidance on how to access individual data layers from federal and state sources can be found in Appendix A of Manual 2.

The most essential GIS layers for a desktop retrofit search are topography, hydrology, and aerial photos. Many of the data layers recommended in Table 4.10 can be derived from other GIS data, or may be available on paper maps.

Table 4.8: Estimated Retrofitting Effort in a 10 Square Mile Subwatershed

Task	Unit	Staff Time
Retrofit Scoping *	Hrs / subwatershed	16
Secure GIS Mapping Layers *	Hrs / subwatershed	40
Retrofit CSA *	Hrs / subwatershed	40
Desktop Search for Retrofit Sites	Hrs / subwatershed	8
Prepare Base Maps for the RRI *	Hrs / subwatershed	24
Advance Field Preparation *	Hrs / subwatershed	8
Conducting the RRI	Hrs / site	2 (for storage retrofit) 1 (for on-site retrofit)
Project concept design	Hrs / site	8 (for storage retrofit) 2 (for on-site retrofit)
Assemble inventory	Hrs / site	2
Project ranking and evaluation	Hrs / subwatershed	40
Subwatershed treatment analysis	Hrs / subwatershed	60

* When conducting investigations across several subwatersheds within a watershed, cost savings may be realized for these tasks as some or all of the effort may be applicable to all subwatersheds.

Table 4.9: How Watershed GIS is Used in Each Step of the Stormwater Retrofit Process

Step	Description	Purpose
1	Retrofit Scoping	Screen subwatersheds with best retrofit potential using comparative retrofit metrics.
2	Desktop Retrofit Analysis	Search for potential retrofit sites and prepare field maps for the Retrofit Reconnaissance Investigation.
3	Retrofit Reconnaissance Investigation	Confirm drainage and impervious area to sites in concept design and investigate retrofit feasibility factors.
4.	Retrofit Inventory	Store key data on concept designs for best retrofit sites.
5.	Retrofit Evaluation and Ranking	Develop project locator map and develop metrics for project ranking.
6.	Subwatershed Treatment Analysis	Develop input parameters for subwatershed treatment analysis modeling exercise.
7.	Final Design and Construction	Maintain and track retrofit project files with design computations, technical support, permit approvals, as-built plans and inspection records.
8.	Inspection, Maintenance and Evaluation	Track status of retrofit construction, inspection and maintenance in the subwatershed.

Table 4.10: Mapping Layers Recommended for Retrofitting		
Mapping Data	**Data Status**	**Needed as GIS?**
Hydrogeomorphic Features		
Topography 5-foot 2-foot 1-foot or finer	 Essential Nice to have Nice to have	 Essential Nice to have Nice to have
Hydrology	Essential	Essential
Wetlands	Essential	Recommended
100-year floodplain	Essential	Recommended
Soils	Essential	Recommended
Boundaries		
Watershed / subwatershed boundaries	Essential	Essential
Parcel boundaries	Essential	Recommended
Municipal boundaries	Recommended	Recommended
Land Use and Land Cover		
Aerial photos	Essential	Essential
Land use / land cover	Essential	Essential
Zoning	Nice to have	Nice to have
Roads	Recommended	Recommended
Buildings	Recommended	Recommended
Parking lots	Recommended	Recommended
Driveways	Recommended	Recommended
Sidewalks	Recommended	Recommended
Turf cover	Recommended	Recommended
Forest cover	Recommended	Recommended
Utilities		
Sanitary sewer lines	Essential	Nice to have
Storm drain network	Essential	Nice to have
Stormwater practices	Recommended	Nice to have
Stormwater outfalls	Recommended	Nice to have
Combined sewers	Recommended	Nice to have
Other utilities	Essential	Nice to have
Note: Other mapping layers might be needed in certain subwatersheds: conservation areas and easements; geology and karst areas; hazardous waste/materials sites; impaired stream segments; permitted NPDES dischargers; rare, threatened or endangered species; stream monitoring stations; underground storage tanks		

Task 2 Conduct a Desktop Search for Retrofit Sites

The team rapidly searches and screens potential retrofit sites in this task to save time in the field. In practice, as much as 3-10% of subwatershed area may be needed to install retrofit practices. Further, this land must be located in the right place and be controlled by the right landowners. These land requirements would seem to be unattainable in most subwatersheds. In reality, many excellent retrofit opportunities can be discovered through detailed map work, given a practiced eye and some imagination. The simple desktop search relies on a visual inspection of recent aerial photography.

A more systematic search for storage retrofit sites is always recommended when subwatershed GIS data are available. The search criteria outlined in Table 4.11 can be used to screen down to a manageable list of potential sites. While GIS is seldom used to search for individual on-site retrofits, it can help identify general subwatershed locations where they are most feasible. Potential on-site retrofit sites can be found by analyzing prior USSR surveys conducted for the subwatershed. Table 4.12 describes the useful on-site retrofit information that can be gleaned from USSR data.

Table 4.11: Desktop Search Criteria for Different Retrofits

Retrofit Location	What to Look For
SR-1: Existing Pond	Evaluate stormwater layer to find existing stormwater ponds with a contributing drainage area greater than 5 acres *or* Superimpose topography, drainage layers and aerial photos to identify low points in the drainage network where dry ponds may exist.
SR-2: Roadway Culvert	Superimpose topography and headwater stream layers (zero, first and second order) over the local and state road network to identify road crossings.
SR-3: Below Outfall	Superimpose publicly-owned stream corridor land parcels at least two acres in area with storm drain outfalls with a diameter greater than 12 inches and less than 60 inches.
SR-4: Conveyance System	Superimpose ditch lines, zero-order streams, conveyance easements or open channels with open land adjacent to the drainage network
SR-5: Transport Right-of-Way	Compare local, state or federal highway right-of-way layers against the stream or drainage network to identify open spaces one acre or greater *or* review highway agency GIS for existing stormwater infrastructure or treatment practices suitable for retrofitting.
SR-6: Large Parking Lot	Match large contiguous parking areas/rooftops greater than 5 acres in size with adjacent open land in public or institutional ownership, or owned by the same landowner.
OS-7: Hotspot Operation	Review land use maps to identify commercial, industrial, or municipal land uses *or* search permit databases to identify industrial operations that hold stormwater permits.
OS-8: Small Parking Lot	Search for parking lots less than five acres in size that are municipally or institutionally owned.
OS-9: Individual Street	Screen for streets that meet street retrofit feasibility criteria, such as slope, right-of-way width, open section drainage, presence/absence of sidewalks and parking lanes.
OS-10: Individual Rooftop	Superimpose property ownership layers with aerial photos or planimetric data to locate large municipal, institutional, commercial or industrial buildings that may be assessed for demonstration rooftop retrofits *or* look for clusters of building permit data that indicates areas experiencing active redevelopment
OS-11: Little Retrofit	A desktop search is not helpful in finding specific locations for little retrofits, although a GIS can help find tax reverted vacant lots and publicly owned parcels, such as parks, schools, recreation centers to investigate in the field.
OS-12: Landscape/ Hardscapes	A desktop search is not helpful in finding specific locations for landscaping and hardscaping retrofits although it can find the general public spaces with high exposure and outdoor amenities, such as parks, schools, central business districts, spaces etc.
OS-13: Underground	A desktop search is not helpful in finding specific locations for underground retrofits, although storm sewer and utility maps are essential for field investigations.

Table 4.12: How the USSR Helps Find On-site Retrofits

Neighborhood Source Assessment
- Examines the percentage of homes with connected rooftops, and other feasibility factors relating to on-site stormwater retrofits
- Evaluates potential storage retrofits of existing stormwater ponds in common areas

Hotspot Site Investigation
- Rates the severity of each hotspot with regard to its potential to generate stormwater runoff or illicit discharges
- Examines the feasibility of on-site storm water retrofits

Pervious Area Assessment
- Evaluates retrofit potential within large parcels of open land (2 acres or greater)

Streets and Storm Drain Analysis
- Ranks the severity of pollutant accumulation on roads and within storm drain systems, and the potential for street sweeping and storm drain cleanouts
- Assesses parking areas for on-site retrofit potential

Task 3 Prepare the Base Field Maps for the RRI

Field maps are needed to conduct the Retrofit Reconnaissance Investigation (RRI). The level of mapping detail is largely determined by available data and preferences of the field crew. The basic purpose of a field map is to orient field crews about where they are in a subwatershed, help them accurately record findings, and record basic topographic and site data.

The base field map should include aerial photography, topography (minimum of 5-foot contours) and hydrology. The map should also show candidate storage retrofit sites and their corresponding drainage areas. Some teams may also add the existing storm drain network and stormwater practices to the base map to make field investigations easier.

A maximum map scale of 1:2,400 is generally recommended for the base map (1” = 200’). Map scales greater than 1:6,000 (1” = 500’) make it hard to find smaller retrofits, key ditch lines and first order streams. Base maps should contain a standard map scale with scaleable intervals (e.g., 25 feet, 50 feet, 100 feet) so distances and areas can be easily determined in the field (Figure 4.2).

It may be worth taking other maps into the field for reference purposes; in particular, land use, wetland, property ownership or utility maps can reveal possible site constraints. While these layers could be added to the base map, they tend to clutter it and make it hard to read. The crew can

Figure 4.2: This sample base map includes aerial photography, 5-foot contours, hydrology, and locations of sites to be assessed.

always analyze these maps after the RRI is done to assess individual retrofit feasibly.

Step 3: The Retrofit Reconnaissance Investigation

The RRI is a rapid field assessment of potential storage and on-site retrofit sites conducted across a subwatershed. The purpose of the RRI is to verify the feasibility of candidate sites and to produce information to support initial concept designs. The RRI involves a careful assessment of site-specific information to determine if a retrofit will actually work at a specific site. Three tasks are needed to complete an RRI:

1. Advance preparation in the office
2. Evaluate individual retrofit sites using RRI form
3. Finalize RRI forms back in the office

Task 1 Advanced Preparation

The retrofit team leader is responsible for gathering the equipment and materials needed for field work, as outlined in Table 4.13. The equipment is used to either document a retrofit site (e.g., GPS unit and digital camera) or assess basic site constraints (e.g., measuring tape, pocket rod, soil auger, and manhole puller). Several dozen blank copies of the RRI field form should be copied on three-hole paper and organized into a three-ring binder (see Appendix A for a blank RRI form). The RRI form can also be entered into a hand-held data storage device.

A retrofit field guide summarizes subwatershed retrofit objectives, sizing rules, standard setbacks, wetland indicators and other information to assist the crew. The level of detail provided in the field guide is calibrated to the retrofit experience of the field crews. Experienced crews generally need little guidance, whereas less experienced crews may need more consistent information on retrofit options. The guide ensures that all crews take a similar retrofitting approach – looking for specific types of retrofits per the subwatershed objectives, following the same sizing rules, etc. A template for customizing a retrofit field guide for an individual watershed can be found in Appendix A

Table 4.13: Getting Ready for the RRI

Equipment	Base Map
• Clipboards and pencils • GPS unit • Digital camera • Scale and pocket calculator • 100-foot measuring tape • Pocket rod or local level • Soil auger • Manhole puller, tennis ball • Safety gear (cell phone, first aid kit, etc.)	• Aerial photos • Topography (5-foot contours) • Hydrology • Storm drain network • Existing stormwater practices • Street names • Sites to be assessed and contributing drainage areas
Materials	**Supplementary Maps (If Available)**
• Field forms • Retrofit field guide • Authorization letters • Contact numbers for emergency assistance • Photo IDs and business cards	• Road map • Land use • Wetlands • Property ownership • Utility maps (if not available as GIS)

Authorization letters are recommended if crews are assessing sites in or near private property (Figure 4.3). The letters should be printed on local government letterhead and include the following information:

- Name and contact information of someone who can be contacted to answer questions about the project
- Purpose of the inventory and explanation of what the field crew is doing
- Dates and times that the field work will be conducted
- Company and names of staff conducting the field work

It is a good idea to mail copies of the authorization letter to property owners in advance of the field work. Field crews should carry several copies of the letter to give to suspicious residents, and remember to leave a copy on the windshield of field cars. The crew should be supplied with a list of emergency contact numbers to report any leaks, spills, or other water quality problems they encounter to the appropriate local authorities (Figure 4.3).

A retrofit inventory crew normally consists of two people who can visit from 10 to 15 sites each day. Typically, one member of the field team is responsible for completing the RRI form, while the other takes digital photographs and generates GPS points. Both crew members should work together to investigate the site and to brainstorm potential retrofit concepts. Ideally, at least one crew member should have prior retrofitting experience or be well versed in stormwater engineering. The second crew member should have a basic understanding of hydrology, subwatershed retrofit objectives, and the types of plumbing indicators to look for at a site. Since retrofitting requires creativity, consider mixing field crews. For example, pairing an engineer with a biologist or a landscape architect may result in a retrofit that achieves stormwater treatment goals, but is also more sensitive to biological impacts and native vegetation. The crew leader should arrange for an orientation before going out in the field to ensure crews:

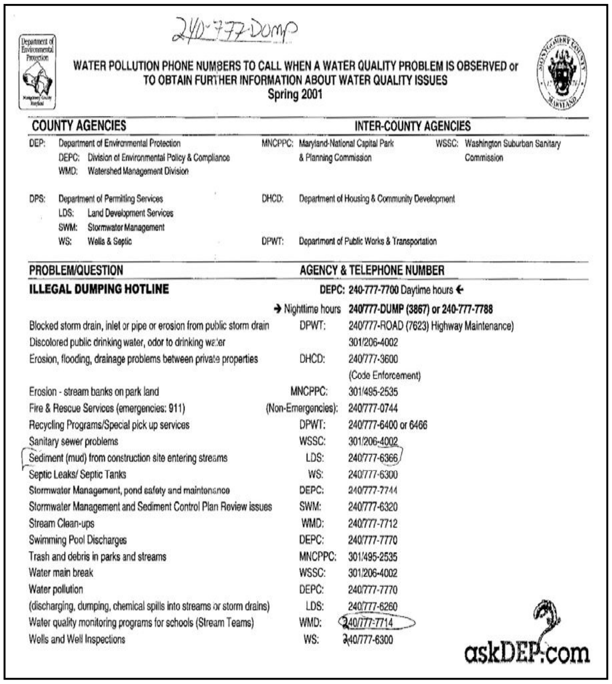
- Understand overall retrofit objectives and the preferred methods of stormwater treatment
- Agree on how to complete the RRI form and properly assign site IDs
- Understand the symbols used on the base maps
- Know who to call in case of emergencies.

Preliminary routes can be planned for the subwatershed to visit the candidate retrofit sites. Well-planned routes will help maximize efforts, but flexibility is also important. Field conditions are often different than expected and new retrofit opportunities may be discovered in the field that were not identified in the office.

Task 2 Evaluate Individual Retrofit Sites Using RRI Form

The crew completes the seven parts of the RRI form at each individual retrofit site:

1. Header Information
2. Site Description
3. Drainage Area to Proposed Retrofit
4. Existing Stormwater Management
5. Proposed Retrofit
6. Site Constraints
7. Sketch and Notes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Department of Environmental Protection

WATER POLLUTION PHONE NUMBERS TO CALL WHEN A WATER QUALITY PROBLEM IS OBSERVED or TO OBTAIN FURTHER INFORMATION ABOUT WATER QUALITY ISSUES
Spring 2001

COUNTY AGENCIES

DEP: Department of Environmental Protection
DEPC: Division of Environmental Policy & Compliance
WMD: Watershed Management Division

DPS: Department of Permitting Services
LDS: Land Development Services
SWM: Stormwater Management
WS: Wells & Septic

INTER-COUNTY AGENCIES

MNCPPC: Maryland-National Capital Park & Planning Commission
WSSC: Washington Suburban Sanitary Commission
DHCD: Department of Housing & Community Development
DPWT: Department of Public Works & Transportation

PROBLEM/QUESTION	AGENCY & TELEPHONE NUMBER	
ILLEGAL DUMPING HOTLINE	**DEPC:**	**240-777-7700** Daytime hours
	Nighttime hours	**240/777-DUMP (3867) or 240-777-7788**
Blocked storm drain, inlet or pipe or erosion from public storm drain	DPWT:	240/777-ROAD (7623) Highway Maintenance)
Discolored public drinking water, odor to drinking water		301/206-4002
Erosion, flooding, drainage problems between private properties	DHCD:	240/777-3600 (Code Enforcement)
Erosion - stream banks on park land	MNCPPC:	301/495-2535
Fire & Rescue Services (emergencies: 911)	(Non-Emergencies):	240/777-0744
Recycling Programs/Special pick up services	DPWT:	240/777-6400 or 6466
Sanitary sewer problems	WSSC:	301/206-4002
Sediment (mud) from construction site entering streams	LDS:	240/777-6366
Septic Leaks/ Septic Tanks	WS:	240/777-6300
Stormwater Management, pond safety and maintenance	DEPC:	240/777-7744
Stormwater Management and Sediment Control Plan Review issues	SWM:	240/777-6320
Stream Clean-ups	WMD:	240/777-7712
Swimming Pool Discharges	DEPC:	240/777-7770
Trash and debris in parks and streams	MNCPPC:	301/495-2535
Water main break	WSSC:	301/206-4002
Water pollution	DEPC:	240/777-7770
(discharging, dumping, chemical spills into streams or storm drains)	LDS:	240/777-6260
Water quality monitoring programs for schools (Stream Teams)	WMD:	240/777-7714
Wells and Well Inspections	WS:	240/777-6300

askDEP.com


Westchester gov.com

Andrew J. Spano
County Executive

Soil and Water
Conservation District

Stephen Coleman
Chair

June 13, 2006

To Bronx River Watershed Landowners and Others:

The Bronx River Watershed Coalition, comprised of representatives of municipalities, state agencies and not-for-profit organizations and administered by the Westchester County Department of Planning and Soil and Water Conservation District, has partnered with the Center for Watershed Protection to conduct upland assessments and other fieldwork in the Bronx River watershed. The goal of these assessments is to identify priority restoration projects in the watershed. Once projects are identified, we will work cooperatively and assist landowners and any other appropriate entities to improve water quality and fish and wildlife habitats in the watershed.

This letter is to notify you that fieldwork for this endeavor will be conducted between 8:00 a.m. and 6:00 p.m. from June 13, 2006 through June 14, 2006. Field crews will conduct as much of the assessments as possible from their cars and will make every effort to avoid private property.

If you have any questions, please contact John Smith with the Westchester County Department of Planning/Soil and Water Conservation District at (123) 456-789 or john.smith@localgov.com.

Thank you for your assistance.

Sincerely,

Bronx River Watershed Coalition and Center for Watershed Protection

Figure 4.3: List of Emergency Contact Numbers (left) and Sample Authorization Letter (right)

An RRI form should be filled out for every candidate retrofit site visited, even if it appears infeasible. The next section provides guidance on how to complete each part of the RRI form.

Task 2a: Complete Header Information

Upon arrival at a candidate site, the retrofit crew documents some basic background information, such as:

- The name of the watershed, subwatershed, and the unique site ID number
- Date the site was visited and names of crew conducting the investigation
- Photographs taken at the site, including the specific camera used and the numbers of photographs taken
- Site coordinates, the specific GPS unit used to take them, and landmarks (LMK).

As a general convention, the unique site ID should reflect the subwatershed in which the retrofit is located, and indicate the retrofit location type (e.g., SR-3). An example of unique site ID nomenclature guidance is provided in Figure 4.4. Some crew leaders like to assign a unique site ID number prior to going into the field. If ID numbers are pre-assigned, the crew should be given a range of unassigned numbers to record any unexpected retrofit opportunities encountered in the field. If a GPS unit is unavailable, the site location should be estimated and marked on the base map.

Bronx River Watershed Plan Field Investigations
Unique Site ID Nomenclature Guidance

Unique Site ID = Subwatershed Acronym — Investigation Acronym Sequential Number

Subwatershed Name	Subwatershed Acronym
White Plains Reservoirs	WPR
Kensico Reservoir	KR
Manhattan Park Brook	MP
Davis Brook	DB
Clove Brook	CB
Bronx River Middle Direct Drainage	BRM
Bronx River Lower Direct Drainage	BRL
Bronx River Upper Direct Drainage	BRU
Sprain Brook	SB
Grassy Sprain Brook	GSB
Grassy Sprain Brook Direct Drainage	GSD
Hartsdale Brook	HB
Fox Meadow Brook	FMB
Fulton Brook	FB
Troublesome Brook	TB

Investigation Type	Acronym
Hotspot Site Investigation	H
Neighborhood Source Assessment	N
Pervious Area Assessment	P
Retrofit Reconnaissance Investigation	R

Sequential Numbering begins at "1" for each subwatershed

Examples:
MPB-R1; MPB-R2; MPB-R3; MPB-R4...
HB-R1; HB-R2; HB-R3; HB-R4...

Figure 4.4: An example of unique site ID nomenclature guidance provided to retrofit teams in advance of field work.

<u>Task 2b: Describe the Site</u>

The retrofit crew then takes a few moments to generally describe the proposed retrofit site, including:

- The street address or name of the adjacent business or property owner.
- Whether the property is publicly or privately owned.
- The approximate location of the proposed storage or on-site retrofit

The crew then estimates the available treatment area for the footprint of the retrofit as defined by the largest contiguous unutilized area that has:

- No surface indicators of underground utilities
- No mature forests or wetlands
- Standard setback distances to structures, roads or shorelines

The crew estimates the area in acres (or square feet) either by pacing or drawing a rough footprint on the base map and scaling approximate dimensions, using common area formulas for rectangles, triangles, or circles. More accurate estimates can be generated using a planimeter back in the office.

<u>Task 2c: Evaluate Drainage Area and Plumbing to Proposed Retrofit</u>

The crew then delineates the drainage area to the proposed retrofit site and estimates its total area and impervious cover. Although boundaries can be hard to define, crews need to confirm the drainage area to estimate the target storage volume to size the retrofit. If possible, the crew can delineate the drainage area for larger storage retrofits before going out into the field.

In some cases, maps are not adequate to delineate drainage boundaries, so the crew will need to investigate the drainage area in the field. This entails walking or driving around the site and observing drainage features that define its boundaries. The crew should begin at the proposed retrofit site and move upstream following common indicators of stormwater plumbing such as open channels, curbs and gutters, storm drain inlets, manholes, outfalls, evidence of overland flow, and surface topography (Figure 4.5). The crew then marks the projected drainage boundaries on the field map using topography as a guide. Once the boundaries are established, drainage area may be roughly estimated using a scale. Next, the crew estimates the impervious cover for the retrofit drainage area. This can be done in the office using planimetric GIS data, aerial photography, or average land use/impervious cover relationship (provided in the field guide in Appendix A).

The drainage area investigation for on-site retrofits must be completed in the field and is basically a micro version of the process done for storage retrofits (Figure 4.6). The crew walks the site in an up-gradient direction to look for rooftop drainage, downspouts, curb cuts, and drainage divides. Subtle grades can be deceiving, so the crew may want to roll a tennis ball to determine probable flow paths. The estimated drainage boundaries to the proposed on-site retrofit can be marked on the RRI field form. The area can be estimated by pacing or a tape measure. In addition, the crew should make a visual estimate of impervious cover for the contributing drainage area.

The crew then investigates existing plumbing at the site to look for retrofit opportunities. Crews should look for key stormwater infrastructure indicators to sketch out the existing drainage patterns at the site. The job is much easier if as-built plans are available for the site (Figure 4.7). Each storage and on-site retrofit location has different plumbing. Tables 4.14 and 4.15 provide some tips on what to look for in the field at each retrofit location.

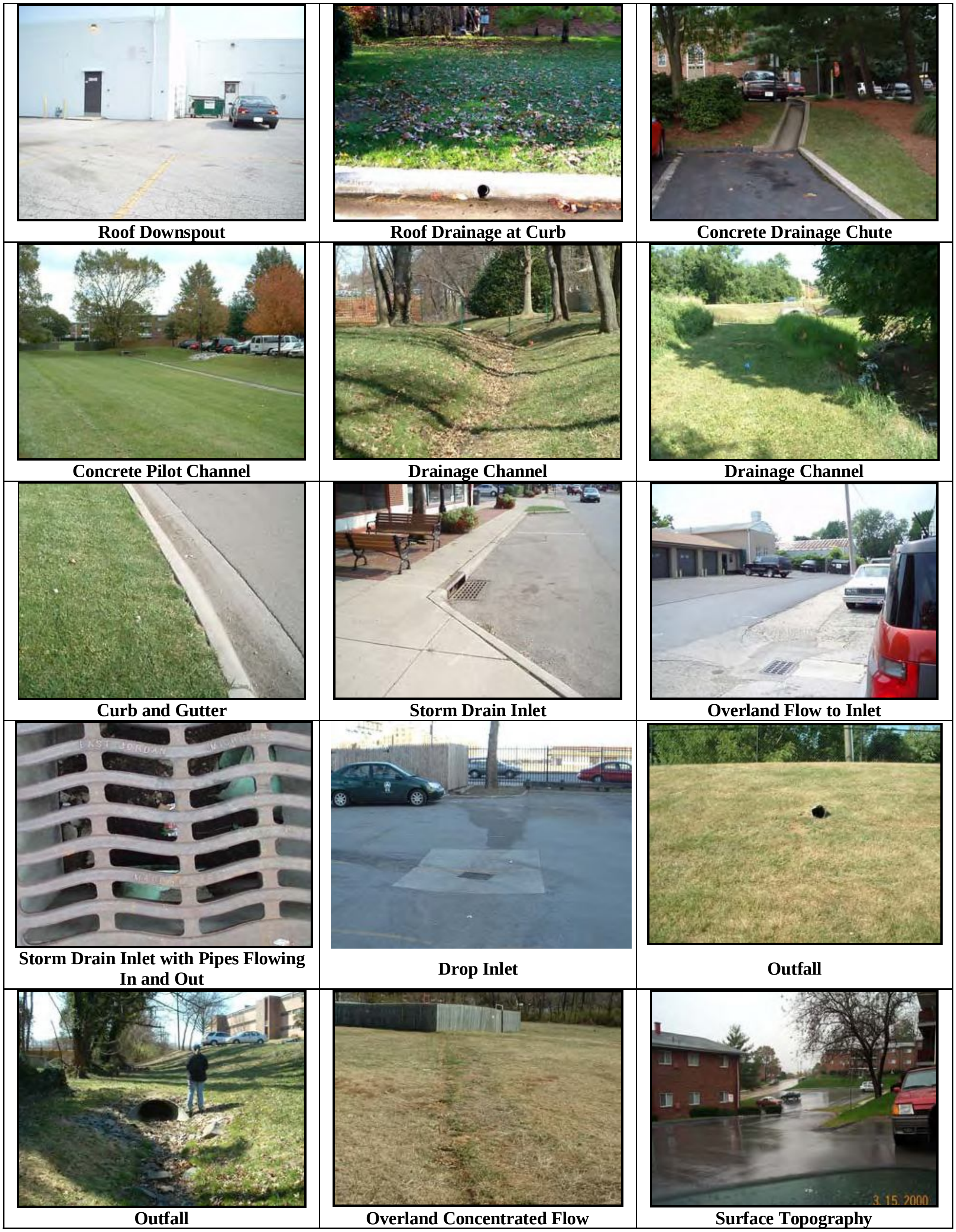


Figure 4.5: Examples of Stormwater Infrastructure Indicators


The on-site investigation starts at this curb cut, which allows runoff to flow down a hillside, eventually causing a headcut discovered during a USA.


The field team determines that there is a drainage divide near the garage in the background. The curb cut is in the center of the photo, near the tree.


Runoff from the rooftop is within the drainage area.


Staff assumes the drainage divide in the other direction is near the buildings in the background.


A drainage divide is identified near the bench.


At first glance, the roof downspouts appear to be connected to an underground storm drain system.


Further investigation reveals the weephole at the curb. The rooftop for this building is within the drainage area.


Staff continue around the building to a parking lot. The drainage divide is identified near the red car.


Staff documents the drainage area to the curb cut.

Figure 4.6: Investigating the drainage area at an apartment complex

Figure 4.7: While comparing an existing stormwater treatment practice to the original plans, the retrofit team realizes that the trash rack was never installed.

Table 4.14: What to Look for When Investigating Storage Retrofit Locations
SR-1: Existing Pond
• Check the condition and elevation of pond inlet(s), internal flow path, outlet, riser and emergency spillway. Check the condition of pond outlet to determine if it is damaged or prone to clogging. Look for excessive sediment deposition, chronic maintenance problems, and woody growth. • Walk above and below the pond to look for possible headwater effects and scour problems to correct, and verify the drainage area. • Decide which retrofit strategy to use: excavate pond bottom, raise embankment, steal flood control storage, modify the riser, improve internal design geometry or add forebay.
SR-2: Above Roadway Culvert
• Evaluate the culverts alignment and invert elevation in relation to the stream, its diameter, material and condition, and potential to create a hydraulic jump. Note any sediment deposition. • Estimate the potential storage volume available upstream using prism method. Get a quick sense of whether the floodplain soils are suitable for excavation to get additional storage, Record the presence of any upstream wetlands, mature forest cover or underground utilities. • Evaluate downstream conditions – Measure the vertical distance from the culvert invert to the stream bed, estimate the rate of flow over the culvert lip, look for scour holes, and look for any flood prone structures in the floodplain.
SR-3: Below Outfall
• Determine whether or not a flow splitter is needed to direct runoff for treatment. • Record the size, diameter, material and condition of both the storm drain pipe and outfall. • Measure the vertical distance between the elevation of the outfall invert, the stream bottom and the top of bank. • Define available treatment area below either side of the proposed split and then establish the point where split flows will enter proposed treatment area. Get a sense of soil conditions and depth to water table. • Look for the best place to bring treated flows back into the stream.
SR-4: In the Conveyance System
• Evaluate channel conditions, including slope, depth, cross-section, soil conditions, vegetative cover, roughness, and signs that it is over-capacity. • Evaluate adjacent treatment potential to the right or left of the channel, including available width, indicators of utilities, potential access points, turf areas in depressions, and adjacent land uses. • Walk several hundred feet in a downstream direction to get a sense of where the channel transforms into a perennial stream, looking for signs of perennial flow, wetlands, and advancing knickpoints.
SR-5: In Transport Right-of-Way
• Check to see whether the highway has open or closed drainage and try to delineate the upstream drainage divide (generally smaller ditches and smaller diameter pipes are preferred). • Sketch out the contributing drainage area and flow path and compare against highway design drawings. • Look for obvious depressions in a down gradient direction that can provide treatment without major excavation. • Ensure that space is available to account for standard highway safety setbacks. • Measure the hydraulic head available for stormwater treatment.
SR-6: Large Parking Lot
• Confirm the size and use of the parking lot. • Assess parking lot grade and sketch the existing plumbing. • Estimate the boundaries of the treatment area. • Evaluate head and conduct a cursory inspection of soil conditions. • Determine if a flow splitter is needed to direct stormwater into the proposed treatment area.

Table 4.15: What to Look for When Investigating On-Site Retrofit Locations
OS-7: Hotspot Operation
• Define the hotspot generating area (HGA) • Evaluate pollution prevention practices • Evaluate hotspot connection to public storm drain system • Define the contributing drainage area to the hotspot generating area
OS-8: Small Parking Lot
• Confirm the size and use of the parking lot • Eyeball parking lot grade and subdivide into smaller drainage units • Evaluate each on-site treatment area for available space • Determine how the treatment area can be reconnected to the existing storm drain system
OS-9: Individual Street
• Investigate existing street conditions, current uses of the right-of-way/front yards, and the location and elevation of the downstream discharge point of entry into storm drain system • If open section drainage, note channel characteristics, utility conflicts, and distance between driveway culverts • If closed section drainage, note locations and characteristics of all storm drain inlets and catch basins
OS-10: Individual Rooftop
• Talk to homeowners to gauge their willingness, retrofit preferences and past home drainage issues • Evaluate general rooftop conditions in the neighborhood and estimate the contributing roof area to a typical roof leader • Measure the length of the flow path from the roof across pervious areas • Use screwdriver or soil auger to get a sense of lawn compaction and soil quality
OS-11: Little Retrofits
• Check to see if the impervious area is really needed • Walk in a down-gradient direction and follow the flow path from the impervious area to the storm drain or channel system • Find a place where sheetflow can be split or otherwise diverted into a pervious area for treatment • Check to see if there is runon to adjacent impervious area (look for evidence of erosion)
OS-12: Landscape – Hardscape
• Look for opportunities to eliminate impervious areas, to treat rooftop runoff and to expand existing tree pits • Ensure sidewalks and plaza areas are sloped towards treatment areas • Compare the surface area delivering runoff to the surface area of the planting area • Determine where treatment areas will overflow • Note potential conflicts with pedestrian traffic and access
OS-13: Underground
• Look for indicators of underground utilities • Pop any manholes or grates to determine the invert elevation and diameter of the storm drain pipe that will accept runoff from the underground treatment area

Task 3: Size the Proposed Retrofit

At this point, the crew considers how to translate subwatershed objectives into a retrofit design for the site and collect information needed for retrofit ranking later on. This involves computing the target and actual storage volumes at the proposed retrofit site and choosing the best stormwater option.

Task 3a. Compute the Retrofit Storage Volume

The crew estimates the target storage volume needed for the retrofit site established earlier during retrofit scoping – water quality, runoff reduction, or channel protection. The normal target for water quality is to capture and treat the 90% storm, as defined by the local rainfall frequency spectrum (see Chapter 1). The target storage volume is computed as a standard rainfall depth across the drainage area, using the following simple equation:

$V_t = P/12 * Rv * DA$

Where:
V_t = Target storage volume (acre feet)
P = Target rainfall depth (in inches for the 90% storm)
Rv = Runoff Coefficient = 0.05 + 0.009(IC)
DA = Drainage Area (acres)
12 = Conversion factor (inches to feet)

If channel protection is a main concern, the basic goal will be to provide 24 hours of extended detention for the runoff generated from the 1-year 24-hour design storm. As a rule of thumb, the target storage capacity for channel protection is about 60% of the one-year storm runoff volume. The following equation can be used to estimate target storage for channel protection:

$V_t = P/12 * IC/100 * DA * 0.6$

Where:
V_t = Target storage volume (acre feet)
P = One-year 24-hour storm depth (inches)
IC = Impervious Cover (%)
DA = Drainage Area (acres)
12 = Conversion factor (inches to feet)
0.6 = Pond routing factor

<u>Task 3b. Compute Available Retrofit Storage</u>

The crew then estimates how much storage volume or surface area is actually available at the retrofit site. To compute available storage, the retrofit crew should revisit its earlier estimate of available treatment area (i.e., the retrofit footprint drawn on the field map). The crew then determines the maximum depth of the proposed retrofit. The maximum depth is normally set by the elevation of the storm drain or channel that the retrofit will discharge to as well as the average depth for the stormwater treatment option employed (Table 4.16). For ponds and wetlands, the retrofit crew may then use the following equation to estimate available storage:

$V_{av} = 2/3 * d * SA$

Where:
V_{av} = Available storage at the site (acre-feet)
d = Estimated max depth (feet)
SA = Surface area of the facility (acres)
2/3 = average volume factor

Available storage can also be estimated based on the typical surface area or depth requirements of different stormwater treatment options (Table 4.16). These simple rules assume treatment of a one inch rainfall and are used to quickly gain a sense of the surface area needed for water quality treatment.

<u>Task 3c. Choose the Best Treatment Option</u>

The crew concludes by prescribing the best combination of stormwater treatment options for the retrofit site that maximizes removal of the pollutant of concern, minimizes construction cost and addresses major site constraints (Figures 4.8 and 4.9). More guidance on stormwater treatment options can be found in Chapter 3 and Appendix I.

Task 4: Evaluate Retrofit Site Constraints

The crew inspects the site to look for possible feasibility constraints for the proposed retrofit. Potential constraints vary depending on the retrofit location and stormwater treatment options employed.

However, the crew should always look for the following general constraints:

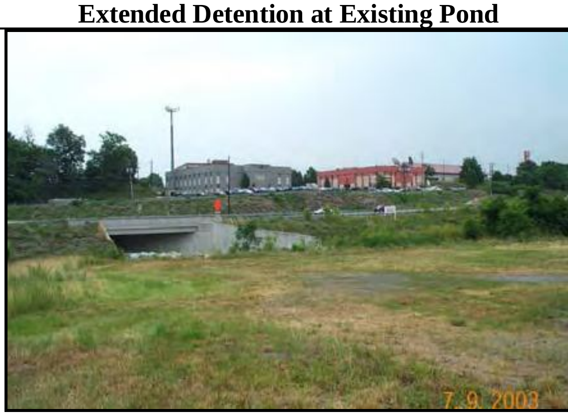
- *Adjacent Land Uses:* The crew should observe current land use and activities within and adjacent to the proposed retrofit. Often, retrofits are rendered infeasible due to competing uses (e.g., the available treatment area is already being used as a dog park, ball field or overflow parking area; Figure 4.10). In one case, an otherwise great retrofit site was eliminated because it was needed for an emergency helicopter landing area for an adjacent hospital.
- *Conflicts with Existing Utilities:* The crew should walk the site looking for surface indicators of dry or wet underground utilities. Figure 4.11 illustrates some common indicators for sanitary sewers, water lines, gas, electric, and cable utilities. The crew should not forget overhead utilities, as tree growth in some retrofits could create future conflicts. The approximate location and depth of any utilities should be noted on the concept sketch to help the crew get more precise information when they return to the office.

Table 4.16: Drainage Area – Surface Area Relationships

Stormwater Treatment Option	% of Contributing Drainage Area	Average Depth (ft)
Dry ED Ponds	1 to 3%	6
Wet Pond	1 to 3%	6
Constructed Wetland	3 to 5%	2
Bioretention	5 to 10%	1-2
Sand Filters	0 to 5%	2
Infiltration	0 to 5%	1-2
Swales	5 to 15%	2
Filter Strips	5 to 15%	1
Other Retrofits		
Dry wells	Each dry well can treat 500 sf of roof	1
Rain barrel (50 gal)	Max area draining to rain barrel 500 sf	3-5
Cistern (500 gal)	Max area draining to cistern 1000 sf	5-10
Planter boxes	Max area draining to box 15,000 sf	1.0
Green roofs	1 to 1 ratio of impervious area treated	0.5
Permeable pavers	1 to 1 ratio of impervious area treated	0
Rain gardens	10% of rooftop area	1

Extended Detention at Existing Pond

Underground Sand Filter at a Hotspot



Created Wetlands Above Roadway Culvert

Bioretention at a Small Parking Lot

Wet Pond Below Outfalls

Swale Along an Individual Street

Figure 4.8: Choosing the right stormwater treatment option for the retrofit location

Created Wetlands Within Conveyance

Bioretention Adjacent to Individual Rooftop

Extended Detention Within Transport ROW

Stormwater Tree Pit Within a Hardscaped Area

Bioretention at a Large Parking Lot

Underground Sand Filter at Existing Inlet

Install berm or baffle to lengthen flow path

Remove concrete pilot channel; excavate for pretreatment and forebay

Figure 4.9: Choosing the right stormwater treatment option for the retrofit location

Figure 4.10: The potential retrofit location (left) may be eliminated since it is used as recreational space in conjunction with the adjacent playground.

- *Construction and Maintenance Access:* The crew should check whether heavy equipment can access the retrofit site during construction and future maintenance operations. The crew should look for the best point of entry and note its width and slope. Good maintenance access is defined as the ability to access proposed inlets, outlets and forebays from a paved road that has a slope no greater than 12% and a width of 12 to 20 feet. The access should permit vehicles to turn-around and be vested as a permanent easement. The crew should note whether retrofit constraints would interfere with existing traffic or parking lot use.

- *Wetland, Floodplain and Forests:* Crews should always try to anticipate potential environmental permitting issues related to any wetlands, floodplains, mature forests or stream channels present at the site. Ideally, the crew should have some experience in plant identification, and indicate whether any follow-up surveys might be needed for future permitting. The crew should also note the presence of any invasive plants that might influence how the vegetation will be managed at the retrofit site.

- *Soils:* The crew can use a soil auger or screw driver to get a general sense of how underlying soils will influence retrofit design and construction costs. The crew should look for signs of compaction, poor infiltration, shallow bedrock, or a high water table. The soils analysis will be cursory, but should allow the crew to determine if more detailed soil or geotechnical investigations will be needed to support retrofit design.

Task 5: Complete Field Sketch and Notes

Space is provided on the RRI form for sketches and notes. The crew should sketch a plan view of the proposed storage retrofit and adjacent areas (Figure 4.12). The plan view should include both existing and proposed site conditions, drainage paths, and stormwater conveyance system. A profile view may be sketched for more complex storage retrofits and for on-site retrofits where elevations are tight, available head is limited, or existing storm drain inlets and outlets may present design challenges down the road. Rough cross sections should also be sketched for unique retrofit design elements, such as weirs, risers, and flow splitters. The goal of the sketch is to provide enough information to fully convey all aspects of the proposed retrofit so that another designer could pick it up and proceed with final concept design.

For on-site retrofits, a plan view sketch of the entire site is usually warranted if multiple retrofits are proposed for the same site. In some cases, a generic concept sketch can be substituted when many similar on-site retrofits will be installed (e.g., rain gardens installed in multiple homes in a particular neighborhood). The narrative that accompanies the generic concept sketch design should note any design adaptations to consider during implementation and recommend the best delivery mechanism to make it happen.

Task 6. Finalize RRI Forms Back in the Office

The retrofit crew normally finalizes the RRI form back in the office. The crew often needs more information to complete the field concept, evaluate is feasibility and determine if another restoration project is more appropriate for the site. Crews often suffer from fatigue after field work and may put off finishing the RRI form or doing quality control. As time elapses, however, crews forget important site details and may have a hard time translating the field sketch into a good concept design. Crews should finalize the RRI form while it is still fresh in their minds using the following punchlist of common quality control issues:

- *Confirm property ownership for the site:* Consult parcel data or local databases to determine ownership at each retrofit location, and obtain landowner contact information.
- *Confirm drainage area:* Site-specific mapping data, such as storm drain maps, pond design calculations, or fine-scale topo are used to get a final accurate estimate of the contributing drainage area to the retrofit.
- *Confirm drainage area impervious cover:* Aerial photography, planimetric GIS data or impervious cover coefficients can provide a good estimate of impervious cover.
- *Analyze utility and soil maps:* Site-specific utility maps should be consulted to confirm the available treatment area is actually suitable for retrofitting. Refer to local soils maps to get a general sense of soils at the site.
- *Complete concept design sketch:* A final plan and profile view of the proposed retrofit should be drawn to scale so that accurate numbers can be computed for the actual retrofit storage volume. Most concept sketches should be redone on two-foot contours, and the team leader should make sure any missing elements from the field recon are added.
- *Confirm volume computations:* In many cases, either the target or available storage volume may change as a result of the preceding steps. Therefore, the team leader should always review the final retrofit volume computations.
- *Review existing stormwater practice as-built drawings:* If these drawings are available, they are a great design resource for pond and conveyance retrofits since they provide valuable details on the workings and purpose of

stormwater practices that are complex, overgrown or hard to access.

- *Confirm storm drain invert elevations:* If detailed storm drain maps are available, it is useful to confirm spot elevations. It doesn't matter if these maps are old and non-digital, as they contain more precise elevation data than shown on GIS. Make sure, however, to use consistent topographic benchmarks.

The retrofit team then makes a final recommendation on whether the site is suitable to proceed to concept design. Generally, a decision to stop is made when a site is severely constrained or cannot meet the walkaway volume. A feasible retrofit should not be eliminated from consideration until the retrofit ranking process is completed. In the event that a retrofit is not feasible, the RRI form provides space to suggest an alternative restoration project (Table 4.17).

Sewer Stacks

Fire Hydrant – Water Line

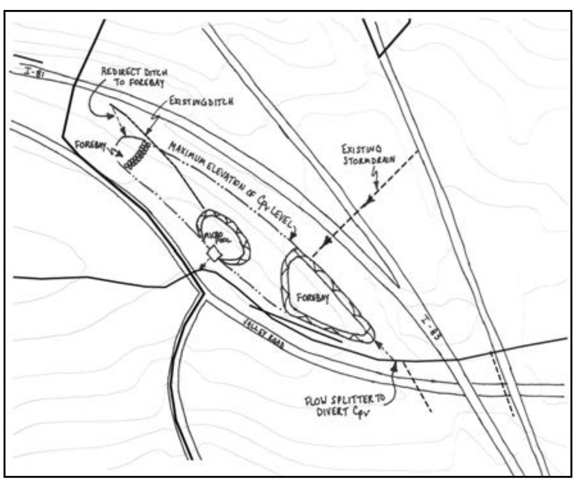
Electric Box Grates

Overhead Wires

Gas Meter

Cable Box

Figure 4.11: Examples of Some Common Utility Indicators



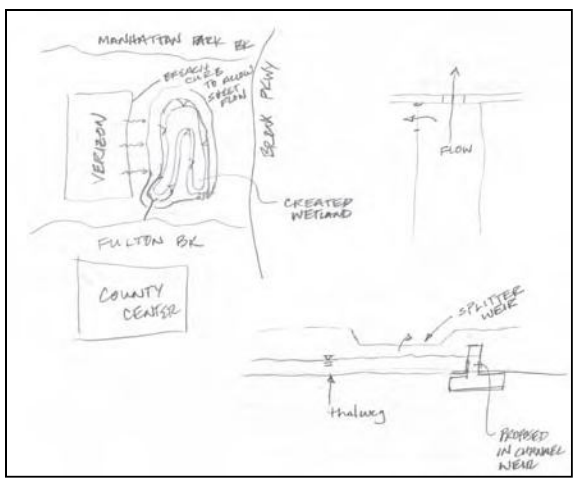


Figure 4.12: Examples of Retrofit Field Sketches

Table 4.17: Alternative Restoration Projects to Consider When Retrofit Is Not Feasible	
Storage Retrofits	**On-Site Retrofits**
SR-1: Existing Ponds • Reforest pond and its buffer • Plant wetland plant species in benches • Notify owner to perform maintenance • Designate for local Adopt-a-Pond program **SR-2: Above Roadway Culverts** • Upstream wetland restoration • Culvert repair or replacement • Fish barrier removal • Downstream stream repair • Riparian reforestation • Stream adoption **SR-3: Below Outfalls** • Outfall stabilization • Stream daylighting • Riparian reforestation **SR-4: In the Conveyance System** • Natural channel design • De-channelization • Riparian reforestation • Wetland restoration **SR-5: In Transport Right-of-Way** • Reforestation • Spill controls **SR-6: Large Parking Lot** • On-site parking lot retrofits • Reforestation • Pollution prevention practices • Regular vacuum sweeping and litter control	**OS-7: Hotspot Operations** • Pollution prevention • Spill prevention and response • Secondary containment **OS-8: Small Parking Lots** • Tree planting • Vacuum sweeping and litter control • Parking lot pollution prevention practices **OS-9 Individual Streets** • Street sweeping • Storm drain cleanouts • Storm drain marking • Commercial pollution prevention practices **OS-10 Individual Rooftop** • Watershed education • Neighborhood stewardship practices • Reforestation **OS-11 Little Retrofit** • Reforestation • Erosion Repair **OS- 12 Landscape/Hardscape** • Reduced fertilizer and pesticide use • Use of native plants • Urban forestry practices • Smart site practices for redevelopment **OS-13 Underground** • Intensive street sweeping • Regular cleanouts of storm drain inlets • Pollution prevention practices • Detection and elimination of illicit discharges

Step 4: Compile the Retrofit Inventory

This step produces concept designs for individual retrofit sites, and compiles them in a retrofit inventory for the entire subwatershed, in three simple tasks:

Task 4.1: Prepare Storage Retrofit Concept Designs

After the field investigation, the team prepares a concept design to assess retrofit feasibility and compare it against other proposed retrofits for the subwatershed. A concept design for a storage retrofit is neither a final design nor a detailed construction drawing. Concept designs are often expressed as a percentage of effort to get to final design. At this stage of the retrofit process, a 15% design is usually sufficient, but a 30% design may be needed for larger or more complex storage retrofit projects. A 15% design consists of a decent sketch, an analysis of project feasibility, storage calculations, pollutant load reduction estimates and planning-level construction cost estimate. A 30% design has more detailed engineering computations and some preliminary hydrology and other modeling to determine the size and feasibility of the retrofit.

The design team begins by analyzing the final RRI form for the storage retrofit. The designer then appends additional items to complete the concept design:

Project Feasibility: Designers should outline the specific hurdles needed to actually implement the retrofit by specifically referencing the type and number of environmental permits needed, landowner approval or easements that must be secured, special engineering studies needed to support final design and any access issues that may complicate retrofit construction. The designer should also indicate the probability of acceptance by neighbors or the landowner.

Storage Calculations: Designers should present their final calculation of the target WQv storage for the retrofit and confirm its actual storage volume (in acre-feet).

Pollutant Removal Rate: Designers can compute the pollutant load delivered to the retrofit using the Simple Method (taking input parameters directly from the RRI form). Next, designers adjust the median removal rate for the pollutant of concern, based on a review of site conditions and design factors for the individual retrofit using the design point method. Appendix B provides detailed guidance on how to perform both calculations. The final product is a pollutant removal estimate expressed in terms of lbs/year.

Initial Cost Estimate: A preliminary cost estimate can be derived based on impervious area treated using the retrofit unit cost data presented in Chapter 2. All cost estimates should be adjusted for any unusual site factors that might drive up construction costs. Designers should also indicate whether any of the following factors will be need to be addressed to construct the retrofit:

- Land acquisition
- Poor construction access
- Hauling material off-site
- Utility relocation
- Multiple environmental permits

Task 4.2: Finalize On-Site Retrofit Delivery Methods

Concept designs for on-site retrofits are slightly different. They are primarily intended to show how on-site retrofits can be delivered on a widespread basis over a neighborhood or specific land use. The designer should estimate the number of homes, yards, businesses or other individual units where the on-site retrofit could potentially be applied across the subwatershed. For example, Neighborhood Source Assessment data can estimate the number of residential rooftops that could be treated or disconnected. The remainder of an on-site concept plan consists of the following sections:

Generic Sketch: A final generic concept design drawing of the basic on-site retrofit approach should be prepared, along with notes on any site-specific constraints that may require minor design adaptations.

Delivery Mechanism: Designers should describe the proposed delivery mechanism for the proposed on-site retrofit, such as resident education, direct technical assistance, workshops, door-to-door outreach, free construction materials or financial incentives. Profile Sheets OS-10 and OS-11 provide specific guidance on potential delivery mechanisms for common on-site retrofits.

Target Implementation Rate: Designers should estimate a realistic rate of adoption or implementation for the on-site retrofit, which is obviously linked to the delivery mechanism selected.

Aggregate Pollutant Removal: The team then estimates the aggregate pollutant load treated by individual on-site retrofits, and selects a reasonable pollutant removal rate to determine the total pollutant load reduction. Table 4.18 presents an example of how to estimate pollutant removal through the delivery of rain gardens in three residential neighborhoods.

Aggregate Treatment Costs: The same scaleable process can define the aggregate cost for on-site retrofits (Table 4.19). Designers estimate unit costs for each individual installation and retrofit delivery, and then scale up at the neighborhood level. In the rain garden example, the combined cost for retrofit installation and delivery is nearly $20,000 per impervious acre treated, or about $13,250 per pound of phosphorus removed.

Task 4.3 Assemble the Retrofit Inventory

Three simple tasks are performed to compile an inventory of all stormwater retrofits that can be implemented in a subwatershed:

1. *Conduct final quality control on individual retrofit concept designs*: Final project concept designs should be reviewed one last time for accuracy and thoroughness, preferably by someone not on from the original field crew. The team leader should ensure that all field forms, digital photos, sketches, field notes, and other project data are organized into a single project folder. Individual retrofit concepts are then finalized in the form of a two to four-page retrofit summary that includes the feasibility assessment, sketch, narrative and initial cost estimate.

2. *Assemble the retrofits into a master binder and spreadsheet or GIS*: Individual retrofit summaries are then assembled into a master binder (Figure 4.13). A spreadsheet can be created that organizes retrofits by their unique site

ID, impervious area treated, retrofit location, stormwater treatment option prescribed, pollutant reduction and cost. The spreadsheet may also serve as an index for corresponding section of the master binders. When completed, the master binder serves as the subwatershed retrofit archive.

3. *Produce a subwatershed retrofit locator map and inventory summary table*. The front-end of the retrofit inventory should contain a subwatershed retrofit locator map to organize retrofit data needed for evaluation and ranking (Figure 4.14).

Table 4.18: Example of How On-site Pollutant Removal Is Computed

Neighborhood	Total # of Rooftops	Roofs Treated[1]	Total IC (acres) [2]	Total TP Load (lbs/yr) [3]	Removal Rate [4]	TP Reduced [5]
A	200	25%	0.91	2.12	65%	1.38
B	500	40%	4.59	10.69	65%	6.95
C	300	30%	2.29	5.34	65%	3.47
Total	1,000	-	7.79	18.15	-	11.80

Notes:
[1] Assumes aggressive delivery program using door to door outreach, direct technical assistance and homeowner financial incentives
[2] Assumes 1,000 square feet of rooftop treated in rain garden per house
[3] Total P using Simple Method: C = 0.30, P = 40 inches, Rv = 0.95
[4] Median bioretention TP removal rate in Chapter 3
[5] pounds of TP removed per year

Table 4.19: Deriving Neighborhood Scale Cost Estimates for On-site Retrofits

Neighborhood	# Rooftops Treated [1]	Unit Costs [2] (Per Home)	Delivery Cost [3]	Total Cost [4]
A	50	$ 350	$ 75	$ 21,250
B	200	$ 350	$ 125	$ 95,000
C	100	$ 350	$ 50	$ 40,000
Total	350	-	-	$ 156,250

Notes
[1] Each 1,000 sf of roof produces 83 cubic feet of runoff
[2] Assume volunteer rain garden installation @ 4.00 cf with 5% Design & Engineering
[3] Unit cost for different retrofit delivery programs (per house)
[4] Total cost for installation and delivery for 350 homes

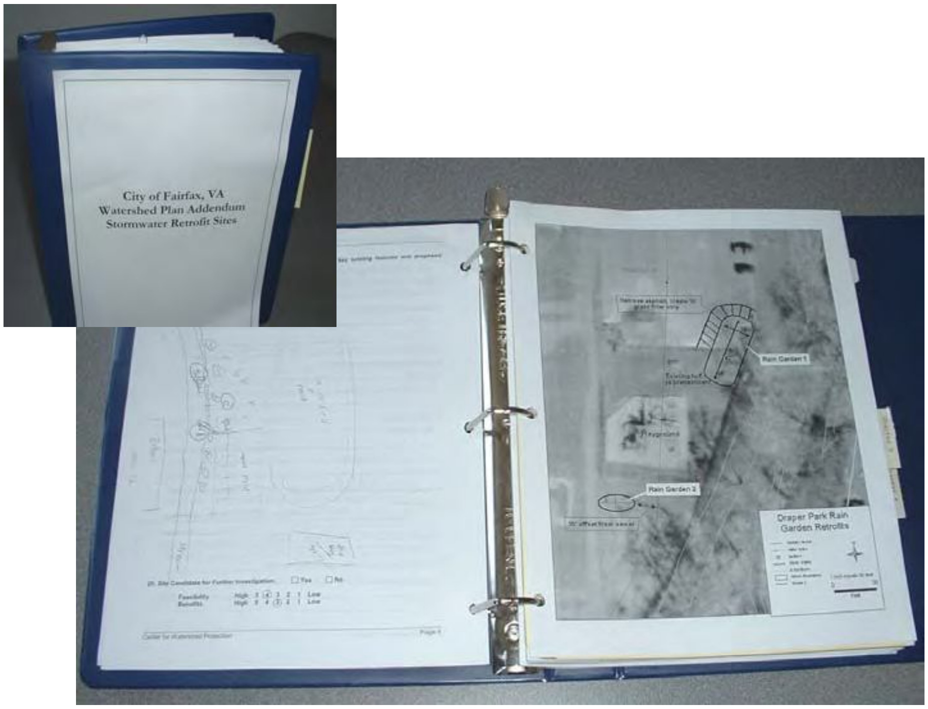


Figure 4.13: This binder was used to keep all completed retrofit forms, preliminary concept designs and a table of all retrofit sites visited.

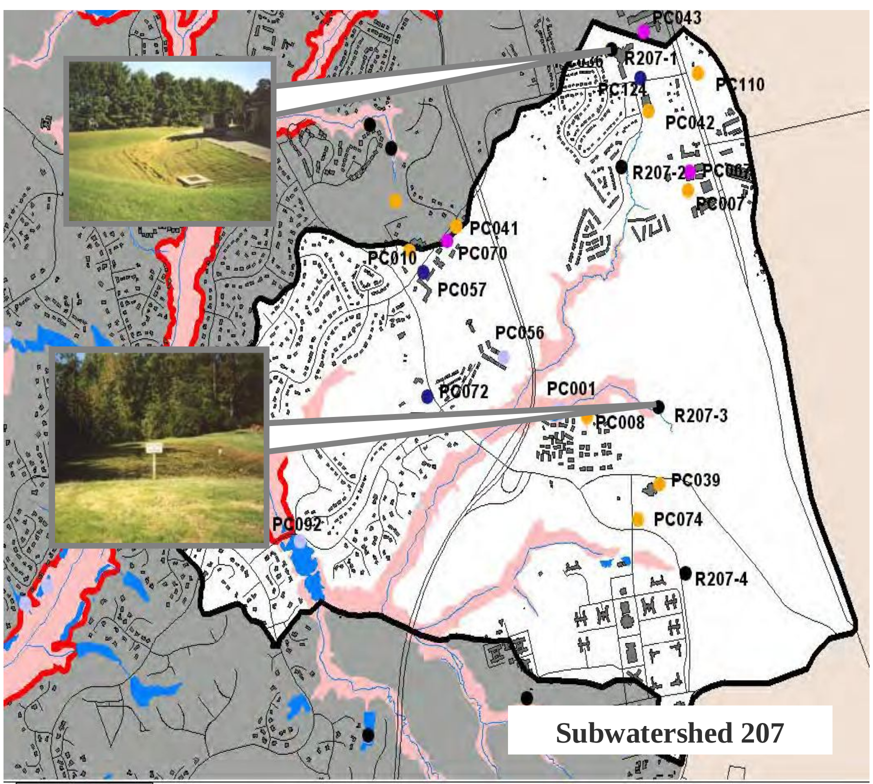


Figure 4.14: Example of a retrofit locator map created for a subwatershed retrofit archive.

Step 5: Rank the Proposed Retrofits

The next step involves prioritizing the best retrofits for future implementation. Since most communities have limited capital budgets for retrofit design and construction, they need a prudent and cost effective strategy to guide implementation. The ranking process involves three basic tasks:

5.1. Consult neighbors and stakeholders to get project input
5.2. Choose retrofit screening criteria
5.3. Create a retrofit priority list

Task 5.1 Consult Neighbors and Stakeholders to Get Project Input

Storage retrofits can significantly alter the local landscape, and neighbors and landowners often have many real or perceived concerns about retrofit practices. It is wise, therefore, to get neighborhood input before costly field surveys and engineering studies are performed for retrofits that may get dropped later because of community opposition.

Every storage retrofit recommended for final design and permitting should be presented to the public at least once. Residents who are informed in advance about the benefits of retrofitting are more likely to accept projects. Consequently, it is important to give them an early opportunity to comment on proposed retrofits and respond to their concerns prior to final ranking and project design. Some of the more common concerns residents express are that storage retrofits will:

- Result in the loss of existing trees
- Increase unwanted public access to their backyards
- Pose safety risks for children, such as drowning in deep pools
- Create mosquito breeding conditions and increase potential for West Nile Virus
- Attract vermin, snakes, or rats
- Produce ragweed and other plants that cause allergies
- Become a poorly maintained eyesore
- Cause noise and neighborhood disturbance during construction
- Detract from property values
- Eliminate an existing public or private use of open land
- Waste taxpayer money that could be spent elsewhere in the community

The retrofit team should anticipate these concerns and be ready to respond to them in an even-handed manner. Table 4.20 outlines common perceptions, realities and design responses for many common retrofit concerns. These objections should never be ignored or glossed over since many residents are already somewhat suspicious of local government.

Neighborhood consultation is normally scheduled in the evening to coincide with a regular homeowner or civic association meeting (Figure 4.15). The meetings should

Figure 4.15: Landowner concerns can be addressed during neighborhood consultation meetings.

clearly explain exactly what is being proposed, what will happen during construction, and what the retrofit will look like when finished. Subwatershed maps, project renderings, and photos of similar storage retrofits can all help show residents what to expect.

The meeting should also include a presentation on why retrofits are needed and the planning process that led to the proposed retrofit. Neighborhood meetings are also an excellent way to educate residents about neighborhood pollution sources, stewardship practices and available municipal stewardship services. Most of all, the meeting should be structured to give adjacent residents the opportunity to voice their concerns, issues and questions about the retrofit. Additional tips on conducting effective neighborhood consultation meetings can be found in Profile Sheet 19 in Manual 2.

Task 5.2 Choose Retrofit Screening Factors

The next task chooses the best combination of screening factors to compare individual retrofit project concept designs (see Table 4.21). The screening factors should allow a direct and fair comparison among both storage and on-site retrofits in a subwatershed. Next, a relative weight is assigned to each screening factor that reflects its perceived influence on retrofit project success. Then, the retrofit team then analyzes the range of scores among all retrofits to determine the scoring rules that will be used to award or deduct points from individual projects.

Task 5.3: Create Retrofit Priority List

The design team pulls pertinent information from the retrofit inventory to score individual retrofit projects according to the scoring system developed in the preceding task (Figure 4.16). Individual project scores are entered into a spreadsheet and totaled. Project scores are then ranked from highest to lowest to establish the retrofit priority list. High scoring projects should be double-checked to look for hidden "project killers." This occurs when a retrofit project has a high total score, but has a low or zero score for one or more individual screening factors (suggesting that it is hard to implement). Examples of stormwater retrofit ranking factors are provided in Table 4.22. The application of a scoring system to a hypothetical group of retrofit projects is shown in Table 4.23.

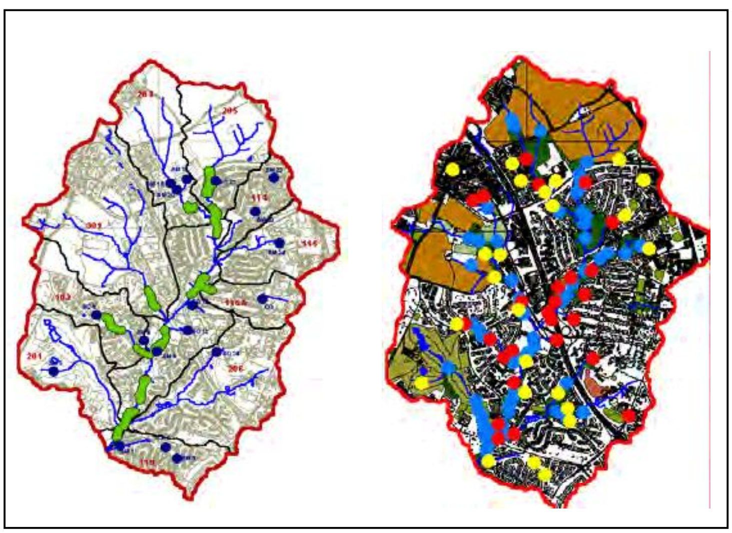


Figure 4.16: Scoring helps identify priority retrofit sites (left) from all potential retrofit sites visited (right)

Table 4.20: Perception, Reality, and Response to Common Neighborhood Concerns about Storage Retrofits

Perception	Reality	Potential Design Responses	Supporting Resources
Loss of Mature Trees	*High with poor retrofit layout*	Survey trees prior to layout…Fingerprint retrofit around mature tree…Specify tree protection measures during construction Reforest at least 2:1 for cleared trees.	Cappiella *et al*. (2006a)
Drowning	*Low: w/ proper design*	Use shallow wetlands rather than deep pool…Safety and aquatic benches around micropools and forebays…Side-slope controls in pond buffer...Fence sharp drop offs	Marcy and Flack (1981); Jones and Jones (1982); Eccher (1991)
Mosquitoes	*Low to Medium: depending on design*	Aquatic benches… Deeper pools … Stock w/ *Gambusia* if native…Avoid undersized retrofits…Avoid stagnation…Education about mosquito habitat…Regular maintenance including mosquito management….Mowing and removal of overgrown wetland vegetation	Schueler (1995b); Hunt and Lord (2006b); Hunt *et al*. (2005); Santana *et al* (1994); Ladd and Frankenburg (2003); Walton (2003)
Vermin (ticks, rats, snakes)	*Low*	Regular mowing of publicly used areas. Manage to grow into forest	Hunt and Lord (2006b) Cappiella *et al.* (2006b)
Odors	*Medium*	Avoid under-sized retrofits in residential areas…Keep constant inflows…Install aeration devices or fountains…Remove dead algae and rooted plants as part of maintenance…Increase pond depth	
Looks Ugly	*Low to Medium*	Pondscaping...Involve landscape architect in retrofit design…Irregular shorelines…Increase landscaping budget…Minimize concrete surfaces and paint risers…Tree conservation…Screening plantings…Reforestation	Schueler, 1992; MDE (2000); Echols and Pennypacker (2006); France (2003)
Vegetation Growth	*Medium*	Regular mowing…Allow trees to grow in pond buffer…Landscape maintenance contracts	Hunt and Lord (2006b)
Maintenance	*High*	Defined maintenance agreements…Designate retrofit in adopt-a-pond…Public maintenance	NVPDC (2000) and Sturm (2003), CWP (2004b)
Trash/Debris	*High*	Wetland benches…Annual shoreline cleanups…Enforcement of illegal dumping/littering	Hunt and Lord (2006b)
Property Values	*Low*	Well designed wet ponds and wetlands increase property value (dry ponds they replace decrease property value)	Emerling-DiNovo (1995); Land and Water (1996); Schueler (1995a)
Polluted Sediment	*Low*	Assess upland hotspot uses before design. Install pretreatment…Include spill containment…Offsite sediment disposal…Resident education…No swimming signs	Hey and Schaefer (1983); Dewberry and Davis (1990); Yousef and Lin (1990); Schueler (1994a)
Lost Community Uses	*Med to High*	Ask neighbors about how the parcel is used…Check out site on a weekend to see how it is being used	
Bad Neighbor	*Low*	Incorporate trails, interpretive signs, gazebos, benches and monitoring into the design	
Construction Issues	*Medium*	Incorporate measures into construction contracts…Weekday construction…Silence vehicle back-up alarms…Noise suppression enclosures on equipment…Close engine housing panels…Stringent ESC controls…Traffic and parking management	
Resident Geese	*Medium to High*	Minimize turf cover in retrofit buffer…Use stormwater wetland…Install aquatic benches…Place a grid of string across the pond to prevent easy landing…Let neighborhood dogs roam	Hunt and Lord (2006); Rodewald (2001) Schueler (1992)

Table 4.21: Examples of Potential Retrofit Screening Factors
Cost Per Treated Area: This screening factor expresses cost in terms of the acres of impervious cover treated by the retrofit, and is preferred to total construction cost since it allows storage and on-site practices to be directly compared.
Cost Per Pollutant Removed: If pollutant reduction is the primary retrofit objective, projects should be screened based on the relative cost to remove pollutants. This requires a little more analysis to compute pollutant loads delivered to the retrofit site using the methods in Appendix B and then adjusting them based on the expected pollutant removal rate for the retrofit.
Stream Channel Protection Capability: If stream channel protection is a primary retrofit objective, this factor rates how the retrofit will help to reduce channel erosion through either storage of the channel protection volume or runoff reduction.
Compatibility with Core Subwatershed Objective: This factor rates how well the proposed retrofit conforms to the core retrofitting objective for the subwatershed. Maximum points are awarded for retrofits that directly support all objectives (e.g., provide maximum removal of pollutant of concern). Fewer points are awarded for retrofits that only indirectly support subwatershed objectives, and no points are awarded if the retrofit does not address subwatershed objectives in a meaningful way.
Maintenance Burden: Retrofit projects differ greatly in their long-term maintenance burden. The long-term maintenance needs of each retrofit should be assessed and points deducted if vegetation management, sediment removal and clogging are expected to be problems. Points may also be deducted if maintenance is not clearly vested with a responsible party.
Landowner Cooperation: This screening factor rates the willingness of private or public landowners to allow the retrofit to be installed on their property. Points are deducted for projects where permission is uncertain, easements must be secured, or landowners are uncooperative.
Permitting Burden: Some retrofit projects require many different permits and approvals before ground can be broken. In many cases, permitting agencies may require special studies, impose costly permit conditions, or disapprove the project altogether. Points are deducted for projects subject to multiple permits or to a single difficult permit (e.g., wetlands disturbance).
Synergy with Other Restoration Practices: This factor evaluates whether the retrofit can be integrated with other restoration practices at the same site or stream reach to maximize restoration benefits. An example would be a storage retrofit located above a stream restoration project.
Neighborhood Acceptance: This factor ranks the community acceptance of the retrofit based on feedback from neighborhood consultation meetings. Points are deducted for controversial projects, or for situations where concerns are raised about safety, forest loss, aesthetics, public access, construction noise and impact on property values. Maximum points are awarded for projects that get enthusiastic neighborhood support and have prospects for actual community involvement during construction or maintenance.
Access: This factor assesses the ability to get heavy construction equipment to the retrofit site for construction and maintenance. Points are deducted for sites with steep or unstable side-slopes, where construction access disrupts neighbors, when significant tree clearing is required, or when easements for access or maintenance must be secured from a private landowner.
Use of Innovative Practices: Some retrofits are preferred because they utilize an innovative design or technology that has not yet been implemented in the community. These projects are often awarded extra points because of their demonstration value.
Partnership Opportunities: This screening factor awards points based on the number of potential restoration partners that may be involved in project implementation. Projects with many partners or a new partner are normally awarded more points since they can leverage resources available for future retrofits.
Public Visibility: This factor examines the visibility and potential education value of the proposed retrofit. Points are awarded for projects that have public access, experience heavy use, are linked to trails and bikeways or have opportunities for signage and education. Points are deducted for projects situated on private land, out of view or restricted or prohibited access.
Habitat Creation: This factor evaluates whether the retrofit can create new terrestrial or aquatic habitat features or connect existing habitat features. Maximum points are awarded for projects that emphasize wetland, vernal pool, forest, or in-stream habitat creation.
Other Community Benefits: This factor is a sort of grab bag that evaluates the retrofit with respect to any additional community benefits it may provide (recreation, increased property values, education, open space, trails, greenways, neighborhood revitalization, etc.).

Table 4.22: Example Stormwater Retrofit Ranking Criteria		
Stormwater Retrofit Ranking Criteria (35 Total Points Possible)		**Possible Points**
1.	**Impervious Area Treated**	**5**
	Less than 100 acres	[1]
	101-250 acres	[3]
	Greater than 250 acres	[5]
2.	**Water Quality Target**	**10**
a.	**Runoff Depth Treated (inches per impervious acre)**	**5**
	Less than 0.25	[1]
	0.26 - 0.50	[3]
	0.51 - 1.00	[5]
b.	**TP Pollutant Load Reduction**	**5**
	Less than 20%	[1]
	21% to 49%	[3]
	50% or more	[5]
3.	**Planning Level Construction Cost (per acre of drainage area)**	**5**
	Greater than $10,001	[1]
	$5,00 to $10,000	[2]
	$2,501 to $5,000	[3]
	$1,001 to $2,500	[4]
	Less than $1,000/acre	[5]
4.	**Ownership**	**5**
	Assumed Private	[0]
	Public	[5]
5.	**Access**	**5**
	Poor	[1]
	Good	[3]
	Excellent	[5]
6.	**Project Visibility**	**5**
	Poor (site is on private property or cannot be seen from the street)	[1]
	Good (site adjacent to a street)	[3]
	Excellent (site adjacent to a highly traveled street or public property)	[5]

Table 4.23: Example Stormwater Retrofit Prioritization															
ID	**Ranking Factors**														
	Impervious Area Treated		**Runoff Depth Treated**		**Pollutant Load Reduction**		**Planning Level Cost**		**Ownership**		**Construction Access**		**Project Visibility**		**Total Points**
	(ac)	**(pts)**	**(in / imp ac)**	**(pts)**	**(adjusted RR)**	**(pts)**	**(per ac)**	**(pts)**		**(pts)**		**(pts)**		**(pts)**	**(pts)**
R-17	2.9	1	0.5	3	55	5	$8,070	2	Public	5	Excellent	5	Excellent	5	**26**
R-03	413.3	5	0.5	3	15	1	$200	5	Private	0	Excellent	5	Excellent	5	**24**
R-08	0.3	1	0.5	3	65	5	$14,700	1	Public	5	Good	3	Excellent	5	**23**
R-02	2.7	1	1.0	5	35	3	$8,430	2	Private	0	Excellent	5	Excellent	5	**21**
R-16	6.5	1	0.5	3	60	5	$7,260	2	Private	0	Excellent	5	Excellent	5	**21**
R-18	159.8	3	0.5	3	10	1	$330	5	Private	0	Excellent	5	Good	3	**20**
R-06	11.7	1	1.0	5	15	1	$1,950	4	Private	0	Excellent	5	Good	3	**19**
R-04	264.2	5	0.1	1	40	3	$80	5	Private	0	Poor	1	Poor	1	**16**
R-05	7.0	1	1.0	5	60r	5	$15,000	1	Private	0	Good	3	Poor	1	**16**

Step 6: Conduct a Subwatershed Treatment Analysis

Subwatershed treatment is defined as the proportion of subwatershed area that is effectively treated by stormwater retrofits. In simple terms, it refers to the fraction of subwatershed area (or impervious area) served if all proposed retrofits are built. A Subwatershed Treatment Analysis (STA) evaluates whether the proposed combination of stormwater retrofits can achieve enough treatment to meet subwatershed restoration objectives. The STA requires the use of the Watershed Treatment Model (Caraco, 2001) or a similar model to estimate the reductions in the pollutant of concern. Detailed guidance on performing an STA is provided in Manual 2. The retrofit inventory should contain all of the information needed to support an STA, so it can be done in three short tasks.

Task 6.1 Compute Pollutant Removal by Storage Retrofits: This task computes the aggregate pollutant reduction achieved by individual retrofit projects at the subwatershed level. The pollutant removal estimates developed for the final concept designs can be directly inserted into the WTM to compute the cumulative benefit of the proposed suite of retrofits.

Task 6.2 Compute Pollutant Removal by On-site Retrofits: A similar approach is used to determine pollutant load reduction benefits for on-site retrofits. Once again, the design team consults the on-site retrofit concept designs, and estimates the total contributing drainage area treated in the subwatershed using the scaling methods outlined in Step 4. In some cases, a further discount in pollutant removal is needed to prevent double counting (e.g., on-site retrofit located above downstream storage retrofit).

Task 6.3: Compare Subwatershed Results to Restoration Objectives: The STA quickly computes whether the proposed suite of retrofits can achieved the pollutant reduction goals established in the scoping phase. In most cases, the initial list of priority retrofits will fall short of the mark. In this event, the team can re-prioritize retrofits, propose more retrofits (e.g., on-site retrofits), look for addition pollutant reductions via pollution source controls or discharge prevention, or revise subwatershed objectives.

An example of how to calculate an STA for a hypothetical watershed is shown in Figure 4.17. The community seeks to reduce pollutant load by 25% to restore an urban lake. The design team proposes retrofitting the 4.5 square mile subwatershed with four storage retrofits and on-site retrofits in one target neighborhood. The proposed retrofits capture drainage from 1,379 acres and treat 62% of subwatershed impervious cover. For

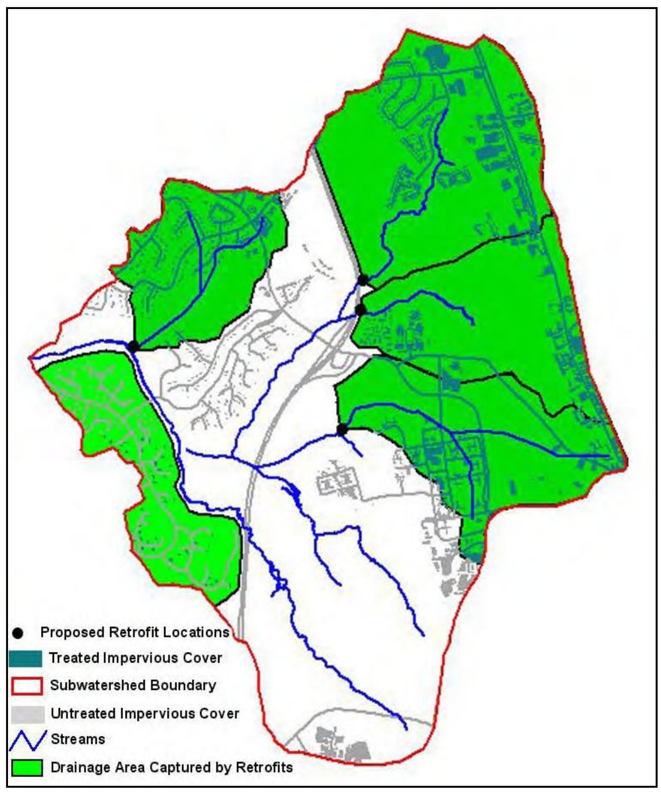


Figure 4.17: Subwatershed Treatment Analysis Example

each proposed retrofit, the drainage area, imperviousness, and pre-retrofit pollutant load were calculated, as shown in Table 4.24. The retrofit team then inserted adjusted removal rates based on the design point method for each individual retrofit project and performed an STA for the subwatershed as a whole. Based on the results, the team concluded that the proposed retrofits were capable of reducing pollutant loads by 251 lbs/yr. Given the total subwatershed loading of 789 lbs/yr, this produced an expected subwatershed pollutant reduction of about 32%, which exceeded the target reduction goal.

Step 7: Final Design and Construction

The final step of retrofit implementation involves design and actual construction. Costs involved in final design and permitting of storage retrofits may range from 32 to 50% of base construction cost.

The process of constructing a retrofit involves five tasks:

7.1 Secure Environmental Permits
7.2 Obtain Landowner Approvals and Easements
7.3 Perform Special Engineering and Surveying Work to Support Design
7.4 Put Together the Design Package
7.5 Contract and Construction Management

Task 7.1 Secure Environmental Permits

Permitting issues for storage retrofits can involve impacts to existing wetlands, forests and floodplains. Table 4.25 provides a summary of typical surveys needed for environmental permits. While good designers try to avoid or minimize impacts, some are unavoidable to meet reasonable storage targets. Permitting agencies will scrutinize the project to make sure impacts are minimized and are clearly outweighed by the expected environmental benefits of the proposed retrofit. Designers should take a step back and be their own worst critic – this is often when ethical designers choose to walk away from a proposed retrofit because it may do more harm than good. Designers will always need to use their best professional judgment to balance potential impacts that are hard to predict against the benefits to be provided by the retrofit.

Table 4.24: Computation of Storage and On-Site Retrofits

Unique Site ID	Stormwater Treatment Option	Drainage Area (acres)	Pre-Retrofit Pollutant Loading (lbs./year)	Median Pollutant Removal Efficiency (%)	Design Points	Adjusted Removal Efficiency (%)	Pollutants Removed (lbs)
R-1	Extended Detention	231	86.7	20	+ 1	25	21.7
R-2	Wet Pond	333	138.2	50	-3	40	55.3
R-3	Constructed Wetlands	485	214.0	50	+ 5	75	160.5
R-4	Extended Detention	325	27.0	20	+ 3	40	10.8
OS-1	Bioretention rain gardens at 50 houses	3.8	8.9	65	-1	30	2.7
	Untreated	1501	314	-	-	-	0
Total		2878	789				251 (32%)

Task 7.2 Obtain Landowner Approval and Easements

The retrofit team should never underestimate the time and effort involved in getting approvals to proceed with retrofit construction (Table 4.26). Approval issues are magnified when a retrofit is located on private property, or when easements must be secured for construction or maintenance access. Approvals are somewhat more manageable when the retrofit is located on public land, but still require a great deal of interagency coordination and negotiation. Most owners want to know the long-term maintenance arrangements for the retrofit and who will be the maintainer.

If property ownership or boundaries are in doubt, the designer should check with the local planning authority on plat requirements and review procedures and hire a survey crew to document property boundaries. Designers should not assume that property owners will be willing retrofit partners. Owners may need to be educated about retrofit benefits and offered some incentives to gain approval.

Task 7.3 Perform Special Engineering and Surveying Work to Support Design

A number of special engineering studies and field surveys are needed to directly support final design of retrofit projects. The exact type and number of surveys depends on the complexity of the retrofit and site conditions. While these studies increase overall costs for project design, they help the designer anticipate potential construction problems, secure needed approvals, and ensure proper retrofit function. Some common engineering studies and field surveys associated with storage retrofits are shown in Table 4.27.

Task 7.4 Put Together the Design Package

Final design translates the retrofit concept into a construction drawing and specifications (Figure 4.18). Designers assemble a final design package, attached secured permits and approvals, and prepare bid documents to construct the retrofit project. The design package for retrofit projects incorporates the same elements used to construct stormwater projects at new development sites, including:

- Hydrologic and hydraulic modeling computations
- Detailed topographic mapping
- Property line establishment
- Site grading and earthwork estimates
- Structural design
- Geotechnical investigations
- Erosion and sediment control plans
- Construction sequencing and staging
- Planting plans
- Bid specifications

Table 4.25: Typical Environmental Permits Needed for Storage Retrofits

Permits	SR-1 Pond	SR-2 Culvert	SR-3 Outfall	SR-4 Conveyance	SR-5 ROW	SR-6 Parking Lot
Wetland delineation	◉	●	◉	●	◉	○
Wetland functional assessment	◉	◉	◉	◉	◉	○
404 wetland permit	◉	●	◉	◉	◉	○
Forest stand delineation	◉	●	◉	◉	◉	◉
Forest inundation analysis	◉	●	◉	○	○	○
Forest conservation permit	◉	●	◉	◉	○	◉
Fish passage survey	◉	●	○	○	○	○
Section 401 WQC Permit	●	●	●	◉	◉	◉
Floodplain alteration permit	◉	◉	●	◉	○	○
Dam safety review permit	●	●	◉	○	○	○
Local ESC Permit	●	●	●	●	●	●
Key: ● Frequently needed; ◉ Sometimes needed; ○ Seldom needed						

Table 4.26: Key Approvals and Easements for Storage Retrofits

Approval or Easement	SR-1 Pond	SR-2 Culvert	SR-3 Outfall	SR-4 Conveyance	SR-5 ROW	SR-6 Parking Lot
Local SWM review	●	●	●	●	●	●
Highway approval	◉	●	◉	◉	●	◉
Park authority approval	○	◉	◉	◉	○	◉
Access easements	●	●	●	◉	◉	◉
Expanded drainage easements	◉	◉	◉	◉	◉	◉
Maintenance escrow	◉	◉	◉	◉	◉	◉
Neighborhood consultation	●	◉	◉	●	○	◉
Landowner notification	●	◉	◉	●	◉	●
Key: ● Frequently needed; ◉ Sometimes needed; ○ Seldom needed						

Table 4.27: Special Engineering and Survey Work to Support Storage Retrofit Design

Engineering or Survey Work	SR-1 Pond	SR-2 Culvert	SR-3 Outfall	SR-4 Conveyance	SR-5 ROW	SR-6 Parking Lot
Updated land cover in CDA	●	●	◉	◉	◉	○
Soil borings	●	●	●	●	●	●
Soil infiltration testing	○	○	◉	◉	◉	◉
Soil depth to groundwater	●	●	●	●	◉	◉
Site topo survey (1 ft)	●	●	●	●	●	●
Spot elevations and inverts	●	●	●	●	●	●
Hydraulic cross section of upstream channels/pipe	◉	◉	◉	◉	◉	○
Tailwater/backwater analysis	◉	◉	●	◉	◉	○
Floodplain analysis	◉	◉	◉	◉	○	○
Dam hazard analysis	●	◉	○	○	○	○
Culvert capacity	○	●	○	◉	○	○
Downstream channel stability	◉	●	◉	●	◉	◉
Easement research	●	◉	◉	●	◉	●
Utility surveys	●	●	●	●	●	●
Traffic studies	○	◉	○	○	●	◉
Parking demand studies	○	○	○	○	○	●
Discharge investigation	◉	◉	●	◉	○	○
As-built conditions	◉	◉	◉	◉	◉	◉
Existing H&H routing	●	●	○	◉	○	○
Upstream geomorphology	○	◉	○	○	○	○
Downstream geomorphology	◉	●	○	●	○	○
Water balance analysis	◉	○	◉	○	○	○
Key: ● Frequently needed ◉ Sometimes needed ○ Seldom needed						

Retrofits often involve a host of special construction considerations that should be reflected in the design package. Some common construction issues are described in Table 4.28, and in the retrofit profile sheets presented in Chapter 2.

Task 7.5 Contract and Construction Management

There are three basic approaches to moving a retrofit project into the construction phase:

- *In-House Construction Crews:* Use crews from public works, transportation, or parks departments to construct the retrofit.
- *Bid As A "Retrofit-Only" Project:* One or a group of retrofits can be packaged for bidding, so that the contractors are only bidding on the actual retrofit work.
- *Bundle Retrofits With Larger Project:* Retrofits can be put into a bigger construction package for road work, parking lot improvement, school or park renovations, drainage projects, etc.

The pros and cons of each approach are outlined in Table 4.29.

The main issue for a local program is to institutionalize retrofit construction, so that the effort can be sustained over a long time period. In that regard, all three approaches may be important for a successful local program. Also, the retrofit team should become familiar with local and state procurement procedures, and find the most efficient ways to move projects from the drafting board to the site.

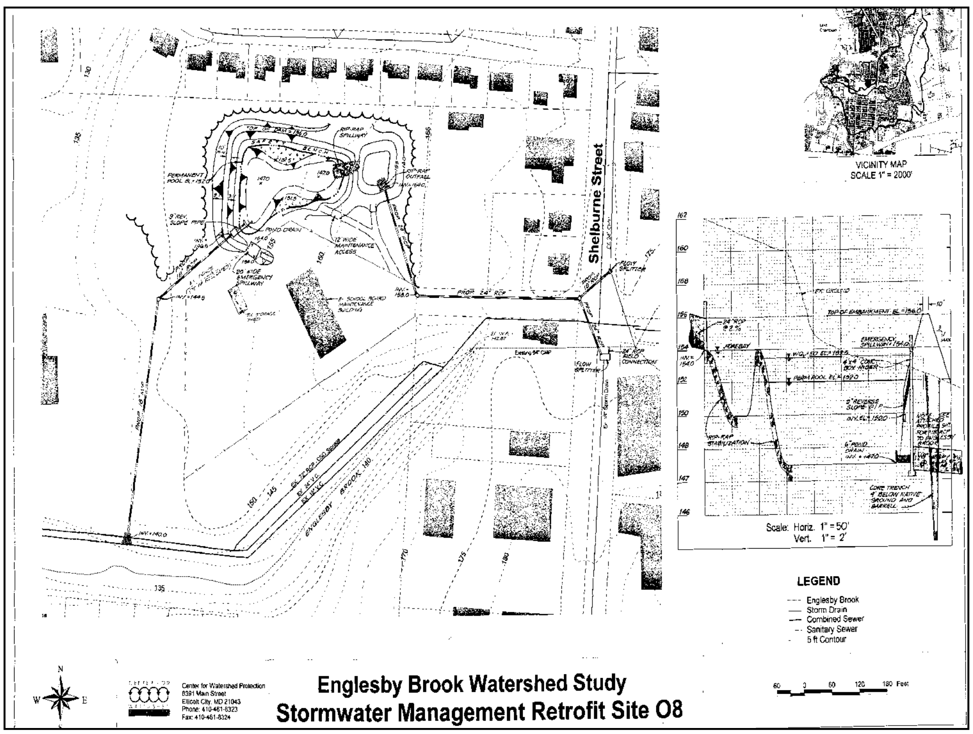


Figure 4.18: Construction drawings and specifications are part of the final retrofit design package

Table 4.28: Special Construction Considerations for Storage Retrofits

Construction Issue	SR-1 Pond	SR-2 Culvert	SR-3 Outfall	SR-4 Conveyance	SR-5 ROW	SR-6 Parking Lot
Temporary Stockpiling	●	◉	◉	●	●	●
Tight Construction Staging	●	●	◉	●	●	◉
Dewatering / Pumping	●	●	●	◉	○	○
Temporary SW Diversion	●	●	◉	◉	○	○
In-Stream ESC work	○	●	◉	◉	○	○
Traffic Barriers/Management	○	●	○	○	●	●
Fencing to Exclude Public	●	◉	◉	◉	◉	●
Flow Splitter Inspection	○	○	●	◉	◉	◉
Retrofit Equipment Washout	◉	●	◉	●	○	○
Off-Site Hauling	●	●	●	●	◉	◉
Utility Marking	●	◉	◉	◉	●	●
Specialized Equipment	◉	●	●	●	●	○
Key: ● Frequent problem; ◉ Sometimes a problem; ○ Seldom a problem						

Step 8: Inspection, Maintenance and Evaluation

Stormwater retrofitting is a continuous process, given that maintenance responsibility lasts throughout the entire life of the retrofit practice. Construction inspection, and retrofit evaluation tasks are all essential to ensure that it functions properly over its design life.

Task 8.1 Construction Inspection

Construction inspections are critical, since retrofits involve unique design elements on highly constrained sites. Contractors may also not be familiar with specialized construction techniques or innovative retrofit practices. Therefore, designers should frequently inspect the retrofit throughout the construction process, answering contractor questions, approving design field modifications, holding regular progress meetings, conducting construction testing, and reviewing construction records.

A final construction inspection is needed prior to completion of the as-built certification (Figure 4.19). If improvements are needed, inspectors compile a punchlist for the contractor of items to correct. As-built certification ensures the retrofit installation is constructed according to construction plans, and is a useful resource for future maintenance inspections.

Table 4.29: Pros and Cons of Different Ways to Secure Construction		
Approach	**Pros**	**Cons**
1. In-House Crews	• Cost-effective • Allows for on-the-job training of local staff • Spreads retrofit understanding and ethic across organization	• Usually takes longer • Crews may not have access to needed equipment • Specialized skills may be lacking • Can be difficult to secure time and resources to get job done – routine tasks need to be deferred
2. Bid as Retrofit-Only	• Can attract specialized and skilled contractors interested in stormwater work • Can proceed at its own schedule • For smaller projects, procurement procedures can be simpler	• Often difficult to get reasonable bids on small, specialized, or unfamiliar work • Inefficient in terms of mobilization and construction tasks • Often requires same level of project management as larger projects
3. Bundle Retrofit With Larger Project	• Can be efficient way to secure construction • Leverages skills and resources of capital projects staff • Best way to get reasonable bid	• Must negotiate “add-on” to budgets that are usually tight • Selected contractor may be unfamiliar with retrofit work • Schedule is subject to vagaries of larger project • Retrofit component may not be priority for local CIP inspectors

Figure 4.19: A final inspection is needed to identify and correct any problems before as-built certification

Task 8.2 Retrofit Maintenance

Successfully retrofit programs plan and budget for future retrofit maintenance. The public and key restoration partners normally have high expectations that the appearance of retrofits installed on public land will be kept up. At the same time, retrofits normally require more frequent maintenance compared to new stormwater practices for several reasons. First, many retrofits tend to be slightly undersized and may require more frequent cleanout. Also, since space is at a premium, maintenance access and staging can be complicated. Lastly, retrofits often contain design features such as flow splitters, pretreatment cells and overflows that are prone to clogging. Therefore, communities will need to explicitly define how their retrofits will be maintained over time. Excellent guidance on developing an effective local maintenance program can be found in CWP (2007).

When retrofits become part of public stormwater infrastructure, communities need to take the several steps to ensure their future performance and longevity:

- Develop a specific maintenance plan for each retrofit that contains specific maintenance tasks, schedules and vendors, and clearly outlines any third party responsibilities.
- Perform annual retrofit maintenance inspections
- Create and maintain a retrofit tracking system to store essential information on the design, construction and maintenance history of individual retrofits.
- Allocate at least 15% of the retrofit capital budget for ongoing maintenance.
- Retain a maintenance call contractor so the community can quickly respond to unexpected or chronic retrofit maintenance problems.
- Train municipal maintenance crews on unique maintenance and vegetation management practices associated with retrofits on golf courses, parks, highways and municipal lands.
- Consider an on-going education program to remind homeowners on how to maintain their retrofits that may have been subsidized by the community.

Task 8.3 Retrofit Project Evaluation

Every stormwater retrofit is an experiment – designers need to measure whether the retrofit projects they build are really working as designed. Two approaches can be used to monitor the performance of retrofit practices. The first approach is a simple visual assessment of the structural or vegetative integrity of a group of retrofits, whereas the second approach seeks to measure the pollution removal performance associated with an individual retrofit (see Manual 2).

The visual assessment approach involves inspecting groups of retrofits to assess their function, longevity, and survival over time. This may include inspections of hydraulic performance and physical integrity, survival of the aquatic plant community, or potential impacts to the upland plant community. The visual assessments provide key performance data to improve future retrofit design and construction.

Performance monitoring relies on intensive stormwater monitoring of individual retrofits to sample their pollutant removal capability. This may be measured directly through storm sampling of pollutant mass into and out of the retrofit, or indirectly through sampling of pollutant accumulation in bottom sediments.

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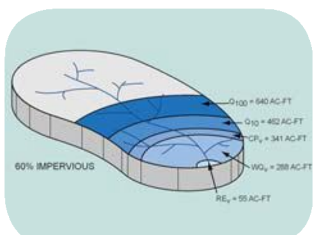
Urban Stormwater Retrofit Practices

Appendices

August 2007



CENTER FOR WATERSHED PROTECTION

Manual 3

Appendix A: Retrofit Reconnaissance Investigation Form and Retrofit Field Guide Template

Retrofit Reconnaissance Investigation **RRI**

WATERSHED:	SUBWATERSHED:	UNIQUE SITE ID:	
DATE:	ASSESSED BY:	CAMERA ID:	PICTURES:
GPS ID:	LMK ID:	LAT:	LONG:

SITE DESCRIPTION

Name:____
Address:____

Ownership: ☐ Public ☐ Private ☐ Unknown
If Public, Government Jurisdiction: ☐ Local ☐ State ☐ DOT ☐ Other:______________________

Corresponding USSR/USA Field Sheet? ☐ Yes ☐ No If yes, Unique Site ID:_________________

Proposed Retrofit Location:

Storage
☐ Existing Pond ☐ Above Roadway Culvert
☐ Below Outfall ☐ In Conveyance System
☐ In Road ROW ☐ Near Large Parking Lot
☐ Other:_______________________________

On-Site
☐ Hotspot Operation ☐ Individual Rooftop
☐ Small Parking Lot ☐ Small Impervious Area
☐ Individual Street ☐ Landscape / Hardscape
☐ Underground ☐ Other:_______________

DRAINAGE AREA TO PROPOSED RETROFIT

Drainage Area ≈ _________________
Imperviousness ≈ _________________%
Impervious Area ≈ _______________

Notes:

Drainage Area Land Use:
☐ Residential
  ☐ SFH (< 1 ac lots)
  ☐ SFH (> 1 ac lots)
  ☐ Townhouses
  ☐ Multi-Family
☐ Commercial
☐ Institutional
☐ Industrial
☐ Transport-Related
☐ Park
☐ Undeveloped
☐ Other:_____________

EXISTING STORMWATER MANAGEMENT

Existing Stormwater Practice: ☐ Yes ☐ No ☐ Possible
If Yes, Describe:

Describe Existing Site Conditions, Including Existing Site Drainage and Conveyance:

Existing Head Available and Points Where Measured:

PROPOSED RETROFIT

Purpose of Retrofit:
☐ Water Quality ☐ Recharge ☐ Channel Protection ☐ Flood Control
☐ Demonstration / Education ☐ Repair ☐ Other:________________________________

Retrofit Volume Computations - Target Storage:

Retrofit Volume Computations - Available Storage:

Proposed Treatment Option:
☐ Extended Detention ☐ Wet Pond ☐ Created Wetland ☐ Bioretention
☐ Filtering Practice ☐ Infiltration ☐ Swale ☐ Other:______________________

Describe Elements of Proposed Retrofit, Including Surface Area, Maximum Depth of Treatment, and Conveyance:

SITE CONSTRAINTS

Adjacent Land Use:
☐ Residential ☐ Commercial ☐ Institutional
☐ Industrial ☐ Transport-Related ☐ Park
☐ Undeveloped ☐ Other:____________________

Possible Conflicts Due to Adjacent Land Use? ☐ Yes ☐ No
If Yes, Describe:

Access:
☐ No Constraints
Constrained due to
☐ Slope ☐ Space
☐ Utilities ☐ Tree Impacts
☐ Structures ☐ Property Ownership
☐ Other:____________________

Conflicts with Existing Utilities:
☐ None
☐ Unknown

Yes	Possible	
☐	☐	Sewer
☐	☐	Water
☐	☐	Gas
☐	☐	Cable
☐	☐	Electric
☐	☐	Electric to Streetlights
☐		Overhead Wires
☐	☐	Other:______________

Potential Permitting Factors:

Dam Safety Permits Necessary	☐ Probable	☐ Not Probable
Impacts to Wetlands	☐ Probable	☐ Not Probable
Impacts to a Stream	☐ Probable	☐ Not Probable
Floodplain Fill	☐ Probable	☐ Not Probable
Impacts to Forests	☐ Probable	☐ Not Probable
Impacts to Specimen Trees	☐ Probable	☐ Not Probable

How many?______________
Approx. DBH______________

Other factors:____
____

Soils:

Soil auger test holes:	☐ Yes	☐ No
Evidence of poor infiltration (clays, fines):	☐ Yes	☐ No
Evidence of shallow bedrock:	☐ Yes	☐ No
Evidence of high water table (gleying, saturation):	☐ Yes	☐ No

SKETCH

DESIGN OR DELIVERY NOTES

FOLLOW-UP NEEDED TO COMPLETE FIELD CONCEPT

- ☐ Confirm property ownership
- ☐ Confirm drainage area
- ☐ Confirm drainage area impervious cover
- ☐ Confirm volume computations
- ☐ Complete concept sketch
- ☐ Obtain existing stormwater practice as-builts
- ☐ Obtain site as-builts
- ☐ Obtain detailed topography
- ☐ Obtain utility mapping
- ☐ Confirm storm drain invert elevations
- ☐ Confirm soil types
- ☐ Other:______________________________

INITIAL FEASIBILITY AND CONSTRUCTION CONSIDERATIONS

SITE CANDIDATE FOR FURTHER INVESTIGATION:	☐ YES	☐ NO	☐ MAYBE
IS SITE CANDIDATE FOR EARLY ACTION PROJECT(S):	☐ YES	☐ NO	☐ MAYBE
IF NO, SITE CANDIDATE FOR OTHER RESTORATION PROJECT(S):	☐ YES	☐ NO	☐ MAYBE

IF YES, TYPE(S):______________________________

THIS RRI FIELD GUIDE TEMPLATE SHOULD BE COMPLETED WITH LOCAL DATA AND ADAPTED TO MEET THE NEEDS OF LOCAL RETROFIT FIELD CREWS

UNIQUE SITE ID NOMENCLATURE GUIDANCE

Unique Site ID = Subwatershed Acronym –Sequential Number

Subwatershed Name	Subwatershed Acronym

Investigation Type	Acronym
Retrofit Reconnaissance Investigation	R

Sequential Numbering begins at "1" for each subwatershed

DELINEATING DRAINAGE AREA AND ESTIMATING CURRENT IMPERVIOUS COVER

Simple Pipe – Drainage Area Ratios	
Pipe Diameter (inches)	**Drainage Area (approx. acres)**
6	0.1 to 1
12	1 to 2
24	2 to 5
36	5 to 25
48	25 to 100
60	100 to 200

Land Use / Impervious Cover Relationships	
Land Use Category	**Impervious Cover (%)**
Agriculture	1.9
2 Acre Lot Residential	10.6
1 Acre Lot Residential	14.3
½ Acre Lot Residential	21.2
1/4 Acre Lot Residential	27.8
1/8 Acre Lot Residential	32.6
Townhome Residential	40.9
Multifamily Residential	44.4
Light Industrial	53.4
Commercial	72.2

RETROFITTING OBJECTIVES

Core Retrofitting Objectives:	
Designated Pollutant(s) of Concern:	
Type of Storage Needed:	

Event	Depth (inches)
Water Quality Storm	
Minimum Water Quality Depth (“walkaway” volume)	
Runoff Reduction Depth	
1-year 24-hour Storm (channel protection)	

Event	Depth (inches)
2-year 24-hour Storm	
10-year 24-hour Storm	
100-year 24-hour Storm	

Preferred Stormwater Treatment Options

Ability of Stormwater Treatment Options to Address Retrofit Objectives								
Retrofit Objective	**Stormwater Treatment Option**							
	Extended Detention	**Wet Ponds**	**Wetlands**	**Bioretention**	**Filtering**	**Infiltration**	**Swales**	**Other**
Correct Past Mistakes	●	●	●	●	◉	●	●	◉
Reduce Flood Damage	●	●	●	○	○	◉	○	○
Education / Demonstration	◉	◉	●	●	●	●	●	●
Trap Trash & Floatables	●	●	●	◉	●	○	○	○
Reduce Flows to Combined Sewer	◉	○	◉	●	○	●	◉	●
Renovate Stream Corridor	◉	●	●	●	○	◉	◉	○
Reduce Bank Erosion	●	◉	◉	◉	○	◉	◉	◉
Support Stream Repair	●	◉	●	◉	◉	●	◉	○
Full Watershed Restoration	●	●	●	●	●	●	●	●

KEY
● = Primary stormwater treatment option to address objective
◉ = Secondary stormwater treatment option
○ = Supplemental stormwater treatment option

Comparison of Pollutant Removal Capability							
Stormwater Treatment Option	**Stormwater Pollutant**						
	TSS	**TP**	**TN**	**Metals**	**Bacteria**	**Organic Carbon**	**Oil & Grease**
Extended Detention	◉	X	○	○	○	X	◉
Wet Ponds	●	◉	○	◉	◉	○	◉
Wetlands	◉	◉	○	○	◉	X	●
Bioretention	◉	X	○	●	●	◉	●
Filtering	●	◉	○	◉	◉	◉	●
Infiltration	●	◉	○	●	?	●	●
Swales	●	X	○	◉	X	◉	●
Rooftop	*Varies*						

KEY
● = Excellent Removal (76 to 100%)
◉ = Good Removal (51 to 75%)
○ = Fair Removal (26 to 51%)
X = Low Removal (0 to 25%)
? = Unknown Removal

NOTES
See Profile Sheets in Chapter 2 for precise removal rates and ranges and Appendix B for documentation on derivation of removal rates

Computing the Retrofit Storage Volume

The ***water quality target volume*** can be determined using the following equation:

$$V_t = P/12 * Rv * DA$$

Where:
- V_t = Target storage volume (acre feet)
- P = Target rainfall depth (in inches for the 90% storm)
- Rv = Runoff coefficient = 0.05 + 0.009 (IC)
- DA = Drainage area (acres)
- 12 = Conversion factor (inches to feet)

To calculate ***channel protection target volume***, use the following equation:

$$V_t = P/12 * IC/100 * DA * 0.6$$

Where:
- V_t = Target storage volume (acre feet)
- P = 1-year 24-hour storm depth (inches)
- IC = Impervious cover (%)
- DA = Drainage area (acres)
- 12 = Conversion factor (inches to feet)
- 0.6 = Pond routing factor

Computing Available Retrofit Storage

For ponds and wetlands, use the following simplified equation to estimate available storage:

$$V_{av} = 2/3 * d * SA$$

Where:
- V_{av} = Available storage at the site (acre-feet)
- SA = Surface area of the facility (acres)
- d = Estimated max depth (feet)
- 2/3 = Average volume factor

For other stormwater treatment options, available storage can be estimated based on the typical surface area or depth requirements of different stormwater treatment options:

Drainage Area – Surface Area Relationships		
Stormwater Treatment Option	**% of Contributing Drainage Area**	**Average Depth (ft)**
Dry ED Ponds	1 to 3%	6
Wet Pond	1 to 3%	6
Constructed Wetland	3 to 5%	2
Bioretention	5 to 10%	1-2
Sand Filters	0 to 5%	2
Infiltration	0 to 5%	1-2
Swales	5 to 15%	2
Filter Strips	5 to 15%	1
Other Retrofits	**Sizing Considerations**	**Average Depth (ft)**
Dry wells	Each dry well can treat 500 sf of roof	1
Rain barrel (50 gal)	Max area draining to rain barrel 500 sf	3-5
Cistern (500 gal)	Max area draining to cistern 1000 sf	5-10
Planter boxes	Max area draining to box 15,000 sf	1.0
Green roofs	1 to 1 ratio of impervious area treated	0.5
Permeable pavers	1 to 1 ratio of impervious area treated	0
Rain gardens	10% of rooftop area	1

Minimum Setbacks

Minimum Distance… *	To Be Maintained From…
10 feet	Property Line
25 feet	Building Foundation
100 feet	Septic System Fields
100 feet	Private Well
1,200 feet	Public Water Supply Well
400 feet	Surface Drinking Water Source
100 feet	Surface Water
Do not submerge	Sewer Line
10 feet	Dry Utilities
15 feet	Overhead Wires
10 feet	Road (Seepage)
30 feet	Highway
*** Confirm that these common setbacks are consistent with local regulations**	

Emergency Contact Information

Field Crew #1 cell phone:	
Field Crew #2 cell phone:	
Fire, non-emergency:	
Police, non-Emergency:	
Illegal dumping hotline:	
Blocked storm drain inlet or pipe:	
Erosion or drainage problems on private property:	
Erosion or drainage problems on public property:	
Sanitary sewer problems:	
Sediment from construction site entering stream:	
Septic leaks / septic tanks:	
Stormwater pond safety or maintenance issue:	
Swimming pool discharge:	
Trash and debris in parks and streams:	
Water main break:	

Appendix B: Defining Retrofit Pollutant Load Reduction

Appendix B: Defining Retrofit Pollutant Load Reduction

I. The Simple Method

The Simple Method estimates the annual pollutant load exported in stormwater runoff from small urban catchments (Schueler, 1987). The Simple Method sacrifices some precision for the sake of simplicity and ease of use, but is a reasonably accurate way to predict the pollutant load reduced by individual stormwater retrofits. The annual pollutant load exported in pounds per year from the contributing drainage area to a retrofit can be determined by solving the equation provided in Table B.1. Each of the terms in the equation can be extracted from data contained in a retrofit concept design.

Depth of Rainfall (P)

P represents the depth of precipitation that falls on the contributing drainage area of the retrofit site during the course of a normal year. Annual rainfall data for select U.S. cities can be obtained from Table 1.2 or derived from local rainfall gages with reliable, long-term (> 20 years) records.

Correction Factor (P_j)

Some of the storms that occur during a given year are so minor that they generate no stormwater runoff. The rainfall from these small storms produce is stored in surface depressions and either evaporates into the air or infiltrates into the ground. To account for these storms, the correction factor (P_j) is used. The design team can analyze local rainfall-runoff patterns to determine the value of P_j or simply use prior analyses from the Washington DC area that indicate Pj is approximately 10% of the annual rainfall depth (Schueler, 1987). The default value for P_j should be 0.9 unless local rainfall-runoff analyses are available.

Runoff Coefficient (R_v)

The runoff coefficient (R_v) is a useful measure of a development site's response to rainfall events. In theory, it is calculated using the equation provided in Table B.2.

Table B.1: Pollutant Load Export Equation
$L = [(P)(Pj)(Rv) \div (12)^{a}](C)(A)(2.72)^{a}$
Where: L = Average annual pollutant load (pounds) P = Average annual rainfall depth (inches) P_j = Fraction of rainfall events that produce runoff R_v = Runoff coefficient, which expresses the fraction of rainfall that is converted into runoff C = Event mean concentration of the pollutant in urban runoff (mg/l) A = Area of the contributing drainage (acres)
[a] 12 and 2.72 are unit conversion factors

Table B.2: The Runoff Coefficient
$R_v = R/P$ Where: R = Volume of storm runoff (watershed-inches) P = Volume of storm rainfall (watershed-inches)

The designer is trying to solve the equation for R and does not know the value of R_v. A study of rainfall/runoff relationships for many small watersheds across the U.S. showed that R_v has a distinctly linear relationship with impervious cover (Schueler, 1987). The runoff coefficient increases in direct proportion to the percent impervious cover (I) present in a catchment. The resulting equation shown in Table B.3 can be used to estimate R_v for the contributing drainage area to a retrofit site.

Site Area (A)

The contributing drainage area (A, in acres) can be directly obtained from the drainage area provided in the retrofit concept plan.

Table B.3: Calculating the Runoff Coefficient
$R_v = 0.05 + 0.009(I)$ Where: I = The amount of impervious cover on the site, expressed as a percentage of the total site area. "I" should be expressed as a whole number within the equation (i.e. a site that is 75% impervious would use I = 75 when calculating R_v)

Pollutant Concentration (C)

The last input data needed is the event mean concentration (EMC) of the stormwater pollutant of concern (C) for the retrofit site. Ideally, local stormwater quality monitoring data would be used to define the value of C, although such data may not be available. As an alternative, designers can consult national stormwater quality monitoring databases that define event mean concentration statistics derived from a large population of runoff monitoring samples. The National Stormwater Quality Database (NSQD) is an extremely helpful tool to define expected EMCs for a wide range of different stormwater pollutants (Pitt *et al.*, 2004). Table B.4 summarizes EMCs for more than 20 common stormwater pollutants in runoff from residential, commercial, industrial, roadway and open space land uses. An updated NSQD is scheduled for release in late 2007.

Some designers may want to choose an alternative EMC value to represent a particular stormwater hotspot or because an on-site retrofit serves a single urban source area. While much less monitoring data is available to characterize hotspot runoff, some of the published data significantly depart from the EMC values predicted by the NSQD. Designers may wish to consult Table B.5 in these situations.

<u>Proper Use of the Simple Method</u>

Several caveats should be observed when applying the Simple Method:

- The Simple Method provides an estimate of the stormwater pollutant load exported from individual retrofit sites less than one square mile in area. More sophisticated water quality simulation models are needed to analyze larger drainage areas.
- It is important to remember that the Simple Method do not represent the total pollutant load exported from a retrofit site, particularly when the contributing drainage area is large enough to generate

appreciable baseflow. The baseflow pollutant load can safely be neglected at the scale of a retrofit site, until the contributing drainage area exceeds about a hundred acres. For example, in a large, sparsely developed subwatershed (e.g. impervious cover of less than 5%), as much as 75% of the annual storm water runoff volume may occur as baseflow instead of surface runoff (Schueler, 1987). In this case, the pollutant load carried by baseflow may be equivalent to the amount of pollution carried by surface runoff.

Table B.4: Summary of Pollutant EMCs in Stormwater Runoff

	All Data	Residential	Commercial	Industrial	Freeways	Open Space
# of Storms Sampled	*3,765*	*1,042*	*527*	*566*	*185*	*49*
Median Event Mean Concentrations (mg/L or ppm, except where noted)						
TDS	80	72	72	86	77.5	125
TSS	59	49	43	81	99	48.5
BOD_5	8.6	9.0	11.0	9.0	8.0	5.4
COD	53	54.5	58	58.6	100	42.1
Fecal Coliform[1]	5,091	7,000	4,600	2,400	1,700	7,200
NO2 + NO3	0.60	0.60	0.6	0.69	0.28	0.59
TKN	1.4	1.5	1.5	1.4	2.0	0.74
Total N	2.0	2.1	2.1	2.09	2.28	1.33
Dissolved P	0.13	0.18	0.11	0.10	0.20	0.13
Total P	0.27	0.31	0.22	0.25	0.25	0.31
Dissolved Cu[2]	8.0	7.0	7.57	8.0	10.9	--
Total Cu[2]	16	12	17	20.8	34.7	10
Dissolved Zn[2]	52	31.5	59	112	51	--
Total Zn[2]	116	73	150	199	200	40

Source: Pitt *et al.*, 2004.
[1] MPN/100 mL, which represents the most probable number (MPN) of bacteria that would be found in 100 mL of water
[2] Cu and Zn values are shown in μg/l

Table B.5: Summary of Pollutant EMCs Associated with Stormwater Hotspots						
	TSS	Total P	Total N	Fecal Coliform[1]	Total Cu[2]	Total Zn[2]
Land Use	Median Event Mean Concentrations (mg/L or ppm, except where noted)					
Lawns	602	2.1	9.1	2,400	17	50
Landscaping	37	--	--	9,400	94	263
Residential Roof	19	0.11	1.5	26	200	312
Commercial Roof	9	0.14	2.1	110	7	256
Industrial Roof	17	--	--	580	62	1390
Res/Comm Parking Lot	27	0.15	1.9	180	51	139
Industrial Parking Lot	228	--	--	270	34	224
Driveway	173	0.56	2.1	1,700	17	107
Local Residential Street	172	0.55	1.4	3,700	25	173
Commercial Street	468	--	--	1,200	73	450
Gas Station	31	--	--	--	88	290
Auto Recycler	335	--	--	--	103	520
Heavy Industry	124	--	--	--	148	1600

Sources: Claytor *et al.*, 1996; Steuer *et al.*, 1997; Bannerman, 1993; and Waschbuch, 2000.
[1] MPN/100 mL, which represents the most probable number (MPN) of bacteria that would be found in 100 mL of water
[2] Cu and Zn values are shown in μg/l

II. Calculating Pollutant Loads and Pollutant Load Reduction

Pollutant load reduction by individual stormwater retrofits is computed in a six-step process, as shown in Table B.6, and described below:

Step 1: Calculate CDA Impervious Cover

This step calculates the impervious cover (I) present in the drainage area contributing to the proposed retrofit. Operationally, impervious cover is defined as any hard surface in the catchment that cannot infiltrate rainfall, such as rooftops, roads, sidewalks, driveways and any other compacted gravel or dirt surfaces. As a general rule, man-made surfaces that are not vegetated should be considered impervious. Chapter 4.3 describes the methods used to measure or estimate impervious cover in the retrofit contributing drainage area (Cappiella and Brown, 2001). Unless upland restoration practices remove or disconnect impervious cover in the contributing drainage area, impervious cover before and after the retrofit will be the same.

Step 2: Calculate Pre-Retrofit Pollutant Load

The second step computes the pollutant load exported from the drainage area prior to the retrofit using the equation shown in Table B.7.

Step 3: Identify the Stormwater Retrofit

This step identifies the stormwater treatment option(s) that will be applied to the retrofit site, which can be taken directly from the retrofit concept design.

Table B.6: Process for Calculating Pre- and Post-Retrofit Pollutant Loads	
Step	**Task**
1	Calculate Site Imperviousness
2	Calculate the Pre-Retrofit Pollutant Load
3	Identify the Stormwater Retrofit
4	Determine the Retrofit Pollutant Removal Efficiency
5	Calculate the Post-Retrofit Pollutant Load
6	Calculate the Pollutant Load Reduction of the Retrofit

Table B.7: Method for Calculating Pre-Retrofit Pollutant Loading

$L_{pre} = [(P)(Pj)(Rv)/12^a](C)(A)(2.72)^a$

Where:
L_{pre} = Average annual pollutant load exported from the site prior to stormwater retrofitting (pounds)
P = Average annual rainfall depth (inches)
P_j = Fraction of rainfall events that produce runoff
R_v = Runoff coefficient
C = Event mean concentration of the pollutant in urban runoff (mg/l)
A = Area of the contributing drainage area (acres)

[a] 12 and 2.72 are unit conversion factors

Step 4: Use the Design Point Method to Determine Retrofit Pollutant Removal Efficiency

Median pollutant removal rates for each stormwater treatment option are presented in Chapter 3. These rates need to be adjusted to account for site-specific factors and design features than can enhance or reduce their pollutant removal rates using the design point method. The method consists of a series of tables that award or deduct points for certain site-specific conditions and design factors present at the individual retrofit site. The designer selects the appropriate design point table for the stormwater treatment option they plan to use, reviews the proposed retrofit design and computes a total retrofit design score. If the design score is positive, the removal rate for the pollutant of concern is increased using the equation provided in Table B.8. If the retrofit score is negative, the removal rate is reduced using the equation provided in Table B.9.

The example provided in Box B.1 illustrates the use of the design point method on a hypothetical retrofit site. Note that the net design score excludes the design factors that only influence phosphorus removal, while the net phosphorus score includes them. The designer should use the net phosphorus score to adjust the phosphorus removal rate and the net design score to adjust the removal rates for all other pollutants.

Table B.8: Adjusting Removal Rates for Retrofits with a Positive Design Score

Adjusted RR = Median RR + [(DS ÷ 5) ∗ (High End RR – Median RR)]

Where:
RR = Removal rate (%)
DS = Design score

Note: A maximum of five positive design points is allowed

Table B.9: Adjusting Removal Rates for Retrofits with a Negative Design Score

Adjusted RR = Median RR + [(DS ÷ 5) ∗ (Median RR – Low End RR)]

Where:
RR = Removal rate (%)
DS = Design score

Note: A maximum of five negative design points is allowed

Box B.1: Applying the Design Point Method

A bioretention retrofit is being proposed to serve a contributing drainage area that is one acre in size and 35% impervious. After review of the retrofit concept design, the designer awards the following points for the project:

Negative Factors that Reduce Removal Rates

- Does not provide full WQ_v, due to space constraints
- Filter bed less than 18 inches deep, due to limited available head
- Single cell design, due to space constraints
- Underdrain needed, to address cold climate conditions and impermeable soils

Positive Factors that Enhance Removal Rates

- Filter media soil P-Index less than 30, to enhance phosphorus removal
- Upflow pipe on underdrain, to enhance nitrogen removal

Design Factors	***X***	***Points***
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Tested filter media soil P Index less than 30 (phosphorus only)	**X**	+ 3
Filter bed deeper than 30 inches		+ 1
Two cell design with pretreatment		+ 1
Permeable soils; no underdrain needed		+ 2
Upflow pipe on underdrain	**X**	+1
Impermeable soils; underdrain needed	**X**	- 1
Filter bed less than 18 inches deep	**X**	- 1
Single cell design	**X**	- 1
Bioretention cell is less than 5% of CDA		-1
Does not provide full water quality storage volume	**X**	- 2
Filter media not tested for P Index (phosphorus only)		- 3
NET DESIGN SCORE (max of 5 points)		**- 4**
NET PHOSPHORUS SCORE		**- 1**

Since both design scores are negative (-4 and -1), the median pollutant removal rates are decreased using the equation provided in Table B.9. The adjusted removal rates for the retrofit are shown below:

Total Suspended Solids	24%	Bacteria	26%
Total Phosphorus	-11%	Hydrocarbons	82%
Total Nitrogen	41%	Chloride	0%
Total Zinc	48%	Trash/Debris	82%
Total Copper	48%		

The example shows why it is so important to maximize site and design factors to enhance the pollutant removal performance of the retrofit. In many cases, the designer may revise their concept design to include design features that can attain a higher net design point score.

Step 5: Calculate Post-Retrofit Pollutant Load

This step calculates the pollutant load exported from the drainage area contributing to the retrofit using the equation shown in Table B.10.

Step 6: Calculate the Pollutant Load Reduction of the Retrofit

The final step calculates the pollutant load reduced by the proposed stormwater retrofit, which is simply the post-retrofit pollutant load, subtracted from the pre-retrofit pollutant load (Table B.11).

Table B.10: Method for Calculating Post-Retrofit Pollutant Loading
$L_{post} = L_{pre} * [1 - (RR)]$
Where: L_{post} = Annual pollutant load exported from the site after stormwater retrofit (pounds/yr) RR = Adjusted removal rate (%) calculated in Step 4 L_{pre} = Annual pollutant load exported from the site before the stormwater retrofit (pounds/year)

Table B.11: Method for Calculating the Pollutant Load Reduction of the Retrofit
$LR = L_{post} - L_{pre}$
Where: LR = Annual pollutant load removed by the proposed retrofit (pounds/year) L_{post} = Annual pollutant load exported from the site after stormwater retrofitting (pounds/year) L_{pre} = Annual pollutant load exported from the site prior to stormwater retrofitting (pounds/year)

III. Design Point Tables

This section presents the design point tables for seven stormwater treatment options.

1. ED Retrofits		
Design Factors	***X***	***Points***
Wet ED or Multiple Cell Design		+ 2
Exceeds target WQv by more than 25%		+ 1
Exceeds target WQv by more than 50%		+ 2
Off-line design		+ 1
Flow path greater than 1.5 to 1		+ 1
Sediment forebay		+ 1
Constructed wetland elements included in design		+ 1
On-line design		- 1
Flow path less than 1:1		- 1
Pond SA/CDA ratio less than 2%		- 2
Does not provide full WQv volume		- 2
Pond intersects with groundwater		- 2
NET DESIGN SCORE (max. of 5 points)		

2. Wet Pond Retrofits		
Design Factors	***X***	***Points***
Wet ED or Multiple Pond Design		+ 2
Exceeds target WQv by more than 50%		+ 2
Exceeds target WQv by more than 25%		+ 1
Off-line design		+ 1
Flow path greater than 1.5 to 1		+ 1
Sediment forebay at major outfalls		+ 1
Wetland elements cover at least 10% of surface area		+ 1
Single cell pond		- 1
Flow path less than 1:1		- 1
On-line design		- 1
Pond SA/CDA ratio less than 2%		- 2
Does not provide full WQv volume		- 2
Pond intersects with groundwater		- 2
NET DESIGN SCORE (max of 5 points)		

3. Wetland Retrofits		
Design Factors	***X***	***Points***
Pond-Wetland or Multiple Cell Design		+ 2
Exceeds target WQv by more than 50%		+ 2
Complex wetland microtopography		+ 2
Exceeds target WQv by more than 25%		+ 1
Flow path greater than 1.5 to 1		+ 1
Wooded wetland design		+ 1
Off-line design		+ 1
No forebay or pretreatment features		- 1
Wetland intersects with groundwater		- 1
Flow path is less than 1:1		- 1
No wetland planting plan specified		- 2
Wetland SA to CDA ratio is less than 1.5%		- 2
Does not provide full WQv volume		- 2
NET DESIGN SCORE (max of 5 points)		

4. Bioretention Retrofits		
Design Factors	***X***	***Points***
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Tested filter media soil P Index less than 30 (phosphorus only)		+ 3
Filter bed deeper than 30 inches		+ 1
Two cell design with pretreatment		+ 1
Permeable soils; no underdrain needed		+ 2
Upflow pipe on underdrain		+1
Impermeable soils; underdrain needed		- 1
Filter bed less than 18 inches deep		- 1
Single cell design		- 1
Bioretention cell is less than 5% of CDA		-1
Does not provide full water quality storage volume		- 2
Filter media not tested for P Index (phosphorus only)		- 3
NET DESIGN SCORE (max of 5 points)		
NET PHOSPHORUS SCORE (max of 5 points)		

5. Filtering Retrofits		
Design Factors	***X***	***Points***
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Site is a severe or confirmed hotspot		+ 2
Organic media used within filter bed (all pollutants except N/P)		+ 2
Two cells with at least 25% WQv allocated to pretreatment		+ 1
Filter bed SA is at least 2.5% of CDA		+ 1
Filter bed exposed to sunlight		+ 1
Off-line design w/ storm bypass		+ 1
Dry pretreatment		- 1
On-line design, w/o storm bypass		- 1
Underground design (except MCTT)		- 1
Filter design is hard to access for maintenance		- 2
Does not provide full WQv volume		- 3
NET DESIGN SCORE (max of 5 points)		

6. Infiltration Retrofits		
Design Factors	**X**	**Points**
Exceeds target WQv by more than 50%		+ 3
Exceeds target WQv by more than 25%		+ 2
Tested infiltration rates between 1.0 and 4.0 in/hr		+ 2
At least two forms of pretreatment prior to infiltration		+ 2
CDA is nearly 100% impervious		+ 1
Off-line design w/ cleanout pipe		+ 1
Underdrain utilized		- 1
Filter fabric used on trench bottom		- 1
CDA more than 1.0 acre		- 1
Soil infiltration rates < 1.0 in/hr or > 4.0 in/hr		- 2
Pervious areas or construction clearing in CDA		- 2
Does not provide full WQv volume		- 3
NET DESIGN SCORE (max of 5 points)		

7. Swale Retrofits		
Design Factors	***X***	***Points***
Exceeds target WQv by more than 50%		+ 3
Dry or wet swale design		+ 2
Exceeds target WQv by more than 25%		+ 2
Longitudinal swale slope between 0.5 to 2.0%		+ 1
Velocity within swale < 1 fps during WQ storm		+ 1
Measured soil infiltration rates exceed 1.0 in/hr		+ 1
Multiple cells with pretreatment		+ 1
Off-line design w/ storm bypass		+ 1
Longitudinal swale slope < 0.5% or > 2%		- 1
Measured soil infiltration rates less than 1.0 in/hr		- 1
Swale sideslopes more than 5:1 h:v		- 1
Swale intersects groundwater (except wet swale)		- 1
No pretreatment to the swale or channel		- 1
Swales conveys stormflows up to 10 year storm		- 2
Does not provide full WQv volume		- 2
Grass channel		- 3
NET DESIGN SCORE (max of 5 points)		

Appendix C: Deriving the Channel Protection Storage Volume

Appendix C: Deriving the Channel Protection Storage Volume

Channel protection can help mitigate the impacts of development on streams by preventing an increased frequency of channel-forming events. The most commonly used channel protection method provides 24 hours of extended detention of the runoff generated by the 1-year, 24-hour storm. This method stores and gradually releases runoff so that critical erosive velocities in downstream channels are not exceeded. This appendix presents a technique that can be used to estimate the channel protection storage volume for an individual stormwater retrofit.

I. Storage Volume Estimation

The method used to estimate the channel protection volume was first proposed by Harrington (1987) and uses a modified version of the graphical peak discharge design procedure presented in Technical Reference 55 (TR-55) (NRCS, 1986). A seven-step method is presented to help designers compute several common hydrologic parameters needed to estimate the channel protection storage volume (Table C.1).

Step 1: Compute the 1-Year, 24-Hour Runoff Volume

The first step calculates the 1-year, 24-hour runoff volume using either the Curve Number (CN) Method presented in TR-55 or the Simple Method (Appendix B), although the two methods will yield different results.

Previous studies have found that the CN Method tends to underestimate the volume of runoff created by rainfall events of less than 2 inches (NYDEC, 2003) and that its accuracy may be limited when the runoff created by a storm is less than 0.5 inches (NRCS, 1986). The Simple Method also has its caveats (Appendix B). The designer may want to estimate the required channel protection volume using both methods and compare the results.

Step 2: Determine the Time of Concentration for the Subwatershed

The time of concentration (T_c) is the time that it takes for stormwater runoff to travel from the most hydraulically distant point in a subwatershed to the retrofit site. It is computed by delineating the stormwater flow path over pervious areas, open channels and storm drain pipes to get to the retrofit using standard velocity equations to compute the time it takes for stormwater runoff to travel the longest route. TR-55 presents more specific guidance on computing T_c.

Step 3: Compute the Initial Abstraction and Initial Abstraction Ratio

The initial abstraction (I_a) term represents all rainfall losses that occur before runoff begins. The losses include water retained in surface depressions, water intercepted by vegetation and water lost to evaporation and infiltration. I_a is highly variable but generally correlates with soil and land cover parameters and is directly related to the CN of the subwatershed (NRCS, 1986). If the CN Method was used to calculate the 1-year, 24-hour runoff volume (Step 1), the value of CN is already known and the value of I_a can be obtained from Table C.2 or can be calculated using the following equation:

$I_a = 200/CN - 2$

Where:
I_a = Initial abstraction (inches)
CN = Subwatershed curve number (dimensionless)

If the 1-year, 24-hour runoff volume was calculated using the Simple Method, the value of CN can be back calculated using the following relationship between the runoff volume, curve number and precipitation depth (NYDEC, 2003):

$CN = 1000/[10 + 5P + 10Q - 10(Q^2 + 1.25QP)^{1/2}]$

Where:
P = Rainfall resulting from the 1-year, 24-hour storm event (inches)
Q = Runoff volume resulting from the 1-year, 24-hour storm event (inches)

The value of I_a can then be obtained from Table C.2 or by using the equation provided above. Once I_a is computed, the initial abstraction ratio (I_a/P) can be computed simply by dividing the initial abstraction by the rainfall depth. This ratio represents the fraction of the rainfall that is retained in surface depressions, intercepted by vegetation or lost to evaporation and infiltration.

<u>Step 4: Compute the Uncontrolled Peak Discharge</u>

The next step computes the uncontrolled peak discharge from the subwatershed (NRCS, 1986). This requires the determination of the unit peak discharge factor (q_u). This value can readily be determined using the values of T_c and I_a/P and knowledge of the rainfall distribution (Type I, IA, II, III) within the subwatershed (Figure C.1). With this information, the proper value of q_u can be selected from Figure C.2, C.3, C.4, or C.5.

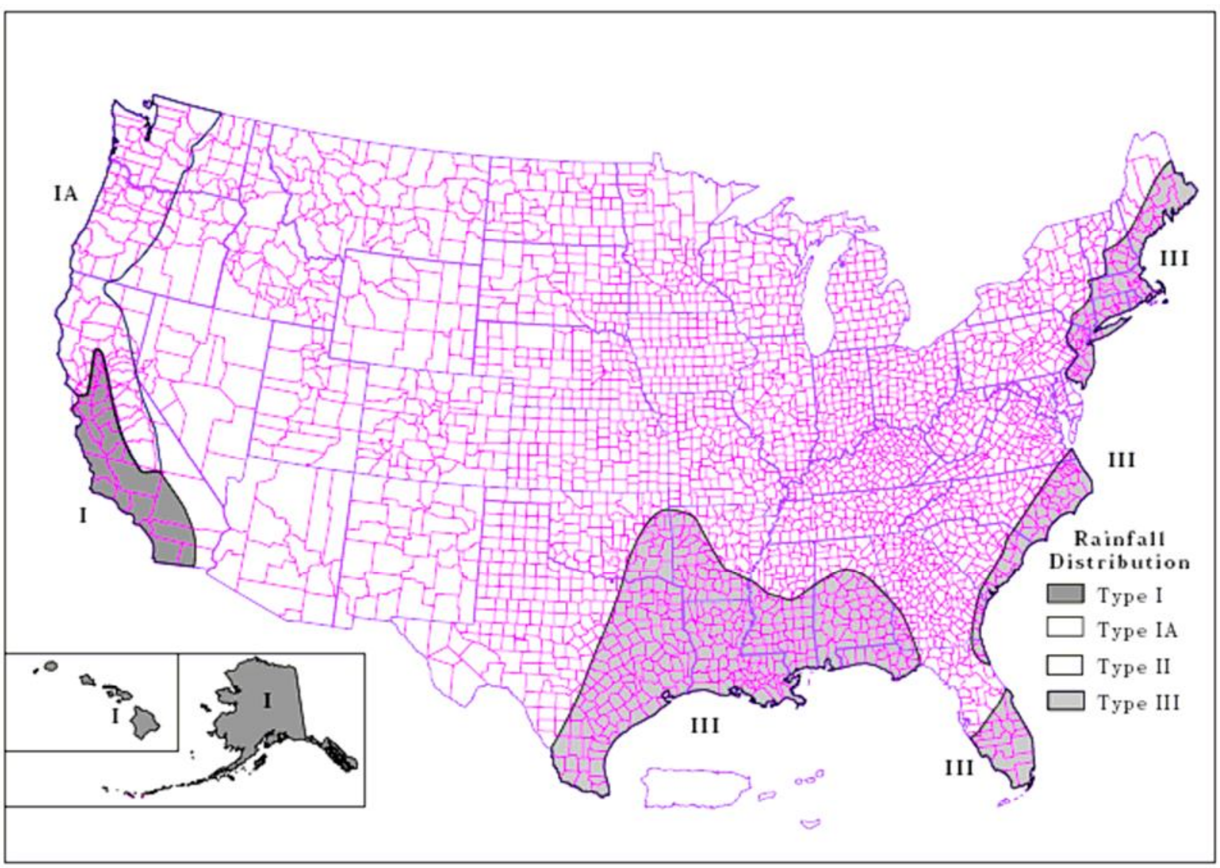
Table C.1: Process for Estimating Channel Protection Volume

Step No.	Task
1	Compute the 1-Year, 24-Hour Runoff Volume
2	Determine the Time of Concentration for the Subwatershed
3	Compute the Initial Abstraction and Initial Abstraction Ratio
4	Compute the Uncontrolled Peak Discharge (Inflow)
5	Find the Ratio of the Uncontrolled Peak Discharge to the Controlled Peak Discharge
6	Calculate the Ratio of Storage Volume to Runoff Volume
7	Determine the Extended Detention Storage Volume

Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

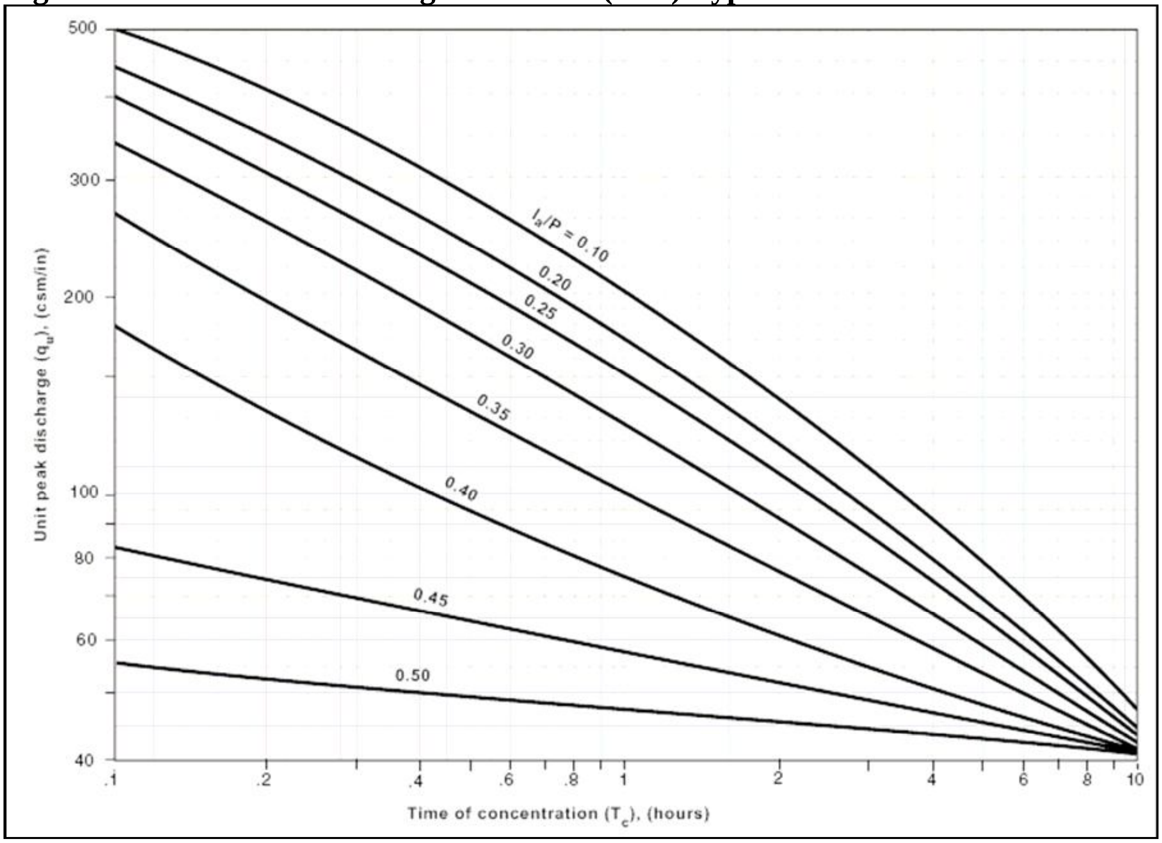
Table C.2: The Relationship Between CN and I_a
Source: NRCS, 1986

Figure C.1: NRCS Rainfall Distribution Boundaries



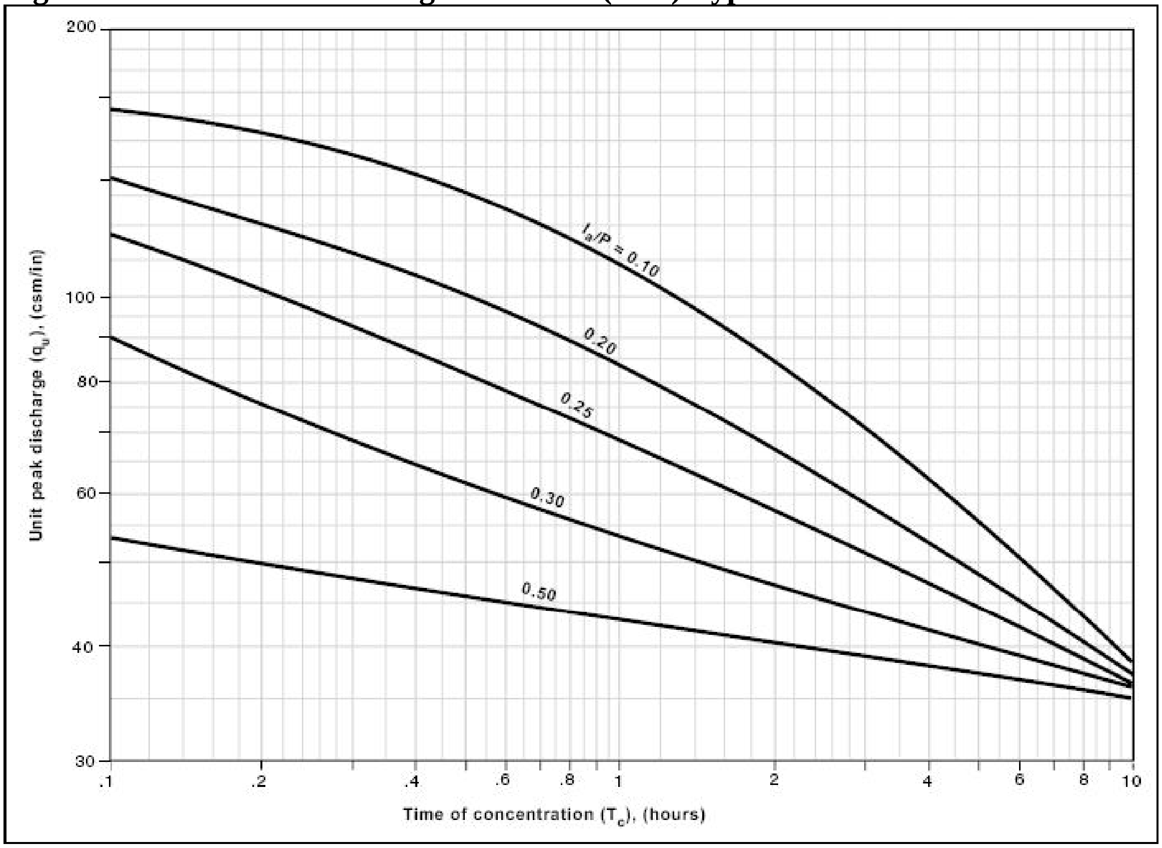
Source: NRCS, 1986

Figure C.2: Unit Peak Discharge for NRCS (SCS) Type I Rainfall Distribution



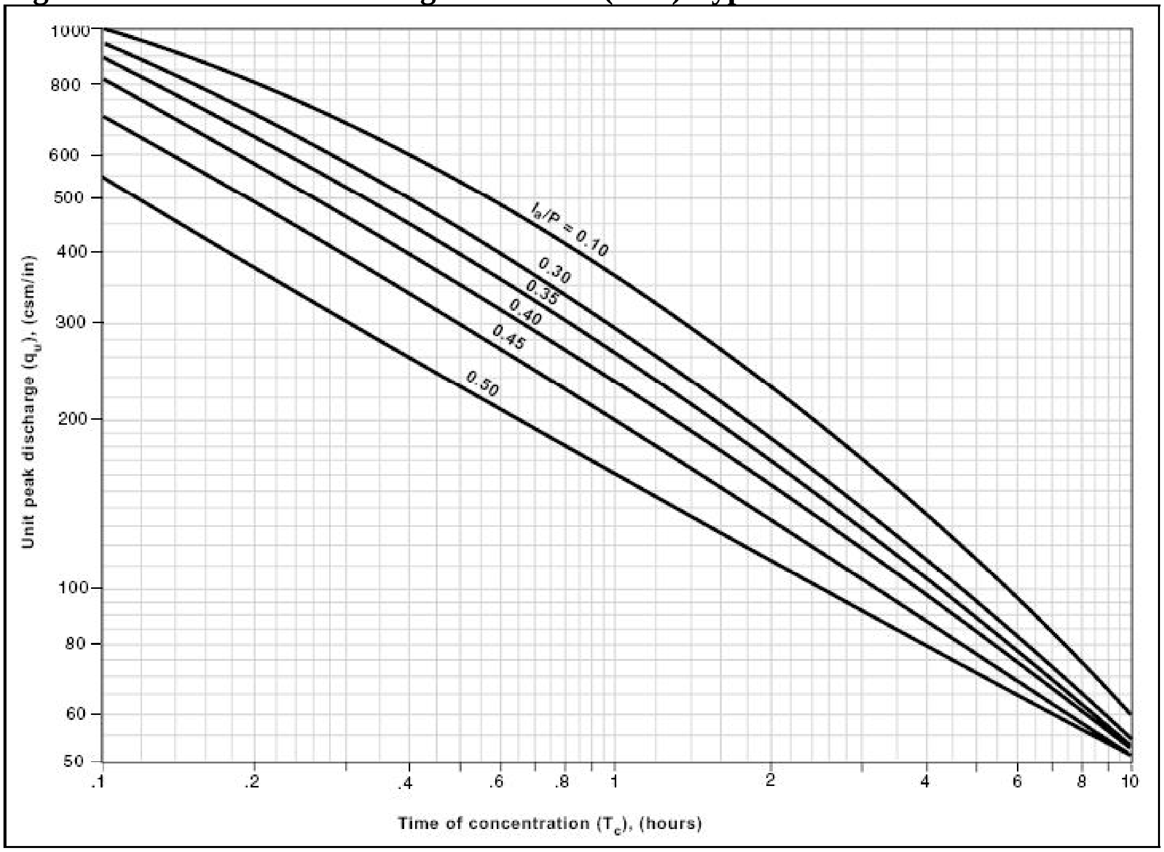
Source: NRCS, 1986

Figure C.3: Unit Peak Discharge for NRCS (SCS) Type IA Rainfall Distribution



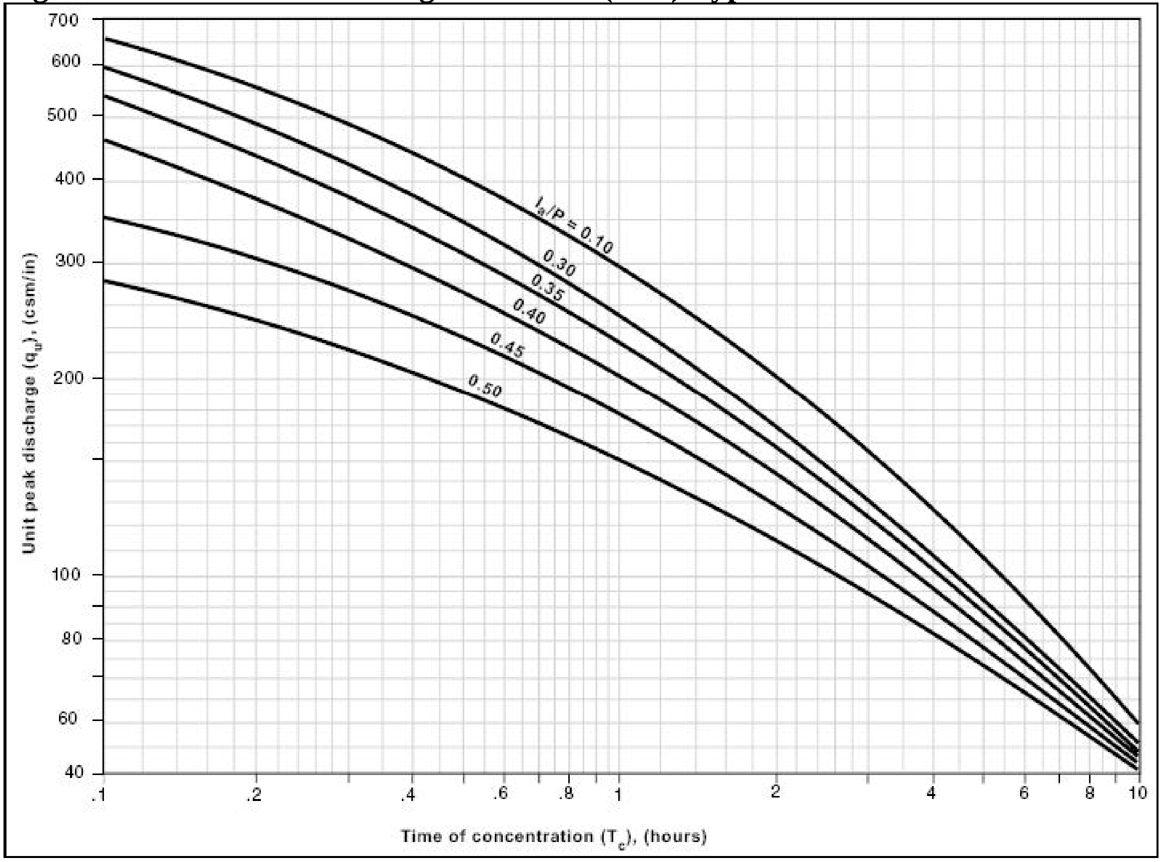
Source: NRCS, 1986

Figure C.4: Unit Peak Discharge for NRCS (SCS) Type II Rainfall Distribution



Source: NRCS, 1986

Figure C.5: Unit Peak Discharge for NRCS (SCS) Type III Rainfall Distribution



Source: NRCS, 1986

If the computed initial abstraction ratio (I_a/P) is outside the range of values provided in Figures C.2 - C.5, then the appropriate boundary value should be used. Linear interpolation can be used to estimate the unit peak discharge when the value of I_a/P falls between the values provided in the figures (NRCS, 1986).

Using the value of the unit peak discharge (q_u), the uncontrolled peak discharge (q_i) resulting from the 1-year, 24-hour storm event can be estimated using the following equation:

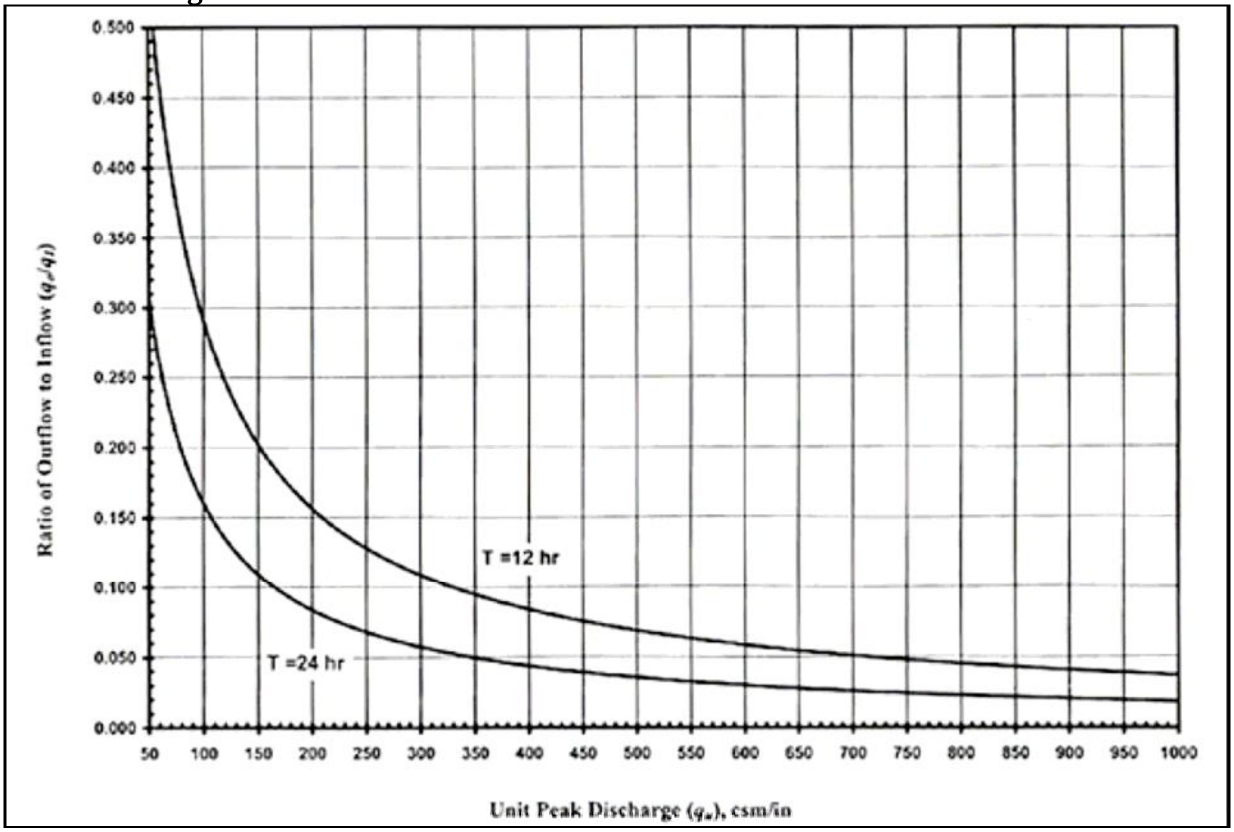
$$q_i = (q_u)(A)(Q)$$

Where:
q_i = Uncontrolled peak discharge (cfs)
q_u = Unit peak discharge (csm/in)
Q = Runoff volume resulting from the 1-year, 24-hour storm event (inches)
A = Area of the subwatershed (sq. miles)

Step 5: Find the Ratio of the Uncontrolled Peak Discharge to the Controlled Peak Discharge

The next step involves determining the ratio of the uncontrolled peak discharge to the controlled peak discharge (q_o/q_i). Once the unit peak discharge (q_u) and required extended detention time (T) (e.g. typically 24 hours) are known, Figure C.6 can be used to determine the value of q_o/q_i.

Figure C.6: Calculating the Ratio of the Uncontrolled Peak Discharge to the Controlled Peak Discharge



Source: MSSC, 2005

If the retrofit discharges to a cold water trout stream, it may be wise to limit the extended detention time to a maximum of 12 hours to reduce the stream warming effect.

Step 6: Calculate the Ratio of Storage Volume to Runoff Volume

The next step calculates the ratio of storage volume to runoff volume (V_s/V_r). Using the value of q_o/q_i obtained from Figure C.6 and the appropriate rainfall distribution (Type I, IA, II, III), the value of V_s/V_r can be obtained from Figure C.7.

The ratio of storage volume to runoff volume (V_s/V_r), can also be calculated numerically for a Type II or Type III rainfall distribution:

$$V_s/V_r = 0.683 - (1.43)(q_o/q_i) + (1.64)(q_o/q_i)^2 - (0.804)(q_o/q_i)^3$$

Where:
V_s = Required storage volume (acre-feet)
V_r = Runoff volume (acre-feet)
q_o = Controlled peak discharge/peak outflow discharge (cfs)
q_i = Uncontrolled peak discharge/peak inflow discharge (cfs)

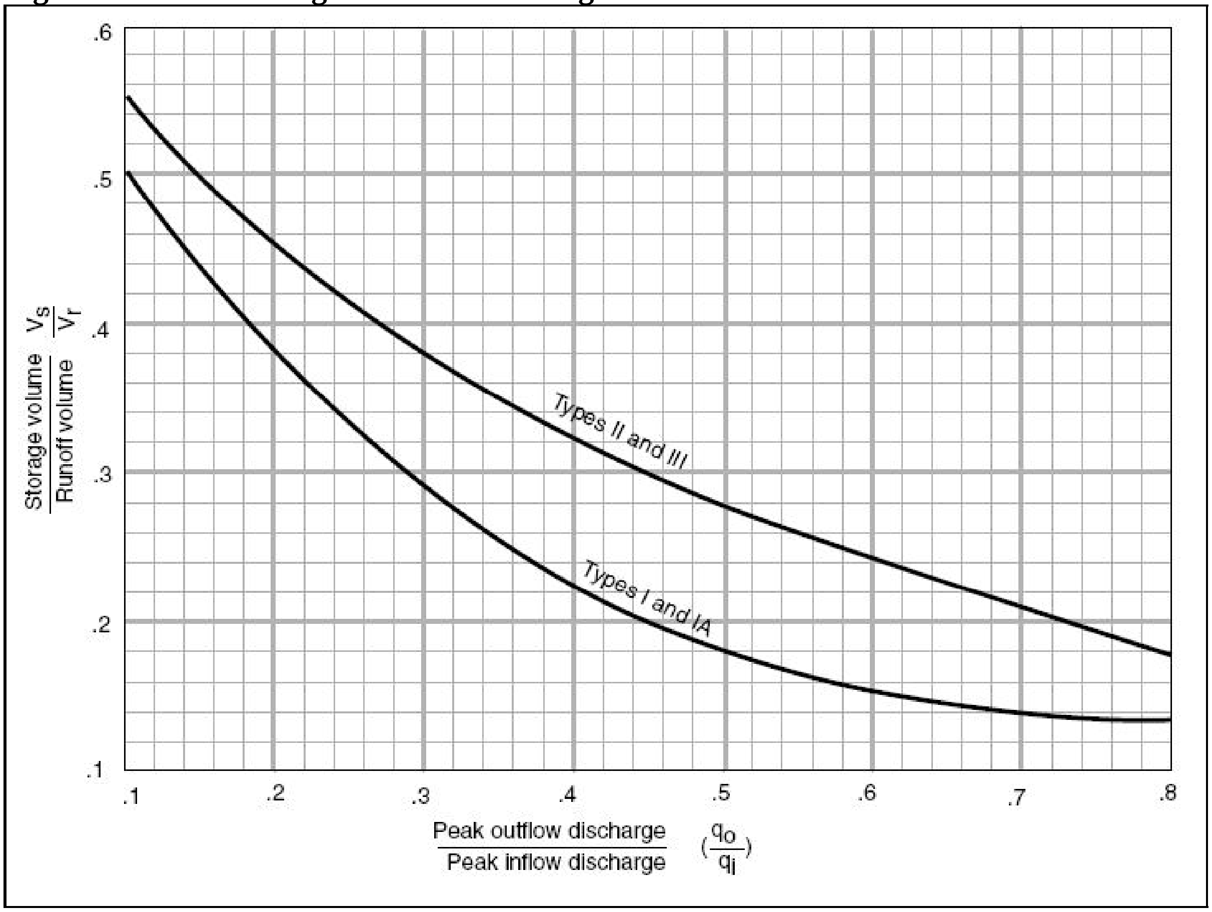
Step 7: Determine the Extended Detention Storage Volume

The final step in the process is to determine the required extended detention storage volume. Using the value of V_s/V_r obtained from Figure C.7 (or the equation provided in Step 6), the required extended detention volume can be calculated using the following equation:

$$V_s = (V_s/V_r)(V_r)$$

Where:
V_s = Required storage volume (acre-feet)
V_r = Runoff volume (acre-feet)

Figure C.7: Calculating the Ratio of Storage Volume to Runoff Volume



Source: NRCS, 1986

II. Estimated Channel Protection Volumes for Select U.S. Cities

Table C.3 provides an estimate of the channel protection volume needed for various levels of watershed impervious cover in select U.S. cities. A short-cut design rule is that the storage capacity needed to provide channel protection is about 60% of the runoff volume generated by the 1-year, 24-hour storm. This rule was used to derive the estimates. Designers can quickly refer to this table to initially estimate the target channel protection storage volume needed at a retrofit site.

Table C.3: Estimated CPv for Select U.S. Cities (cubic feet/acre)

City	1-Yr, 24-Hr Rainfall (in.)	Watershed Imperviousness (%)			
		10%	30%	60%	90%
		CPv (cf per acre)[1]			
Atlanta, GA	3.6	1,098	2,509	4,626	6,743
Knoxville, TN	2.5	762	1,742	3,213	4,683
New York City, NY	2.7	823	1,882	3,470	5,057
Greensboro, NC	2.7	823	1,882	3,470	5,057
Boston, MA	2.6	793	1,812	3,341	4,870
Baltimore, MD	2.6	793	1,812	3,341	4,870
Buffalo, NY	2.0	610	1,394	2,570	3,746
Washington, DC	2.6	793	1,812	3,341	4,870
Columbus, OH	2.2	671	1,533	2,827	4,121
Kansas City, MO	3.2	976	2,230	4,112	5,994
Seattle, WA	1.6	488	1,115	2,056	2,997
Burlington, VT	1.7	518	1,185	2,185	3,184
Dallas, TX	3.2	976	2,230	4,112	5,994
Austin, TX	3.2	976	2,230	4,112	5,994
Minneapolis, MN	2.4	732	1,673	3,084	4,495
Coeur D'Alene, ID	1.1	335	767	1,414	2,060
Salt Lake City, UT	1.1	335	767	1,414	2,060
Denver, CO	1.4	427	976	1,799	2,622
Phoenix, AZ	1.1	335	767	1,414	2,060
Las Vegas, NV	0.8	244	558	1,028	1,498

Appendix D: Retrofit Pollutant Removal Rates

Appendix D: Retrofit Pollutant Removal Rates

I. Basic Approach

This appendix documents how the pollutant removal rates for the stormwater treatment options presented in Chapter 3 were derived. The basic approach used to derive the pollutant removal rates was to update the National Pollutant Removal Performance Database (Winer, 2000) with new performance studies published in the last five years. The updated database was then statistically analyzed to derive new median and quartile values for each major group of stormwater treatment practices. The low end and high end are the 25th and 75th quartiles, respectively. Also, removal rates were rounded to the nearest 5 % for ease of use.

Where data gaps remained, engineering judgment was used to derive pollutant removal rates as described in Section II. These removal rates are indicated by **bold type** in the ensuing tables and designers should regard them as a provisional estimate until additional pollutant removal performance data becomes available. The notes section of the tables can provide more information on these derived rates.

II. Documentation of Pollutant Removal Rates

Recurring data gaps existed for organic carbon, hydrocarbons, chlorides, trash/debris and, for some practices, bacteria. The particular assumptions to derive removal rates for these pollutants are summarized below.

- *Organic Carbon* – Organic carbon is used to describe all total organic carbon, BOD or COD removal data contained in the original database (Winer, 2000). Very little new monitoring data was available, so the medians and quartiles were re-computed from the 2000 database.

- *Hydrocarbons* - Previous studies have found that the ability of stormwater treatment practices to remove petroleum hydrocarbons is closely related to their ability to remove suspended solids (Winer, 2000). This is due to the fact that hydrocarbons quickly adsorb to sediment particles and organic matter suspended in stormwater runoff (Schueler and Shepp, 1993). Consequently, hydrocarbon removal was assumed to be generally comparable to total suspended solids removal.

- *Chlorides* - Because chloride is extremely soluble, it is very difficult to remove from stormwater runoff. A review of 10 performance monitoring studies in cold climate regions failed to find any instance of positive removal rates for chlorides for any stormwater treatment practice. Indeed, many practices actually had negative removal rates. It was therefore assumed that chloride removal rates would be zero for all stormwater treatment options.

- *Trash/Debris* – No performance monitoring data were available to define removal rates for trash and debris. It was assumed that the pollutant removal mechanisms for trash and debris are similar to those used to remove total suspended solids (e.g. gravitational settling, screening). One key difference is that some materials float on the surface, although most would still be trapped in the stormwater practice unless there was a major overflow. It was therefore assumed that trash and debris removal rates would be equal or slightly greater than the suspended solids removal rate for most stormwater practices.

Table D.1: Range of Reported Removal Rates for Dry Extended Detention Ponds			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	20	50	70
Total Phosphorus	15	20	25
Soluble Phosphorus	-10	-5	10
Total Nitrogen	5	25	30
Organic Carbon	15	25	35
Total Zinc	0	30	60
Total Copper	20	30	40
Bacteria	**25**	**35**	**50**
Hydrocarbons	**40**	**70**	**80**
Chloride	**0**	**0**	**0**
Trash/Debris	**65**	**80**	**85**
Notes: Ten monitoring studies evaluated the performance of dry ED ponds for most parameters. Only two monitoring studies were available on **bacteria removal rates** for dry extended detention ponds, so engineering judgment was needed to establish the final removal rates. The primary mechanisms that facilitate bacteria removal are exposure to UV light and gravitational settling (Schueler, 1999). These removal mechanisms have been documented for wet ponds, which have been more extensively monitored for bacteria removal in wet ponds. Since stormwater runoff is not retained within dry ED ponds for as long as wet ponds, settling times and exposure to UV light are reduced. Dry ED ponds also have a greater risk of sediment resuspension than wet ponds, which can reintroduce previously removed bacteria back into the water column. It was therefore assumed that bacteria removal rates for dry ED ponds were approximately half of those measured for wet ponds.			

Table D.2: Range of Reported Removal Rates for Wet Ponds			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	60	80	90
Total Phosphorus	40	50	75
Soluble Phosphorus	40	65	75
Total Nitrogen	15	30	40
Organic Carbon	25	45	65
Total Zinc	40	65	70
Total Copper	45	60	75
Bacteria	50	70	95
Hydrocarbons	**60**	**80**	**90**
Chloride	0	0	0
Trash/Debris	**75**	**90**	**95**
Note: 46 wet ponds have been monitored over the past two decades so the removal rate range shown above should be reasonably accurate. **Hydrocarbon** and **trash/debris** removal rates should be considered provisional			

Table D.3: Range of Reported Removal Rates for Stormwater Wetlands			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	45	70	85
Total Phosphorus	15	50	75
Soluble Phosphorus	5	25	55
Total Nitrogen	0	25	55
Organic Carbon	0	20	45
Total Zinc	30	40	70
Total Copper	20	50	65
Bacteria	**40**	**60**	**85**
Hydrocarbons	**50**	**75**	**90**
Chloride	0	0	0
Trash/Debris	**75**	**90**	**95**

Notes: 40 monitoring studies were available to define rates for total suspended solids, total phosphorus, soluble phosphorus, total nitrogen, organic carbon, total zinc and total copper for constructed wetlands. Only three studies measured **bacteria removal** by constructed wetlands. Research profiled in Strecker et al. (2004) indicated bacterial removal rates for constructed wetlands is generally positive, but typically lower than wet ponds. It was therefore assumed that bacteria removal rates would be at least 10% lower than in wet ponds.

Table D.4: Range of Reported Removal Rates for Bioretention Areas			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	**15**	**60**	**75**
Total Phosphorus	-75	5	30
Soluble Phosphorus	-10	5	50
Total Nitrogen	40	45	55
Organic Carbon	**40**	**55**	**70**
Total Zinc	40	80	95
Total Copper	40	80	95
Bacteria	**25**	**40**	**70**
Hydrocarbons	**80**	**90**	**95**
Chloride	0	0	0
Trash/Debris	**80**	**90**	**95**

Notes: Ten new bioretention monitoring studies have been released in the last few years that meet the quality control criteria to be included in the updated database so it is now possible to define removal rates for total phosphorus, soluble phosphorus, total nitrogen, total zinc and total copper. Surprisingly, there were only four studies to define the **total suspended solids removal rate**. Similar pollutant removal mechanisms operate in both bioretention and filtering practices (sedimentation, filtration). The median total suspended solids removal rate for filtering practices is similar to the high end rate for bioretention, which suggests that bioretention rates can be expected to go up as more performance data becomes available. No **bacteria removal rates** were available in the literature as of 2006. Initial research reported by Hunt and his colleagues in 2007 suggest that bacteria removal rates were high. Therefore, it was once again assumed that bioretention would function in the same manner as filtering practices and have similar removal rates. The **phosphorus removal rates** reported for bioretention are clearly bi-modal. Sites where the soil media had high phosphorus content tended to leach phosphorus and experience negative removal rates. Sites where soils with a low P-index volume consistently performed at the upper end of the phosphorus removal range. Again, as more performance data become available and soil media testing becomes standard, the range of rates for bioretention is expected to shift.

Table D.5: Range of Reported Removal Rates for Stormwater Filters			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	80	85	90
Total Phosphorus	40	60	65
Soluble Phosphorus	-10	5	65
Total Nitrogen	30	30	50
Organic Carbon	40	55	70
Total Zinc	70	90	90
Total Copper	35	40	70
Bacteria	25	40	70
Hydrocarbons	**80**	**85**	**95**
Chloride	**0**	**0**	**0**
Trash/Debris	**85**	**90**	**95**
Note: Nearly 20 studies have evaluated filtering practices, so reliable removal rates are reported for total suspended solids, total phosphorus, soluble phosphorus, total nitrogen, total zinc, total copper and bacteria. It should be noted that while total nitrogen removal is positive, most filters leak nitrate-nitrogen. Also, performance of vertical sand filters and the MCTT were excluded from the statistical analysis.			

Table D.6: Range of Reported Removal Rates for Infiltration Practices			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	**60**	**90**	**95**
Total Phosphorus	50	65	95
Soluble Phosphorus	**55**	**85**	**95**
Total Nitrogen	0	40	65
Organic Carbon	80	90	95
Total Zinc	65	65	85
Total Copper	**60**	**85**	**90**
Bacteria	**25**	**40**	**70**
Hydrocarbons	**60**	**90**	**95**
Chloride	**0**	**0**	**0**
Trash/Debris	**85**	**90**	**95**
Notes: Performance monitoring data for infiltration practices continue to be limited although the number of studies had doubled since 2000 (N=12). Total phosphorus, total nitrogen and total zinc all meet the minimum five-study test to be included for statistical analysis. Only three studies were available to characterize **total suspended solids, soluble phosphorus and total copper removal rates**. Recent research tends to confirm the range in removal rates (UNHSC, 2005). No data was found for **hydrocarbon, chloride and trash/debris** removal, so these were estimated using the general removal assumptions described earlier. **Bacteria removal rates** were also lacking, so it was once again assumed that they would be similar to those reported for filtering practices.			

Table D.7: Range of Reported Removal Rates for Swales			
Pollutant	**Low End**	**Median**	**High End**
Total Suspended Solids	70	80	90
Total Phosphorus	-15	25	45
Soluble Phosphorus	-95	-40	25
Total Nitrogen	40	55	75
Organic Carbon	55	70	85
Total Zinc	60	70	80
Total Copper	45	65	80
Bacteria	**- 65**	**-25**	**25**
Hydrocarbons	**70**	**80**	**90**
Chloride	0	0	0
Trash/Debris	**0**	**0**	**50**

Notes: 17 studies were available from the database to establish removal rates for total suspended solids, total phosphorus, soluble phosphorus, total nitrogen, total zinc and total copper. Only four studies were available for bacteria removal and all were negative. However, a positive 25% rate was established for the high end, since pollutant removal mechanisms in dry swales should have some capability to remove bacteria in the soil. Several studies monitored chloride and found only negative removal. No removal data was available for trash/debris, although it was presumed to be low due to washout of trash during high flows. A 50% removal rate was established for the high end for swale designs that contain treatment cells with actual trapping capability.

Appendix E: Derivation of Unit Costs for Stormwater Retrofits and New Stormwater Treatment Construction

Appendix E: Derivation of Unit Costs for Stormwater Retrofits and New Stormwater Treatment Construction

I. Basic Approach, Findings and Caveats

A. Basic Cost Approach

The cost analysis involved a review of existing cost studies for new stormwater treatment options including studies by Wossink and Hunt (2003), Brown and Schueler (1997), Hathaway and Hunt (2006), WDNR (2003), LGPC (2003), Chicago DEP (2003), Liptan and Strecker (2003) and WSSI (2006). In addition, Hoyt (2007) performed an analysis of actual retrofit construction costs for nearly 100 projects around the country with the following sample size: new storage retrofits (N= 16), pond retrofits (N=31), on-site bioretention retrofits (N =18) and other retrofits (N = 29).

The basic approach was as follows:

- All construction costs were indexed and updated to 2006 dollars using the Engineering News Record Construction Cost Index (RS Means, 2006)
- All studies that utilized cost equations were solved for common retrofit boundary conditions to create a cost range (e.g., drainage area and impervious cover). For example, the range in pond costs was bounded at the high end (10 acres CDA, 15% IC) and the low end (250 acres CDA and 65% IC)
- Retrofit costs were expressed on a common basis ($/cubic foot treated or $/impervious acre treated)
- Total costs were calculated as the base construction cost multiplied by the design/engineering (D&E) rate. Both factors differed between new BMP and retrofit construction
- While a median cost is given for each new stormwater practice or retrofit type, cots are best expressed as a range. In most cases, the range was defined as the 25 to 75% quartiles of the known costs.
- When multiple cost estimates differed for the same retrofit practice, original studies were analyzed for cost-specific factors to explain the difference in terms of design or labor factors that might develop more predictive cost categories.
- Some engineering judgment was needed to classify costs such as the differential costs between new stormwater and retrofit construction.

B. Findings

- Retrofit costs are extremely variable depending on site conditions and retrofit design complexity. In many cases, construction costs were an order of magnitude different for the same volume of stormwater treated (Table E.1).
- Retrofit base construction costs generally exceeded the cost of new stormwater practices by a factor of 1.5 to 6.
- Construction costs for storage retrofits are generally lower than on-site retrofits based on the cost per impervious acre treated. The most influential retrofit cost

factor is the total acreage of impervious cover treated by a retrofit. Unit costs decline as acreage treated increases. By contrast, smaller on-site retrofits that treat less than a ½ acre of impervious cover tend to be two orders of magnitude more expensive per treated area than storage retrofit practices.

- Design and engineering (D&E) costs for storage retrofits exceed those for new stormwater practices when their much higher base retrofit construction costs are factored in.
- The D&E estimate for pond construction derived by Brown and Schueler (1997) of 32% was used to define costs for project management, design, permitting, landscaping and erosion and sediment control
- A 32% D&E rate also applies to on-site retrofits, based on Hoyt's 2007 review of the D&E costs for 17 projects.
- The components of D&E costs differ between storage retrofits (where permitting, and engineering studies dominate) than on-site retrofits (where design and project management dominates).
- A 40% D&E rate should be used for any retrofit requiring major environmental permits.
- The D&E rate differs based on retrofit location. For example, a 5% value was assigned for little retrofits, rain barrels and small rain gardens

Table E.1: Retrofit Construction Costs
2006 $ to Treat an Impervious Acre

Retrofit Type	Low End [1]	Median	High End
Pond Retrofit	$ 3,600	$ 11,100	$ 37,100
New Storage Retrofit	$ 9,000	$ 19,400	$ 32,200
Urban On-site Retrofit [2]	$ 58,000	$ 88,000	$ 150,000

[1] Low end is the 25% quartile value, high end is the 75th quartile value
[2] Mean contributing drainage area to practice = 0.58 acres

Table E.2: Base Construction Costs for New Stormwater Practices BMPs
2006 $ per impervious acre treated

Stormwater Practice	Low End	Median	High End	Source:
Constructed Wetlands [1]	$ 2,000	$ 2,900	$ 9,600	Cost Equation
Extended Detention [1]	2,200	3,800	7,500	Cost Equation
Wet Ponds [1]	3,100	8,350	28,750	Cost Equation
Water Quality Swales [2]	10,900	18,150	36,300	Derived
Bioretention	19,900	25,400	41,750	Cost Equation
Infiltration [3]	19,900	25,400	41,750	Derived
Residential Rooftop	10,900	27,200	49,000	Derived
Filtering Practices	18,150	58,100	79.900	Cost Equation
Non-Residential Roof	21,800	90,750	1,100,000	Derived

[1] based on typical range of CDA and IC noted in the basic approach section
[2] Derived from a cost per square foot
[3] Assumed to be comparable to bioretention costs
Please check documentation notes for all practices later in Part II of this Appendix

Base retrofit costs can be compared to the costs for constructing new stormwater practices shown in Table E.2. The cost ranges shown for new stormwater practices should not be used to estimate retrofit costs unless the designer is confident that all the site conditions outlined in Table E.3 can be met. Few proposed retrofit sites will meet these conditions.

Table E.4 compares the range in unit treatment costs for a large number of retrofit techniques while Chapter 2 offers more detailed cost data for each retrofit location in a subwatershed.

Table E.3: Guidance on when new STO cost equations can be used

- Abundant surface land is present on the site to provide flexibility in retrofit layout and design
- Site has adequate head and has no major utilities to work around
- Site topography is such that a neutral earthwork balance can be achieved (i.e., no off-site hauling)
- No flow splitters, riser modifications or other special plumbing is needed to make the site work
- No significant environmental permits are required
- No major landscaping or planting plan is needed in the design

Table E.4 Range of Retrofit Costs (2006 $ per cubic foot of runoff treated)

Retrofit Technique	Median Cost	Range
Pond Retrofits	$ 3.00	$ 1.00 to 10.00
Rain Gardens	$ 4.00	$ 3.00 to 5.00
New Storage Retrofits	$ 5.00	$ 2.50 to 9.00
Larger Bioretention Retrofits	$ 10.50	$ 7.50 to 17.25
Water Quality Swale Retrofit	$ 12.50	$ 7.00 to 22.00
Cisterns	$ 15.00	$ 6.00 to 25.00
French Drain/Dry Well	$ 12.00	$ 10.50 to 13.50
Infiltration Retrofits	$ 15.00	$ 10.00 to 23.00
Rain Barrels	$ 25.00	$ 12.50 to 40.00
Structural Sand Filter	$ 20.00	$ 16.00 to 22.00
Impervious Cover Conversion	$ 20.00	$ 18.50 to 21.50
Stormwater Planter	$ 27.00	$ 18.00 to 36.00
Small Bioretention Retrofits	$ 30.00	$ 25.00 to 40.00
Underground Sand Filter	$ 65.00	$ 28.00 to 75.00
Stormwater Tree Pits	$ 70.00	$ 58.00 to 83.00
Permeable Pavers	$ 120.00	$ 96.00 to 144.00
Extensive Green Rooftops	$ 225.00	$ 144.00 to 300.00
Intensive Green Rooftops	$ 360.00	$ 300.00 to 420.00

Note: Costs shown are base construction costs and do not include additional D&E costs, which can range from 5 to 40%

C. Caveats

The cost analysis described herein is subject to a number of important caveats that should be fully understood before using it to estimate retrofit project costs.

- Construction costs vary regionally based on labor rates, construction materials and design standards. The new construction cost data were largely drawn from North Carolina and Maryland studies, while retrofit cost data were derived from a larger national cross-section of projects (VA, NY, DE, CA, TX, OR, MD, OR, VA).

- Most on-site retrofits included in the national cost database were experimental designs or demonstration projects that had high initial construction costs. It is expected that unit retrofit costs will stay the same or even decline in future years as designers gain more experience and utilize more cost-effective and standardized construction techniques for these practices.

- All construction costs shown here exclude land acquisition costs. If land must be acquired, retrofit costs increase sharply, and some costly retrofit options, such as underground treatment, become more cost-effective.

- Construction costs do not include the costs needed to find the retrofit site (i.e., costs to perform a retrofit inventory, develop a concept design, assess project feasibility or rank priority projects in a subwatershed plan).

- Limited data were available to derive costs for several stormwater treatment options including infiltration and water quality swales, and some on-site retrofit techniques (e.g., expanded tree pits). These estimates should be viewed with caution until more actual retrofit cost data is generated.

- The base construction cost does not include costs for retrofit design and engineering (D&E) that is estimated by multiplying base construction cost of storage retrofits by a fixed percentage ranging from 5 to 40%. For on-site retrofits, the D&E factor ranges from 5 to 32%.

- Retrofit costs can be extremely variable, and actual costs for individual retrofit projects can significantly exceed the range shown, depending on site conditions. Designers should carefully evaluate the retrofit construction inflators/deflators shown in Chapter 2 and adjust their cost estimates accordingly.

- The construction cost for several on-site retrofits such as permeable pavers and green rooftops do not reflect the incremental cost difference of the surface they substitute or replace (e.g., regular asphalt vs. permeable pavers; conventional rooftop vs. green rooftop). If the surface needs replacing, actual retrofit costs should be expressed as the incremental cost difference from the conventional surface and the new retrofit.

- Reported costs for several on-site retrofits such as bioretention, rain gardens, and rain barrels vary greatly depending on whether it is assumed they will be designed and installed by volunteers or by paid contractors. Even when on-site retrofits are installed by volunteers, localities may still need to incur a retrofit delivery cost to make them happen.

- The water quality sizing assumption for this retrofit cost analysis was treatment of one inch of runoff per impervious acre acre (or 3630 cubic feet of storage per impervious acre). If local water quality sizing target criteria depart from this assumption, the cost data should be adjusted accordingly.

II. Documentation of Unit Cost Data

This section outlines the assumptions and methods used to derive unit costs for new stormwater practices and retrofit practices.

A. ED Ponds

New Construction: The Brown and Schueler (1997) ED pond cost equation was updated to 2006 dollars using the ENR Construction Cost Index, which yielded the following equation:

$$CC = (11.54)(V_s^{0.780})$$

Where
V_s = storage volume in cubic feet

The equation was then solved for a common set of retrofit boundary conditions to create a range of expected construction costs:

Low end: 250 acre contributing drainage area (CDA) and 65% impervious cover (IC)
Average: 50 acre CDA and 35% IC
High end: 10 acre CDA and 15% IC

The base construction costs for each boundary condition were then converted into costs per impervious acre treated.

Retrofit Construction: The new storage retrofit database compiled by Hoyt (2007) contained numerous retrofits that used ED in combination with other stormwater practices to achieve full retrofit treatment. When these results are compared to the costs for new ED pond construction, it is evident that retrofits are about five times more expensive (median: $19,440 per impervious acre treated vs. $3,800). The median retrofit cost for new storage retrofits in Table E.1 should be used if the proposed ED retrofit is combined with wetland and/or wet pond treatment. The lower end cost of $ 9,000 is more appropriate for standalone ED retrofits. The new ED pond cost equation can be used if the retrofit satisfies the construction conditions outlined in Table E.3.

B. Wet Pond

New Construction: The same basic methods were used to update the three new wet pond construction costs from Brown and Schueler (1997) and Wossink and Hunt (2003). The updated 2006 equations are as follows:

Wet extended detention ponds
$$CC = (12.02)(V_s^{0.750})$$
Wet ponds
$$CC = (277.89)(V_s^{0.553})$$
Wet ponds:
$$CC = (17{,}333)(A^{0.672})$$

where A = contributing drainage area (acres) and only applies to CDA from 1 to 67 acres

The three equations were solved for the same retrofit boundary conditions established for ED ponds to define a low, middle and high-end range for expected construction costs. The results from all three equations were averaged, although the low end of the W&H equation was omitted because it was outside of the data range of its sample ponds. Unit construction costs for each boundary condition were then converted into cost per impervious acre treated.

Retrofit Construction: The new storage retrofit database compiled by Hoyt (2007) contained numerous retrofits that relied on wet ponds for water quality treatment. When these costs are compared to the costs for new wet pond construction, it is evident that retrofits are about 2.3 times more expensive than new stormwater wetland construction (median: $19,440 vs. $8,350). This difference is reasonable given the more complicated construction conditions expected at wet pond retrofit sites. The median retrofit cost shown in Table E.1 is recommended for planning purposes, subject to the construction cost inflators/deflators outlined in Chapter 2. In rare cases, the new wet pond cost equations can be used if the retrofit site satisfies the new development construction conditions outlined in Table E.3.

C. Constructed Wetlands

New Construction: The same basic methods were used to update the two wetland construction costs derived by Brown and Schueler (1997) and Wossink and Hunt (2003) into 2006 dollars. The adjusted equations are as follows:

All ponds and wetlands

$$CC = (29.43)(V_s^{0.701})$$

Stormwater wetlands

$$CC = (4{,}800)(A^{0.484})$$

Note: Equation applies to 4 – 200 acre CDA

The equations were solved for the previously stated retrofit boundary conditions to create a range of expected construction costs, although the cost estimates generated between the two equations were not always in close agreement. For example, the low-end wetland cost estimate predicted by the Wossink and Hunt equation was omitted from the analysis because it is outside of the range of their wetland sample population. Some engineering judgment was needed to reconcile the low-end, middle and high-end unit costs for constructed wetlands.

Retrofit Construction: The new storage retrofit database compiled by Hoyt (2007) contained numerous retrofits that combined constructed wetlands with ED and/or wet ponds to achieve treatment. When these results are compared to the costs for new constructed wetland construction, retrofits appear to be nearly 7 times more expensive (median: $19,440 vs. $2,900). At first glance, this discrepancy is difficult to explain, but involves the inherent difference between new and retrofit construction of stormwater wetlands. The cost for new constructed wetlands is comparatively low since their shallow design requires much less excavation (which is normally the greatest component of base construction cost). Designers essentially rely on a greater site footprint to save excavation costs, which is seldom available in a retrofitting situation. Very few retrofits in the Hoyt (2007) database were solely constructed wetlands; most devoted considerable storage to extended detention and wet pond treatment in order to squeeze the wetland into a tight retrofit site.

Consequently, the median new storage retrofit unit cost in Table E.1 is reasonable to use if constructed wetlands are designed with ED or wet ponds cells. Designers may wish to adjust this cost higher or lower depending of the site-specific construction cost inflators/deflators outlined in Chapter 2. If it is an ideal site, and corresponds to the new development construction conditions outlined in Table E.3, the most appropriate new constructed wetland cost equation can be used as an alternate.

D. Bioretention

New Construction: Several equations were updated to estimate new bioretention costs on projects greater than one acre in contributing drainage area (Brown and Schueler, 1997 and Wossink and Hunt 2003). Adjusted to 2006 dollars, the two equations are:

$CC = (8.02)(WQ_v^{0.990})$
$CC = (12,664)(A^{1.088})$ *(clay soils)*

These equations apply to more engineered bioretention areas and typically include underdrains, soil media and some type of pretreatment cell. The Wossink and Hunt equation for bioretention in sandy soils (where underdrains are not needed and less soil amendment is required) were not used, since this is not a common condition for retrofits on disturbed urban soils. The equations were solved for several hypothetical retrofit situations to establish expected boundary conditions as follows:

1.0 acre CDA and 100% IC
1.5 acre CDA and 65% IC
3.0 acre CDA and 35% IC

This approach helped define a low-end, middle and high-end unit costs for bioretention. Some engineering judgment was needed since the two equations were not always in agreement. For example, the low-end prediction from the Wossink and Hunt equation appeared unrealistically low and the middle value of ($5.50/cubic foot) was used to tie down the low end unit cost for new bioretention construction instead. The resulting cost estimates were then compared against the unit costs for rain gardens reported by Hathaway and Hunt (2006) and were found to be in general agreement.

Retrofit Construction: The cost of bioretention retrofits varies greatly depending on the contributing drainage area, design objective, installer and site conditions at the proposed retrofit site. Therefore, a four-tiered approach was used to define retrofit costs:

1. *Small highly urban retrofits*: The Hoyt (2007) database contained numerous bioretention retrofits built on highly urban uses with less than a half acre of CDA. The median cost for these bioretention retrofits was 3.5 times greater than the cost for a new bioretention area ($88,000 vs. $25,500 per impervious acre treated). The higher cost is due to need for demolition, extensive landscaping, full media replacement, underdrains and new connections to existing storm drain system. In addition, these retrofits are all professionally installed. Consequently, an average cost range of $25 to $40 per cubic foot treated is recommended for bioretention retrofits with less than 0.5 acre CDA. The higher end of the range applies when bioretention retrofits are designed as a landscape feature (i.e., special stone, intensive plant materials and special grading/berms).

2. *Rain gardens*: Numerous researchers have reported a much lower unit cost ($3 to $5 per cubic foot) to construct rain gardens (Hathaway and Hunt, 2006, WDNR (2003) and WSSI (2006). The term “rain gardens” is used here to define shallow bioretention areas in relatively permeable soils that lack underdrains and are installed with volunteer labor. This situation may occur

for homeowner installation of rain gardens and some demonstration retrofits.

3. *Typical bioretention retrofits*: Most bioretention retrofits fall between these two extremes, but are still likely to exceed the costs for new bioretention areas. Bioretention retrofits typically require more pretreatment, re-grading, new inlets and intensive landscaping than their new development counterparts. Not much data, however, were available to define this cost difference. Based on engineering judgment, a multiplier of 1.5 was applied to the new bioretention unit cost data to reflect the expected costs for typical bioretention retrofits ($10.50 per cubic foot treated, range of $7.50 to $17.75). Designers should adjust the project estimate to reflect the site-specific construction cost inflators/deflators described in Chapter 3.

4. *Ideal bioretention retrofits*. Some proposed sites are a natural for bioretention retrofit (e.g., abundant treatment area located in a depression, use of simple curb cuts to direct runoff into the retrofit, sandy soils, a simple planting plan etc.). Retrofit sites that satisfy the new development site conditions in Table E.3 may use unit costs for new bioretention construction (median $7.00 range of $5.50 to 10.50 per cubic foot treated)

E. Filtering Practices

New Construction: The costs for new stormwater filters depend on the complexity of their design, so a tiered cost estimation approach was followed. Sand filters were classified into three categories, as follows:

1. Surface sand filter (no concrete poured and no major structural elements)
2. Structural sand filter (perimeter or surface filter w/ two cells with major concrete/structural elements or special media)
3. Underground sand filter (deep excavation, concrete vault construction and special treatment media)

The Brown and Schueler (1997) cost equation was updated to 2006 dollars to define costs for surface sand filters, whereas the Wossink and Hunt (2003) equation was relied on to define costs for structural sand filters:

$CC = (59{,}678)(A^{0.882})$
Note: Applies to CDA of 0.5 to 9 acres

The cost equations were solved the equation for typical retrofit boundary conditions, as follows:

1.0 acre CDA and 100% IC
1.5 acre CDA and 65% IC
3.0 acre CDA and 35% IC

Based on these boundary conditions, expected low-end, middle and high-end values were determined for surface and structural sand filters. Some engineering judgment was used to adjust the high end predictions of the Wossink and Hunt equation downward, based on cross-checking with earlier cost estimates reported by Schueler (2000a).

Two sources were used to derive unit construction costs for underground sand filters (Schueler, 2000a) and Hoyt's 2007 review of nine underground and multi-chamber treatment train retrofit projects. The costs were quite variable, but a projected cost range of $28 to $75 covered most of the projects.

Retrofit Construction – Given limited cost data and the similarity between new and retrofit filter costs, the three tier approach for estimating filtering practice costs was not adjusted to account for retrofitting. It was also reasoned was that most sand filters for new development are built at tight and constrained sites that are comparable to most retrofit situations.

F. Infiltration Practices

New Construction - No new construction cost data was discovered in the literature to estimate the unit costs to construct new infiltration practices. Given the inherent similarity in the construction process between bioretention and infiltration, it was therefore assumed that infiltration construction costs would be equivalent for new bioretention areas (see Table E.2).

Retrofit Construction – Very little infiltration retrofit cost data has been reported, presumably because of poor urban soil conditions have limited their use. It was assumed that infiltration retrofit costs would be twice that of new bioretention areas to account for expanded soil testing, pretreatment cells, erosion and sediment control and landscaping.

H. Water Quality Swales

New Construction – Several assumptions and methods were needed to derive unit construction costs for new water quality swales, which are frequently reported on a linear foot (Claytor, 2003) or a square foot basis (Hathaway and Hunt (2006). Most estimates are for grass swales that use checkdams to get surface storage. No data were available for dry swales which are similar in construction to bioretention areas (e.g., underdrains and full media replacement). It was assumed that this class of water quality swales would be equivalent to the high end of new bioretention areas reported in Table E.2

The unit costs for water quality swales reported by Claytor (2003) were updated to 2006 dollars, and were converted to a per cubic foot basis using the following common retrofit channel conditions:

- 4 foot bottom width, 6 inch average ponding depth, 3:1 side slopes ($8.20/cubic foot)
- 8 foot bottom width, 6 inch average ponding depth, 3:1 side slopes ($4.75/cubic foot)
- 12 foot bottom width, 6 inch average ponding depth, 3:1 side slopes ($3.50/cubic foot)

Consequently, the low end for new water quality swale costs was established using the Claytor approach, and the high end using “running” bioretention.

Retrofit Construction- Swale retrofit costs were assumed to be twice that of new water quality swale construction due to the need for greater re-grading, creation of multiple cells, vegetation establishment, soil amendments, and work within tight easements.

I. Other On-Site Retrofit Techniques

The last group of retrofit cost data is the data for individual on-site practices. Cost data for these practices were derived from recent cost studies. Cost data were generally converted to a per cubic foot basis using unit conversions and assumptions about typical treatment areas. The particular methods used to derive the cost data for each of the individual on-site practices are summarized below.

1. Stormwater Planters

Cost data from Hoyt (2007) was used to develop the unit costs for stormwater planters.

- Range: $83,500 to $104,500 per impervious acre treated

A unit conversion factor of 3630 CF was used to convert the impervious acre treated data to a per cubic foot basis:

- Range: $23.00/CF to $29.00/CF

The median cost was set at $26.00/CF and a cost range was established assuming that the low end and high end costs were 30% lower and higher than the median cost. The resulting range was $18.00/CF to $34.00/CF.

2. Cisterns

Cost data from Hoyt (2007) and Hathaway and Hunt (2006) were used to develop the unit costs for cisterns.

- Range: $20,000/IC to $80,000/IC
- Range: $1.00/gal to $3.00/gal

Unit conversions were used to convert the cost data to a per cubic foot basis:

- Range: $5.50/CF to $22.00/CF
- Range: $7.50/CF to $22.00/CF

Based on the results, a median cost was established at $15.00/CF (range:$6.00/CF to $22.00/CF).

3. Green Roofs

Updated cost data from Hoyt (2007), Chicago (2003), Portland BES (2006a) and WSSI (2006) were used to develop the unit costs for green roofs.

Extensive Green Roofs

- Range: $405,500 /IC to $770,500/IC (Hoyt, 2007)
- Range: $9.50/SF to $14.00/SF (Chicago, 2003)
- Range: $10.00/SF to $15.00/SF (Portland BES, 2006a)

Intensive Green Roofs

- Range: $18.00/SF to $30.00/SF (Chicago, 2003)
- $32.00/SF (WSSI, 2006)

Unit conversions were used to convert the cost data to a per cubic foot basis.

Extensive Green Roofs

- Range: $110/CF to $215/CF (Hoyt, 2007)
- Range: $115/CF to $170/CF (Chicago, 2003)
- Range: $120/CF to $180/CF (Portland BES, 2006a)

Intensive Green Roofs

- Range: $215/CF to $360/CF (Chicago, 2003)
- $385/CF (WSSI, 2006)

Based on the results, the median and ranges for extensive and intensive green roofs were established.

Extensive Green Roofs

- Range: $110/CF to $225/CF
- Median: $170/CF

Intensive Green Roofs

- Range: $225/CF to $400/CF
- Median: $310/CF

4. Permeable Pavers

Hathaway and Hunt (2006) re ported a $10/SF unit cost for permeable pavers.

Unit conversions, based on treating one inch of runoff from one impervious acre (e.g. 3,630 CF), were used to convert the cost data to a per cubic foot basis.

- $120/CF

The range of costs was established by assuming that the low end and high end costs are 30% lower and higher, respectively, than the median cost. The resulting cost range was $80/CF to $160/CF.

5. Rain Barrels

Cost data from Hathaway and Hunt (2006) and Portland BES (2006b) were used to develop the unit costs for rain barrels.

- Range: $50 to $300 per 55 gallon rain barrel (Portland BES, 2006b)
- $320 per 55 gallon rain barrel (Hathaway & Hunt, 2006)

Unit conversions were used to convert the cost data to a per cubic foot basis.

- Range: $7.50/CF to $41.00/CF (Portland BES, 2006b)
- $43.50/CF (Hathaway & Hunt, 2006)

Based on the results, the median and range were set at $25.00/CF and $7.50/CF to $40.00/CF, respectively.

6. Rain Gardens

Cost data from Hathaway and Hunt (2006) and WDNR (2003) were used to develop the unit costs for rain gardens.

- Range: $3.00/SF to $5.00/SF (Hathaway & Hunt, 2006)
- Range (homeowner installation): $3.00/SF to $5.00/SF (WDNR, 2003)
- Range (professional installation): $12.00/SF to $15.00/SF (WDNR, 2003)

The costs were converted to a cubic foot basis assuming the runoff from one inch of rainfall from one impervious acre (3,630 CF) and assuming a 12 inch ponding depth within the rain gardens.

Based on the results, three categories of rain garden installation were defined. These included volunteer installation, professional installation with standard landscaping and professional installation with deluxe landscaping:

Volunteer Installation
It was assumed that the cost data presented by Hathaway and Hunt (2006) represented the construction cost for rain gardens installed by volunteers. Therefore, the median and range were set at $4.00/CF and $3.00/CF to $5.00/CF, respectively, for rain gardens installed by volunteers.

Professional Installation with Standard Landscaping
We assumed that the construction cost for professionally installed rain gardens with standard landscaping was somewhere between the other two types of installations (e.g. volunteer installation and professional

installation with deluxe landscaping). The median and range were set at $7.50/CF and $5.00/CF to $10.00/CF, respectively.

This cost data matches well with the cost data presented for the “ideal bioretention retrofit” scenario. The two applications are very similar (e.g. professional installation, practice located in depressional area, simple conveyance to practice, sandy soils with no need for underdrain, simple planting plan), so the construction cost of the two practices should be similar.

Professional Installation with Deluxe Landscaping
It was assumed that the cost data presented by WDNR (2003) represented the construction cost for professionally installed rain gardens with deluxe landscaping (e.g. decorative stone, intensive landscaping). Therefore, the median and range were set at $12.50/CF and $10.00/CF to $15.00/CF, respectively.

7. French Drains/Dry Wells

Cost data from LGPC (2003) was used to develop the unit costs for french drains and dry wells.

- Range: $15/LF to $17/LF

In order to convert the cost data to a per cubic foot basis, the length of a french drain needed to treat one inch of runoff from one impervious acre was calculated. It was assumed that the french drain would be 2 feet deep and 2 feet wide (e.g. the dimensions of a typical french drain) and that the gravel used to fill the french drain would have a void ratio of 0.35. Based on these assumptions, 2,595 linear feet of french drain would be needed to treat 1 acre of impervious cover (e.g. [43,560 SF ∗ 1 IN] ÷ [12 IN/FT ∗ 2 FT * 0.35] ÷ 2 FT = 2,595 FT).

- Range: $10.50/CF to $12.50/CF

Based on the results, the range was set at $10.50/CF to $12.50/CF. The average unit cost (e.g. $11.50/CF) was set as the median.

8. Impervious Cover Conversion

Cost data from RS Means (2006) were used to develop the unit costs for impervious cover conversion.

- Asphalt Removal: $40,000/AC
- Concrete Removal: $55,000/AC
- Site Restoration: $26,150/AC

Site restoration includes soil preparation, fine grading, seeding and erosion control (Table 1).

A unit conversion, based on treating one inch of runoff from one impervious acre (e.g. 3,630 CF), was used to convert the cost data to a per cubic foot basis.

- Asphalt Removal: $11.00/CF
- Concrete Removal: $15.00/CF
- Site Restoration: $7.00/CF

The range was established by assuming that the costs for asphalt and concrete removal represent the low end and high end costs, respectively, for impervious cover removal. The range was therefore set at $18.00/CF to $22.00/CF. The average unit cost (e.g. $20.00/CF) was set as the median cost.

Table 1: Site Restoration for Impervious Cover Conversion		
Description	**Unit Cost**	**Unit**
Soil preparation (till topsoil)	$0.05	SF
Fine grading	$0.25	SF
Seeding (prairie/meadow mix)	$0.05	SF
Erosion control blanket	$0.25	SF
Total cost	$0.60	SF
Source: RS Means, 2006		

9. Filter Strips

Cost data from RS Means (2006) were used to develop the unit costs for filter strips.

- Site Restoration: $0.70/SF
- Level Spreader: $4.00/LF

Site restoration includes brush clearing and removal, soil preparation, fine grading, seeding and erosion control (Table 2).

A unit conversion based on treating one inch of runoff from one impervious acre (e.g. 3,630 CF) was used to convert the square foot filter strip cost data to a per cubic foot basis. To convert the unit cost for the level spreader, it was assumed that the overland flow path in the filter strip's contributing drainage area would be 75 feet long (the use of a longer overland flow path would not ensure that sheet flow is provided to the filter strip). Based on this assumption, 580 linear feet of filter strip and level spreader would be needed to treat 1 acre of impervious surface (e.g. 43,560 SF ÷ 75 FT = 580 FT).

- Level Spreader: $2,320/IC
- Level Spreader: $0.60/CF

To convert the unit cost for site restoration, it was assumed that the minimum filter strip width would be 25 feet and the maximum filter strip width would be 75 feet. Based on these assumptions, a minimum of 14,500 square feet and a maximum of 43,500 square feet would be need to treat 1 acre of impervious cover (e.g. 580 FT ∗ 25 FT = 14,500 SF and 580 FT ∗ 75 FT = 43,500 SF)

- Site Restoration: $10,000/IC to $30,500/IC
- Site Restoration: $3.00/CF to $8.50/CF

Based on the results, the range was set at $3.50/CF to $8.50/CF. The average unit cost ($6.00/CF) was set as the median.

10. Soil Compost Amendment

Cost data provided by Schueler (2000b), updated to 2006 dollars, was used to develop the unit costs for soil compost amendments.

- Range: $0.27/SF to $0.98/SF

Unit conversions were used to convert the cost data to a per cubic foot basis.

- Range: $3.20/CF to $11.80/SF

Based on the results, the median and range were set at $7.50/CF and $3.20/CF to $11.80/CF, respectively.

11. Street Bioretention Areas

The cost data compiled by Hoyt (2007) includes data from a number of small bioretention retrofits built in highly urbanized areas with less than 0.5 acres of contributing drainage area. The construction of these retrofits requires professional installation and demolition, soil replacement, underdrains, connections to the existing storm drain system and extensive landscaping.

The construction of street bioretention areas requires equally careful construction. Therefore, the construction cost of street bioretention areas was assumed to be the same as that of small, highly urban bioretention retrofits. The median and range were set at $30.00/CF and $25.00/CF to $40.00/CF, respectively. The higher end of the range should be used when the bioretention area is designed as a landscape feature (e.g., decorative stone, intensive landscaping)

Table E.2: Site Restoration for Filter Strips

Description	Unit Cost	Unit
Site preparation (brush clearing and removal)	$0.10	SF
Soil preparation (till topsoil)	$0.05	SF
Fine grading	$0.25	SF
Seeding (prairie/meadow mix)	$0.05	SF
Erosion control blanket	$0.25	SF
Total cost	$0.70	SF
Level spreader (based on 1 CF stone/LF)	$4.00	LF
Source: RS Means, 2006		

Appendix F: Rooftop Retrofit Design Sheets

RR-1

Rooftop Retrofit Design Sheets

STORMWATER PLANTERS

Stormwater or foundation planters are an on-site retrofit practice that can treat rooftop runoff. They consist of confined planters that store and/or infiltrate runoff through a soil bed to reduce runoff volumes and pollutant loads (Figure 1). Two major design variations exist based on the condition of the underlying soil. The *infiltration planter* is designed to allow runoff to first filter through the planter soil and then infiltrate down through native soils. The *filter* or *flow-through planter box* has compacted bottom soils or an impervious liner that prevents infiltration. When it overflows, water surcharges from the bottom of the planter after it filters through the soil through a perforated underdrain and discharges to the storm drain system. Both planter designs are sized to temporarily store runoff in a reservoir above the planter soil.

Stormwater planters combine an aesthetic landscaping feature with a functional form of stormwater treatment. Stormwater planters generally receive runoff from adjacent rooftop downspouts. As runoff passes through the planter, pollutants are captured on soils. Stormwater planters are landscaped with plants that are tolerant to both periods of drought and inundation.

Stormwater planters are useful in treating rooftop runoff in highly urban areas, such as a central business district. They can also be used to establish a pervious area within the hardscape of a plaza, courtyard, riverfront, or streetscape. While they treat a very small drainage area, they can be incorporated into municipal or corporate demonstration projects. Since each planter treats runoff from a few hundred to a few thousand square feet of contributing rooftop (plus the additional area of the planter bed itself), it takes quite a few planters to provide meaningful stormwater treatment in a subwatershed. On the other hand, planters are one of the few on-site or storage retrofit options available to treat ultra-urban sites.

The two primary factors to assess when considering stormwater planter retrofits are the contributing roof area to each roof leader, and how and where the excess runoff will be discharged from the planter. A planter designed to encourage infiltration should have adequate waterproofing and dewatering components to prevent foundation seepage.

Design

Two basic design variations for stormwater planters are the infiltration planter and the filter planter.

An **infiltration planter** filters rooftop runoff through planter soils followed by infiltration

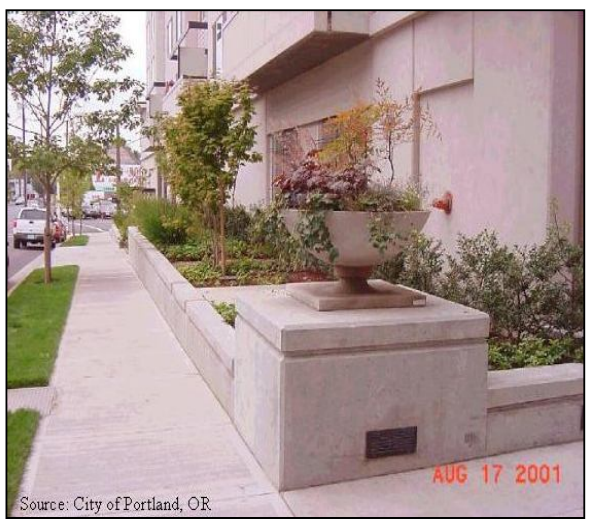
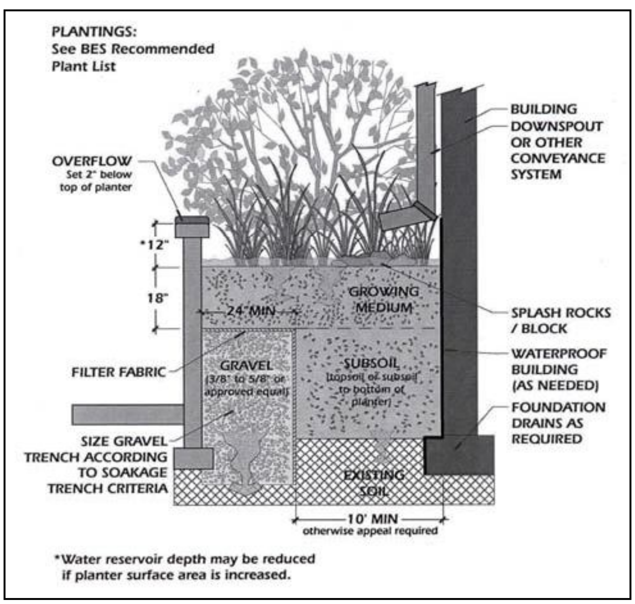


Figure 1: Portland Stormwater Planter

into soils below the planter (Figure 2). The recommended minimum width is 30 inches; length and shape can be decided by architectural considerations. The planter should be sized to temporarily store at least one-half inch of runoff from the contributing rooftop area in a reservoir above the planter bed. Infiltration planters should be placed at least ten feet away from a building to prevent possible flooding or basement seepage damage.

A **filter planter** has an impervious liner on the bottom of the planter. The minimum planter width is 18 inches with the shape and length governed by architectural considerations. Runoff is temporarily stored in a reservoir located above the planter bed. Overflow pipes are installed to discharge runoff when maximum ponding depths are exceeded to avoid water spilling over the side of the planter (Figure 3). Since a filter planter is self-contained and does not infiltrate into the ground, it can be installed right next to a building.

All planters should be placed at grade level or above ground, and sized to allow captured runoff to drain out within four hours after a storm event. Plant materials should be capable of withstanding moist and seasonally dry conditions. Planting media should have an infiltration rate of at least two inches per hour. The sand and gravel on the bottom of the planter should have a minimum infiltration rate of five inches per hour. The planter can be constructed of stone, concrete, brick, wood or other durable material. If treated wood is used, care should be taken so that trace metals and creosote do not leach out of the planter. Supplemental irrigation may be necessary in some regions to ensure plant survival during dry weather.



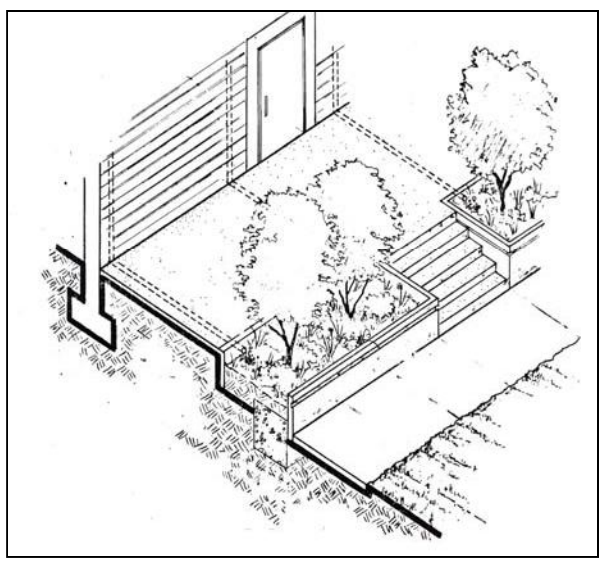
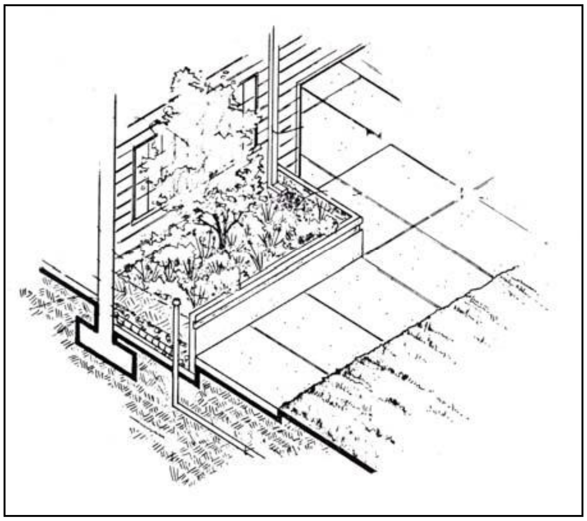


Figure 2: Infiltration Planter Schematic (left) and Infiltration Planter Box (right)
Source: Portland Stormwater Manual, 2002



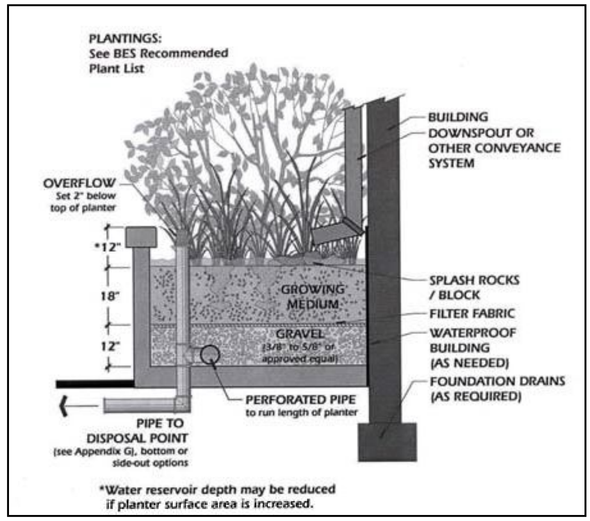


Figure 3: Finished Flow-Through Stormwater Planter (left) and Schematic (right)

Construction - It is advisable to use a single contractor throughout the construction and landscaping maintenance. Contractors should understand the purpose of stormwater planters including appropriate sizing, filtering media, setbacks from current utilities and buildings and care and maintenance of planted material.

Maintenance - Maintenance for stormwater planters involves routine landscaping, checking the integrity of the planter structure, and removal of organic matter. Planter container and overflow pipes should be inspected annually to ensure continued efficiency. Particular care should be taken to ensure that desired infiltration rates are being maintained through the planter soil and subsoils.

Cost – The median cost to construct stormwater planters is estimated to be $27.00 per cubic foot of runoff treated (ranging from $18.00 to $36.00)

Further Resources

City of Portland. 2004. *Stormwater Management Manual – Revised*. http://www.portlandonline.com/bes/index.cfm?c=35122&

Low Impact Development (LID) Center www.lowimpactdevelopment.org/

New York State. *New York State Stormwater Management Design Manual: Stormwater Planters.* *http://www.rpi.edu/~kilduff/Stormwater/planters1.pdf*

RR-2	Rooftop Retrofit Design Sheets	
	CISTERNS	

Cisterns capture and reuse rooftop runoff from non-residential sites in a subwatershed. They consist of devices that retain runoff storage volume in aboveground or underground storage tanks (Figure 1). Runoff collected in the tank can be used for outdoor watering, gray water needs or in some cases, even drinking water supply. Stored rainwater provides an opportunity to conserve water and reduce water utility bills. Cisterns are generally much larger than rain barrels and typically have a capacity of more than 10,000 gallons. Since outdoor residential irrigation can account for up to 40% of domestic water consumption in the hot summer months, cisterns can conserve water and reduce the demand on the municipal water system (LID Center, 2003).Cisterns are not yet widely used in most regions of the country but can be incorporated into high-density green buildings.

Feasibility

Cisterns are an effective on-site retrofit option for treating rooftop runoff from selected commercial, industrial, institutional and municipal sites. In many cases, cisterns are a component of "green buildings," such as those certified by LEED. They are particularly useful on sites that are nearly completely built out, and simply represent an aboveground or underground storage alternative.
When assessing a potential cistern retrofit site, designers need to consider the total contributing roof area, as well as the existing "plumbing" system that moves water off of the roof. The capacity required in the cistern can be quickly estimated by a simple storage rule: storage of one inch of runoff from a thousand square feet of roof translates to 83 cubic feet of cistern capacity. The next critical factor is the how the cistern will be de-watered in between storms (i.e., pumped to the storm drain system during dry weather, used for supplemental irrigation, or pumped indoors for gray water plumbing). The last design factor to consider is whether the building owner is capable of operating the cistern.

Local rainfall data should be thoroughly analyzed before sizing cisterns. A monthly rain and snowfall budget may be needed to accurately size a cistern for a site. If freezing conditions are expected in the winter months, cisterns may need to be located below the frost line or inside the building.

Lack of space and the presence of surrounding trees can constrain the use of cisterns. Space problems can be overcome if the cistern is located on the roof or underground. Overhead trees can be a source of falling leaves that can clog the holding tank, or attract rodents and birds whose droppings can contaminate the tank. Cisterns should be located away from trees or other overhead vegetation. If the cistern will be used for gray water or potable water use, designers should also consult the local water authority to see what permits are needed.

Figure 1a: Wooden Cisterns at the Chesapeake Bay Foundation Headquarters

Figure 1b: Large Building Cistern System, Austin, TX

Implementation

Design - Most cisterns are prefabricated units that are sized to meet the required needs of the roof. Typical materials used to construct cisterns are wood, metal and reinforced concrete with a watertight compound. All materials should be sealed using a water safe, non-toxic substance. The cistern should also be equipped with a manhole opening to permit access for cleaning, inspection, and maintenance.

Construction - It is advisable to have an experienced contractor that is familiar with cistern sizing, installation materials, and proper site placement.

Maintenance - Maintenance requirements for cisterns are relatively low if they are only intended to provide supplemental irrigation water. Cisterns designed for drinking water supply have much higher maintenance requirements, such as frequent water quality testing and inspection of filtering systems. Cisterns, along with all their accessories should undergo regular inspections at least twice a year.

Cost - The cost of cisterns varies depending on their construction material and whether they are located above or below ground. The reported cost is $15,000 per cubic foot of runoff treated, with a range of $6,000 to $25,000.

Further Resources

Low Impact Development (LID) Center. *Rain barrels and Cisterns.* http://www.lid-stormwater.net/raincist/raincist_home.htm

Chesapeake Bay Foundation (CBF). 2003. *Phillip Merrill Environmental Center* http://www.cbf.org/site/PageServer?pagename=about_merrillcenter_water_main

University of Florida. Cisterns to Collect Non-Potable Water for Domestic Use. http://edis.ifas.ufl.edu/BODY_AE029

RR-3

Rooftop Retrofit Design Sheets

GREEN ROOFTOPS

Description

Green rooftops are used to store and treat rooftop runoff. Also known as a "living roof" or "eco-roof," they consist of a layer of vegetation and soil installed on top of a conventional roof (Figure 1). A green rooftop can be installed on small garages and larger industrial, commercial and municipal buildings. Green rooftops can be designed as extensive or intensive systems. Extensive systems have a thin layer of soil and a cover of grass or moss, while intensive systems have a thicker soil layer, may contain shrubs, trees and other vegetation, and are designed as a landscape amenity.

Green rooftops can be applied to both new and existing roofs, and can be installed on flat roofs or even roofs with slopes up to 30% provided special strapping and erosion control devices are used (Peck and Kuhn, 2003).

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, with reports of 65 to 100% in summer and 10 to 40% in winter (Liptan and Strecker, 2003; Roofscapes, Inc., 2003). Green roofs are most effective in reducing runoff volume for land uses with high percentages of rooftop coverage such as commercial, industrial and multifamily housing (Stephens, *et al*, 2002).

Green roofs also provide owners with many additional benefits, including insulation, energy savings, aesthetic value, wildlife habitat, and improved air quality. Some studies have also found that green roofs can extend the life of a conventional roof by up to 20 years.

Feasibility

Green rooftops are a useful on-site retrofit option for new municipal construction, commercial, multi-family, or institutional buildings. In many cases, green rooftops are a component of "green buildings," such as those specified by LEED. They are particularly useful on sites that are nearly completely built out. Other good opportunities to retrofit rooftops are conventional rooftops that have reached the end of their design life and need replacement. Incremental replacement of conventional rooftops with green rooftops can be an effective, long-range (e.g., 20 + years) strategy to incrementally control runoff in ultra-urban subwatersheds.

Figure 1: Green Rooftop on Chicago's City Hall
Source: Roofscapes Inc. www.roofmeadow.com

Many building owners are hesitant to make the conversion to green roofs, given the higher initial capital cost (despite the long term energy savings). Therefore municipalities need to develop an effective delivery mechanism in the form of credits or subsidies or even modify their current building codes to permit green rooftops.

Regional and Climatic Considerations - Plant selection for green rooftops is an integral design consideration, which is governed by local climate and design objectives (Figure 2). A qualified botanist or landscape architect should be consulted when choosing plant material. For extensive systems, plant material should be confined to hardier, indigenous varieties of grass and *sedum*. Root size and depth should also be considered to ensure that the plant will stabilize the shallow soil media. Plant choices can be much more diverse for intensive systems.

The location of the building plays an important role in the design process. The height of the roof, its exposure to wind, snow loading, orientation to the sun, and shading by surrounding buildings all have an impact on the selection of appropriate plant species.

Site Constraints and Permits - The key factors to consider when investigating a rooftop retrofit includes its area, age, and accessibility, structural capacity, and commitment of ownership.

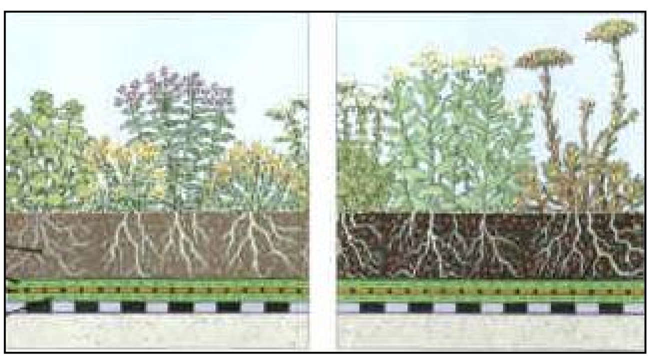


Figure 2: Extensive Cross-Section
Source: Unterlage, 1997

Structural Capacity of the Roof: A key constraint is whether the existing roof can support the additional weight of soil and plants. A licensed structural engineer or architect should conduct a structural analysis to determine the type of green roof system and any needed structural reinforcement.

Access to the Roof: Safe access must be available for workers and materials during both construction and maintenance.

Local Building Codes: Building codes often differ in each municipality, and local planning and zoning authorities should be consulted to obtain proper permits.

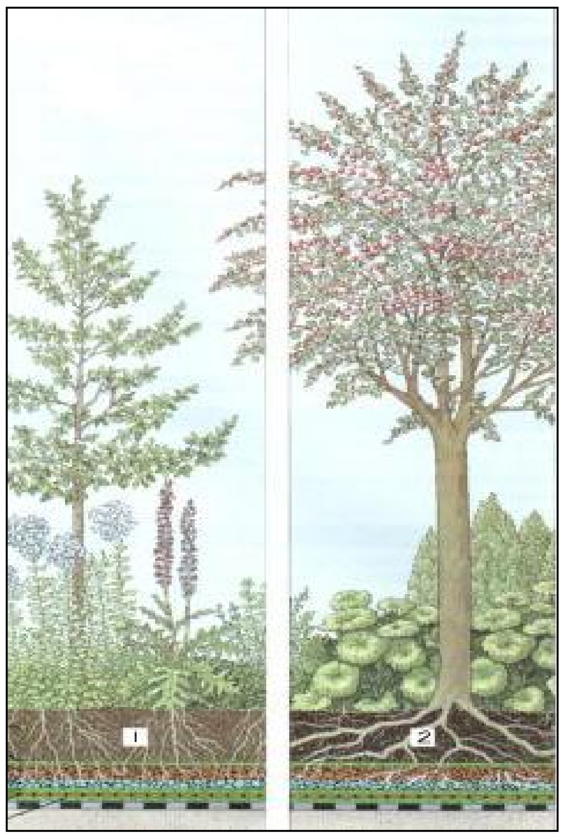


Figure 3: Cross-section of Intensive Green Roof
Source: Unterlage, 1997

Implementation

Each green rooftop is unique, given the purpose of the building, its architecture and the preferences of the builder and end user. Several common features should be kept in mind during green rooftop design, construction and maintenance.

Design – The two design options are the extensive and intensive systems, which vary in cost, depth of growing medium and choice of plants. **Extensive systems** are characterized by low weight, lower capital cost, minimal plant diversity, and reduced maintenance requirements (Figure 2). The growing medium is usually a mixture of sand, gravel, crushed brick, peat, or organic matter combined with soil. The soil media ranges between two and six inches in depth and increases the roof load by 16 to 35 pounds per square foot when fully saturated. Generally, extensive systems can be retrofit on most existing roofs without costly structural reinforcement. Since the growing medium is shallow and the microclimate is harsh, plant species should be low and hardy, which typically involves alpine or arid species, such as *sedum.*

Intensive systems have a deeper soil layer and a corresponding greater weight (Figure 3). Intensive systems have higher construction costs, greater plant diversity, and more expensive landscaping and maintenance needs. In many cases, intensive roofs are accessible to the public and are incorporated into the building as an interactive architectural feature (Figure 4). The growing medium is often soil based and ranges in depth from eight to 24 inches, with a saturated roof loading of between 60 and 200 pounds per square foot. Designers can use a diverse range of trees, shrubs and groundcover because the deeper growing medium allows longer root systems. This allows the designer to develop a more complex ecosystem. Maintenance requirements, however, are more costly and continuous, compared to extensive systems. In some cases, supplemental irrigation systems may be needed. Both a structural engineer and an experienced installer are recommended for intensive systems.

Designers should indicate how they will handle excess runoff that cannot be absorbed by the green rooftop, which is normally drained using downspouts. Most retrofits should be able to use the existing rooftop drainage system with only minor modifications.

Construction – An experienced installer should be used to avoid conflicts and maintain accountability. The green roof should be constructed in sections for easier inspection and maintenance access to the membrane and roof drains.

Maintenance - A green roof should be inspected after construction for plant establishment, leaks and other functional or structural concerns. Maintenance may include watering, fertilizing and weeding, which are greatest in the first two years as plants become established. The use of native vegetation is recommended to reduce plant maintenance. Irrigation and fertilization is only required during the first year before plants are established. After the first year, maintenance consists of two visits a year for weeding of invasive species, and membrane inspections .

Figure 4: Benches and pathways can be incorporated into green roofs

Cost – The estimated cost for extensive green rooftops is $225.00 per cubic foot treated (ranging from $144 to $300). Intensive green rooftops are even more expensive with a median of $360.00 per cubic foot treated (ranging from $300 to $420). While green rooftops are more expensive than other retrofit options, their lifecycle costs may be comparable to traditional roofs, when energy savings and roof longevity are factored in. Operation and maintenance costs are $0.09 to $0.23 per square foot per year (Stephens, *et al*., 2002). Design costs typically run 5-10% of the total project cost and administration and site review costs are 2.5 - 5% of the total project cost (Peck and Kuhn, 2003).

Further Resources

City of Chicago. Rooftop Gardens and Green Roofs. http://egov.cityofchicago.org/city/webportal/portalDeptCategoryAction.do?deptCategoryOID=-536889314&contentType=COC_EDITORIAL&topChannelName=Dept&entityName=Environment&deptMainCategoryOID=-536887205

TectaGreen, Tecta America Corp. *Green Roof Systems*. http://www.greenroof.com/greenroofsys.shtml

Peck, S. and M. Kuhn. *Design Guidelines for Green Roofs.* http://www.aaa.ab.ca/pages/members/documents/GreenRoofs_000.pdf

Roofscapes, Inc. *Green Technology for the Urban Environment.* www.roofmeadow.com

Greenroofs.com. http://www.greenroofs.com

Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. http://www.metrocouncil.org/environment/Watershed/bmp/manual.htm

Maryland Department of the Environment. Green Roof - Fact Sheet. http://www.mde.state.md.us/assets/document/sedimentStormwater/SWM_greenroof.pdf

RR-4

Rooftop Retrofit Design Sheets

RAIN BARRELS

Description

Rain barrels are used to capture, store and reuse residential rooftop runoff. They consist of a simple stormwater collection device that stores rainwater from individual rooftop downspouts. Stored water can be used as a source of outdoor water for car washing or lawn or garden watering. The rooftop runoff stored in a rain barrel would normally flow onto a paved surface and eventually into a storm drain. Rain barrels typically have a capacity of 50 to 100 gallons of water (Figure 1).

Rain barrels can be applied to new and existing residential developments. They are most applicable for single family residential and townhouse uses. Rain barrels can have benefits on both a site level and subwatershed wide basis. Rain barrels promote water conservation, reduce water demand, and lower irrigation costs and demand (a rain barrel can save homeowners about 1,300 gallons of water during the peak summer months). Rain barrels are inexpensive and easy to build and install and create stronger watershed awareness.

Feasibility

Rain barrels are a common on-site retrofit practice to treat rooftop runoff from individual homes. Because each rain barrel retrofit treats such a small area, dozens or hundreds are needed to make a measurable difference at the subwatershed level. Consequently, widespread homeowner implementation of rain barrels requires targeted education, technical assistance and financial subsidies.

The potential to retrofit with rain barrels is normally evaluated as part of the neighborhood source assessment of the USSR. The most important factor is the proportion of existing homes that are directly connected to the storm drain system. In general, neighborhoods with residential lot sizes as small as 4000 square feet can be effectively retrofit with rain barrels (Figure 2). Negative neighborhood factors include the presence of basements, limited space for barrel de-watering, and lack of active homeowner association.

Regional and Climatic Considerations - Several issues pertaining to water quality, climate, and algae and mosquito control

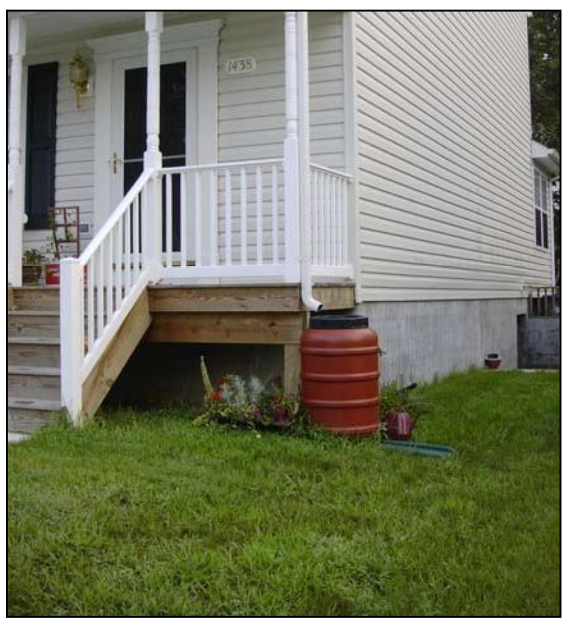


Figure 1: Installed Rain Barrel

should be taken into account in design. Water quality is usually not a major issue unless the stored water will be used for drinking water, which is not recommended without additional filtering and treatment. Rooftop runoff contains trace metals, such as zinc, copper and lead. The presence of these metals, however, should not adversely affect the use of rooftop runoff for supplemental lawn and garden irrigation.

Rain barrels require modification in regions with cold winters. Rain barrels do not function if temperatures regularly reach the freezing mark during winter months. Consequently, rain barrels should be drained and disconnected during winter months to ensure that frozen water does not damage the rain barrel, to back up into downspouts or overflow into a building foundation. Alternatively, rain barrels can be installed inside a building or garage.

Figure 2: Rain barrel installed on a balcony due to space constraints on a small lot.

It is important to reduce the amount of organic matter entering the barrel to prevent algae from growing in a rain barrel. This can be a problem for rain barrels serving a downspout whose gutters fill with leaves and other debris.

Since rain barrels have standing water, there is some risk that they may become mosquito-breeding sites. Simple solutions to reduce mosquito breeding include routine emptying of the barrel on a five day cycle to interfere with breeding time required by mosquitoes or screening the rainwater inlet so mosquitoes cannot enter the rain barrel (USWG, 2003).

Site Constraints and Permits - Rain barrels may not be appropriate in high-density urban settings where there is little or no green space to irrigate using the collected water. Similarly, neighborhoods where homes are close together may not have adequate surface area to safely discharge rain barrel overflow. Lastly, installation of rain barrels in neighborhoods where downspouts are already disconnected provides little or no retrofit benefit.

Implementation

Design - Rain barrels are much easier to design compared to other on-site retrofit practices. Still, the rain barrel should always incorporate the same basic design elements of any good stormwater practice, such as pretreatment (clean gutters), adequate storage capacity, and safe conveyance of flooding with rain barrel overflows).

Construction - Rain barrels can be purchased or custom made from large plastic drums (typically 55-gallon drums). They are relatively easy to construct using a few basic components available from hardware stores. Installation of a typical rain barrel involves disconnecting individual downspouts and redirecting it into the top of the rain barrel.

Rain barrels have an overflow pipe that redirects the rainwater back into the downspout or onto the lawn or other pervious surface when the rain barrel is full. Other rain barrel components may include spigots, connector barrels, mosquito proofing, and even water filters (CWP, 2003).

Maintenance – The maintenance required for rain barrels involves regular dewatering of the barrel to preserve capacity for the next storm event. Roof gutters should be inspected to ensure that leaves and organic matter are not entering the downspout to the rain barrel. In addition, the rain barrel, gutters, and downspouts need to be checked for leaks or obstructions. Lastly, the overflow pipe should be checked to ensure that overflow is draining in a non-erosive manner

Cost - Although costs vary across manufacturers, the average cost of a single rain barrel ranges from about $50 to $300, with an average of about $150 The cost per cubic foot treated is about $25 per cubic foot treated (ranging from $7 to $40) Costs can be reduced if volunteers or watershed groups perform the instillation. Consult Profile Sheet 0S-10 for some helpful resources on rain barrel delivery.

Further Resources

The following internet resources are recommended for a detailed description on how to build and install a rain barrel.

How to Build and Install a Rain Barrel
http://www.cwp.org/Community_Watersheds/brochure.pdf

Rain Barrels for Dummies: Unofficial Guidance for Backyard Retrofitters.
http://www.cwp.org/Community_Watersheds/Rain_Barrel.htm

King County, WA. Rain Barrel Information and Sources for the Pacific Northwest.
http://dnr.metrokc.gov/wlr/PI/rainbarrels.htm

Low Impact Development Center (LID). Rain Barrels and Cisterns.
http://www.lid-stormwater.net/raincist/raincist_maintain.htm

Maryland Green Building Program: Building a Simple Rain Barrel.
http://www.dnr.state.md.us/ed/rainbarrel.html

City of Bremerton. Rain Barrel Program: A Modern Spin On An Old Idea.
http://www.cityofbremerton.com/content/sw_makeyourownrainbarrel.html

Portland, OR Downspout Disconnection Program
http://www.portlandonline.com/bes/index.cfm?c=43081

RR-5	Rooftop Retrofit Design Sheets	
	RAIN GARDENS	

Rain gardens capture, filter and infiltrate residential rooftop runoff, and consist of small, landscaped depressions that are usually 6 to 18 inches deep. A sand/soil mixture below the depression is planted with native shrubs, grasses or flowering plants (Figure 1). Rooftop runoff is detained in the depression for no more than a day until it either infiltrates or evapotranspires. Rain gardens can replenish groundwater, reduce stormwater volumes, and remove pollutants. A rain garden allows at least 30% more water to infiltrate into the ground compared to a conventional lawn (UWEO, 2002).

Rain gardens can be applied to existing single-family homes within targeted neighborhoods. Rain gardens have many benefits including increased watershed awareness and personal stewardship, improved neighborhood appearance, and creation of habitat for birds and butterflies. Rain gardens must be properly maintained; otherwise they may create basement flooding and standing water, and become an eyesore. For this reason, implementation of rain gardens requires a dedicated homeowner and community buy-in.

Feasibility

Rain gardens are essentially a non-engineered form of bioretention that treats rooftop runoff from individual roof leader. (see Profile Sheet ST-4). Because each rain garden treats a rather small area, dozens or hundreds are needed to make a measurable difference at the subwatershed level. Consequently, widespread homeowner implementation of rain gardens requires targeted education, technical assistance and financial subsidies.

The potential to retrofit rain gardens is normally evaluated as part of the neighborhood source assessment of the USSR. The most

Figure 1: Rain Garden

important factor is the proportion of existing homes that are directly connected to storm drain system. In general, neighborhoods with large residential lot sizes are most suitable (1/4 acre lots and larger). Negative neighborhood factors include the presence of basements, compacted soils, and poor neighborhood awareness. Positive factors are large rooftop areas that are directly connected to the storm drain system, lots with extensive tree canopy and good neighborhood housekeeping.

Regional and Climatic Considerations - One common misperception associated with rain gardens is that they provide a breeding ground for mosquitoes. Mosquitoes need three to seven days to breed, and standing water in the rain garden should last for only a few hours after most storms USWG, 2003).

Plant selection is also an important element of a successful rain garden. Considerations should include drought-tolerant plants that will not require much watering, but can withstand wet soils for up to 24 hours. Plant selection also depends on the amount of sun the garden receives. Xeriscaping (the practice of landscaping to conserve water) is recommended in arid climates (Figure 2). For a listing of the native plants in your region, visit: http://plants.usda.gov/ (USDA NRCS). This database allows the user to search for plants by name (common or scientific) or by state or county.

Site Constraints and Permits - The site constraints for rain gardens include soils and proximity to the house. The garden should be located a minimum of 10 feet away from the house to prevent basement seepage. Rain gardens work best in areas with well-drained soils. However, performance can be enhanced in poorly draining soils by providing an underdrain system or soil amendments.

Implementation

Design - The surface area of a rain garden should be between 20% and 30% of the roof area it drains to it to ensure it can temporarily hold water from a 1-inch rainstorm. Further guidance on sizing a rain garden is provided in Table 1.

To ensure that the water flows from the impervious surface to the garden, maintain at least a 1% slope from the lawn down to the rain garden (a shallow swale can be used). A downspout extension can be used to direct rooftop flow into the garden.

Construction - Construction of rain gardens is simple but requires physical labor to dig the garden, prepare the soil, and plant desired species. Select plants that have a well-established root system and plant them approximately one foot apart (UWEO, 2002). More information on how to install rain gardens can be found online in the Further Resources section.

Figure 2: Xeriscaped Garden

Table 1: Rain Garden Sizing Example
30' x 30' house footprint
¼ of this area drains to one downspout
15' x 15' = 225 sf
20% of 225sf = 45sf
30% of 225sf = 67.5 sf
The rain garden area should be between 45 and 67.5 square feet, depending on the soil type (use 20% for sandier soils in Soil Group A)

Maintenance - Maintenance of rain gardens is essential to ensure public acceptance and proper performance, and reduce nuisance problems. Typical maintenance includes periodic watering and weeding. The use of native plants can significantly reduce overall yard maintenance needs since they require less mowing, watering and fertilizer than conventional lawns.

Cost - 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 on the complexity of the project. Rain gardens typically cost about $4.00 per cubic foot of runoff treated (ranging from $3 to $5). Do-it-yourselfers can create beautiful rain gardens for a fraction of this cost.

Further Resources

Center for Watershed Protection *How to Install a Rain Garden.* http://www.cwp.org/Community_Watersheds/brochure.pdf

UWEO (University of Wisconsin Extension Office). Rain Gardens: http://clean-water.uwex.edu/pubs/pdf/home.gardens.pdf

Bannerman, R. and E. Considine. 2003. Rain Gardens: A how-to manual for homeowners http://www.dnr.state.wi.us/org/water/wm/dsfm/shore/documents/rgmanual.pdf

Center for Watershed Protection . *Rain Garden Applications and Simple Calculations.* http://www.cwp.org/Community_Watersheds/Rain_Garden.htm

Friends of Bassett Creek. 2000. *Rain Gardens: Gardening with Water Quality in Mind.* http://www.mninter.net/~stack/bassett/gardens.html.

Minneapolis, MN Neighborhood Rain Gardens http://www.fultonneighborhood.org/lfrwm.htm

Portland, OR Downspout Disconnection Program http://www.portlandonline.com/bes/index.cfm?c=43081

Rain Gardens for Stormwater Bioretention and Ecological Restoration.. http://www.nwf.org/campusecology/files/reillyprop.pdf

"Plotting to Infiltrate? Try Rain Gardens." *Yard and Garden Line News* 3(6). http://www.extension.umn.edu/yardandgarden/YGLNews/YGLN-May0101.html

West Michigan Environmental Action Council and the City of Grand Rapids RainGardens.org. http://www.raingardens.org

RR-6	Rooftop Retrofit Design Sheets	
	FRENCH DRAINS and DRY WELLS	

French drains and dry wells are an on-site retrofit practice that can capture and infiltrate residential rooftop runoff. Runoff from rooftop leaders is directed to the trench via a downspout or swale, is temporarily stored in the voids of the stone-filled 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, their design and application differ slightly. A french drain is a shallow underground trench with a perforated pipes running along the bottom (Figure 1). A typical dry well is a deeper and shorter excavated trench with perforated pipes that run both vertically and horizontally through the stone (Figure 2).

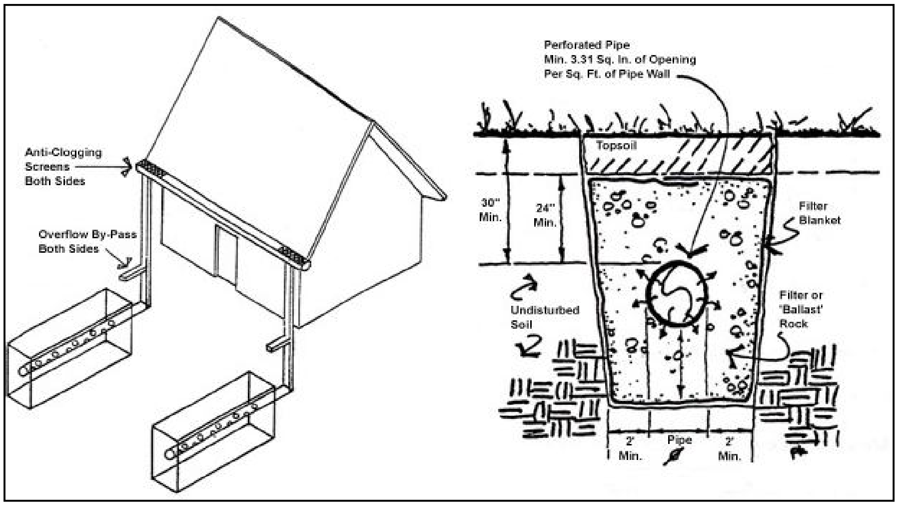


Figure 1: Schematic of French Drain

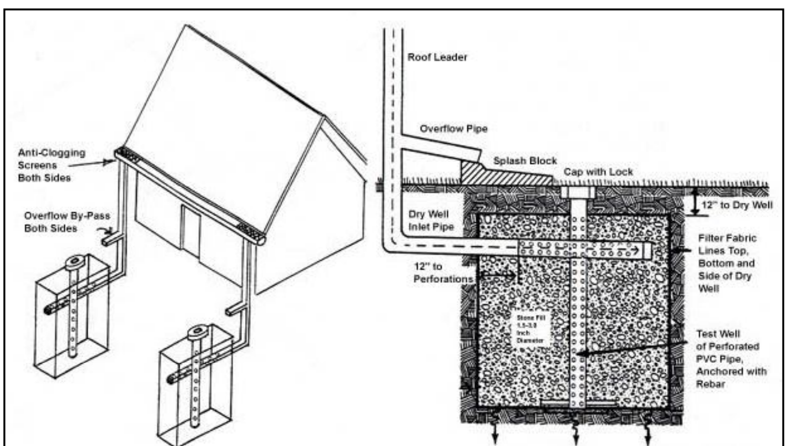


Figure 2: Schematic of Dry Well

French drains are almost exclusively used for residential sites, whereas dry wells can be used at both residential and commercial sites. Each practice serves a small drainage area, such as a single rooftop or roof leader. While not much space is needed to install these practices, very high-density neighborhoods will have limited opportunities.

Feasibility

Because each french drain/dry well treats a rather small area, dozens or hundreds are needed to make a measurable difference at the subwatershed level. Consequently, widespread homeowner implementation of these practices requires targeted technical assistance and financial subsidies.

The potential to retrofit with french drains/drywells is normally evaluated as part of the Neighborhood Source Assessment of the USSR The most important factor is the proportion of existing homes that are directly connected to the storm drain system. In general, neighborhoods with large residential lot sizes are most suitable (1/4 acre lots and larger). Negative neighborhood factors include the presence of basements, compacted soils, and poor neighborhood awareness or involvement. Positive factors are large rooftop areas that are directly connected to the storm drain system, lots with extensive tree canopy, and neighborhoods known for good housekeeping and active involvement.

Regional and Climatic Considerations - Dry wells and french drains do not function during winter months in colder climates unless the trench extends below the frost line. Also, dry wells are not feasible in regions with high water tables.

Site Constraints and Permits - The three main site constraints pertaining to french drains and dry wells are soils, hydrology and slope (LGPC, 2003). The soils must be permeable enough to ensure adequate infiltration within 48 hours. An infiltration rate of at least 0.5 inches per hour is recommended for underlying soils. To limit the risk of groundwater contamination, the bottom of these devices should be located at least three feet above the seasonally high water table or bedrock layer. Steep slopes and fill soils should also be avoided. These practices should be located on the down slope side of buildings and extend at least ten feet from building foundations to prevent potential seepage into basements (ARC, 2001).

Implementation

Design - Several design features can make french drains and dry wells more effective. First, it is important to provide pretreatment to reduce the high rate of clogging typically associated with these practices. While pretreatment options are limited, a screen placed on top of rooftop gutters can help to filter out materials such as leaves and other debris (LGPC, 2003). Guidance for sizing a french drain is provided in Table 1.

The design should provide some type of runoff bypass to direct large storm flows away from the house. The bypass is often an aboveground opening of the downspout as shown in Figures 1 and 2.

Table 1: French Drain Sizing Example
French Drain Surface Area = $\frac{(DA)(P)}{12(D)(V)}$
30' x 30' house footprint ¼ of this area drains to downspout Rainfall Depth (P) = 1" Drainage Area (DA) = 15'x 15' = 225ft^2 Depth of Proposed Trench (D) = 2ft Voids Ratio for Gravel (V) = 0.35 $\frac{(225)(1)}{12(2)(0.35)} = 26.8$ ft^2 Trench dimensions: 13' length; 2' wide; 2' deep
Notes: Depth (D) can vary depending on site constraints Rainfall Depth (P) can vary; should reflect retrofit water quality target volume or local water quality criteria

Construction - Dry wells generally require more construction effort than other on-site practices due to the deeper excavation required. These practices require relatively simple materials, such as perforated pipe, stone (two to four inches in diameter) and filter fabric. Basic construction involves digging a slightly sloped trench (to carry the water away from the house), lining the sides of the trench with the filter fabric, laying the perforated pipe, and then backfilling the trench with gravel or stone.

Maintenance - Because these practices are out of sight, maintenance tends to be neglected. Regular maintenance consists of a cleaning out leaves and debris caught in the gutter screen and periodic replacement of the reservoir with clean rock. Inspection of the observation well should be done annually to ensure that the stone fill is level to the ground surface and that the filter fabric has not become clogged with material (ADEQ, 2000).

Cost – The unit cost to install these practices is about $12.00 per cubic foot treated (ranging from $10.50 to $13.50).

Further Resources

Guidance for Design, Installation, and Operation and Maintenance of Dry Wells. Phoenix, AZ. http://www.azdeq.gov/environ/water/permits/download/dwguid.pdf

Stormwater Management Guide for Minor Projects. http://www.lgpc.state.ny.us/pdf/strmguid.htm

Development Planning for Stormwater Management: A Manual for the Standard Urban Stormwater Mitigation Plan. http://www.ladpw.org/wmd/NPDES/table_contents.cfm

New York State Stormwater Management Design Manual. http://www.dec.ny.gov/chemical/29072.html

New Jersey Stormwater Best Management Practices Manual. *Standard for Dry Wells*. http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.3%20print.pdf

Houston Landscape Images: Drainage System Components. http://www.houstonlandscape.com/Drain_Systems.htm

Grounds Magazine. *How to Install a French Drain* http://www.grounds-mag.com/mag/grounds_maintenance_install_french_drain/

RR-7

Rooftop Retrofit Design Sheets

PERMEABLE PAVERS

Permeable pavers treat or reduce parking lot runoff using a porous or semi-porous material on driveways, access roads, parking lots and walkways. Permeable pavers can also allow for surface storage or infiltration of runoff, which can reduce stormwater flows compared to traditional surfaces like concrete or asphalt pavement.

The basic design presented here is for permeable pavers, which consist of a permeable asphalt or concrete surface that allows stormwater to quickly infiltrate into soils or a shallow underground stone reservoir (Figure 1). Runoff then percolates into the soil, where it recharges groundwater and traps stormwater pollutants. Other materials include grass paving blocks, interlocking concrete modules and brick pavers to provide some infiltration and detention of runoff.

Feasibility

Permeable pavers can be used as a retrofit to treat runoff from parking lots or adjacent rooftops. Good opportunities can be found in spillover parking areas, schools, municipal facilities and urban hardscapes (see Profile Sheet OS-12). Other opportunities include redevelopment of commercial sites, especially when parking lots are renovated or expanded.

It is extremely important to confirm that local soils can support adequate infiltration, since past grading, filling, disturbance and compaction can greatly alter their original infiltration qualities. The greatest opportunity to retrofit infiltration exists for sensitive or impacted subwatersheds, where some of the original soil structure may still exist. By contrast, most of the soils in subwatersheds are not likely to be suitable for infiltration. Some regions of the country still have highly permeable soils, which do allow for widespread use of permeable pavers (e.g., glacial tills, sand).

When evaluating a proposed permeable paver retrofit, designers should assess the same constraints for infiltration practices (see Profile Sheet ST-6d in Appendix I). Additional factors to consider include traffic volume and the intended use and ownership of the surface. Permeable pavers are much more versatile, because they do rely less on soil infiltration as compared to surface storage to provide runoff treatment.

Regional and Climate Concerns - Permeable pavers can be applied in most regions of the country, but needs to be adapted to meet the unique challenges of cold climates. Permeable pavers should not be used when sand or other

Figure 1: Permeable Pavement

materials are applied for winter traction since they quickly clog the pavers. Similarly, care should be taken when applying salt to permeable pavers, since chlorides can migrate into the groundwater. Permeable pavers have been successfully used in cold climate in Norway where design features were incorporated to reduce frost heave. Further, some experience suggests that snow melts faster on a porous surface because of rapid drainage below the snow surfaces.

Site Constraints and Permits – Permeable pavers has the same site constraints of any infiltration practice and should meet the following criteria:

- Soils need to have an infiltration rate between one-half and three inches per hour
- The bottom of the stone reservoir should be completely flat so that infiltrated runoff will be able to infiltrate through the entire surface
- Permeable pavers should be located at least three feet above the seasonally high groundwater table, and at least 100 feet away from drinking water wells
- Permeable pavers should not be used to treat stormwater hotspot areas due to the potential for groundwater contamination

Implementation

Design - Pretreatment, treatment, conveyance, and maintenance reduction should be considered in all permeable pavers retrofits.

In most permeable pavers designs, the pavers itself acts as pretreatment to the stone reservoir below. Because the surface serves this purpose, frequent maintenance of the pavers surface is critical to prevent clogging. Another pretreatment element is a fine gravel layer above the coarse gravel treatment reservoir. The effectiveness of both of these pretreatment measures can be inconsistent, which is one reason frequent vacuum sweeping is needed to keep the surface clean.

One design option intended as a backup water removal mechanism within a permeable pavers system is an "overflow edge." An “overflow-edge” is a trench surrounding the edge of a permeable pavers area. The trench connects to the stone reservoir below the surface of the pavers. Although this feature does not in itself reduce maintenance requirements, it acts as a backup in case the surface clogs. If the surface clogs, stormwater will flow over the surface and into the trench, where some infiltration and treatment will occur. The stone reservoir below the pavers should be composed of layers of small stone and be sized for the WQv storm event.

Variations to the reservoir design include the use of perforated corrugated metal piping, plastic arch pipe, and plastic lattice blocks. Water is conveyed through the stone reservoir from the surface of the pavers, then infiltrates into the underlying soil at the bottom of this stone reservoir. A layer of sand or choker stone should be placed below the stone reservoir to prevent preferential flow paths and to maintain a flat bottom.

Designs should include methods to convey larger storms to the storm drain system. One option is to set storm drain inlets slightly above the surface elevation of the pavers. This allows for temporary ponding above the surface if the surface clogs, but bypasses larger flows that are too large to be treated by the system.

Variations in the design of permeable pavers can address treatment of offsite sources. In one design variation, the stone reservoir below the filter can also treat runoff from other sources such as rooftop runoff. In this design, pipes are connected to the stone reservoir to direct flow throughout the bottom of the storage reservoir.

Construction - Installation of permeable pavers is a specialized project and should involve experienced contractors. It is also important to ensure that the drainage area is fully stabilized prior to construction to slightly prevent sediment from clogging the pavers.

Maintenance - Permeable pavers requires slightly more maintenance than traditional pavement in order to ensure continued porosity of the surface. Owners should understand that using a sealer or repaving permeable pavers is not a viable option. Areas contributing to the permeable pavers site need to be mowed and bare areas should be seeded. The surface should be vacuumed three to four times each year to remove sediment and debris.

A carefully worded maintenance agreement is essential to provide specific guidance for the parking lot. The agreement should clearly specify how to conduct routine maintenance tasks, and repave the surface when the pavers reaches the end of their design life. Ideally, signs should be posted on the site identifying permeable paver areas to increase public awareness.

Inspections of permeable pavers should include inspection of surface for spalling or deterioration and testing to ensure that water is draining between storms. Adequate drawdown should occur within 24 to 48 hours.

Cost - Permeable pavers are more expensive than traditional asphalt or concrete pavement. While traditional pavement is approximately $.50 to $1.00 per square foot, permeable pavers can range from $2 to $3 per square foot, depending on the design. The cost per cubic foot of runoff treated is about $120.00 (ranging from $96.00 to $144.00). However, if the cost estimates were to include the savings due to a reduced need for storm drains and land consumption for stormwater treatment, the cost differential for permeable pavers drops sharply.

Further Resources

BioPaver.
http://www.biopaver.com/problems.html

Concrete Network. *Permeable/Porous Pavers.*
http://www.concretenetwork.com/concrete/porous_concrete_pavers/

Green Builder. A Source Book for Green and Sustainable Building: Pervious Paving Materials.
http://www.greenbuilder.com/sourcebook/PerviousMaterials.html

Pavers Search. *Paver Products and Resources for Homeowners and Professionals.*
http://www.paversearch.com/permeable-pavers-menu.htm

Puget Sound Online. *Natural Approaches to Stormwater Management: Permeable Pavement.*
http://www.psat.wa.gov/Publications/LID_studies/permeable_pavement.htm

Appendix G: Example Concept Design

R-9 Stormwater Planter at St. Martin Church

Location

The sidewalk on Fayette Street adjacent to St. Martin Church at the intersection of Fulton and Fayette Streets.

Figure 1: Downspout from St. Martin Church on Fayette.

Site Description

The downspouts on the Fayette Street side of St. Martin Church discharge to a trench drain, which then discharges directly to the street (Figures 1 and 2).

Proposed Practice

The proposed practice for this site is an aboveground, flow-through stormwater planter that will capture and treat rooftop runoff.

Stormwater planters are small landscaped stormwater treatment practices that use soil filtration to reduce stormwater quantity and improve water quality, similar to rain gardens and green roofs. Flow-through planters are contained planters with an underdrain system that conveys filtered stormwater to the storm drain system (Figure 3)

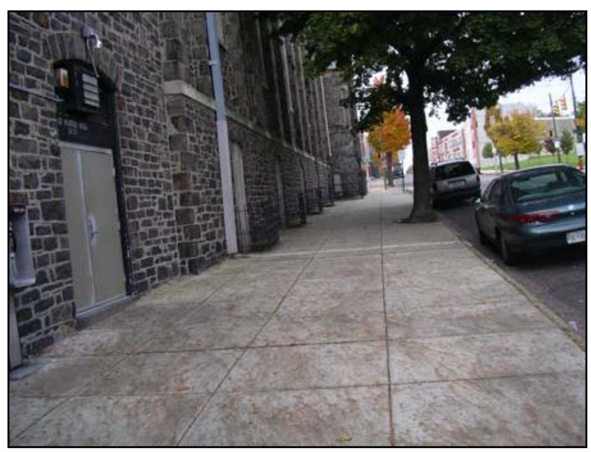


Figure 2: Sidewalk along Fayette where stormwater planter will be located.

Visual Glossary Reference

- #3. Planter boxes

Drainage Area

- The northern portion of the roof drains to the downspout where the stormwater planter will be located. The drainage area to this downspout is approximately 2,500 ft^2.

An aerial view of the estimated drainage area is attached.

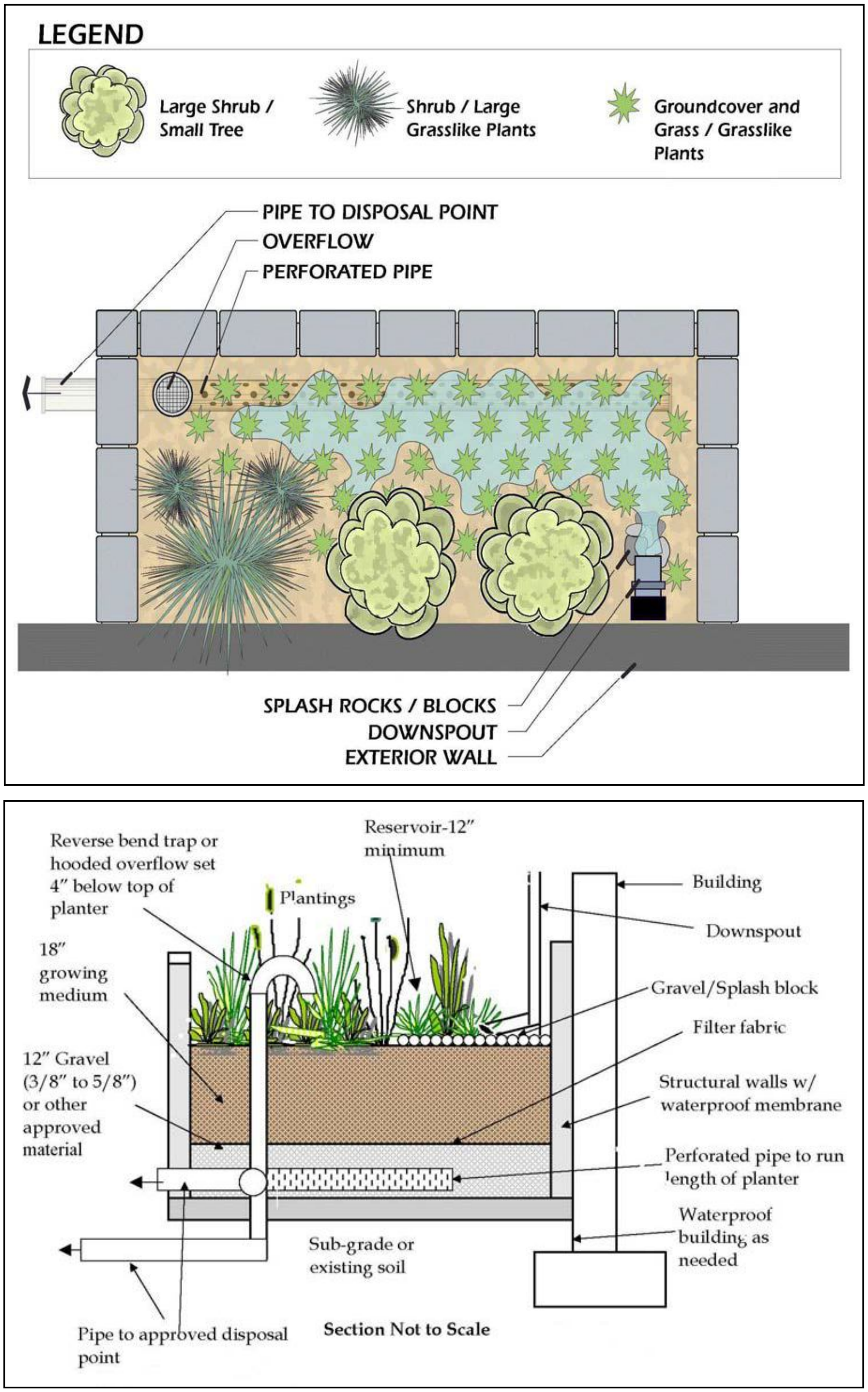


Figure 3: Plan view (top) and cross section view (bottom) of a flow-through stormwater planter (Source: Portland, OR, 2004).

Sizing Computations

- Stormwater runoff volume treated = 0.25 in, or ≈ 50 ft^3
- Target surface area of the stormwater planter = 67.5 ft^2
- Proposed dimensions of the planter = 9 ft by 7.5 ft
- Minimum soil depth = 1.5 ft
- Average ponding depth = 0.5 ft
- Maximum ponding depth = 1.0 ft
- Filter time ≈ 4 hours

Detailed sizing computations are attached.

Features

The stormwater planter will be placed on the sidewalk adjacent to the north side of the church on Fayette Street (Figure 4). Specific design notes follow:

- The planter will be an aboveground system – excavation will not be necessary.
- The downspout will be shortened and directed into the top of the planter. To prevent erosion, splash rocks should be placed below the downspout.
- The planter has been designed to pond water for 4 hours, with a maximum ponding depth of 12 inches. The dimensions of the proposed planter are 9 feet (along building) by 7.5 feet.
- The planting medium depth will be 18 inches. The gravel drainage layer will have a depth of 12 inches. Filter fabric will separate the planting medium from the gravel drainage layer, and should extend upwards along the walls of the planter to the top of the planting medium.
- A 4-inch vertical hooded PVC pipe will serve as an overflow control to redirect high flows out of the planter to the existing trench drain. This will require that a hole be "punched through" the pavement covering the trench drain to allow for insertion of the overflow pipe. The invert of the pipe's "hood" should be set 4 inches below the top of the planter.
- A 4-inch perforated PVC pipe in the drainage layer will direct treated runoff to the existing trench drain. This perforated PVC pipe should be connected to the vertical PVC overflow pipe. The over end of the perforated PVC pipe should be capped.
- Native plant species that are adaptable to the wet/dry conditions that will be present need to be selected.

A plan view and a cross section view of the proposed stormwater planter are attached.

Construction Sequence

- Cut the downspout so that the end can be placed over the stormwater planter. Use a downspout elbow to direct the end of the downspout into the stormwater planter.

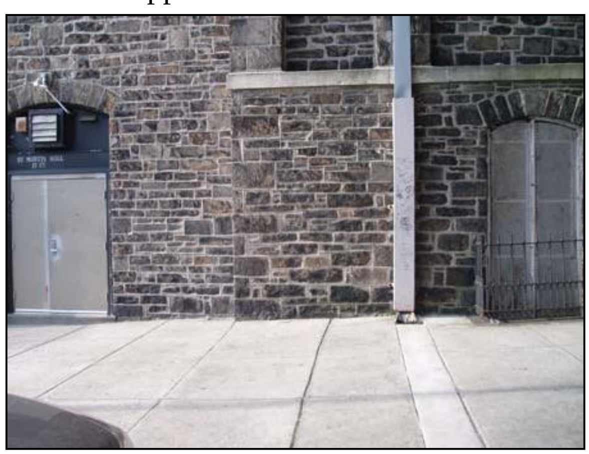


Figure 4: Proposed location of the stormwater planter, along the building between the window and corner (to the right of the door).

- Construct planter with the interior dimensions shown on the attached drawings. Drill hole through bottom of planter and sidewalk to allow for insertion of overflow control pipe.
- Assemble the vertical hooded PVC overflow pipe. Drill holes in the PVC pipe that will serve as the underdrain. Attached the perforated underdrain pipe to the overflow pipe. Set in the planter.
- Place 12 inches of 3/8" to 5/8" washed gravel in the bottom of the planter.
- Lay filter fabric across the top of the gravel drainage layer. The filter fabric should extend upwards along the walls of the planter to the top of the planting medium.
- Fill the planter with 18 inches of planting media. Slight overfilling is recommended to account for settlement.
- Presoak the planting media prior to planting vegetation to allow for settlement.
- Excavate or fill to achieve proper design elevation, leaving space for the upper layer of mulch that will bring the surface to final elevation (approx. 12 inches below the top of the planter).
- Place several 2" to 4" splash stones under the downspout.
- Plant vegetation and mulch.

Materials Specifications

Planter box:
- The planter box should be constructed with the interior dimensions shown on the attached drawings. The surface dimensions of the planting bed should be 9.0 ft by 7.5 ft.
- Materials suitable for planter wall construction include stone, concrete, brick, clay, plastic, wood, or other durable material.
- Treated wood may leach toxic chemicals and contaminate stormwater, and should not be used.
- A pre-manufactured container, such as a concrete vault, may be suitable for this practice.
- If using wood or some other permeable materials, the walls and bottom of the planter box should be lined with an impermeable membrane.

Downspout elbow:
- One downspout elbow

Splash rocks:
- Several 2" to 4" diameter rocks.

Planting medium:
- Approx. 101 $ft^3 \approx 3.8\ yd^3$ of well-blended, homogenous mixture of 50-60% construction sand; 20-30% top soil; and 20-30% organic leaf compost. This mixture should be a uniform mix, free of stones, stumps, etc.
  - Sand – clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 with grain size of 0.02" – 0.04".
  - Top soil – sandy loam, loamy sand, or loam texture per USDA textural triangle with less than 5% clay content.
  - Organic leaf compost – aged leaf mulch.

Filter fabric:

- Approx. 117 ft^2 of filter fabric.
- This filter fabric should meet a minimum permittivity rate of 75 gal/min/ft^2.

Gravel:

- Approx. 67.5 $ft^3 \approx 2.5\ yd^3$ of 3/8" to 5/8"washed gravel

Underdrain and overflow drain system:

- Approx. 11 feet of 4" PVC schedule 40 pipe.
- One 4" PVC schedule 40 hood or trap (two 90^o elbow PVC socket fittings may be used instead).
- One 4" PVC schedule 40 cap socket fitting.
- The perforated underdrain may be connected to the vertical overflow drain using a Schedule 40 Tee PVC Socket Fitting
- The perforated underdrain pipe may be created by drilling holes in 4" PVC Schedule 40 pipe. The holes should be 1/4" in diameter, 6" center to center, along three longitudinal rows.

Planting Considerations

- Vegetation selected for the stormwater planter should be relatively self-sustaining and adaptable.
- Native plant species are recommended, and fertilizer and pesticide use should be avoided whenever possible.
- Vegetation should be able to withstand extended dry and wet periods. Vegetation may be in standing water for up to four hours.
- Tree planting is discouraged in the planter due to the depth of planting medium (18").

A sample of appropriate plant materials is attached (MDE, 2000).

Maintenance Considerations

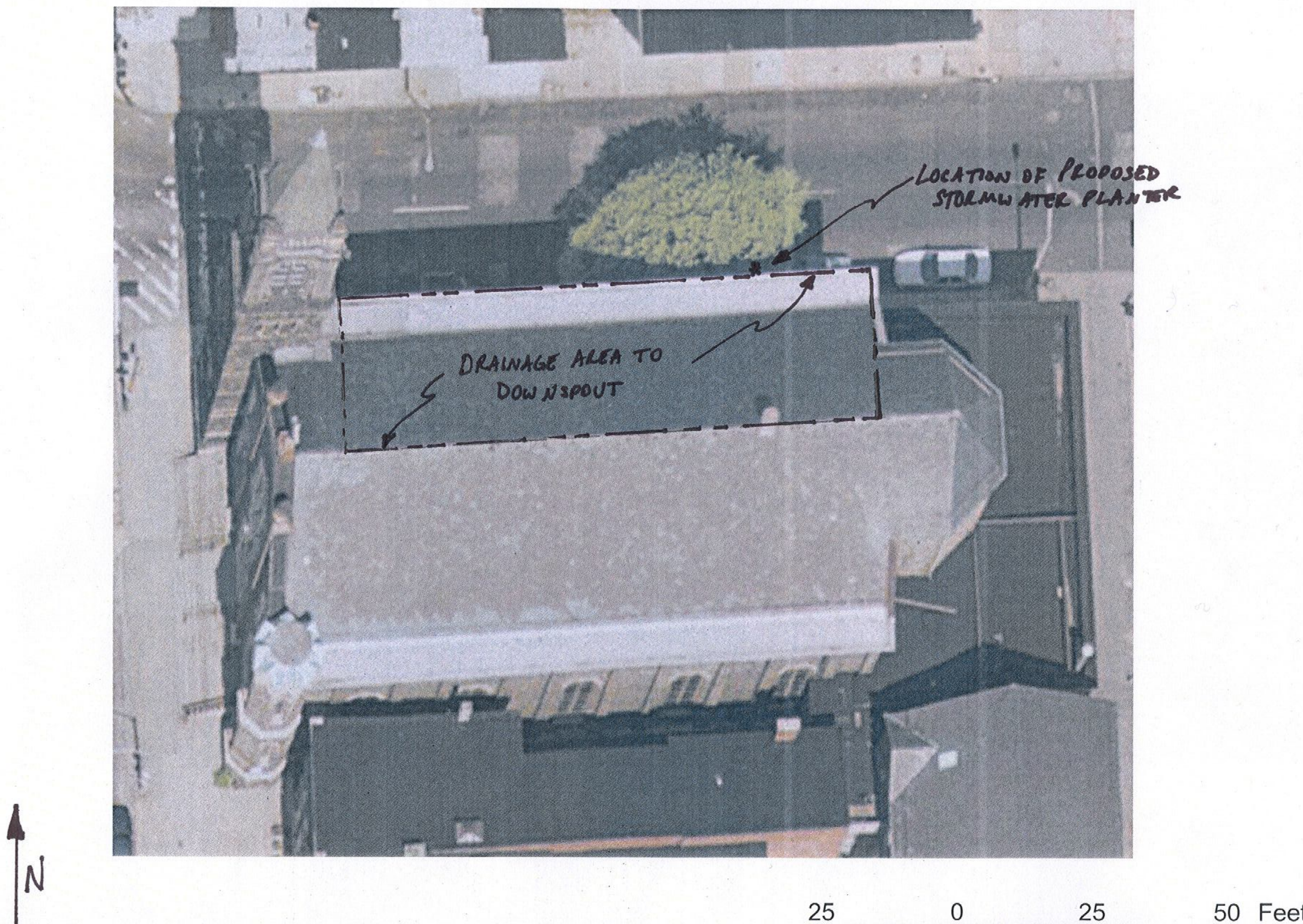
- Following completion, the stormwater planter should be inspected after each storm event greater than 0.5 inches, and at least twice in the first six months. Subsequently, inspections should be conducted annually and after storm events equal to or greater than the 1-year storm event.
- Routine maintenance activities include pruning and replacing dead or dying vegetation, plant thinning, and erosion repair.

Specific inspection and maintenance considerations include:

- Downspout: Debris shall be removed routinely (e.g., no less than every 6 months) and upon discovery. Damaged pipe shall be repaired upon discovery.
- Splash Blocks: Should be replaced if necessary.
- Planter: Water should drain from reservoir within 3-4 hours of storm event. Sources of clogging shall be identified and corrected. Topsoil may need to be amended with sand or replaced all together.

- Planting medium: Excavation and replacement of the soil and gravel layer may be necessary to correct low infiltration rates. Sediment accumulation should be hand removed with minimum damage to vegetation. Sediment should be removed if it is more than 4 inches thick or so thick as to damage or kill vegetation. Litter and debris shall be removed routinely (e.g., no less than quarterly) and upon discovery.
- Planter: Any structural deficiencies in the planter including rot, cracks, and failure should be repaired.
- Overflow Pipe: Damaged pipe shall be repaired or replaced upon discovery.
- Vegetation: Should be healthy and dense enough to provide filtering while protecting underlying soils from erosion. Mulch shall be replenished at least annually. Vegetation that limits access or interferes with planter operation should be pruned or removed. Fallen leaves and debris from deciduous plant foliage should be raked and removed.

R-9 Stormwater Planter at St. Martin Church



R-9 SW Planter @ St. Martin Church

Drainage Area

$\cong 100\,ft \times 25\,ft = 2500\,ft^2$

↳ treats north half of roof

Sizing Computations

* WQ_v per MD Manual

$$WQ_v = \frac{(P)(R_v)(A)}{12}$$

where $P = 1.0"$

$R_v = 0.05 + 0.009(I)$

$= 0.05 + 0.009(100) = 0.95$

$A = 2{,}500\,ft^2$

$$WQ_v = \frac{(1\,in)(0.95)(2500\,ft^2)}{12} = 198\,ft^3 = \underline{200\,ft^3}$$

* Required Surface Area

$$A_f = \frac{(WQ_v)(d_f)}{(k)(h_f + d_f)(t_f)}$$

where $WQ_v = 200\,ft^3$

d_f = depth of soil = 1.5 ft

k = hydraulic conductivity = 2 in/hr = 4 ft/day

h_f = avg height of water = 6 in = 0.5 ft

t_f = filter time = 4 hrs = 0.17 days

$$A_f = \frac{(200\,ft^3)(1.5\,ft)}{(4\,ft/day)(0.5\,ft + 1.5\,ft)(0.17\,days)}$$

$$= 220\,ft^2$$

∴ min surface area = $220\,ft^2$
min soil depth = 1.5 ft

* Available Area ≈ (9.0 ft) × (7.5 ft) = $67.5\,ft^2$

→ try P = 0.25

$$WQ_v = \frac{(0.25\,in)(0.95)(2500\,ft^2)}{12} = 49.5\,ft^3$$

→ revised A_f

$$A_f = \frac{(49.5\,ft^3)(1.5\,ft)}{(4\,ft/day)(0.5\,ft + 1.5\,ft)(0.17\,days)}$$

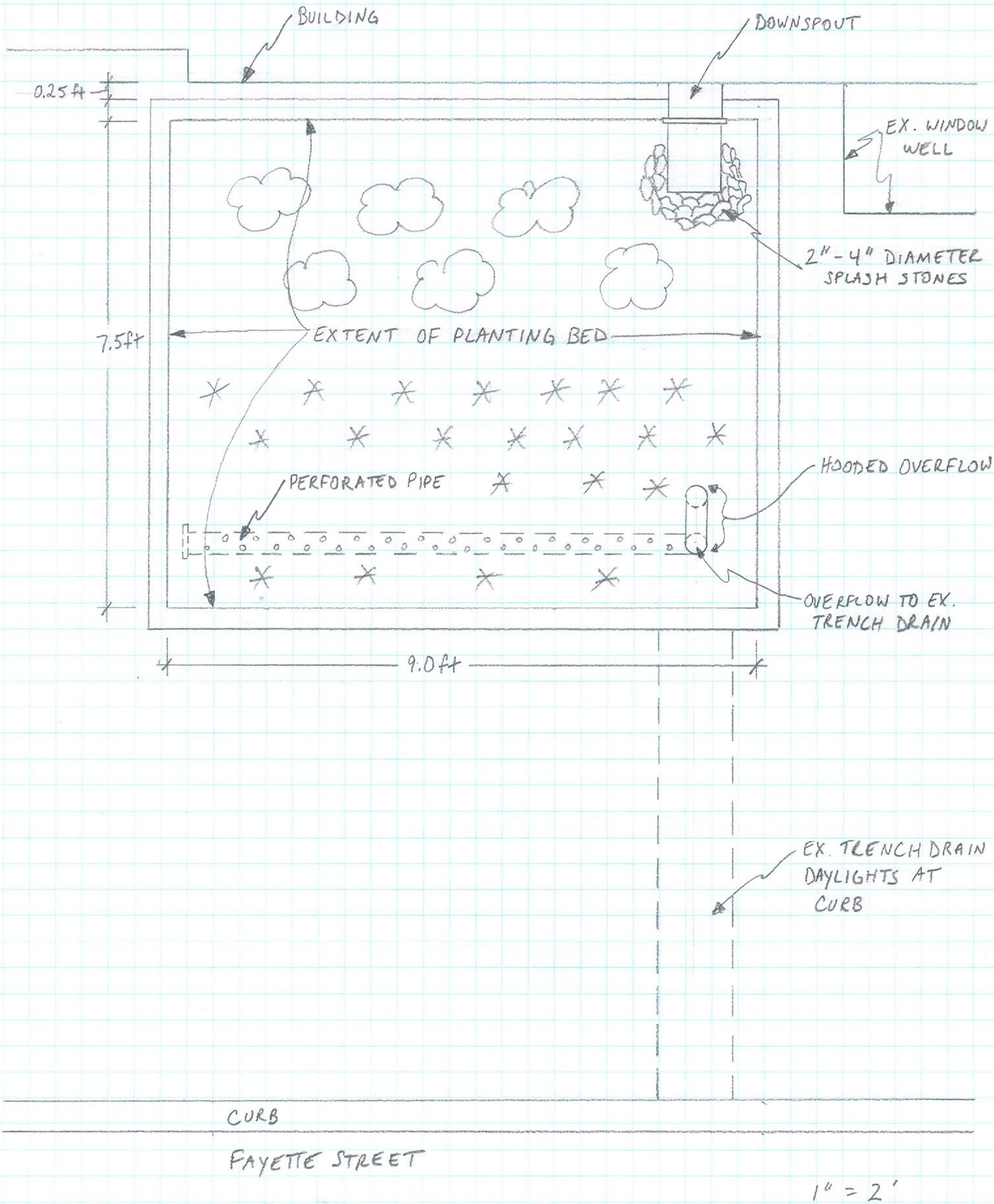
$$= 54.6\,ft^2$$

→ depth of rainfall treated ≈ 0.25

∴ target surface area = $67.5\,ft^2$
min soil depth = 1.5 ft

→ planter dimensions = 9 ft × 7.5 ft

R-9 STORMWATER PLANTER PLAN VIEW



R-9 STORMWATER PLANTER CROSS SECTION

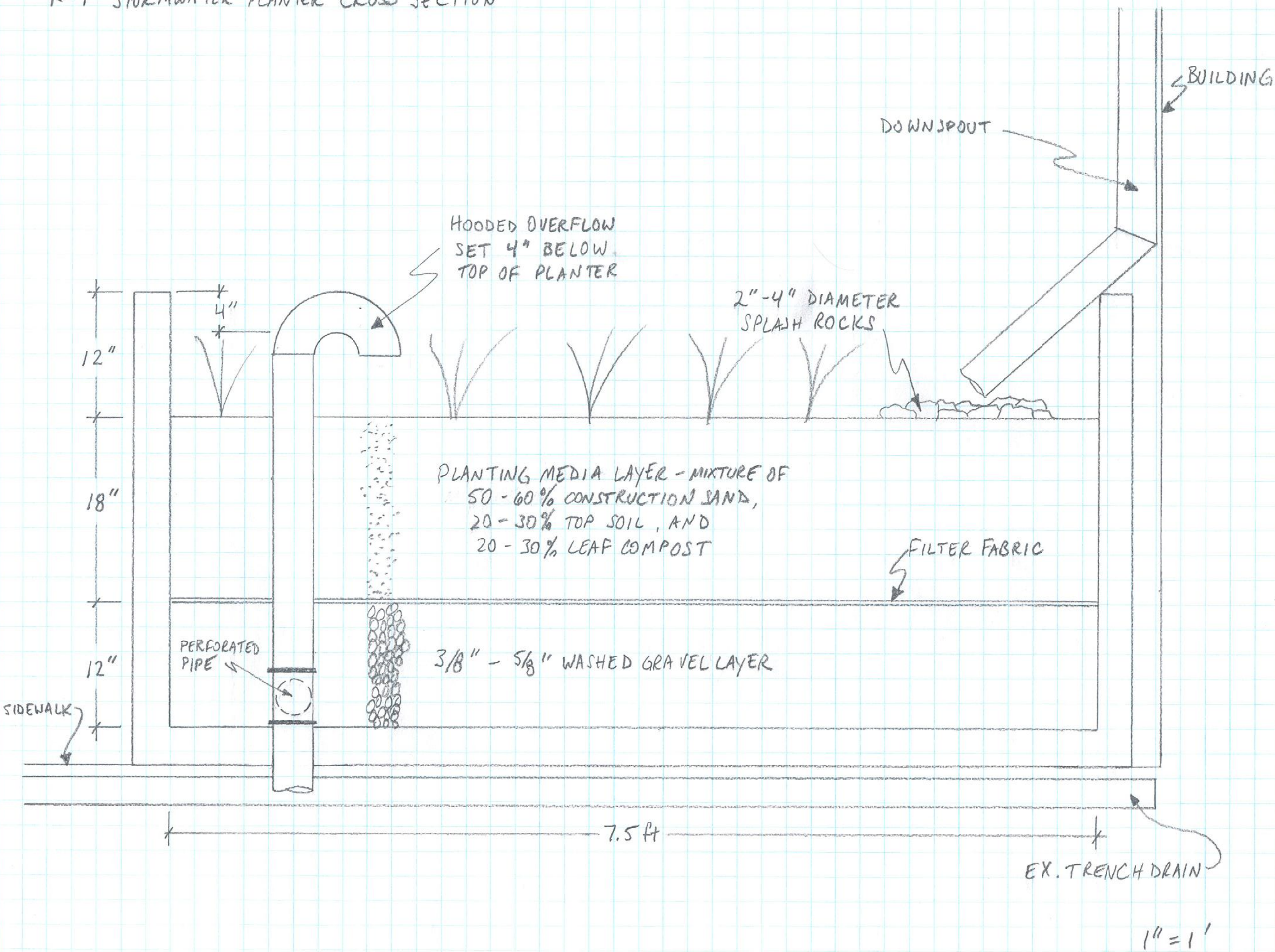


Table A.4 Commonly Used Species for Bioretention Areas

Trees	Shrubs	Herbaceous Species
Acer rubrum Red Maple	*Aesculus pariviflora* Bottlebrush Buckeye	*Andropogon virginicus* Broomsedge
Betula nigra River Birch	*Cephalanthus occidentalis* Buttonbush	*Eupatorium perpurea* Joe Pye Weed
Juniperus virginiana Eastern Red Cedar	*Hamemelis virginiana* Witch Hazel	*Scirpus pungens* Three Square Bulrush
Chionanthus virginicus Fringe-tree	*Vaccinium corymbosum* Highbush Blueberry	*Iris versicolor* Blue Flag
Nyssa sylvatica Black Gum	*Ilex glabra* Inkberry	*Lobelia cardinalis* Cardinal Flower
Diospyros virginiana Persimmon	*Ilex verticillata* Winterberry	*Panicum virgatum* Switchgrass
Platanus occidentalis Sycamore	*Viburnum dentatum* Arrowwood	*Dichanthelium scoparium* Broom Panic Grass
Quercus palustris Pin Oak	*Lindera benzoin* Spicebush	*Rudbeckia laciniata* Tall Coneflower
Quercus phellos Willow Oak	*Myrica pennsylvanica* Bayberry	*Scirpus cyperinus* Woolgrass
Salix nigra Black willow		*Vernonia noveboracensis* New York Ironweed

Note 1: For more options on plant selection for bioretention, consult Bioretention Manual (ETAB, 1993) or the Design of Stormwater Filtering Systems (Claytor and Schueler, 1997).

Appendix H: Infiltration Testing Procedures

Appendix H: Infiltration Testing Procedures

If a retrofit site appears to have soils that will permit the infiltration of stormwater runoff, the use of an infiltration retrofit may be possible. On-site testing should be conducted to establish the infiltration capacity of the native soils and determine the feasibility of the infiltration retrofit.

This appendix presents a basic infiltration testing procedure that can be used determine soil infiltration rates at a retrofit site.

I. Test Pit/Boring Procedures

1. 1 test pit or standard soil boring should be provided for every 200 square feet of proposed infiltration or bioretention facility.

2. The location of each test pit or standard soil boring should correspond to the location of the proposed facility.

3. Excavate each test pit or dig each standard soil boring to a depth at least 2 feet below the bottom of the proposed facility.

4. If the groundwater table is located within three feet of the bottom of the proposed facility, determine the depth to the groundwater table immediately upon excavation and again 24 hours after excavation.

5. Conduct Standard Penetration Testing (SPT) every 2 feet to a depth that is 2 feet below the bottom of the proposed facility.

6. Determine the USDA or Unified Soil Classification system textures at the bottom of the proposed facility and at a depth that is 2 feet below the bottom of the proposed facility. All soil horizons should be classified and described.

7. If bedrock is located within two feet of the bottom of the proposed facility, determine the depth to the bedrock layer.

8. Test pit/soil boring stakes should be left in the field to identify where soil investigations were performed.

II. Infiltration Testing Procedures

1. 1 infiltration test should be provided for every 200 square feet of proposed infiltration or bioretention facility.

2. The location of each infiltration test should correspond to the location of the proposed facility.

3. Install a test casing (e.g., rigid, 4 to 6 inch diameter pipe) to a depth 24 inches below the bottom of the proposed infiltration or bioretention facility.

4. Remove all loose material from sides the test casing and any smeared soil surfaces from the bottom of the test

casing to provide a natural soil interface into which water may percolate. If desired, a 2-inch layer of coarse sand or fine gravel may be placed at the bottom of the test casing to prevent clogging and scouring of the underlying soils. Fill test casing with clean water to a depth of 24 inches and allow underlying soils to pre-soak for 24 hours.

5. 24 hours later, refill the test casing with another 24 inches of clean water and measure the drop in water level within the test casing after one hour. Repeat the procedure three additional times by filling the test casing with clean water and measuring the drop in water level after one hour. A total of four observations will be completed. The infiltration rate of the underlying soils may either be reported as the average of all four observations or the value of the last observation. The infiltration rate should be reported in inches per hour.

6. Infiltration testing can be performed within an open test pit or a standard soil boring.

7. After infiltration testing is completed, the test casing should be removed and the test pit or soil boring backfilled and restored.

Appendix I: Retrofit Design Sheets

ST-1d	Retrofit Design Sheets	
	EXTENDED DETENTION	

Typical Constraints

Some common constraints for retrofitting extended detention ponds include:

Space Required: A typical ED pond requires a footprint of 1 to 3% of its contributing drainage area, depending on depth of the pond (the deeper the pond, the smaller footprint needed).

Available Head: Bottom elevations for ED retrofits are typically determined by the existing elevation of the downstream conveyance system (e.g., a stream, channel or pipe). Backwater in the upstream conveyance system can also constrain the head available at the retrofit site. Typically, a minimum of about six to 10 feet of head is needed to construct an ED retrofit.

Contributing Drainage Area: A minimum contributing drainage area is recommended for each ED design variant. For micropool ED ponds, a minimum of 10 acres is suggested in humid regions to sustain a permanent micropool to prevent clogging. A minimum of 25 acres is recommended in humid regions to maintain constant water elevations in wet ED ponds and ED wetlands. The minimum drainage area may increase in arid or semi-arid climates. A water balance should be conducted if the designer needs to maintain a constant pool elevation. ED may still work on drainage areas less than 10 acres, but designers should be aware that these “pocket” ponds will have very small orifices that will be prone to clogging, experience fluctuating water levels, and generate future maintenance problems.

Minimum Setbacks: Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. Generally, ED retrofits should be setback at least 10 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Utilities: Site designers should check to see if any utilities cross the proposed retrofit site. ED retrofits should not submerge existing sewer manholes as this can lead to infiltration/inflow problems and make maintenance access more difficult. Dry utilities such as underground electric or cable should never be inundated.

Depth to Water Table: The depth to the groundwater table is typically not a major concern for ED retrofits. In fact, intercepting a high water table can sustain a shallow pool or pocket wetland within the retrofit. Designers should keep in mind that groundwater inputs may reduce retrofit pollutant removal capability and could sharply increase excavation costs.

Depth to Bedrock: If bedrock layers are discovered near the surface of the proposed retrofit, it may be too difficult or expensive to excavate the storage needed for ED retrofits.

Special Community and Environmental Considerations about ED Retrofits

ED retrofits can create several community and environmental concerns to anticipate during design:

Aesthetics: ED retrofits tend to accumulate sediment and trash, especially if they are undersized. Many residents perceive dry ED ponds as being unsightly and creating nuisance conditions. Fluctuating water levels in ED retrofits also create a tough landscaping environment. In general, designers should avoid retrofit designs that rely solely on dry ED.

Existing Wetlands: ED retrofits should not be constructed within existing natural wetlands nor should they inundate or otherwise change the hydroperiod of existing wetlands.

Existing Forests: Clearing of mature trees should be avoided during retrofit layout. Designers should be aware that even modest changes in inundation frequency can kill upstream trees (Wright *et al.,* 2007).

Stream Warming Risk: ED ponds have less risk of stream warming than other pond options, but can warm streams if their low flow channel is not shaded. If the retrofit discharges to temperature-sensitive waters, the pond should be forested and have a maximum detention time of 12 hours or less to minimize potential stream warming.

Safety Risk: Dry ED ponds are generally considered to be safer than other pond options since they have few deep pools. Steep side-slopes and unfenced headwalls, however, can still create some safety risks.

Mosquito Risk: The fluctuating water levels within dry ED ponds have potential to create conditions that lead to mosquito breeding. Mosquitoes tend to be more prevalent in irregularly flooded ponds than in ponds with a permanent pool (Santana *et al*., 1994). Designers can minimize the risk by combining ED with a wet pond or wetland.

ED Retrofit Design Issues

ED retrofits are normally squeezed into very tight sites, so designers are always tempted to eliminate standard design features to maximize storage. However, designers should think twice before dropping the following critical design features:

Low Flow Orifice: Unless the drainage area to an ED retrofit is unusually large, the diameter of the ED orifice will be less than six inches in diameter. Small diameter pipes are prone to chronic clogging by organic debris and sediment. Retrofit designers should always look at upstream conditions to assess the potential for higher sediment and woody debris loads. The risk of clogging in such small openings can be reduced by:

- Sticking to a minimum orifice diameter of three inches or greater, even if this means walking away from the proposed retrofit site.
- Protecting the ED low flow orifice by installing a reverse-sloped pipe that extends to mid-depth of the permanent pool or micropool.
- Providing an over-sized forebay to trap sediment, trash and debris before it reaches the ED low flow orifice.
- Installing a trash rack to screen the low flow orifice.

Maximum Vertical Depth of ED: Designers often seek to maximize the depth of ED retrofits to treat a greater volume of runoff within a smaller footprint. Increasing the vertical fluctuation or "bounce" within an ED retrofit, however, can reduce pollutant removal, promote invasive species and create a difficult landscaping environment. In the context of retrofitting, the vertical elevation of ED storage should not extend more than 5 feet above the normal water surface elevation. The bounce effect is not as critical for channel protection or flood control storm events. These storms can exceed the 5 foot vertical limit if they are managed by a multi-stage outlet structure.

ED Retrofit Pond Maintenance Issues

Several maintenance issues can be addressed during retrofit design and future maintenance operations:

Clogging: Retrofits are prone to higher clogging risk at the ED low flow orifice and any upstream flow splitters. These aspects of retrofit plumbing should be inspected at least twice a year after initial construction. Designers should provide easy access to both the micropool and the pond drain to allow maintenance crews to dewater the retrofit.

Sediment Removal: Good maintenance access is also needed to allow crews to remove accumulated sediments. Designers should check to see whether sediments can be spoiled on-site or must be hauled away. The frequency of sediment removal should be increased if:

- o A micropool is used within the ED retrofit
- o The retrofit is undersized relative to the target WQv
- o Significant development activity or winter road sanding is projected to occur in the retrofit's contributing drainage area

Vegetation Management: The constantly changing hydrologic regime of ED retrofits makes it hard to mow or manage vegetative growth. The bottom of dry ED retrofits often become soggy, and water-loving trees such as willows may take over. Retrofit designers should carefully evaluate how vegetation will be cost-effectively managed in the future. Landscape architects can prepare a planting plan that allows the retrofit to mature into a native forest in the right places yet keeps mowable turf along the embankment and all access areas. The wooded wetland concept proposed by Cappiella *et al*., (2005) may be a good option for many ED retrofits.

Trash Removal: Trash, debris and litter tend to accumulate in the forebay, micropool and on the bottom of ED ponds. The maintenance plan should schedule cleanups at least once a year.

A retrofit maintenance plan should be created to address each of the items listed above. The maintenance plan should identify the responsible party and contain a legally enforceable agreement that specifies maintenance duties and schedules.

Adaptation ED for Special Climates and Terrain

Cold Climates: Winter conditions can cause freezing problems within inlets, flow splitters, and ED outlet pipes due to ice formation. Designers can minimize these problems by:

- Not submerging inlet pipes

- Increasing the slope of inlet pipes by a minimum of 1% to discourage standing water and potential ice formation in upstream pipes
- Placing all pipes below the frost line to prevent frost heave and pipe freezing
- Designing low flow orifices to withdraw at least six inches below the typical ice layer
- Placing trash racks at a shallow angle to prevent ice formation

Sand loadings to ED retrofits may increase due to winter road maintenance. Consequently, designers may want to over-size forebays and/or micropools to account for the higher sedimentation rate. ED retrofits can also be designed to operate in a seasonal mode that provides additional WQv storage to treat snowmelt runoff (MSSC, 2005; Caraco *et al*., 1997).

Arid regions: Water rights can be significant issue when it comes to capturing and detaining stormwater runoff in Western states. Also, ED retrofits in arid regions are subject to high sediment loads and may lack vigorous vegetative cover unless they receive supplemental irrigation (Caraco, 2000). The higher evaporation rates and limited inflows of arid regions always make it hard to sustain a permanent pool in the micropool and/or forebay. Designers may want to compute a water balance to determine if pools can be sustained, or if supplemental irrigation will be needed to maintain vegetative cover.

Karst Terrain: Geotechnical investigations are recommended when ED retrofit ponds are situated in active karst areas to minimize the risk of groundwater contamination and avoid sinkhole formation. An impermeable liner and a minimum three foot vertical separation distance from the underlying rock layer is recommended.

Costs to Install ED Retrofits

Extended detention ranks among the least expensive stormwater options, particularly when free storage can be obtained at pond and crossing retrofit sites (SR-1 and SR-2). The cost to install dry ED ponds at new development sites can be determined from the cost equations of Brown and Schueler (1997). The equations (updated to 2006 dollars) predict the base construction cost of new ED construction based on the storage volume of the pond, including excavation, control structures, and appurtenances:

$$BCC = (10.97)(V_s^{0.780})$$

Vs = Total storage volume (ft^3)
BCC = Base construction cost (2006 dollars)

The median cost to construct a new ED pond is about $3,800 per impervious acre treated (range: $2,200 to $7,500). Please note that ED retrofit construction costs are generally at least three times greater (see Chapter 2 and Appendix E).

Design Resources

Several state stormwater manuals provide extensive guidance on ED pond design:

Georgia Stormwater Management Manual
http://www.georgiastormwater.com

Minnesota Stormwater Management Manual
http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Vermont Stormwater Management Manual
http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm

ST-2d	Retrofit Design Sheets
	WET PONDS

Typical Constraints

Some common constraints hinder the use of wet pond retrofits in developed watersheds:

Space Required: The proposed surface area for a wet pond retrofit should be at least 1 to 3 % of its contributing drainage area, depending on the pond's depth.

Contributing Drainage Area: A minimum contributing drainage area of 10 to 25 acres is recommended for wet pond retrofits to maintain constant water elevations, although these can vary by design type and climatic region. Smaller drainage areas may be treated if the retrofit will intercept the groundwater table (but this may reduce pollutant removal and increase excavation costs). Wet ponds can still work on drainage areas less than 10 acres, but designers should be aware that these "pocket" ponds will be prone to clogging, experience fluctuating water levels, and generate more nuisance conditions. A water balance should be conducted if the designer needs to maintain constant pool elevations.

Utilities: Most utilities do not permit existing underground pipes or dry utilities to be submerged as a result of retrofit construction. It may be possible to submerge water or sewer lines if manholes are raised above the maximum water surface elevation of the pond and if the pipes were originally constructed in a watertight manner.

Excavation: Wet ponds normally entail several feet of excavation. Retrofit designers need to understand the quality of subsoils in terms of their suitability for embankment fill, potential excavation problems and whether they need to be hauled off-site.

Available Head: The depth of a wet pond retrofit is usually determined by the head available on the site. The bottom elevation is normally set by the existing downstream conveyance system to which the retrofit discharges (e.g., a stream, channel or pipe). While it is possible to excavate a pool below the outlet invert, this resulting dead storage may not mix well with the rest of the pond, thereby reducing performance and creating nuisance problems. Typically, a minimum of six to eight feet of head are needed to construct a wet pond retrofit.

Minimum Setbacks: Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, and wells. As a general rule, wet pond retrofits should be setback at least 10 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields, and 100 feet from private wells.

Depth to Water Table: The depth to the water table can be a design concern for wet pond retrofits. If the water table is close to the surface, it may make excavation difficult and expensive. Groundwater inputs can also reduce the pollutant removal rates. On the other hand, a high groundwater table can help provide a constant pool elevation to maintain a pocket pond when the contributing drainage area is small.

Depth to Bedrock: If bedrock layers occur near the surface of a proposed retrofit, it may be too expensive to blast the site to get enough storage volume.

Community and Environmental Considerations for Wet Pond Retrofits

Wet ponds are readily accepted by communities if they are properly designed and maintained. Pond retrofits, however, can generate several community and environmental concerns:

Aesthetic Issues: Many residents feel that wet ponds are an attractive landscape feature, promote a greater sense of community and are an attractive habitat for fish and wildlife. Designers should note that these benefits are often diminished if retrofits are under-sized or have small contributing drainage areas.

Existing Wetlands: A wet pond retrofit should not be constructed within an existing natural wetland. Any discharges from the retrofit into an existing natural wetland should be minimized to prevent changes to its hydroperiod.

Existing Forests: Construction of wet pond retrofits may involve major clearing of existing forest cover. Designers can expect a great deal of neighborhood opposition if they do not make a concerted effort to save mature trees during retrofit design and layout.

Stream Warming Risk: Wet ponds can warm streams by two to 10 degrees Fahrenheit, although this may not be a major problem for degraded urban streams (Galli, 1990). To minimize stream warming, wet pond retrofits should be shaded and provide shorter ED detention times (e.g., 12 hours vs. 24).

Safety Risk: Pond safety is an important community concern, as young children have perished by drowning in wet ponds after falling through the ice. Gentle side slopes and safety benches should be provided to avoid potentially dangerous drop-offs, especially when retrofits are located near residential areas. Residents may request fences around the pond or its outfalls in some retrofit situations.

Mosquito Risk: Mosquitoes are not a major problem for larger wet ponds (Santana *et al*., 1994; Ladd and Frankenburg, 2003). However, fluctuating water levels in smaller or under-sized wet ponds could pose some risk for mosquito breeding. Mosquito problems can be minimized through simple design features and maintenance operations described in Chapter 4 and MSSC (2005).

Geese and Waterfowl: Wet ponds with extensive turf and shallow shorelines can attract nuisance populations of resident geese and other waterfowl whose droppings can reduce pond nutrient and bacteria removal. Several design and landscaping features can make a pond retrofit much less attractive to geese (see Schueler, 1992).

Wet Pond Retrofit Design Issues

Wet pond retrofits are often squeezed into very tight sites, so designers can be tempted to eliminate standard design features in order to obtain maximum pool storage. It is generally advisable to sacrifice some storage volume in order to incorporate design features critical to retrofit performance, function and longevity. The following design features should be included in wet pond retrofits:

Pretreatment: Sediment forebays located at major inlets help extend the longevity of wet pond retrofits. Each forebay should be sized to have about 10% of the total retrofit storage volume and have easy access for sediment cleanouts.

Long Flow Path: Retrofits should have an irregular shape and a long flow path from inlet to outlet to increase residence time and pond performance (ideally 2:1). Internal berms can be used to extend flow paths and create multiple pond cells.

Safety/Access Bench: Retrofits should include a flat bench just outside of the perimeter of the permanent pool to allow for maintenance access and reduce safety risks. The bench can be variable in width (10 to 15 feet).

Aquatic Bench: Aquatic benches are shallow areas just inside the perimeter of the normal pool that promote growth of aquatic and wetland plants. The bench also serves as a safety feature, reduces shoreline erosion and conceals floatable trash. In retrofit situations, the aquatic bench can vary in width from three to 10 feet.

Avoid Deep Pools: Designers often seek to maximize the depth of a wet pond retrofit to store a greater runoff volume within a smaller footprint. Pool depths greater than eight feet, however, should be avoided in most retrofit situations. Deep ponds can cause seasonal pond stratification that release pollutants stored in bottom sediments back into the water column (and have a much greater safety risk).

Wet Pond Retrofit Maintenance Issues

Wet ponds normally have less routine maintenance requirements than other stormwater treatment options. The frequency of maintenance operations may need to be scaled up if retrofits are undersized or have a small contributing drainage area. Designers should consult CWP (2004b) for more information on wet pond maintenance problems and solutions. Several maintenance issues can be addressed during retrofit design and future maintenance operations:

Maintenance Access: Good maintenance access should always be provided to the sediment forebay, access bench, riser and outlet structure so crews can more easily perform maintenance tasks. The riser structure should be placed within the embankment.

Sediment Removal: Sediments excavated from wet ponds are not normally classified as toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be needed prior to sediment disposal if the retrofit serves a hotspot land use.

Clogging: There is always some risk that the low flow orifice or upstream flow splitter may clog. These aspects of retrofit hydraulics should be inspected frequently after construction. The retrofit should have a pond drain so crews can de-water the pond to relieve clogging and remove sediments.

Vegetation Management: The maintenance plan should clearly outline how vegetation in the pond and its buffer will be managed or harvested in the future. Methods to establish desired aquatic plants and control invasive plant species should be outlined. Annual mowing of the pond buffer is only required along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year) or as forest.

Trash Removal: The maintenance plan should schedule a shoreline cleanup at least once a year to remove trash and floatables.

Adapting Wet Ponds for Special Climates and Terrain

Cold climates: The performance of wet pond retrofits in cold climates can be enhanced when designers:

- Treat larger runoff volumes in the spring by adopting seasonal operation of the permanent pool (see MSSC, 2005)
- Plant salt-tolerant vegetation in pond benches
- Do not submerge inlet pipes and provide a minimum 1% pipe slope to discourage ice formation
- Locate low flow orifices so they withdraw at least 6 inches below the typical ice layer
- Angle trash racks to prevent ice formation
- Oversize riser and weir structures to avoid ice formation and freezing pipe
- Increase forebay size if road sanding is prevalent in the contributing drainage area

Arid Climates: Wet pond retrofits require special design in regions with low annual rainfall or high evapotranspiration. Ponds are generally not a preferred option if the permanent pool cannot be maintained without supplemental irrigation. Some tips for designing wet ponds in arid climates include the following:

- Pond vegetation flourishes when temperatures are warm and the growing season is long or year-round, which can result in prolific growth of algae, wetland plants, shrubs and trees (Figure 1). Regular mowing or even plant harvesting should be considered to keep vegetative growth in check.
- Designers should always check to make sure there is an adequate water balance to support a permanent pool throughout the year- otherwise the potential of algal blooms, odors and other nuisances can increase sharply. When in doubt, install a clay or synthetic liner to prevent water loss via infiltration.
- Arid regions generate higher sediment loads, so designers should consider adding extra sediment trapping capability in retrofit forebays (Caraco, 2000).

Karst Terrain: Deep pools increase the risk of sinkhole formation and groundwater contamination in regions with active karst. Designers should always conduct geotechnical investigations to assess this risk. Pond retrofits in karst areas should include impermeable liners and maintain at least three feet of vertical separation from the underlying rock layer.

Wet Pond Installation Costs

Wet ponds are more expensive on a unit area basis than constructed wetlands and ED ponds, primarily due to the need for deeper excavation and safety features such as side-slope control and benches (Wossink and Hunt, 2003). Several cost equations (updated to 2006 dollars) can predict the

Figure 1: Warm temperatures have led to algal blooms in this wet pond.

base construction cost of new wet ponds, given their proposed storage volume or drainage area treated.

Wet Extended Detention Ponds (Brown and Schueler, 1997)
$BCC = (10.97)(V_s^{0.750})$

Wet Ponds (Brown and Schueler, 1997)
$BCC = (263.99)(V_s^{0.553})$

Wet Ponds (Wossink and Hunt, 2003)
$BCC = (17{,}333)(A^{0.672})$

Vs = Total storage volume (ft^3)
A = area treated (acres)
BCC = Base construction cost (2006 dollars)

Solving these equations for a range of common pond sizes yields a median construction cost for a new wet pond of $ 8,350 per impervious acre treated (range: $ 3,100 to $28,750). Please note that the wet pond retrofit construction costs are typically 1.5 to 2 times higher than new pond construction (see Chapter 2 and Appendix E).

Wet Pond Design Resources

Many existing state and local stormwater manuals provide extensive guidance on wet pond design:

Vermont Stormwater Management Manual
http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm

Minnesota Stormwater Management Manual
http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Austin, TX Drainage Criteria Manual
http://www.cityofaustin.org/watershed/publications.htm

New York State Stormwater Management Design Manual
http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html

Maryland Stormwater Design Manual
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

ST-3d	Retrofit Design Sheets
	CONSTRUCTED WETLANDS

Typical Constraints

Constructed wetlands are subject to several constraints when it comes to retrofitting:

Contributing Drainage Area: The contributing drainage area must be large enough to sustain a permanent water level within a stormwater wetland. A minimum of 25 acres of drainage area is typically needed to maintain constant water elevations in humid regions, although the precise area varies based on local hydrology. The minimum drainage area can be relaxed if the bottom of the retrofit intercepts the groundwater table or if designers are willing to accept periodic wetland drawdown. Designers should note that these "pocket" wetlands will have lower pollutant removal, higher excavation costs, and a greater risk of invasive plant colonization.

Space Requirements: Wetland retrofits require a footprint ranging between 3 and 5% of the contributing drainage area, depending on the average depth of the wetland and the extent of its deep pool features.

Available Head: The depth of a wetland retrofit is usually constrained by the head available on the site. The bottom elevation is fixed by the elevation of the existing downstream conveyance system to which the retrofit will ultimately discharge. Head requirements for constructed wetlands are typically less than wet ponds because of their shallow nature - a minimum of two to four feet of head is usually needed.

Minimum Setbacks: Local ordinances and design criteria should be consulted to determine minimum setbacks to property lines, structures, utilities, and wells. As a general rule, wetland retrofits should be setback at least 10 feet from property lines, 25 feet from building foundations, 50 feet from septic system fields and 100 feet from private wells.

Depth to Water Table: The depth to the groundwater table is not a major constraint for constructed wetlands as a high water table can maintain wetland conditions within the retrofit. Designers should keep in mind that high groundwater inputs may reduce pollutant removal rates and increase excavation costs.

Community and Environmental Considerations for Constructed Wetlands

Constructed wetlands can generate several community and environmental concerns:

Aesthetics: Wetland retrofits can create wildlife habitat and become an attractive community feature. Designers should carefully think through how the wetland community will evolve over time, as the future plant community seldom resembles the one initially planted. Constructed wetlands require continual vegetative management to maintain desired wetland species, control woody growth and prevent invasive plants from taking over.

Existing Wetlands: It can be tempting to construct a stormwater wetland within an existing natural wetland, but this should never be done unless it is part of a broader effort to restore a degraded urban wetland approved by the local or state wetland review authority. Designers should investigate the wetland status of adjacent areas to determine if the discharge from the constructed wetland will change the hydroperiod of a downstream natural wetland (see Cappiella et al., 2006b, for guidance on minimizing stormwater discharges to existing wetlands).

Regulatory Status: Constructed wetlands built for the express purpose of stormwater treatment are not considered jurisdictional wetlands in most regions of the country, but designers should check with their wetland permit authority to ensure this is the case.

Existing Forests: Given the large footprint of constructed wetlands, there is a strong chance that construction may cause extensive tree clearing. Designers should preserve mature trees during retrofit layout, and may want to use a wooded wetland concept to create a forested wetland community (see Cappiella *et al*., 2006b).

Stream Warming Risk: Constructed wetlands have a moderate risk of stream warming. If the retrofit discharges to temperature-sensitive waters, designers should consider the wooded wetland design, and any ED storage should be released in less than 12 hours.

Safety Risk: Constructed wetlands are safer than other pond options, although forebays and micropools should be designed with benches to reduce safety risks.

Mosquito Risk: Mosquito control can be a concern for stormwater wetlands if they are under-sized or have a small contributing drainage area. Few mosquito problems are reported for well designed, properly-sized and frequently maintained constructed wetlands (Santana *et al*., 1994) but no design can eliminate them completely. Simple precautions can be taken to minimize mosquito breeding habitat within a wetland retrofit, such as constant inflows, benches that create habitat for natural predators, and constant pool elevations (see Walton 2003 and MSSC, 2005).

Design Issues for Constructed Wetland Retrofits

Several elements should be considered when designing constructed wetland retrofits:

Sediment Forebays: Forebays should be located at all major inlets to trap sediment and preserve the capacity of the main wetland treatment cell. A major inlet is defined as serving at least 10% of the retrofit is contributing drainage area. The forebay should be at least four feet deep, contain about 15% of the total retrofit WQv, and have a variable width aquatic bench.

Constructed Wetland Layout: The layout of the stormwater wetland affects its pollutant removal capability and plant diversity. Performance is enhanced when the wetland has multiple cells, longer flowpaths, and a high surface area to volume ratio. Whenever possible, constructed wetlands should be irregularly shaped with a long, sinuous flow path.

Microtopography: Retrofits should have variable microtopography - a mix of shallow, intermediate, and deep areas that promote dense and diverse vegetative cover.

Planting Strategy: Wetland retrofits should outline a realistic, long-term planting strategy to establish and maintain desired wetland vegetation. The plan should indicate how wetland plants will be established within each pondscaping zone (e.g., wetland plants, seed-mixes, volunteer colonization, and tree and shrub stock) and whether soil amendments are needed to get plants started. The future species trajectory of wetland retrofits is hard to predict, so several different strategies should be considered. Several excellent resources on wetland planting strategies are available (Schueler, 1992; and Shaw and Schmidt, 2003).

Wooded Wetland vs. Emergent Wetland Model: The traditional model for constructed wetlands has been a shallow emergent marsh. In many parts of the country, however, forested wetlands are the most common natural wetland community. In these regions, it may be desirable to design the wetland as a wooded wetland to more closely match local wetland types and reduce future wetland management problems (Cappiella et al., 2006a).

Maintenance Access: Good maintenance access should always be provided to the forebay so that crews can remove sediments and preserve wetland treatment capacity. More frequent sediment removal will be needed if the retrofit is undersized or has a small contributing drainage area.

Maintenance Issues for Constructed Wetland Retrofits

Several maintenance issues can be addressed during the design of constructed wetland retrofits:

Sediment Removal: Frequent sediment removal from the forebay is essential to maintain the function and performance of a constructed wetland. Maintenance plans should schedule cleanouts every five years or so, or when inspections indicate that 50% of the forebay capacity has been lost. Designers should also check to see whether removed sediments can be spoiled on-site or must be hauled away. Sediments excavated from constructed wetlands are not usually considered toxic or hazardous, and can be safely disposed by either land application or land filling.

Clogging: There is always some risk that the low flow orifice and any upstream flow splitters may clog. Clogging can quickly change design water elevations for the wetland and possibly kill wetland vegetation. The inlet and outlet structures to the wetland should be inspected frequently to discover any clogging problems.

Vegetation Management: Managing wetland vegetation is an important ongoing maintenance task. Designers should expect significant changes in wetland species composition over time. Invasive plants should be dealt with as soon as they colonize the wetland. Vegetation may need to be periodically harvested if the retrofit becomes overgrown. Construction contracts should include a care and replacement warranty extending at least two growing seasons after initial planting to selectively replant portions of the wetland that fail to take.

Trash Removal: Cleanups should be scheduled at least once a year to remove trash and debris from the retrofit.

Adapting Constructed Wetlands for Special Climates and Terrain

Cold Climates: Wetland performance decreases when snowmelt runoff delivers high pollutant loads. Shallow constructed wetlands can freeze in the winter, which allows runoff to flow over the ice layer and exit without treatment. Inlet and outlet structures close to the surface may also freeze, further diminishing wetland performance. Several design tips can improve wintertime performance for wetland retrofits (see Profile Sheets ST-1d and ST-2d).

Salt loadings are higher in cold climates due to winter road maintenance. High chloride inputs have a detrimental effect on native wetland vegetation, and can shift the wetland to more salt-tolerant species such as cattails (Wright *et al*., 2007). Designers should choose salt-tolerant species when crafting their planting plan and consider reducing salt application in the contributing drainage area to the retrofit.

Arid Climates: Constructed wetlands are hard to establish in regions with low annual rainfall and high evapotranspiration rates. These climates make it difficult to maintain a constant pool water elevation throughout the growing season. Designers should always check to make sure there is an adequate water balance to support a wetland throughout the year - otherwise the potential of algal blooms, odors and other nuisances will increase sharply. When in doubt, install clay or synthetic liners to prevent water loss via infiltration. Wetland vegetation flourishes when temperatures are warm and the growing season is long or year-round. Regular mowing or even harvesting should be considered to keep vegetative growth in check.

Karst Terrain: Even shallow pools in active karst terrain can increase the risk of sinkhole formation and groundwater contamination. Designers should always conduct geotechnical investigations in karst terrain to assess this risk. If in doubt, designers should employ an impermeable liner and maintain at least three feet of vertical separation from the underlying karst layer.

Constructed Wetland Installation Costs

Constructed wetlands are less expensive on a unit area basis than wet ponds and extended detention ponds since they require less excavation and need fewer safety features (Wossink & Hunt, 2003). On the other hand, some constructed wetlands have a larger surface footprint. These construction cost savings may disappear if land must be acquired to install the retrofit.

Wossink and Hunt (2003) developed an equation to predict the cost of new wetland construction based on the acreage of the contributing drainage area treated (updated to 2006 dollars):

$$BCC = (4{,}465)(A^{0.484})$$

Where:
A = Size of contributing drainage area (acres)
BCC = Base construction cost (2006 dollars)

Brown and Schueler (1997) devised a similar equation for new wetland and pond construction based on storage volume needed that yields slightly higher costs:

$$BCC = (27.95)(V_s^{0.701})$$

Where:
V_s = Total storage volume (ft^3)
BCC = Base construction cost (2006 dollars)

Based on typical wetland sizes, the equations yield a median construction cost of $2,900 per impervious acre treated (range: $2,000 to $9,600). Few retrofit sites will meet the criteria for use of these equations. Under most retrofit conditions, wetland retrofit construction costs will be 3 to 4 times greater than new wetland construction (see Chapter 2 and Appendix E).

Constructed Wetland Design Resources

Vermont Stormwater Management Manual
http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm

Connecticut 2004 Stormwater Management Manual
http://dep.state.ct.us/wtr/stormwater/strmwtrman.htm#download

Stormwater Management Manual for Western Washington
http://www.ecy.wa.gov/programs/wq/stormwater/manual.html

Minnesota Stormwater Manual
http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

ST-4d

Retrofit Design Sheets

BIORETENTION

Typical Constraints

Bioretention can be applied in most soils or topography since runoff percolates through an engineered soil bed and is returned to the stormwater system. Key constraints when retrofitting with bioretention include:

Available Space: Not every open area will be a good candidate for bioretention. To start with, designers should look for open areas that are at least five to 10% of the contributing drainage area and are free of underground utilities.

Site Topography: Bioretention is best applied when contributing slopes are more than 1% and less than 5%. Ideally, the proposed treatment area will be located in depression to minimize excavation costs.

Available Head: Bioretention retrofits are fundamentally constrained by the invert elevation of the existing conveyance system they discharge to. These elevations generally establish the bottom elevation needed to tie the underdrain from the bioretention area into the storm drain system. In general, four to five feet of elevation above this invert is needed to drive stormwater through a proposed bioretention area. Less head is needed if underlying soils are permeable enough to dispense with the underdrain.

Water Table: Bioretention should always be separated from the water table to ensure groundwater does not intersect with the filter bed. Mixing can lead to possible groundwater contamination or practice failure. A separation distance of 3 feet is recommended between the bottom of the filter bed and the seasonally high water table.

Overhead Wires: Designers should also check whether future tree growth in the bioretention area will interfere with existing overhead utility lines.

Soils: Soil conditions do not constrain the use of bioretention although they determine whether an underdrain is needed. Impermeable soils in Hydrologic Soil Group C or D usually require an underdrain, whereas A or B soils often do not. Designers should verify soil permeability when designing a bioretention retrofit, using the on-site soil investigation methods presented in Appendix H.

Community and Environmental Considerations for Bioretention Retrofits

Bioretention is a popular practice, since it can meet local landscaping requirements and improve site appearance. The only major drawbacks relate to who will handle future landscape maintenance and whether landowners will modify or replace the bioretention area in the future. If bioretention areas will be installed on private lots, homeowners need to be educated on their routine maintenance tasks and fully understand their intended stormwater function.

Design Issues for Bioretention

Several issues should be considered when designing bioretention retrofits:

Pretreatment: Pretreatment can prevent premature clogging and prolong the effective function of bioretention retrofits. Several pretreatment measures can be used, including directing runoff over a grass filter strip, adding a three to six inch drop or installing a pea gravel diaphragm that spreads flow evenly and drops out larger sediment particles. A two-cell design is recommended when bioretention is used as a storage retrofit or for larger on-site applications. The first cell is a sediment forebay that pretreats runoff and traps sediment before discharge into the main bioretention cell.

Landscaping is critical to the function and appearance of bioretention areas. Where possible, a combination of native trees, shrubs, and herbaceous plant species are preferred. Plants should be able to tolerate both wet and dry conditions. Most upland vegetation does not do well in the deepest center areas that are more frequently inundated. "Wet footed" plants, such as wetland forbs, should be planted near the center, whereas upland species are better for the edges of the bioretention area. Regional lists of plant species suitable for bioretention areas can be found at the end of this profile sheet.

Type of media: The choice of filter media is important to provide adequate drainage, support plant growth and optimize pollutant removal within the filter bed. Early design guidance recommended a mix of 50-60% sand, 20-30% topsoil and 20-30% organic leaf compost. The topsoil component should consist of loamy sand, sandy loam, or loam with a clay content no greater than 5%.

Hunt and Lord (2006a) has recently advocated a bioretention soil mix with a greater proportion of sand (85-88% sand; 8-12% fines; and 3-5% organic matter) as a more effective choice for pollutant removal. They also strongly recommend that topsoil be tested to ensure that it has a low phosphorus index value to prevent phosphorus leaching. If nitrogen removal is the goal, it may be advisable to increase the percentage of soil fines.

Designers should also ensure that the media is well mixed and homogeneous. The media should have an infiltration rate of 1.0 to 2.0 inches per hour as recent research indicates that pollutant removal is optimized in this range.

Depth of Media: Early bioretention design guidance recommended a minimum filter bed depth of 4 feet. However, the filter bed may be reduced in depth to 1.5 to 2.5 feet in certain retrofit applications, particularly when available head is limited. Research has shown that good pollutant removal can still be achieved in filter beds as shallow as 1.5 feet, with the possible exception of nitrogen (Davis, 2005, and Hunt *et al.*, 2006). It is doubtful that filter beds less than 1.5 feet deep can provide reliable pollutant removal efficiency over the long run. Designers should also remember that filter beds need to be at least 4 feet deep to provide enough soil volume for the root structure of mature trees (i.e., use turf, perennials or shrubs instead of trees for shallower filter beds).

Underdrain: In many bioretention retrofits, filtered runoff will be collected by a perforated underdrain and conveyed to the storm drain system. If the site has permeable soils, however, the underdrain can be reduced or eliminated altogether. The need for an underdrain depends on the permeability of the underlying soils, which have often been previously altered or compacted in many retrofit situations. Soil permeability rates should always be verified when designing a bioretention retrofit (see Appendix H). If an underdrain is required at a bioretention retrofit, it should have a minimum diameter of 6 inches and be placed in a foot deep gravel bed.

Overflow: Designers should always incorporate an overflow structure to safely bypass larger storms around the bioretention retrofit. The invert of the overflow should be placed at the maximum water surface elevation of the bioretention area, which is typically 6 to 12 inches above the surface of the filter bed.

Surface Cover: A three-inch layer of hardwood mulch on the surface of the filter bed enhances plant survival, suppresses weed growth, and pretreats runoff before it reaches the filter bed. Shredded hardwood bark mulch makes a very good surface cover, as it retains a significant amount of nitrogen and typically will not float away. On the other hand, hardwood mulch needs to be replaced every few years, may not be durable or attractive enough for certain retrofit situations, and may not be available in some regions of the country. In these situations, designers may wish to consider alternative covers such as turf, river stone, gravel or pumice stone.

Contributing Drainage Area: Designers should always verify that the actual contributing area and inlet elevations are accurately determined at the retrofit site. Designers should walk the site during a rainstorm to look at actual flowpaths to the proposed treatment area, and confirm these boundaries using fine resolution topographic surveys.

Bioretention Maintenance Issues

Bioretention requires seasonal landscaping maintenance to establish and maintain vigorous plant cover:

Vegetation Management: Vegetation management is an important to sustain the pollutant removal and landscaping benefits of the bioretention area. The construction contract should include a care and replacement warranty to ensure vegetation gets properly established and survives during the first growing season after construction.

Surface Cover/Filter Bed: The surface of the filter bed can become clogged with fine sediments over time. Core aeration or deep tilling may relieve the problem. The surface cover layer will need to be removed and replaced every two or three years. The inlets and pretreatment measures for the bioretention retrofit also need frequent inspections to ensure they are working properly and to remove deposited sediments.

Training Landscape Contractors: Maintenance can be performed by landscaping contractors who are already providing similar landscaping services on the property, but they will need training on bioretention maintenance tasks.

Adapting Bioretention for Special Climates and Terrain

Bioretention areas can be applied almost everywhere, with the proper design modifications:

Arid Climates: Bioretention areas should be landscaped with drought-tolerant plant species. A xeriscaping approach is preferred since supplemental irrigation makes little sense in arid and semi-arid climates. It may also be advisable to switch from mulch to a more durable surface cover such as riverstone or pumice. The planting plan may also have fewer trees and plants to minimize the need for supplemental irrigation. Designers should recognize that longer growing seasons increase both the frequency and cost of landscape maintenance.

Cold Climates: Bioretention areas can be used for snow storage as long as an overflow is provided and they are planted with salt-tolerant, non-woody plant species (for a species list, consult MSSC, 2005). While several studies have shown that bioretention operates effectively in winter conditions, it is a good idea to extend the filter bed and underdrain pipe below the frost line and/or oversize the underdrain by one pipe size to reduce the freezing potential.

Karst Terrain: Bioretention should utilize impermeable liners and underdrains when located in an active karst area. A geotechnical investigation may be needed to confirm that three feet of vertical separation exists from the underlying rock layer.

Bioretention Installation Costs

The cost to construct bioretention areas are extremely variable, and are strongly influenced by the area treated, the depth of filter bed, the presence or absence of an underdrain and whether it is professionally designed, installed or landscaped. Wossink and Hunt (2003) report that bioretention has the lowest construction costs of all new stormwater treatment options serving smaller drainage areas from 1 to 5 acres. On the other hand, the unit costs to retrofit bioretention in highly urban settings may be 10 to 20 times higher (See Appendix E). The long-term maintenance costs for bioretention areas are not expected to be very different from normal landscaping maintenance costs.

Brown and Schueler (1997) developed equations to predict the base construction cost of bioretention as a function of the water quality volume provided. When these equations are adjusted to 2006 dollars, they yield:

$$BCC = (7.62)(WQ_v^{0.990})$$

Where:
WQ_v = Water quality volume (ft^3)
BCC = Base construction cost (2006 dollars)

More recently, Wossink and Hunt (2003) developed equations to predict the cost of new bioretention construction as a function of their contributing drainage area. This equation yields lower cost estimates compared to the Brown equation:

$$BCC = (11{,}781)(A^{1.088})$$

Where:
A = Size of contributing drainage area (acres)
BCC = Base construction cost (2006 dollars)

Using these equations, it is possible to establish median bioretention costs of $25,400 per impervious acre treated (range: $19,900 to $41,750). Construction cost drops sharply when site soils are permeable enough to dispense with an underdrain (although this is not a common retrofit situation).

Bioretention Design Resources

Several state and local stormwater manuals provide useful bioretention design guidance:

Prince George's Co., MD Bioretention Manual
http://www.goprincegeorgescounty.com/Government/AgencyIndex/DER/ESD/Bioretention/bioretention.asp?nivel=foldmenu(7)

Lake Co., OH Bioretention Guidance Manual
http://www2.lakecountyohio.org/smd/Forms.htm

Low Impact Development Technical Guidance Manual for Puget Sound, WA
http://www.psat.wa.gov/Publications/LID_tech_manual05/lid_index.htm

Wisconsin Stormwater Management Technical Standards
http://www.dnr.state.wi.us/org/water/wm/nps/stormwater/techstds.htm#Post

Maryland Stormwater Design Manual
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

ST-5d	Retrofit Design Sheets	
	FILTRATION	

Typical Constraints

Stormwater filters can be applied in most regions of the country and most types of urban land. It is important to note that stormwater filters are not always cost-effective to retrofit on a widespread basis, given their high unit cost and small area served. Design constraints for filter retrofits include:

Available Head: The principal retrofit constraint for stormwater filters is available head which is defined as the vertical distance between the top elevation of the filter and the bottom elevation of the existing storm drain system that accepts its runoff. Designers can quickly estimate available head at a proposed retrofit site by locating the closest stormwater inlet or manhole. The difference in elevation between the surface and the invert elevation of the underground storm drain pipe gives a rough approximation of the available head. The head required for stormwater filters ranges from two to ten feet, depending on the design variant. Thus, it is difficult to employ filters in extremely flat terrain since they require gravity flow through the filter. The one exception is the perimeter sand filter, which can be applied at sites with as little as two feet of head.

Contributing Drainage Area: Sand filters are best applied on small sites that are as close to 100% impervious as possible. A maximum contributing drainage area of five acres is recommended for surface sand filters, and a maximum contributing drainage area of two acres is recommended for perimeter or underground filters (Claytor and Schueler, 1996). Filters have been used on larger drainage areas in the past, but they tend to experience greater clogging problems.

Space Required: The amount of space required for a filter retrofit depends on the design variant selected. Both sand and organic surface filters typically consume about 2 to 3% of the contributing drainage area, while perimeter sand filters typically consume less than 1%. Underground stormwater filters generally consume no surface land except manholes needed for maintenance access.

Community and Environmental Concerns for Filter Retrofits

Stormwater filters have a few community and environmental concerns:

Aesthetics: The main drawback with stormwater filters is their appearance - many are imposing concrete boxes that tend to accumulate a lot of trash and debris. Retrofit designers should try to soften up the appearance of surface filters and make sure they are routinely maintained.

Mosquito Breeding: There is a risk that underground and perimeter filters may create potential habitat for mosquito breeding. If this is a concern, designers should keep standing water in sedimentation chambers to a minimum.

Groundwater: Filters are recommended when groundwater protection is an issue since they do not normally interact with groundwater and therefore have less potential to contaminate it.

Design Issues for Filter Retrofit Applications

Several unique design issues are involved with filter retrofits, as follows:

Pretreatment: Adequate pretreatment is needed to prevent premature filter clogging and ensure retrofit longevity. Either wet or dry pretreatment chambers can be used to capture and remove coarse sediment particles before they reach the filter bed. Designers should allocate at least 25% of the total WQv to pretreatment. Additional pretreatment measures may include a grass filter strip installed prior to the filter and regular sweeping of the street or parking lot. If a proprietary filter is used, designers should check to see whether the device has adequate pretreatment volume. The sedimentation chamber should be designed to allow maintenance crews to get vactor trucks close to the retrofit for cleanouts.

Type of Media: The normal filter media consists of clean, washed concrete sand with individual grains between 0.02 and 0.04 inches in diameter. Alternatively, organic media can be used, such as a peat/sand mixture or a leaf compost mixture. The decision to use organic media in a stormwater filter depends on which stormwater pollutants are targeted for removal. Organic media may enhance pollutant removal performance with respect to metals and hydrocarbons (Claytor & Schueler, 1996). Recent research, however, has shown that organic media can actually leach soluble nitrate and phosphorus, suggesting it is a poor choice when nutrients are the pollutant of concern.

Type of Filter: The choice of which sand design filter design to apply depends on available space and head, and the desired level of pollutant removal. In ultra-urban situations where surface space is at a premium, underground sand filters are often the only design that can be used. Surface and perimeter filters are often a more economical choice when adequate surface area is available.

Depth of Media: The depth of the filter media plays a role in how quickly stormwater moves through the filter bed and how well it removes pollutants. Recent design guidance recommends that a minimum filter bed depth ranging from 18 and 24 inches.

Impervious Drainage Area: In retrofit situations, the contributing drainage area should be as close to 100% impervious as possible in order to reduce the risk that eroded sediments will clog the filter.

Overflow: Most filtering practices are designed as off-line systems so that all flows enter the filter, but larger flows overflow to an outlet chamber, and are not treated. Exceptions include the perimeter filter and most underground filters. Runoff from larger storm events should be bypassed using an overflow structure or a flow splitter. Claytor and Schueler (1996) and ARC (2001) provide design guidance for flow splitters for filtering practices.

Drawdown: Stormwater filters should be designed to drain or dewater within 48 hours after a storm event to reduce the potential for nuisance conditions.

Maintenance Issues for Filter Retrofits

Several maintenance issues can addressed during retrofit design to reduce future maintenance operations, including:

Access: Good maintenance access is needed to allow crews to perform regular inspections and maintenance activities. Stormwater filters should be clearly visible at the retrofit site so inspectors and maintenance crews can easily find them. Adequate signs or markings should be provided at manhole access points for underground filters.

Confined Space Issues: Underground filters are often classified as an underground confined space. Consequently, special OSHA rules and training are needed to protect the workers that access them. These procedures often involve training on confined space entry, venting and the use of gas probes.

Sediment/Filter Bed Removal: Sediments will need to be regularly removed from the pretreatment chamber every three to five years. The filter bed media may also need to be replaced on the same schedule.

Site Inspections: Regular site inspections are critical to schedule sediment removal operations, replace filter media and relieve any surface clogging. Frequent inspections are especially needed for underground and perimeter filter retrofits since they are out of sight and can be easily forgotten.

Sediment Testing: Designers should check to see whether the filter is treating runoff from a hotspot site. If so, crews may need to test sediments before disposing of trapped sediments or filter bed media. Sediment testing is not needed if the filter does not receive runoff from a designated stormwater hotspot.

Adapting Filters for Special Climates and Terrain

Stormwater filters can be successfully employed when certain design modifications are made:

Cold Climates: Surface or perimeter filters may not always be effective during the winter months. The main problem is ice that forms over and within the filter bed. Ice formation may briefly cause nuisance flooding if the filter bed is still frozen when spring melt occurs. To avoid these problems, filters should be inspected before the onset of winter (prior to the first freeze) to dewater wet chambers and scarify the filter surface. Other measures to improve winter performance include:

- Placing a weir placed between the pretreatment chamber and filter bed to reduce ice formation as a more effective substitute than a traditional standpipe orifice.
- Extending the filter bed below the frost line to prevent freezing within the filter bed
- Oversizing the underdrain to encourage more rapid drainage to minimize freezing of the filter bed
- Expanding the sediment chamber to account for road sanding. Pretreatment chambers should be sized for up to 40% of the WQv

Arid Climates: Designers may want to increase storage in the pretreatment chamber to handle higher sediment loads expected in arid climates. Dry sedimentation chambers should be sized up to 40% of the WQv. Wet pretreatment is seldom feasible in arid climates.

Karst Terrain: Stormwater filters are a good option in active karst areas since they are not connected to groundwater and therefore minimize the risk of sinkhole formation and groundwater contamination.

Installation Costs for Filtering Practices

Stormwater filters have one of the highest unit construction costs of any stormwater treatment option treating small drainage areas. The cost to construct a stormwater filter depends on the region and design variant used (Table 1). For surface sand filters, Brown and Schueler (1997) reported construction costs ranging between about $3.00 and $8.00 per cubic foot of water quality volume treated (2006 dollars). Wossink and Hunt (2003) developed a cost prediction equation for stormwater filter construction based on drainage area treated. The updated equation is:

$$BCC = (55{,}515)(A^{0.882})$$

Where:
A = Size of contributing drainage area (acres)
BCC = Base construction cost (2006 dollars)

While underground and perimeter sand filters are the most expensive filtering practice, they consume minimal surface land, making them a cost-effective practice in ultra-urban areas where land prices are at a premium.

Design Resources

Several existing stormwater manuals provide useful guidance on stormwater filter design:

District of Columbia Stormwater Management Guidebook
http://dchealth.dc.gov/DOH/site/default.asp?dohNav=|33110|

The Minnesota Stormwater Manual
http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html

Maryland Stormwater Design Manual
http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Design of Stormwater Filtering Systems. Center for Watershed Protection
http://www.cwp.org/PublicationStore/special.htm

Georgia Stormwater Management Manual
http://www.georgiastormwater.com

Design Variant	Median Cost Per Impervious Acre Treated	Range in Cost
Simple Surface Filter	$ 18,150	$ 10,900 to $29,000
Structural Sand Filter	$ 72,000	$ 58,100 to $79,900
Underground Sand Filter	$ 234,000	$ 100,800 to $ 270,000
See Appendix E: Simple surface filter lacks structural elements and reinforced concrete		

ST-6d

Retrofit Design Sheets

INFILTRATION

Typical Constraints

Numerous constraints need to be assessed to ensure infiltration is feasible at a proposed retrofit site, including:

Soils: Soil permeability is the single biggest factor when evaluating infiltration retrofits. A minimum infiltration rate of at least 0.5 inches/hour is needed to make the retrofit work. Several studies have shown that ultimate infiltration rates decline by as much as 50% from initial rates, so designers should be very conservative and not force infiltration on questionable soils. On-site infiltration investigations should always be conducted to establish the actual infiltration capacity of underlying soils using methods presented in Appendix H.

Avoid Stormwater Hotspots: Never infiltrate runoff from a hotspot operation. Make sure to conduct a HSI on all operations in the contributing area to determine the potential risk of groundwater contamination. If a site is classified as a stormwater hotspot, then runoff must be fully treated by another practice prior to infiltration.

Contributing Drainage Area: Infiltration retrofits are best applied to small contributing drainage areas that are as close to 100% impervious as possible. If the contributing contains any pervious area, it must be properly stabilized with dense vegetation, both during and after construction, to prevent eroded sediments from prematurely clogging the facility.

Additionally, the maximum contributing drainage area to an infiltration trench should be limited to one acre or less. The maximum contributing drainage area to underground infiltration systems should be limited to five acres or less. Infiltration practices serving larger drainage areas tend to experience more chronic clogging problems.

Space Required: The typical footprint of an infiltration retrofit ranges from 5 to 10% of its contributing drainage area, but varies depending on its depth, storage void, space, and infiltration rate.

Minimum Setbacks: As a general rule, infiltration retrofits should be setback at least 10 feet from property lines, 25 feet from building foundations, 100 feet from septic system fields, 100 feet from private wells, 100 feet from surface waters, 400 feet from surface drinking water sources and 1,200 feet from public water supply wells.

Depth to Water Table/Bedrock: Infiltration retrofits should be separated at least three feet from the water table to ensure groundwater never intersects with the floor of the infiltration practice, which could cause groundwater contamination or practice failure. A three foot separation distance should be maintained between the bottom of the infiltration retrofit and any confining bedrock layer.

Community and Environmental Considerations for Infiltration Retrofits

Several community and environmental concerns can arise when infiltration retrofits are proposed:

Nuisance Conditions: Poorly designed infiltration retrofits can create potential nuisance problems such as basement flooding, poor yard drainage and standing water. In most cases, these problems can be minimized through adequate setbacks, on-site soil testing and pretreatment.

Mosquito Risk: Infiltration retrofits can potentially create mosquito breeding conditions if they clog and have standing water for extended periods.

Groundwater Protection: Communities that rely on groundwater for drinking water are often concerned about potential stormwater contamination. Designers should investigate the prevailing land use in the contributing drainage area. Runoff from potential stormwater hotspots should never be infiltrated. For residential and institutional land uses, infiltration is desirable since it replenishes groundwater supplies. Infiltration retrofits in these areas should have over-sized and redundant pretreatment to reduce the risk that stormwater pollutants or spills will reach groundwater.

Groundwater Injection Permits: Groundwater injection permits may be required in some areas of the country. Designers should investigate whether or not a proposed infiltration retrofit is subject to a state or local groundwater injection permit.

Design Issues for Infiltration Retrofit Applications

The design of infiltration retrofits should be more conservative than the design of new infiltration practices to promote longevity. A series of design elements can minimize the risk of practice failure:

Pretreatment is essential to extend the longevity of infiltration retrofits. Designers should include at least two pretreatment measures in every retrofit, such as grass swales, filter strips, sump pits, sediment forebays or plunge pools.

Off-line Design: Infiltration retrofits should be designed off-line so they only receive the target WQv and bypass larger storm flows. A flow splitter or overflow structure can be used for this purpose; design guidance for small flow splitters can be found in Claytor and Schueler (1996) and ARC (2001).

Small Contributing Drainage Areas: The contributing drainage area to each infiltration retrofit should be less than one acre, and be distributed in multiple locations around the site. Ideally, the contributing drainage area should be entirely impervious to preclude the possibility that eroded sediments from pervious areas will clog the retrofit. Designers should also try to keep the depth of the infiltration retrofit to less than four to six feet.

Rapid Drawdown: When possible, infiltration retrofits should be sized so that the target WQv rapidly infiltrates within 24 to 36 hours (rather than the standard 48 hour drawdown limit for new practices). This design approach provides a factor of safety to prevent nuisance ponding conditions.

Conservative Infiltration Rates. Underlying soils should have a minimum infiltration rate of at least 0.5 inches per hour. Several test pits are needed to measure the infiltration rates across a proposed retrofit site. Appendix H provides guidance on performing infiltration testing. However, infiltration rates of 1.0 to 2.0 inches per hour are ideal. Designers may wish to cut measured infiltration rates in half to approximate the long term infiltration rate.

No Filter Fabric on Bottom: The use of geotextile filter fabric along the bottom of infiltration retrofits should be avoided. Experience has shown that filter fabric is prone to clogging, and that a layer of coarse washed stone (choker stone) is a more effective substitute.

Observation Wells: One or more observation wells should be installed within infiltration retrofits so that drawdown rate can be measured after storm events. Observation wells typically consist of perforated PVC pipes that are four to six inches in diameter and extend from the surface to the bottom of the infiltration retrofit.

Maintenance Issues with Infiltration Retrofits

Historically, infiltration practices have had a high failure rate compared to other stormwater treatment options (Galli, 1992). A conservative retrofit design approach should greatly reduce the risk of initial retrofit failure (Figure 1). Even so, the future performance of infiltration requires a strong commitment to regular inspection and maintenance. Designers should only choose infiltration when they are confident that the landowner or municipal agency will be a responsible maintainer in the future. The maintainer should be expected to handle the following ongoing tasks:

Figure 1: Failed Infiltration Trench

Site Inspections: Regular site inspections are critical to the performance and longevity of infiltration retrofits. The drawdown rate of the retrofit should be measured at the observation wells at least twice a year. It is recommended that infiltration rates be checked in observation wells three days following a storm event greater than one half inch in depth. If standing water is still observed in the well after three days, this is a clear sign that that clogging has become a problem. Additionally, pretreatment devices and flow diversion structures should be checked for sediment buildup and structural damage.

Sediment Removal/Trench Reconstruction: Sediment will need to be regularly removed from pretreatment facilities. If major clogging occurs, the practice may need to be reconstructed. Good maintenance access is needed to allow crews and heavy equipment to perform maintenance tasks.

A maintenance plan should be created that identifies the party responsible for maintenance and specifies ongoing maintenance tasks over a prescribed schedule.

Adapting Infiltration for Special Climates and Terrain

Although infiltration practices have been successfully employed in both cold and arid climates, several design modifications are needed to ensure they function properly:

Cold Climates: Infiltration retrofits are generally not feasible in extremely cold climates experiencing permafrost, but they can be designed to withstand more moderate winter conditions. The main problem is ice forming in the voids or the subsoils below which may briefly cause nuisance flooding when spring melt occurs. These problems can be avoided if the bottom of the retrofit extends below the frost line.

If the retrofit treats roadside runoff, it may be desirable to divert flow in the winter to prevent movement of chlorides into groundwater and prevent clogging by road sand. Alternatively, pretreatment measures can be oversized to account for the additional sediment load caused by road sanding (up to 40% of the WQv). Care should be taken to ensure that infiltration retrofits are setback at least 25 feet from roadways to prevent potential frost heaving of road pavements.

Arid Climates: The key concern in arid and semi-arid watersheds is the greater risk of potential clogging due to higher sediment loads. Consequently, over-sized pretreatment should be strongly emphasized, and the contributing drainage area should be kept as close to 100% impervious as possible.

Karst Terrain: Infiltration retrofits should not be used in active karst regions unless geotechnical investigations have eliminated concerns about sinkhole formation and groundwater contamination.

Installation Costs for Infiltration Retrofits

Very little construction cost information about infiltration practices is available. Because their construction methods are similar, the cost for infiltration practices are assumed to be comparable to bioretention areas (Appendix E). Consequently, the cost to construct infiltration practices at new development sites is estimated to be $25,400 per impervious acre treated (range: $19,900 to $41,750). Few retrofit sites will meet new development conditions; however, most retrofits will cost 1.5 to 2.0 times more than new infiltration practices.

Infiltration Design Resources

Several recent stormwater manuals present updated design criteria for infiltration practices:

New Jersey Stormwater Best Management Practices Manual
http://www.nj.gov/dep/watershedmgt/bmpmanualfeb2004.htm

Pennsylvania Draft Stormwater Best Management Practices Manual
http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm

Green Technology: The Delaware Urban Runoff Management Approach
http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20&%20Specs_06-05.pdf

New York State Stormwater Management Design Manual
http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html

ST-7d	Retrofit Design Sheets	
	SWALES	

Typical Constraints

Constraints to consider when evaluating a potential swale retrofit include:

Contributing Drainage Area: The maximum contributing drainage area to a swale retrofit should be five acres and preferably less.

Space Required: Swale retrofits usually consume about five to 15% of their contributing drainage area.

Site Topography: Site topography constrains swale retrofits; some gradient is needed to provide water quality treatment but not so much that treatment is impeded. Swales generally work best on sites with relatively flat slopes (e.g., less than 5% slope for grass channels and 2% for wet and dry swales). Steeper slopes create rapid runoff velocities that can cause erosion and do not allow enough contact time for infiltration or filtering. Swales perform poorly in extremely flat terrain because they lack enough grade to create storage cells, and lack head to drive the system.

Available Head: A minimum amount of head is needed to implement each swale retrofit. Dry swales typically require three to five feet of head since they require a filter bed and underdrain. Wet swales require about two feet of head, whereas grass swales need only a foot. Designers should measure gradient in the field to ensure enough head exists to drive the swale retrofit.

Hydraulic Capacity of Existing Open Channel: Most open channels were originally sized with enough capacity to convey runoff from the ten-year storm, and be non-erosive during the two-year design storm event. In many cases, the open channel may be under-capacity due to upstream development or past sedimentation. The capacity of the existing open channel should be verified during the retrofit project investigation. Field observations that may indicate an existing channel is undersized channel include excessive erosion of the channel side slopes, poor vegetative stabilization and overbank debris.

Width of Existing Right of Way or Easement: Designers should investigate whether the existing right of way or stormwater easement is wide enough to accommodate retrofit construction and maintenance access. In most cases, the existing channel will need to be widened or flows split into adjacent off-channel treatment cells.

Depth to Water Table: Designers should separate the bottom of the swale from the groundwater by at least two feet for dry swales and grass channels. It is permissible to intersect the water table for wet swales, since the pool enhances water quality treatment.

*Soils: S*oil permeability influences which swale design variant will work best in the existing channel. Designers should note that past construction and compaction may have severely reduced the permeability of the original swale soils. Several on-site tests should be conducted at the proposed retrofit to measure actual soil infiltration retrofit rates (see Appendix H). In general, grass swales are restricted to soils in Hydrologic Soil Groups A or B. Dry swales also work well on these soils, but can be applied to more impermeable C or D soils if an underdrain is used. Wet swales work best on more impermeable C or D soils.

Utilities: Many utilities run along or underneath open channels, so designers should always check for utility lines or crossings at each swale retrofit site. The presence of dry or wet utilities usually renders a swale retrofit infeasible.

Community and Environmental Considerations for Swale Retrofits

Swale retrofits are normally accepted by communities if they are properly designed and maintained, but require approval by multiple landowners to secure additional right of way. The main concerns of adjacent residents are perceptions that swale retrofits will create nuisance conditions or will be hard to maintain. Common concerns include the continued ability to mow grass, landscape preferences, weeds, standing water, and mosquitoes. For these reasons, wet swales are not recommended in residential settings - the shallow, standing water in the swale is often viewed as a potential nuisance by homeowners. Dry swales are a much better alternative.

Key Design Issues for Swale Retrofits

Several design elements can ensure the swale retrofit performs effectively over the long run:

Pretreatment: Adequate pretreatment is needed to trap sediments before they reach the main treatment cell of the swale retrofit. A small sediment forebay located at the upstream end of the swale often works best. A pea gravel flow spreader along the top of each bank can pretreat lateral runoff from the road shoulder to the swale.

Swale Dimensions: Swales should have a bottom width ranging from two to eight feet to ensure an adequate surface area exists along the bottom of the swale for filtering. If a swale will be wider than eight feet, designers should incorporate berms, check dams, level spreaders or multi-level cross sections to prevent braiding and erosion within the swale bottom. Swale retrofits should be designed with a parabolic or trapezoidal cross section and have side slopes no steeper than 3:1 (h:v). Designers should seek side slopes much less than 3:1 to promote more treatment of lateral sheet flow, if space is available.

Ponding Depth: Drop structures or check dams can be used to create ponding cells along the length of the swale. The maximum ponding depth in a swale should not exceed 18 inches at the most downstream point. The average ponding depth throughout the swale should be 12 inches.

Drawdown: Dry swale retrofits should be designed so that the desired WQv is completely filtered within six hours or less. This drawdown time can be achieved by using a sandy soil mix or an underdrain along the bottom of the swale. No minimum drawdown time is required for wet swale retrofits.

Swale Media: Dry swales require replacement of native soils with a prepared soil media. The soil media provides adequate drainage, supports plant growth and facilitates pollutant removal within the dry swale. The soil media should have an infiltration rate of at least one foot per day and be comprised of a mix of native soil, sand and organic compost similar to bioretention design recommendations presented in ST-4. At least 18 inches of soil media should be mixed into the swale bottom.

Underdrain: Underdrains are provided in dry swale retrofits to ensure they drain properly after storms. The underdrain should have a minimum diameter of 6 inches and be encased in a foot deep gravel bed. Underdrains are not needed in wet swales or grass channels.

Swale Maintenance Requirements

Swale maintenance often fits within normal turf management operations that are already being performed. Swale retrofits are often located near landowners that have real or perceived concerns on how the swale may affect their front yards and property value. Therefore, designers should consider how to:

- Minimize standing water
- Minimize interference of check dams with regular mowing
- Manage vegetative growth in the future
- Educate residents on how to properly maintain the swale over time

Regular inspections should be conducted on the swale retrofit to schedule maintenance operations such as sediment removal, spot revegetation and inlet stabilization. Maintenance crews may need to be educated on the purpose and maintenance needs of swale retrofits installed along streets or highway right-of-way.

Adapting Swales for Special Climates and Terrain

Swale retrofits can be applied in most climates and terrain with some design modifications:

Cold Climates: Swales can store snow and treat snowmelt runoff. If roadway salt is applied, swales should be planted with salt-tolerant and non-woody plant species. Consult the Minnesota Stormwater Manual for a list of salt-tolerant grass species (MSSC, 2005). The dry swale underdrain pipe should extend below the frost line and be oversized by one pipe size to reduce the chances of freeze-up.

Arid Climates: It is extremely hard to maintain a wet swale retrofit in arid and semi-arid climates. Swales should be planted with drought-tolerant vegetation and the planting plan should specify fewer broad-leaved plants to minimize the need for supplemental irrigation. A xeriscaping approach is preferred for any swale in arid or semi-arid regions since irrigation makes little sense and is expensive in these regions.

Karst Terrain: Swale retrofits should utilize impermeable liners and underdrains to prevent sinkhole formation in active karst areas.

Swale Installation Costs

Only limited cost data has been published on swale construction costs. Equations to estimate swale costs for new construction are outlined in Appendix E. The projected cost for swales at new development sites is estimated to be $18,150 per impervious acre treated (range: $10,900 to $36,300). Few retrofit sites will meet the construction conditions for new development sites; most swale retrofits will cost about twice as much, particularly if they involve off-channel treatment.

Swale Design Tools

New York State Stormwater Management Design Manual
http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html

Vermont Stormwater Management Manual
http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm

Stormwater Management Manual for Western Washington
http://www.ecy.wa.gov/programs/wq/stormwater/manual.html#How_to_Find_the_Stormwater_Manual_on_the

CNMI and Guam Stormwater Management Manual
http://www.guamepa.govguam.net/programs/water/index.html